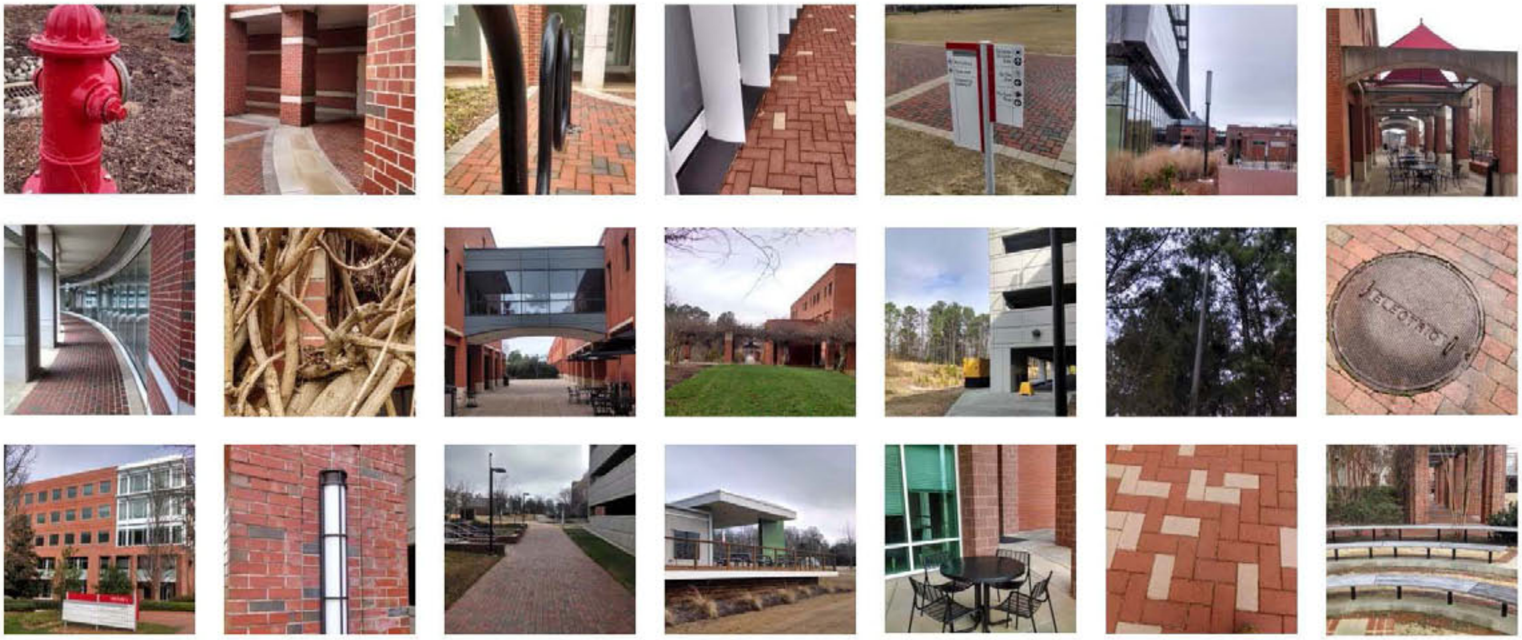
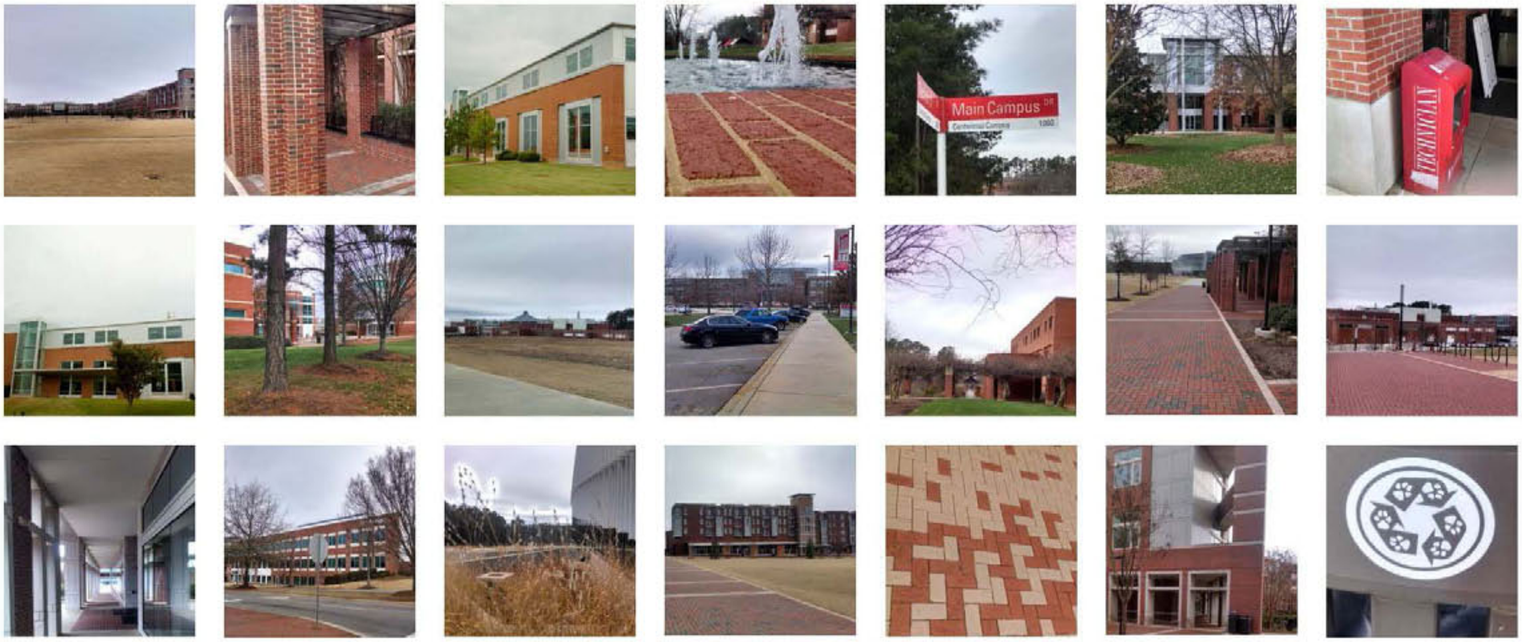


North Carolina State University
Centennial Campus

Smart Grid Master Plan



June
2014

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Executive Summary

The North Carolina State University Centennial Campus is a nationally recognized research campus for Smart Grid initiatives. Due to continued growth, University leadership recognized the need to increase the size of the current electrical distribution system on campus. This need has provided a unique opportunity to expand the electrical system and simultaneously incorporate smart grid technology that will improve the reliability of the electrical system, reduce energy usage, and provide the foundation to support the smart grid research initiatives of the University and corporate partners. The purpose of this smart grid master plan is to identify and prioritize projects which will improve the reliability of the electrical distribution system, improve energy conservation, or support the University's goal of being a national leader in smart grid technology at the Centennial Campus.

This study was developed through a synergistic combination of Jacobs' experience with smart grid technology and master planning along with the in-depth knowledge provided by a variety of University departments including utilities and energy, facilities, campus planning, sustainability, and academic research to develop a plan tailored to the goals and needs of the Centennial Campus. From the data gathered, it was determined that the master plan needed to address three primary smart grid categories: smart grid research, distributed generation, and a smart campus control system. These three categories address the University's unique needs while targeting a significant reduction in energy consumption and improved reliability and are described in further detail as follows:

> **Smart Grid Research** – The University currently conducts a large amount of research related to the smart grid and its components. It was determined that one of the smart grid's most desirable benefits would be providing access to real world testing and data. To maximize this benefit a *Smart Grid Proving Grounds* concept was developed, the *Proving Grounds* is a group of existing and new facilities where researchers and industry can further test and study smart grid technologies. The focal point of the Proving Grounds would be the AC/DC test circuit which would provide a safe means of testing AC and DC power including the integration of a variety of renewable sources such as solar photovoltaics (PV).
>
> **Smart Campus Control System** – The University currently has a variety of building automation systems which control the mechanical systems in a facility. At present, these systems operate independently of each other and the central utility system. A new smart campus control system at Centennial Campus would integrate these systems together and provide constant system wide two way communication. The campus would operate as one fluid system instead of over 20 independent systems. The smart campus control system would utilize advanced analytics to optimize energy consumption on campus while also collecting data for researchers.
>
> **Distributed Generation** – A key component of a smart grid is providing distributed generation sources. Jacobs evaluated a variety of distributed generations sources and system improvements that would increase overall system reliability. The areas addressed included cogeneration, thermal storage, standby generation, and other distributed generation sources. The evaluated distributed generation projects covered a wide range of payback periods.

Various technologies related to the three smart grid categories were reviewed, and specific projects for implementation on Centennial Campus were evaluated. The results and recommendations of the smart grid projects can be found in the Implementation section of the plan.

Mission Statement

The smart grid at NC State University will increase data acquisition and control to enable reductions in energy consumption and costs, while providing reliable and efficient electricity to meet the University's teaching and research mission. It will also build on the established local innovative smart grid sector in Raleigh and provide a collaborative hub for the nearly 96 Triangle based smart grid related companies to interact and showcase technologies. Through strong collaboration and partnerships with non-profits, local governments, businesses, and the community, NC State University will continue to distinguish itself as a sustainability leader and remain at the forefront of cutting edge technology.

Figure 1 - Water Feature at Centennial Campus

Introduction

What is a Smart Grid?

A smart grid is a utility infrastructure which utilizes two way communications to monitor and control a utility grid using real time data to improve reliability and overall system efficiency by incorporating multiple energy consumption and generation sources. The two major smart grid subdivisions are macro and micro. A smart macro grid is typically a utility provider, while a smart micro grid is generally an individual campus such as a university. The smart micro grid is a key component to the successful operation of a macro smart grid. Detailed descriptions of both macro and micro smart grids are provided as follows.

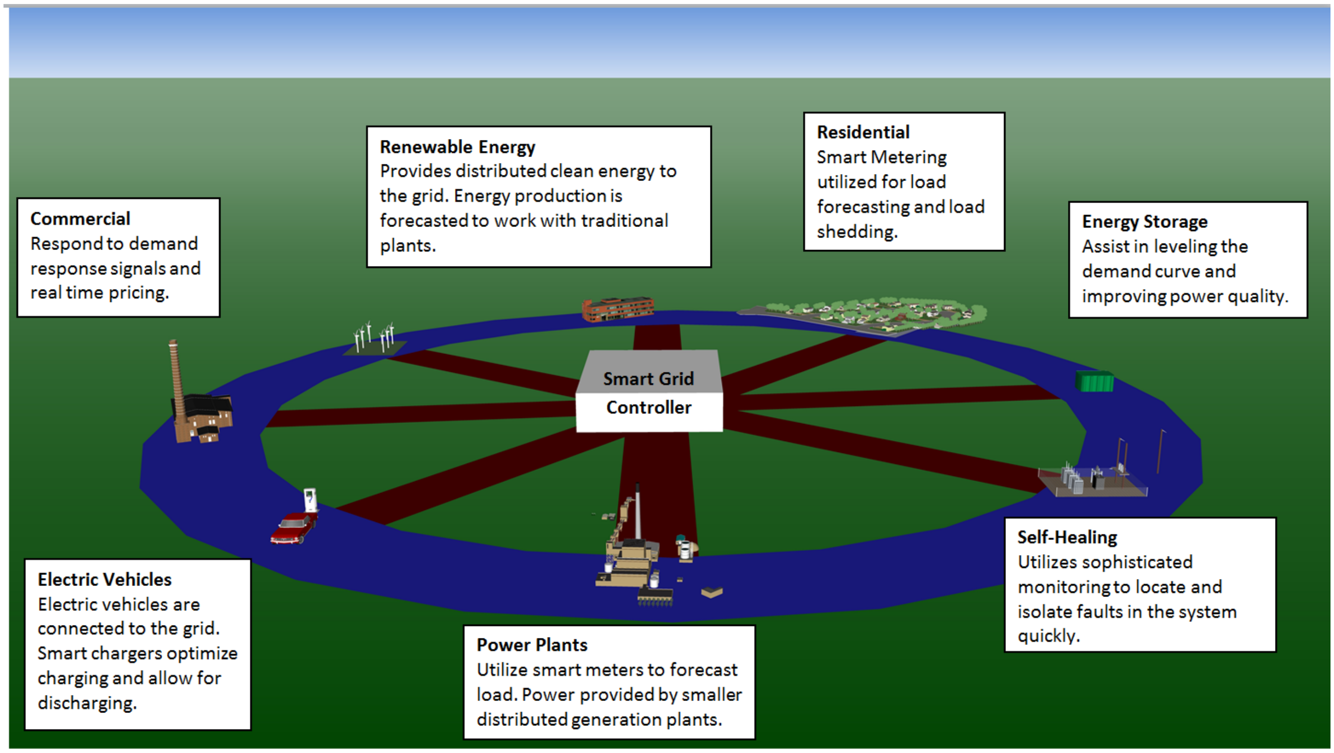


Figure 2 – Smart Macro Grid Diagram

Smart Macro Grid

A utility level smart macro grid focuses on improving reliability and efficiency. To accomplish this, the smart grid uses constant two way communication between the energy production, distribution, and consumption portions of the grid. The monitoring and constant communication enables the smart grid to implement a demand reduction strategy when the system forecasts that the demand will exceed predetermined levels. This increases grid reliability and maximizes the available resources of the electrical infrastructure. Through increased monitoring and control, the smart grid also offers improved reliability and reduced outage time by identifying potential maintenance issues before failure and pinpointing problems for immediate resolution.

Smart Micro Grid

Similar to the smart macro grid, a smart micro grid uses constant two way communication and control to optimize the operation of the grid for high reliability and energy savings. The major difference between the two is the depth of integration. A macro grid integrates information at a systematic level whereas a micro grid integrates the majority of the energy consuming and producing devices. In addition, the micro grid continuously monitors and analyzes consumption at the building level to optimize energy consumption and production including distributed generation and renewable energy.

Analytics are used to determine the most efficient methods of operating energy consuming equipment and to monitor equipment to identify decreases in efficiency. The cost of energy is reduced by repeatedly assessing actual versus forecasted energy consumption, production, and cost to determine what the ideal energy operating scenario is for the micro grid. The micro grid also works in concert with the macro grid by responding to calls for demand reduction from the macro grid.

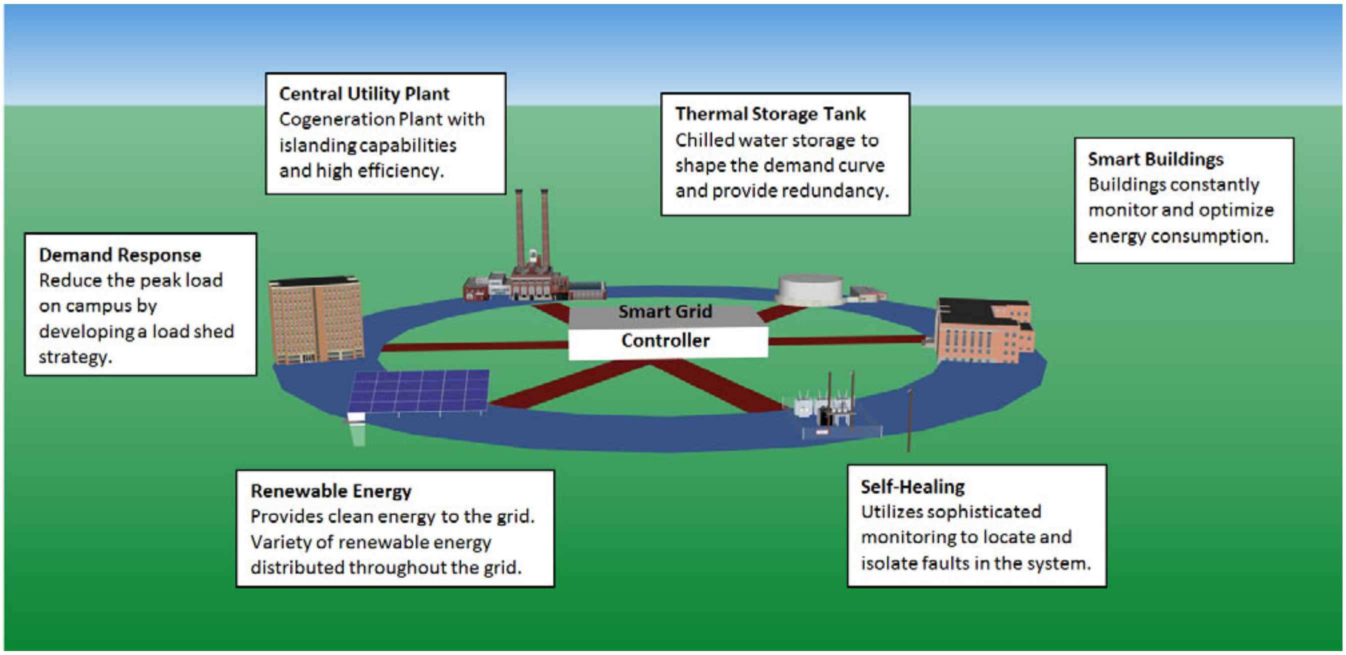


Figure 3 – Smart Micro Grid Diagram

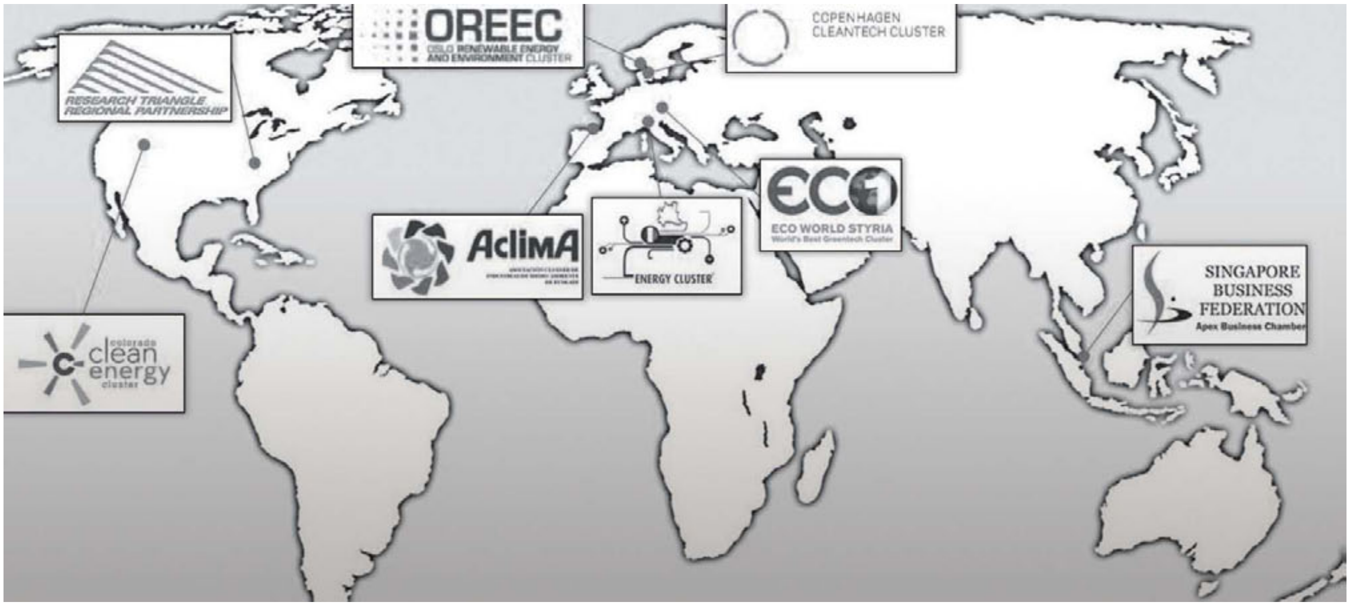


Figure 4 – Clean Tech Cluster World Map

Smart Grid at Centennial Campus

The smart grid at Centennial Campus will provide the technical foundation to demonstrate, utilize, and develop a wide range of smart grid technology that will allow the campus to become the destination for smart grid technology research and development. Due to the size and configuration of the Centennial Campus, the smart grid on campus will have a smart micro grid foundation with a variety of load types including residential, commercial, electric transport, and industrial. The campus will integrate key smart grid elements throughout campus to improve reliability and increase efficiency. Additionally, the smart grid will have several important components dedicated to the research and development of smart grid technology. Combining all of the elements together will allow the smart grid to save energy and improve reliability while serving as an academic learning tool. Additionally, the smart grid will encourage further economic development of the burgeoning local smart grid businesses and support the initiative of the Triangle Clean Tech Cluster.

Goals of a Smart Micro Grid Implementation

NC State is on the way to becoming a leader in smart grid technology. To achieve this goal, the Centennial Campus Smart Grid Master Plan has identified three goals that must be addressed to form the foundation for the successful development and implementation of a smart grid on Centennial Campus.

Leader in Smart Grid Technology and Implementation

Centennial Campus is a leader in research and development in the electrical power field. The FREEDM Center, along with local commercial companies involved with smart grid technology, functions as NC State's platform for smart grid research. **The smart grid at Centennial Campus will provide the University with state of the art technology and facilities to support further development of smart grid technology.**

Grid Devices

For a smart grid to be successful the proper hardware to allow for communication and control must be in place. The smart grid at Centennial Campus will not only utilize state of the art technology for key energy devices, but also implement an open protocol system with the ability to integrate new technologies.

Communication

A key component in smart grid implementation is communication. Whether the communication is a weather forecast for the next day or broadcasting the energy consumption of a dormitory to the students, a constant flow of communication between all aspects of the smart grid is vital to its effectiveness. To address this need, Centennial Campus will have a fully developed two way communication system that integrates energy consumption and production into the micro grid.

Building Technology

Buildings are the largest energy consumers at NC State, which makes them a focal point for conservation. The building systems must work cohesively to reduce energy consumption. The smart grid will implement technology to monitor and optimize key components of each building. Buildings will be continually evaluated and optimized through analytics and campus control strategies to ensure operations are at peak performance and that the demand curve is shaped to reduce energy cost.

Develop a Smart Grid Proving Ground

The smart grid at Centennial Campus will become a technological proving ground where researchers and corporations alike can develop and test new technologies both large and small.

Accessible

The smart grid concept is currently in its infancy and represents a market that will continue to grow in today's energy driven economy. A smart grid at Centennial Campus would support the development of new smart grid technology through the access that it will provide for both University researchers and corporate partners. The smart grid will not only provide easy access to the testing of hardware solutions at low and medium voltages, but also aid in the development of software solutions.

Safe

Being on the cutting edge of technology is important, however conducting research in a safe environment is essential. The University has taken pride in maintaining a safe environment on all of its campus precincts and this emphasis on safety will continue. The smart grid will provide a safe learning environment for new technologies while providing additional protection for the electrical distribution system and building components.

Scalable

A smart grid can encompass everything from a 1000 megawatt natural gas power plant to a small photovoltaic array. The ability to test theories and actual hardware in an operating electrical distribution system at different scales would be a major benefit for NC State. When the Centennial Campus smart grid is completed, it will be capable of providing a test bed for technology big and small.

Reduce Energy Consumption and Improve Reliability

The major benefits of a smart grid are energy reduction and financial savings. **By implementing the smart grid at Centennial Campus, NC State will be able to reduce energy costs, improve reliability, and reduce maintenance costs.**

Energy Optimization

NC State strives to ensure that its buildings are not only functional, but also energy efficient. The Centennial Campus smart grid will improve energy efficiency of campus buildings using analytical analysis of a building's energy consumption. By providing a central control system that interacts with energy producing and consuming components, the smart grid creates an energy management system that is proactive rather than reactive. In addition, the smart grid implementation will apply energy optimization that extends beyond individual buildings by optimizing the operation of the central steam and chilled water systems as well as future utility systems such as cogeneration and thermal storage.

Demand Response

In the southeast region of the United States approximately 75% of the electrical consumption occurs during daytime hours. The fluctuation in load causes a major strain on the electrical utilities. To compensate for the added demand on the generation system, the utility companies place a financial premium on power consumption during the high demand periods such as daytime hours. By shifting energy consumption to the lower demand periods, the unit cost of electricity can be reduced. The smart grid at Centennial Campus will utilize predictive modeling to identify options to shift energy consumption to off peak periods, minimize energy consumption during high demand periods, and shed load when possible without compromising the building operations.

Improve Reliability

As buildings continue to become more advanced and energy efficient, their maintenance needs often are more difficult and time consuming. Building systems are typically too complex for an individual to successfully examine each facility and ensure that each component is working properly. The Centennial Campus smart grid will be able to analyze data from each building and alert appropriate personnel when anomalies appear, improving the system's reliability. The smart grid will similarly reduce time spent investigating problems and the associated costs of related maintenance issues that go undetected.

Centennial Campus at Present

This section provides an overview of the existing conditions on Centennial Campus that are related to smart grid implementation. Primary focus will be upon the buildings, utility infrastructure, and smart grid knowledge currently found on Centennial Campus.

Buildings

Facilities

Due to the various types of commercial and academic activities that occur at the University, there is a large variety of building types on campus. At present, there are 23 facilities totaling over 2 million square feet which are connected to the University's utility infrastructure. These facilities range from a golf course clubhouse to laboratory buildings. Many of the buildings are relatively new and were constructed in the late 1990's and early 2000's. In addition, there are plans for expansion of over 1 million square feet in the next five to ten years.

Figure 5 - Aerial View of Centennial Campus

Building Communications

Since Centennial is a research campus, developing a strong data network infrastructure was critical. Both wired and wireless networks throughout Centennial Campus were implemented and included a SCADA system which runs on a secure network. In addition, an experimental secure wireless network, CentMesh, is found on Centennial Campus. This wireless network allows for the development of new secure uses of wireless networks. All occupied buildings on Centennial Campus have NC State network connectivity via fiber except for the Centennial Middle School, Golf Maintenance Bldg., Golf Clubhouse, The Shores residential complex, and the Red Hat Building. Below is a review of the various utility communication systems including smart meters, substation, central utility plant, building automation systems, and enterprise level control system.

Smart Meters

Currently, Centennial Campus has a mixture of smart and standard meters monitoring electrical usage for every building; the smart meters communicate using the Ethernet network. The meter data is either manually read and recorded or automatically recorded through the smart meters. All of the electrical metering data is currently entered into electronic billing software (EBS) which then sends the data to the enterprise level control system. Chilled water and steam consumption is measured on some buildings utilizing the Building Automation System (BAS), but this data is not recorded for all buildings.

Substation

The current SCADA control system for the substation and electric distribution system which serve Centennial Campus is a high level monitoring system. The system is able to monitor select points, but is unable to control them. If the system detects a fault, an alarm is triggered. Upon receiving an alarm, facility personnel must first investigate to locate the issue and then visit the location to determine the exact source of the problem.

Central Utility Plant

The central utility plant control is currently a localized control system. The system is able to control equipment to meet the set points that are determined by the operator. The set point control is not automated and is based on the operator’s knowledge of the system to determine what the best operating set points are. If required, the plant operator will use the enterprise system to gain an understanding of campus demands and adjust the plant set points to respond accordingly. In addition, the system is programmed with alarms that are triggered by equipment failure.

Figure 6 - Centennial Campus Central Utility Plant

Building Automation Systems

Due to the relatively recent construction of Centennial Campus most of the buildings have a Building Automation System (BAS). A BAS allows building systems, mainly HVAC, to be controlled and monitored. The control and monitoring ability of each system varies from simple temperature monitoring to complex start-up sequences.

There are three BAS manufacturers currently found on Centennial Campus: Johnson Controls, Schneider Electric, and Siemens. Each manufacturer has proprietary software to access and control building level data for their respective systems, but all systems follow an industry standard BAS protocol. Portions of the BAS systems for the buildings are monitored and controlled by the Enterprise Level Control System (ELCS).

Table 1 - Centennial Campus Building BAS

Building	BAS View	BAS Control	BAS Points	BAS System
Chancellors Residence				
LPGC Maintenance Facility	X	X		
LPGC Clubhouse	X	X		
Research II	X	X	800	Site Net R2
Poulton Innovation Center	X		1300	Site Net AX
Research III	X	X	500	I Net
Research IV	X	X	400	JCI
Alumni Bldg.	X	X	500	JCI
BTEC	X	X	900	
Research I	X	X	1200	Site Net R2
Toxicology	X	X	1300	JCI
Partners III	X	X	1700	Site Net R2
James B. Hunt Library	X	X	3000	JCI
Partners II	X	X	900	Site Net R2
Partners I	X	X	1600	Site Net R2
Engineering Building III	X	X	3500	JCI
Engineering Building II	X	X	2000	JCI
Engineering Building I	X	X	1900	JCI
College of Textiles	X	X	2800	Site Net R2
MERC	X	X	2000	JCI
Central Utility Plant	X			Iconics

Figure 7 - The Oval at Centennial Campus

Enterprise Level Control System

NC State has invested in an ELCS which provides an infrastructure that integrates diverse BAS and provides an overall view of campus energy. The ELCS utilizes a Tridium Niagara AX Platform with a java-based and web-enabled framework. The ELCS is integrated into the main air handling units and smart meters only. By connecting to these major components, the system captures a high level picture of building performance. A diagram of the communication is shown in Figure 8 where communication flow is indicated using arrows while systems with no communication to ELCS are marked with "X"s.

With the ELCS, the University has implemented a high level campus load shedding program. If University personnel determine the campus electrical load should be reduced during their peak demand, the ELCS sends out a command for the dedicated outside air handling units to raise their supply air temperature set points. The University has found that this strategy can only be implemented for 30-60 minutes before occupancy comfort issues arise in the buildings.

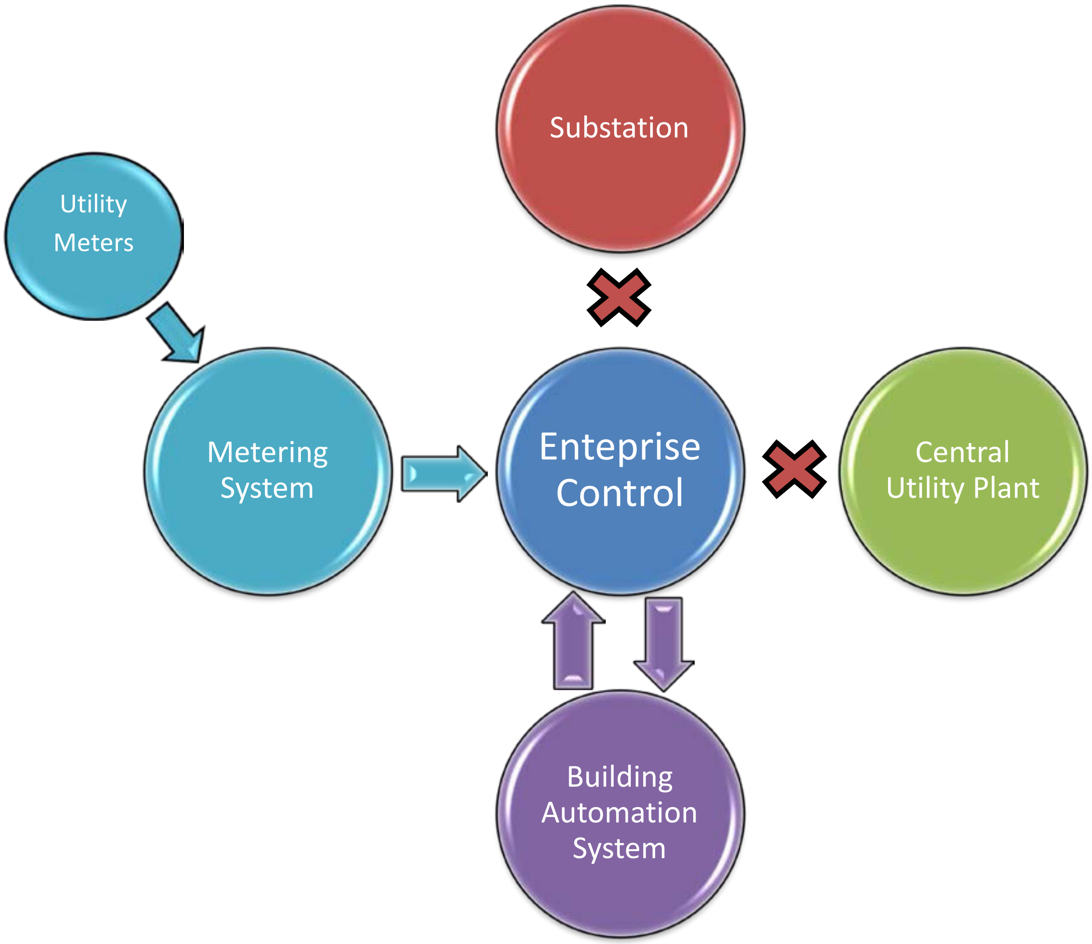


Figure 8 – Existing Centennial Campus Facilities Communication Diagram

Utility Infrastructure

Electrical

Overview

The NCSU electrical distribution system at Centennial Campus begins at Duke Energy Progress's 230kV to 22.9/13.2kV substation, located north of Varsity Drive on the northwest perimeter of the Centennial Campus. At this substation, Duke Energy Progress has a power transformer that provides the University with a single, metered point of delivery at 22.9/13.2kV. From this point, the University distributes power throughout the campus from a 25kV outdoor metal clad lineup of vacuum circuit breakers utilizing underground 25kV power cables distributed in concrete-encased duct bank and manholes.

Most of the feeder routes follow locations on the perimeter of campus and run through utility corridors among and around the various buildings on campus. The distribution feeders provide power to the buildings through the use of pad mounted 25kV switchgear that provides switching provisions and fusing for radial taps that serve individual pad mounted transformers at the various buildings.

Figure 9 - Existing Centennial Campus Substation

Substation Capacities and Configuration

Duke Energy Progress has installed a 230kV to 22.9/13.2kV substation utilizing one (1) three-phase 15.0/20.0/25.0 MVA power transformer. Additional space has been provided in the substation area for the installation of a second similar unit. The low-side of this power transformer is connected to buswork that provides a single point of delivery through one (1) meter to the University. This bus is terminated in a switching structure that has 25kV, 1,200 ampere disconnect switches to isolate the University's point of delivery. From this point of delivery, the University extends two runs of 750 kcmil, 25kV aluminum cable to an outdoor metal clad switchgear lineup containing two (2) 1,200 ampere source breakers, and six (6) 1,200 ampere feeder breakers. The switchgear lineup is currently capable of adding two (2) additional breakers, one (1) on either side of the existing enclosure. With the completion of several projects, including the Hunt Library and Wolf Ridge, the sum of the building peaks is estimated to be 22,733 kVA. This peak loading condition is 151% of the rated capacity of the Duke Energy Progress 15,000kVA transformer's base rating. It should be noted that Duke Energy Progress's substation transformer has a nominal base rating of 15,000kVA, but has two stages of cooling fans that allow for overload capacities of 20,000 and 25,000kVA. If the transformer is allowed to heat to 65° C, there is short term emergency overload capability of 28,000kVA. Based on future peak load projections a new substation will be necessary to handle the expected expansion. The University is currently in the design phase of a substation expansion.

Distribution Feeders

Layout

The University presently operates three (3) 23kV loop circuits identified as A1/B1 Loop (South Feeder), A2/B2 Loop (North Feeder), and A3/B3 Loop (Central Utility Plant). The A1/B1 loop is located south of Varsity Drive in the Main Campus Drive / Capability Drive area, and is arranged in a looped configuration, with the open point adjacent to Monteith Engineering Research Center. The A1/B1 Loop also acts as a source for the looped feeder extension into South Campus for the Alumni Center and the golf course.

The A2/B2 Loop (North Feeder) extends northward out of the substation and includes the northernmost section of Centennial Campus. This area is north of Varsity Drive and west of Main Campus Drive and includes the Partners II and III Buildings, the Engineering I, II and III Buildings, B Tech, Keystone and the Toxicology Building. A third loop, A3/B3, feeds the Central Utility Plant directly as an express feeder. As part of the current substation expansion a phased re-circuiting plan is being designed to handle the additional load.

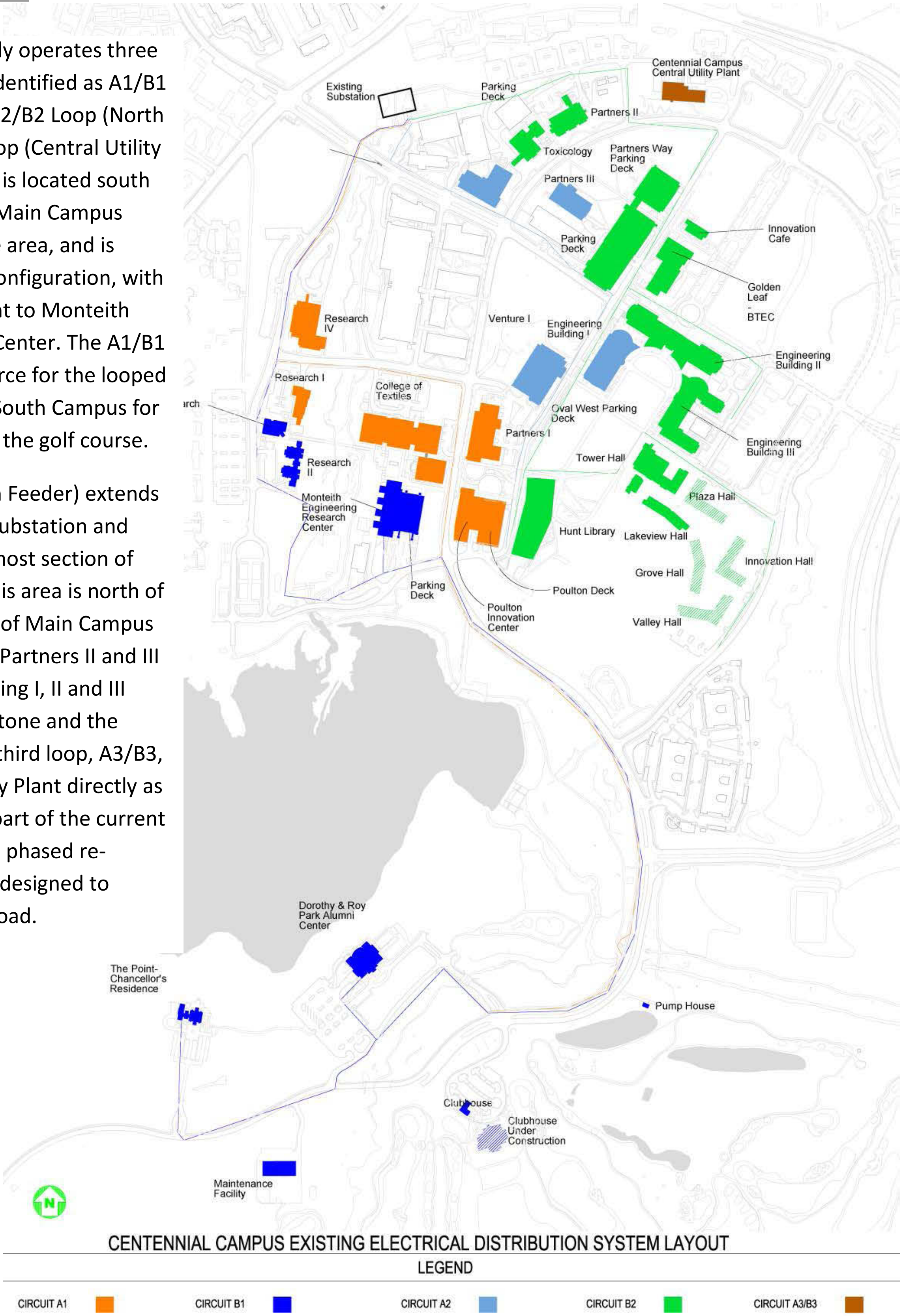


Figure 10 - Centennial Campus Electrical Distribution System

Switching Methods (Sectionalizing Switches/Open Loops)

To distribute power to the various buildings at Centennial Campus, the University has standardized the use of pad mounted 25kV sectionalizing switches. This provides for an incoming and outgoing 600 ampere load-break switch as power is distributed through the sectionalizing switch and includes two (2) fused 200 ampere radial taps that can be taken from the sectionalizing switch to individual pad mounted transformers. Alternate switches provide four (4) fused 200 amp taps with the same 600 amp incoming and 600 amp out-going positions. These sectionalizing switches are standard among utilities and other universities. They offer a cost-effective means of providing fused radial taps to individual pad mounted transformers at the various buildings on campus.

At the approximate mid-point of each looped feeder, a sectionalizing switch is selected where one of the two source switches is left in the open position to provide a normally-open point in the overall feeder loop configuration. Each of the sectionalizing switches is fitted with fault indicators that visually indicate the actual path and/or route of a fault in the event of an equipment or cable failure. These fault indicators provide a quick means of locating a cable or equipment fault, so that switching can occur in a time-efficient manner to isolate faulted equipment and restore power to the tenants on a particular underground feeder.

Reliability

The reliability of the electrical distribution system has thus far been excellent at Centennial Campus. Since the system became operational, only minimal electrical outages caused by natural occurrences such as tornados, being the only reason for electrical outages on campus. The University is continues to improve the electrical distribution system to maximize its reliability.

Electrical Rate

The entire University receives its power from Duke Energy Progress, but not all of the electrical consumption falls under the same rate structure. The main campus is under the Large General Service (LGS) rate, while the Centennial Campus is under a Large General Service- Time of Use (LGS-TOU) rate structure.

The LGS-TOU rate utilizes a demand and consumption billing structure. This type of billing is composed of two main components. The first is demand, the University is charged monthly for the maximum demand (kW) used during the electrical provider’s “On-Peak” period for that month. The second component is consumption, and the University is billed at one rate for the total electrical consumption during “On-Peak” hours and at a different rate during “Off-Peak” hours. On/Off peak hours are determined by season – summer or winter – for which different rates are assigned. On average, demand makes up 20-40% of the bill while the remainder is comprised of consumption charges.

Renewable Energy

Centennial Campus currently generates a small percentage of renewable energy which is largely due to the campus being located in North Carolina. A summary of the renewable energy found at Centennial is as follows:

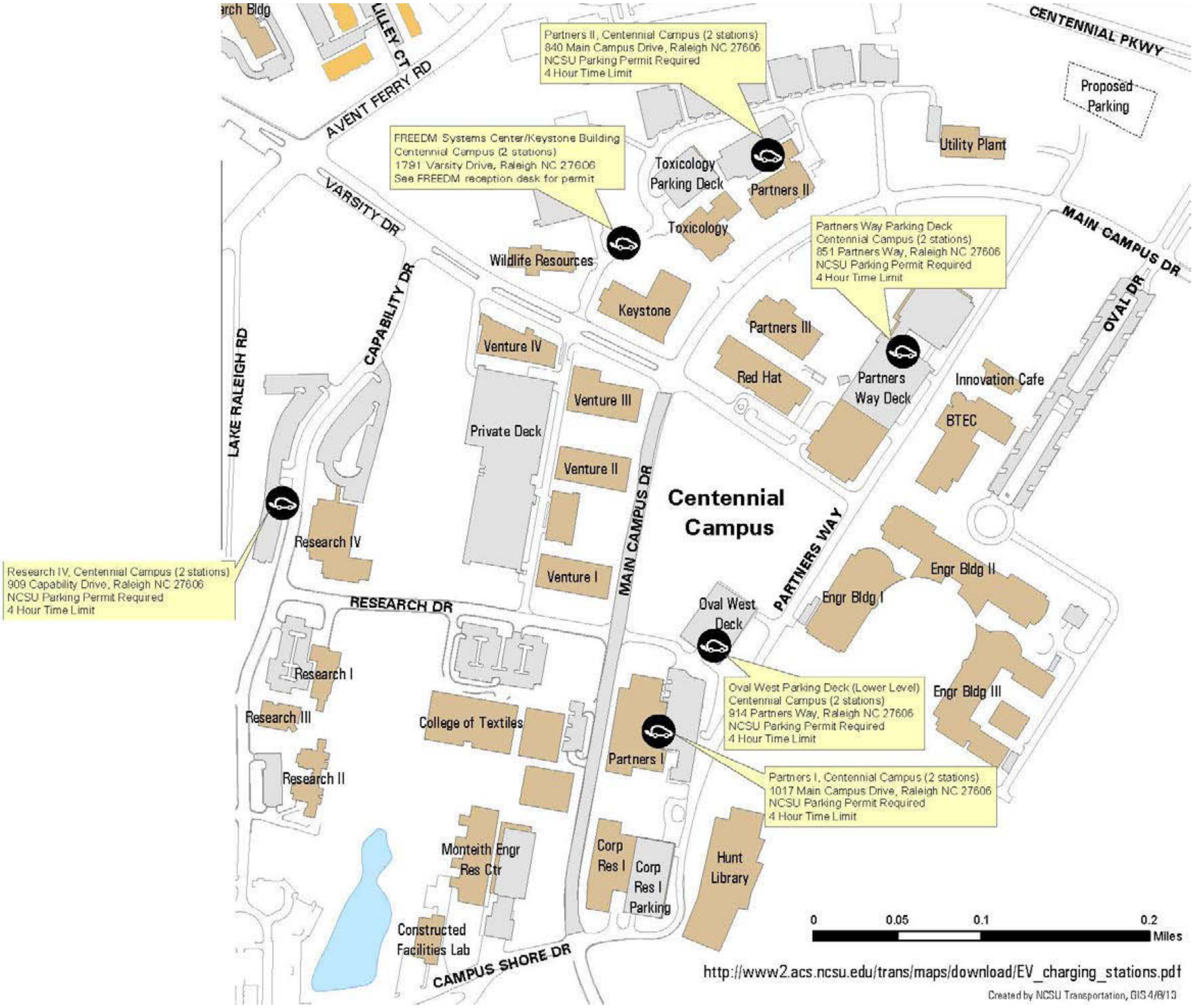
- **The James B. Hunt Library** (2012) - A twelve panel solar thermal array is located on the roof of the building. The panels are used to preheat domestic hot water.
- **Keystone Science Center** (2010) - The 40kW solar array located on the roof of the Center was donated to the FREEDM Systems Center by the Advanced Energy Group. The electricity produced by the panels is used directly by the building.
- **Research IV** (2009) – A 3kW film solar array is installed on the roof of this building. The solar array was donated to the University by Hamlin. The electricity produced by the panels is used directly by the building.
- **Park Alumni Center** (2006) - A one panel solar thermal system is located on the roof of the building. The system is used to preheat domestic hot water.

While there is a limited amount of solar energy generated on campus today, NC State is investigating increasing this amount on the Centennial Campus. The University utilized its academic resources and engaged students to complete a solar feasibility study. The study assessed all the buildings on Centennial to determine the best locations for solar. To date, there has not been a completed implementation of a solar array based on the results of the study.

Figure 11 - Keystone Science Center Solar Array

EV Charging Stations

NCSU has developed an electric vehicle (EV) charging infrastructure at Centennial Campus. The charging stations are located throughout the campus with the Keystone Science Center housing the newest charger. Figure 12 displays the various charging stations on Centennial Campus according to the NCSU transportation department. Most of the existing EV charging stations have been donated to the University and are used to support research activities. The existing charging stations communicate with a campus wide control system for monitoring.



Partners II, Centennial Campus (2 stations)
840 Main Campus Drive, Raleigh NC 27606
NCSU Parking Permit Required
4 Hour Time Limit

FREEDM Systems Center/Keystone Building
Centennial Campus (2 stations)
1791 Varsity Drive, Raleigh NC 27606
See FREEDM reception desk for permit

Partners Way Parking Deck
Centennial Campus (2 stations)
851 Partners Way, Raleigh NC 27606
NCSU Parking Permit Required
4 Hour Time Limit

Research IV, Centennial Campus (2 stations)
909 Capability Drive, Raleigh NC 27606
NCSU Parking Permit Required
4 Hour Time Limit

Oval West Parking Deck (Lower Level)
Centennial Campus (2 stations)
914 Partners Way, Raleigh NC 27606
NCSU Parking Permit Required
4 Hour Time Limit

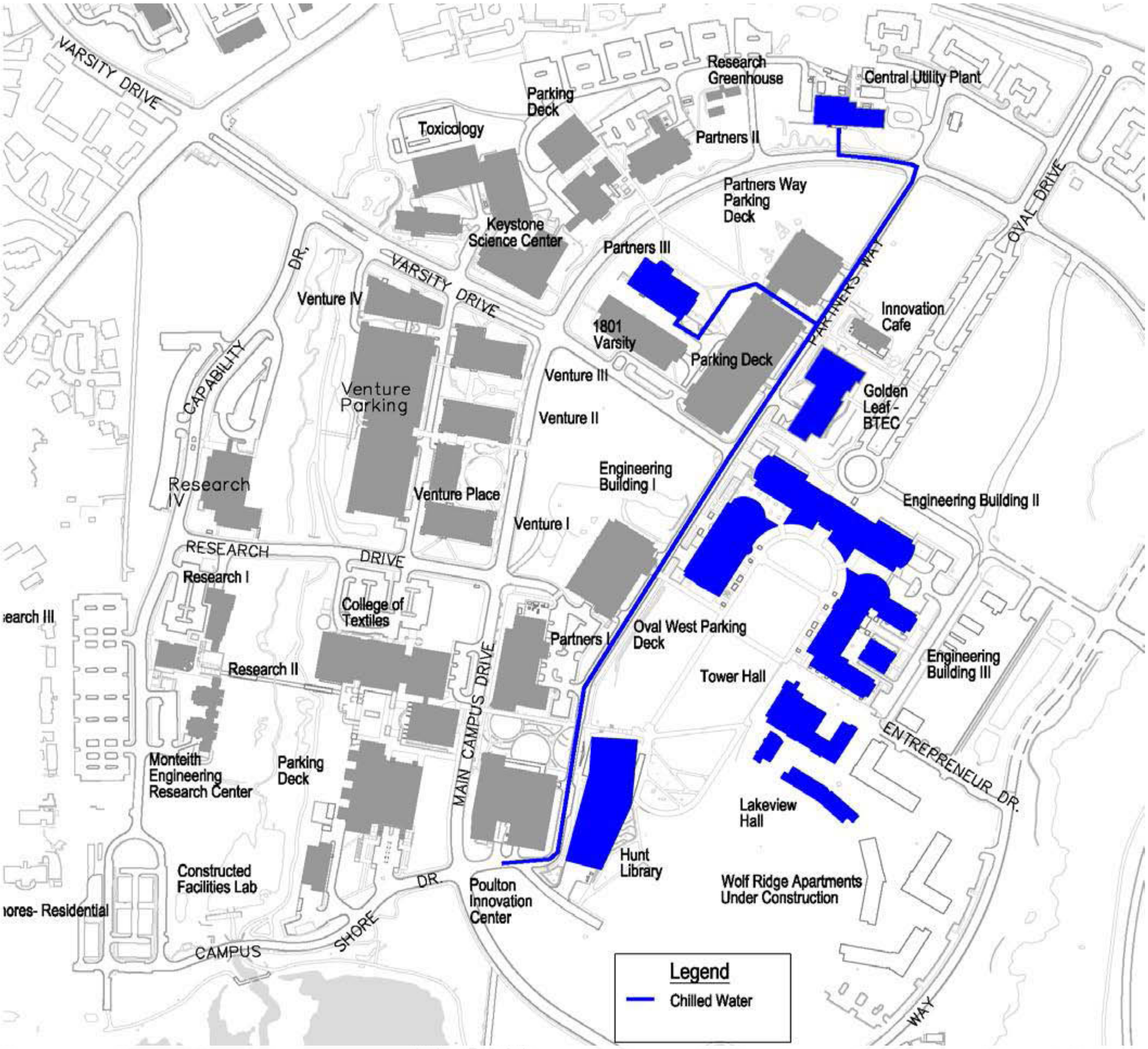
Partners I, Centennial Campus (2 stations)
1017 Main Campus Drive, Raleigh NC 27606
NCSU Parking Permit Required
4 Hour Time Limit

http://www2.acs.ncsu.edu/trans/maps/download/EV_charging_stations.pdf

Created by NCSU Transportation, GIS 4/8/13

Figure 12 - Centennial Campus EV Charging Stations

Chilled Water



The central chilled water system on campus begins at the Centennial Central Utility Plant which produces and distributes chilled water for campus usage. The plant utilizes water cooled chillers to provide a total capacity of 11,000 tons with a firm capacity of 9,000 tons. The chilled water is supplied to the campus at 42°F on average with minimal change in the supply temperature based on demand. The plant is designed to operate with a 12°F temperature differential between the supply and return water.

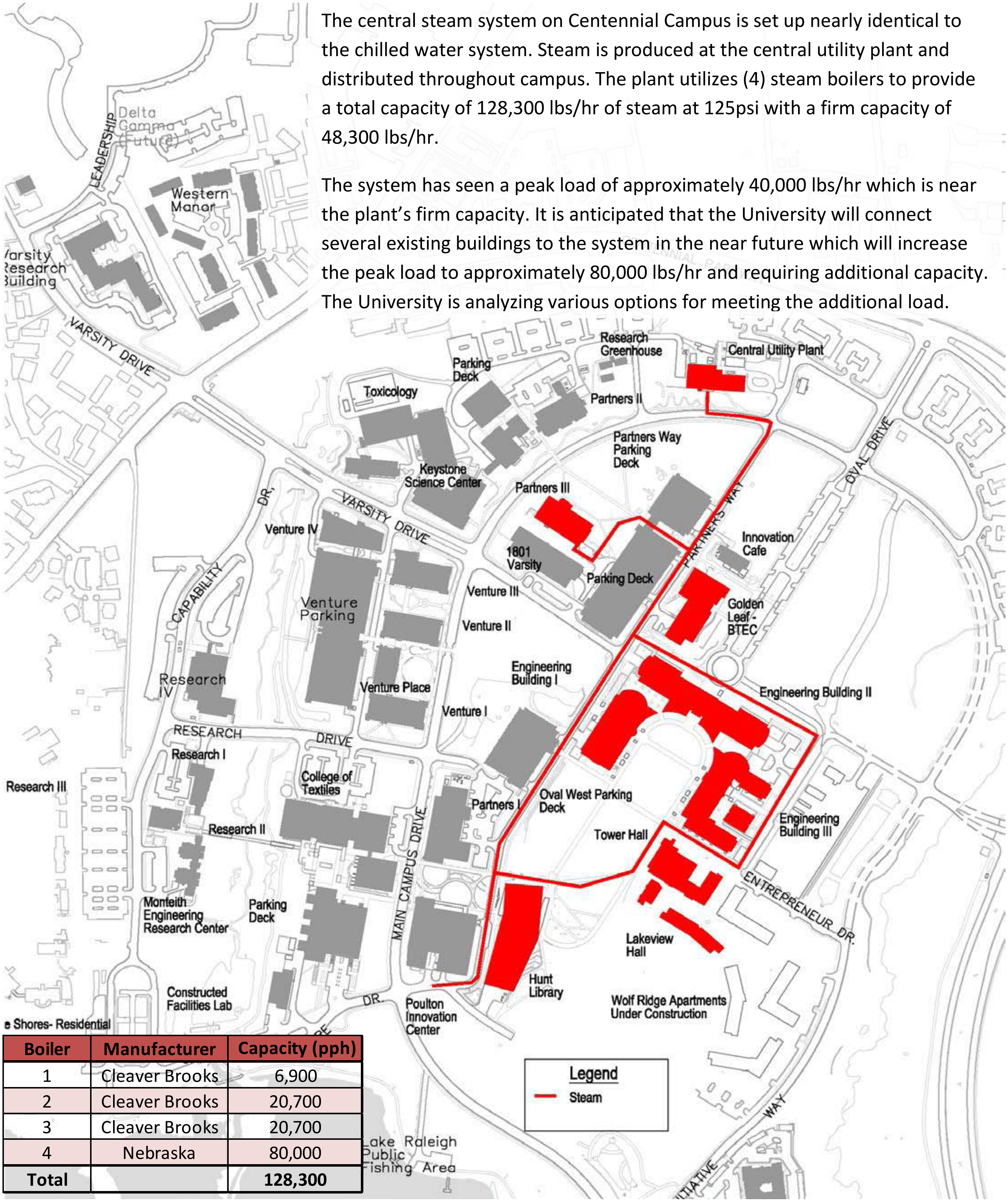
The current chilled water load connected to the plant peaks at around 6,000 tons. The University is planning to extend the chilled water distribution system to connect several buildings. It is estimated that this will increase the peak load to the plant's firm capacity of 9,000 tons. The University is analyzing various options for meeting the additional load.

Figure 13 - Centennial Campus Chilled Water Distribution System

Steam

The central steam system on Centennial Campus is set up nearly identical to the chilled water system. Steam is produced at the central utility plant and distributed throughout campus. The plant utilizes (4) steam boilers to provide a total capacity of 128,300 lbs/hr of steam at 125psi with a firm capacity of 48,300 lbs/hr.

The system has seen a peak load of approximately 40,000 lbs/hr which is near the plant's firm capacity. It is anticipated that the University will connect several existing buildings to the system in the near future which will increase the peak load to approximately 80,000 lbs/hr and requiring additional capacity. The University is analyzing various options for meeting the additional load.



Boiler	Manufacturer	Capacity (pph)
1	Cleaver Brooks	6,900
2	Cleaver Brooks	20,700
3	Cleaver Brooks	20,700
4	Nebraska	80,000
Total		**128,300**

Figure 14 - Centennial Campus Steam Distribution System

Centennial Campus Energy Usage

As would be expected for a campus with over 2 million square feet of research intensive buildings, Centennial Campus consumes a significant amount of energy. The bulk of this energy consumption is electricity used during the day. This section focuses on the primary consumers of energy on Campus including: electricity, centralized chilled water, and centralized steam.

Electricity

To understand how electricity is consumed at Centennial Campus, four methods of analysis were used. These methods included a study of monthly campus consumption, cooling degree day normalization, building energy intensity, and seasonal demand. The data gathered through this analysis provided a comprehensive summary of the Centennial Campus electrical consumption which is vital to developing an effective strategy for smart grid implementation.

Campus Analysis

The first analysis completed was a high level review of the monthly electrical consumption on Centennial Campus. This analysis identified abnormally high consumption and other patterns that merited additional evaluation. Figure 15 illustrates the most recent electrical consumption data that was gathered and displays the campus electrical consumption following bell curve that is typical in the southeastern United States with a few anomalies.

First, peak consumption occurs in September although this is not the hottest month. This is due to the occupancy schedule of the campus which is not fully occupied until the end of August. The two winter months of January and December also need to be noted. While there are several buildings that utilize electric heat, most buildings use natural gas for heat and are therefore not expected to experience seasonal peaks in electrical consumption. A typical University schedule for December and January has reduced occupancy which also reduces energy consumption for those months. This expected reduction in energy during these months is not seen at Centennial.

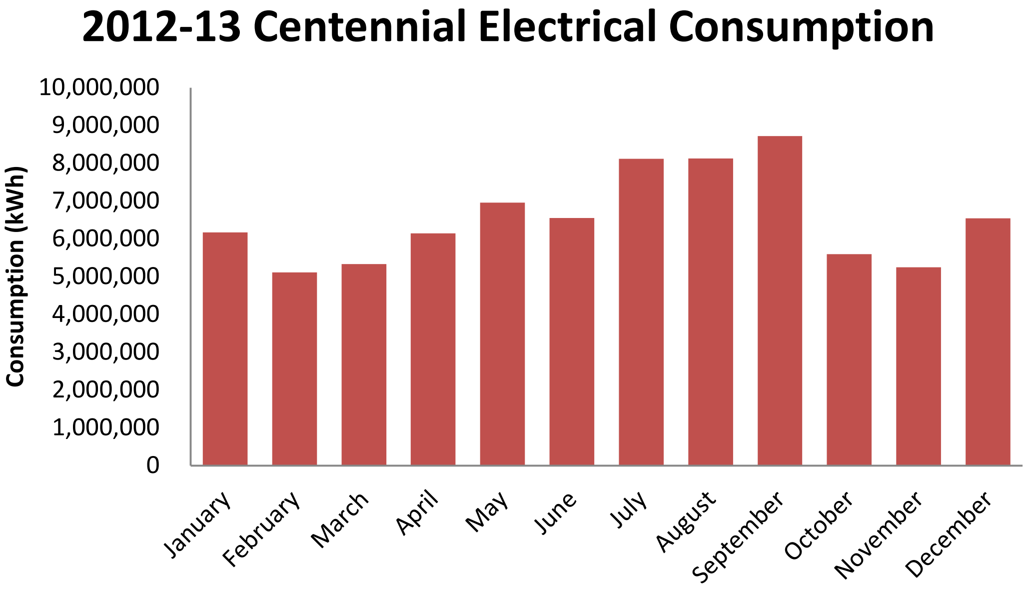


Figure 15 - Centennial Campus Annual Electrical Consumption

Cooling Degree Day Analysis

The second method of analysis performed was comparing monthly usage data to actual weather data from 2012-13. As shown in Figure 16, a calculated electrical consumption number for each month was developed based on the monthly cooling degree days and the real electrical consumption. The actual data was then compared as a percentage to the weather normalized data.

The analysis demonstrated largely expected trends. For example, May is one of the higher consumption months given that, students and faculty are in session for the first half of the month and the temperature is higher. Normalized chilled water consumption decreases during summer months as the occupancy drops. A similar trend is seen in December as the buildings are sparsely occupied during the end of the month lowering the average consumption when compared to the weather normalized data.

The analysis revealed an unexpected trend with a 27% differential between the weather normalized data and the actual data for October. This energy consumption is higher than expected, possibly caused by excess reheat or faulty economizers.

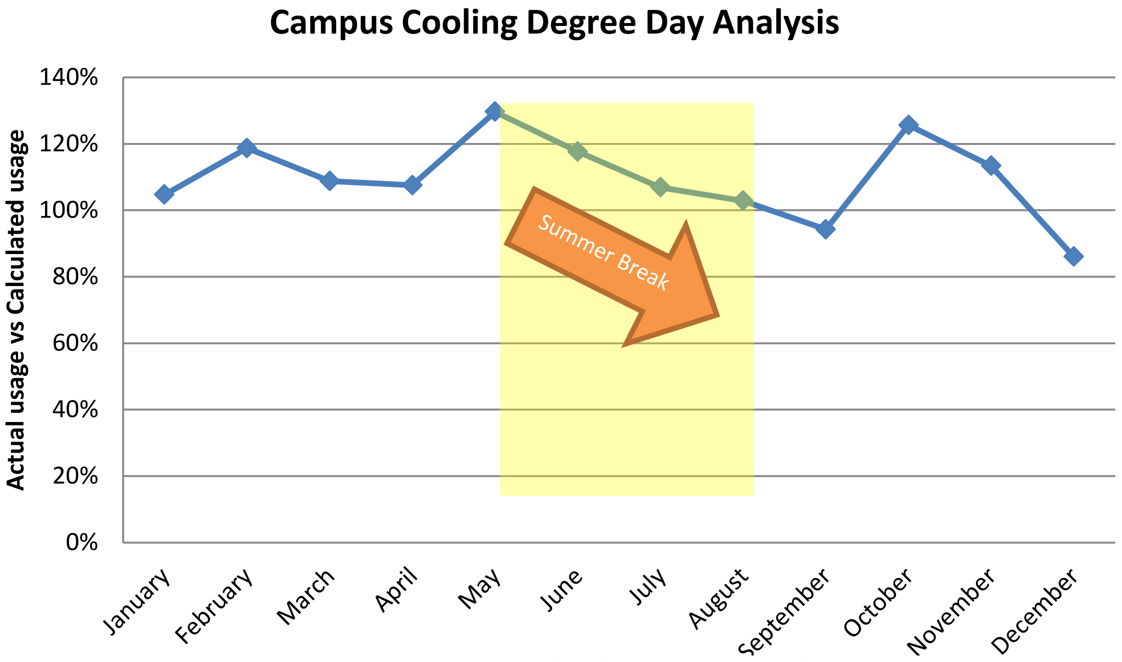


Figure 16 - Centennial Cooling Degree Day Analysis

Building Analysis

In addition to viewing the campus as a whole, the third method of analysis concentrated on energy consumption of individual buildings to pinpoint low performing buildings. The first building analysis was performed by normalizing the data and examining the electrical use intensity (kWh/sf/yr) for each building. This allows for the comparison of energy use for the various buildings in a standardized way. Results of the analysis are depicted in Figure 17.

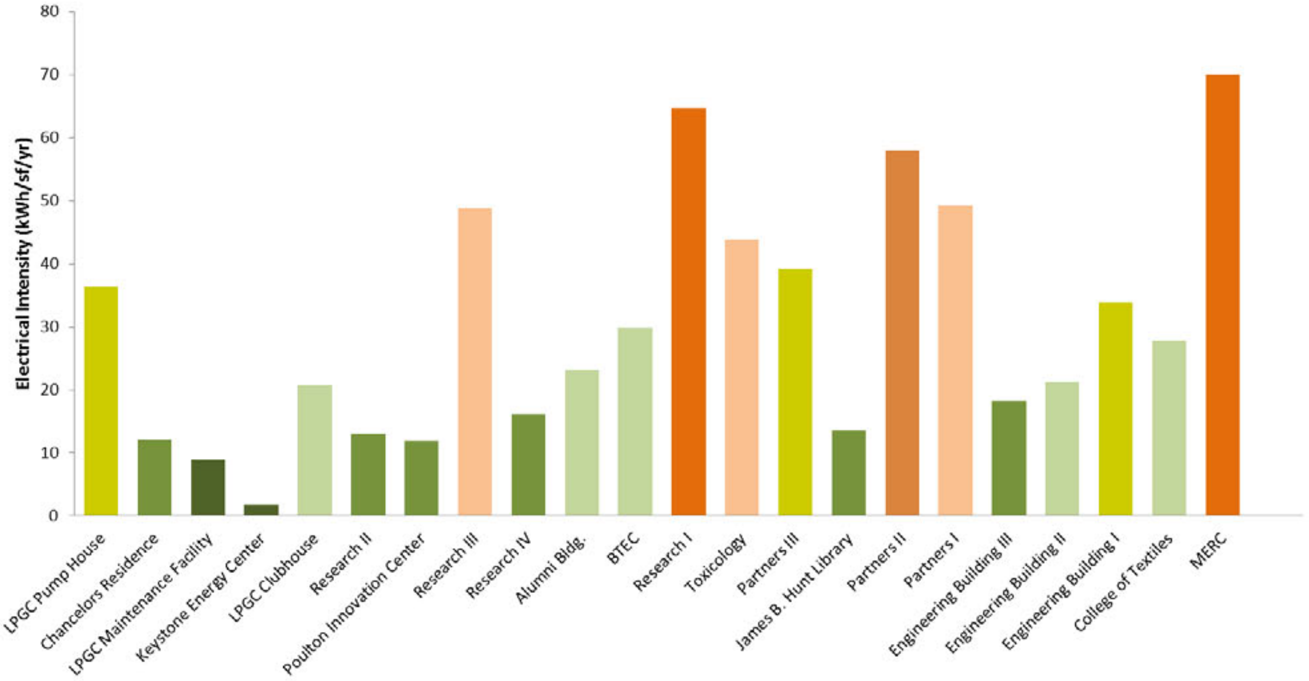


Figure 17 - Centennial Campus 2012-13 Electrical Consumption

In examining the graph, two buildings appear to use an excessive amount of energy, Research I and MERC. Both use natural gas for heating, but have nearly twice the level of electrical intensity of similar facilities. Such findings indicate that the buildings need to be examined further to better understand their energy consumption and to target potential ways to conserve energy.

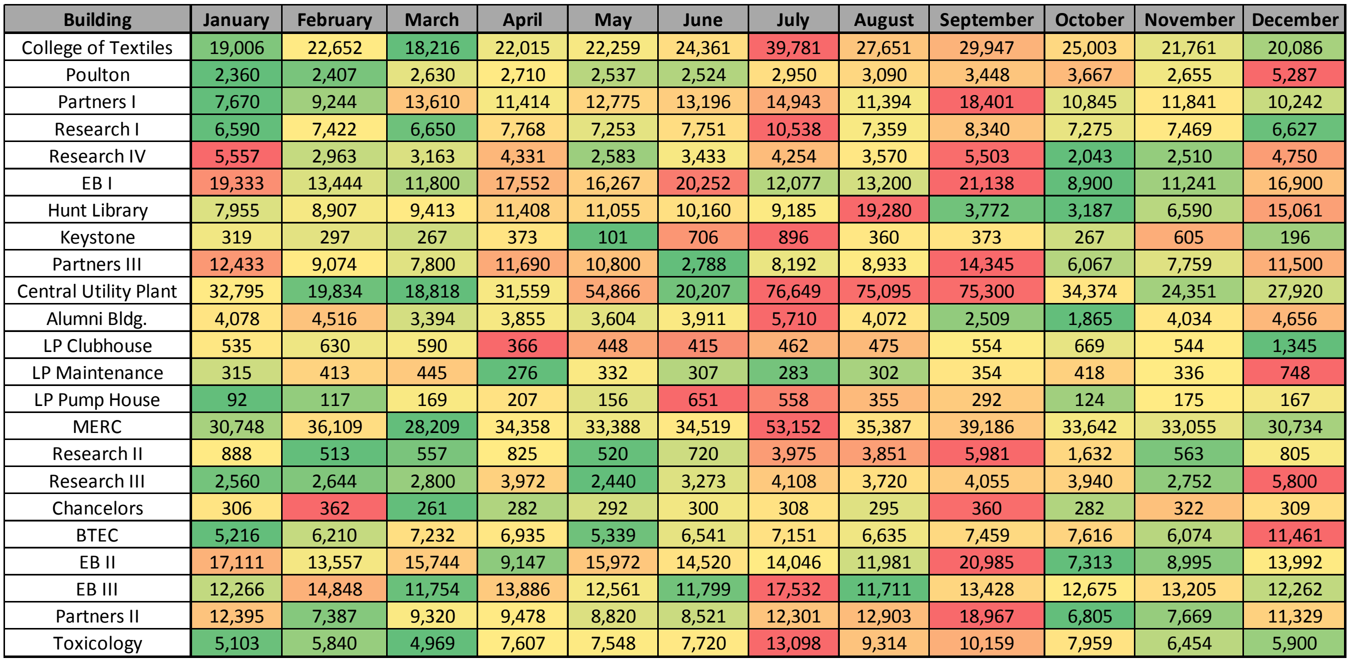
While Research and MERC are easily discernable, potential problems are also seen in other areas such as Engineering Building I (EBI). There are three engineering buildings on campus (EBI, EBII, and EBIII) which are all similar in size and space type. The energy intensity of EBII and EBIII is similar while EBI's intensity is approximately 75% higher which calls for further investigation.

In addition to highlighting the largest energy consumers, the University is able to identify which buildings are operating efficiently and possibly better than expected. Examples of efficiency are Research II, Poulton Innovation Center, and Research IV. All three buildings are operating relatively efficiently and are top performers on campus; this is to be noted as these three buildings are some of the first on Centennial Campus.

This high level analysis of building electrical consumption is not only important to developing a smart grid implementation strategy, but also to evaluating the grid's performance following implementation.

In conjunction with the building energy usage intensity analysis, a monthly review of each building's electrical consumption was also conducted. The review was performed the same 2012-13 electrical data used to create Figure 17. To mitigate any potential issues associated with the different lengths of time elapsed between meter readings, monthly data was converted to average daily consumption utilizing the number of days in the meter reading period. A color scale was then applied to categorize each building's average monthly consumption with dark green indicating lowest annual energy usage for the year, yellow depicting moderate usage, and red illustrating highest usage. The results of the building heat map analysis are shown in Table 2.

Table 2 - Building Electrical Consumption



Building	January	February	March	April	May	June	July	August	September	October	November	December
College of Textiles	19,006	22,652	18,216	22,015	22,259	24,361	39,781	27,651	29,947	25,003	21,761	20,086
Poulton	2,360	2,407	2,630	2,710	2,537	2,524	2,950	3,090	3,448	3,667	2,655	5,287
Partners I	7,670	9,244	13,610	11,414	12,775	13,196	14,943	11,394	18,401	10,845	11,841	10,242
Research I	6,590	7,422	6,650	7,768	7,253	7,751	10,538	7,359	8,340	7,275	7,469	6,627
Research IV	5,557	2,963	3,163	4,331	2,583	3,433	4,254	3,570	5,503	2,043	2,510	4,750
EB I	19,333	13,444	11,800	17,552	16,267	20,252	12,077	13,200	21,138	8,900	11,241	16,900
Hunt Library	7,955	8,907	9,413	11,408	11,055	10,160	9,185	19,280	3,772	3,187	6,590	15,061
Keystone	319	297	267	373	101	706	896	360	373	267	605	196
Partners III	12,433	9,074	7,800	11,690	10,800	2,788	8,192	8,933	14,345	6,067	7,759	11,500
Central Utility Plant	32,795	19,834	18,818	31,559	54,866	20,207	76,649	75,095	75,300	34,374	24,351	27,920
Alumni Bldg.	4,078	4,516	3,394	3,855	3,604	3,911	5,710	4,072	2,509	1,865	4,034	4,656
LP Clubhouse	535	630	590	366	448	415	462	475	554	669	544	1,345
LP Maintenance	315	413	445	276	332	307	283	302	354	418	336	748
LP Pump House	92	117	169	207	156	651	558	355	292	124	175	167
MERC	30,748	36,109	28,209	34,358	33,388	34,519	53,152	35,387	39,186	33,642	33,055	30,734
Research II	888	513	557	825	520	720	3,975	3,851	5,981	1,632	563	805
Research III	2,560	2,644	2,800	3,972	2,440	3,273	4,108	3,720	4,055	3,940	2,752	5,800
Chancelors	306	362	261	282	292	300	308	295	360	282	322	309
BTEC	5,216	6,210	7,232	6,935	5,339	6,541	7,151	6,635	7,459	7,616	6,074	11,461
EB II	17,111	13,557	15,744	9,147	15,972	14,520	14,046	11,981	20,985	7,313	8,995	13,992
EB III	12,266	14,848	11,754	13,886	12,561	11,799	17,532	11,711	13,428	12,675	13,205	12,262
Partners II	12,395	7,387	9,320	9,478	8,820	8,521	12,301	12,903	18,967	6,805	7,669	11,329
Toxicology	5,103	5,840	4,969	7,607	7,548	7,720	13,098	9,314	10,159	7,959	6,454	5,900

Table 2 highlights several noteworthy trends. First, the annual peak for each building's consumption usually occurs in July or September, while the lowest annual consumption is usually seen in January or February.

Several building specific items are also illustrated. The College of Textiles' peak consumption is in July and is approximately 30% higher than all other months. Such an increase for one month may indicate an inefficient cooling system and merits further examination. Another example is Engineering Building I, which experiences peaks in September and January. While a September peak is expected, a peak in January when students are not in session is an anomaly and may indicate an issue with the HVAC system. This particular issue may be larger than shown in Table 2 indicates since Engineering Building I is connected to the central utility loop which likely experienced increased load in February as well.

The two buildings cited above are good examples of potential issues with building electrical consumption. Similar items may be found in many of the buildings on campus. Implementation of a smart grid would aim to quickly and effectively address such anomalies by alerting facility personnel of potential issues at a building or equipment level.

Seasonal Demand Analysis

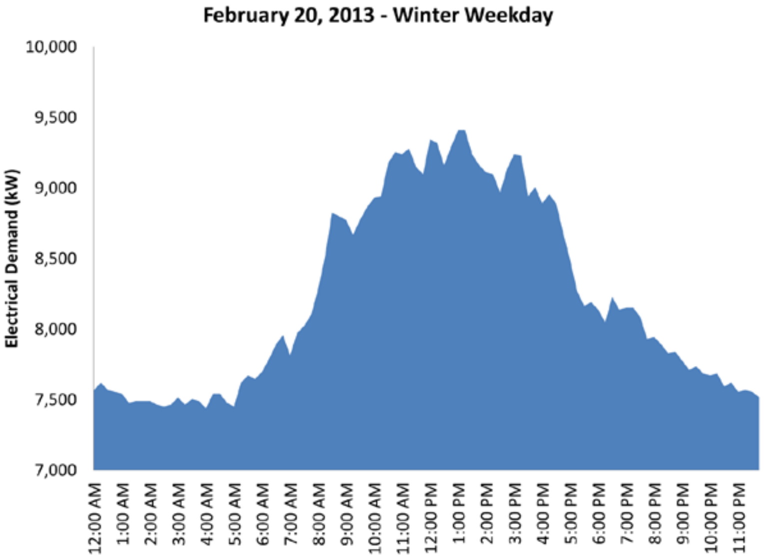
The fourth method of analysis used was a seasonal assessment of the campus' electrical consumption to identify potential optimizations. For each season, a weekday and weekend day was selected and their demand levels were compared. This analysis utilized daily snapshots to depict a typical day in that season and discuss how a smart grid could assist in shaping the energy curve. A more thorough analysis may yield slightly different conclusions.

Overall

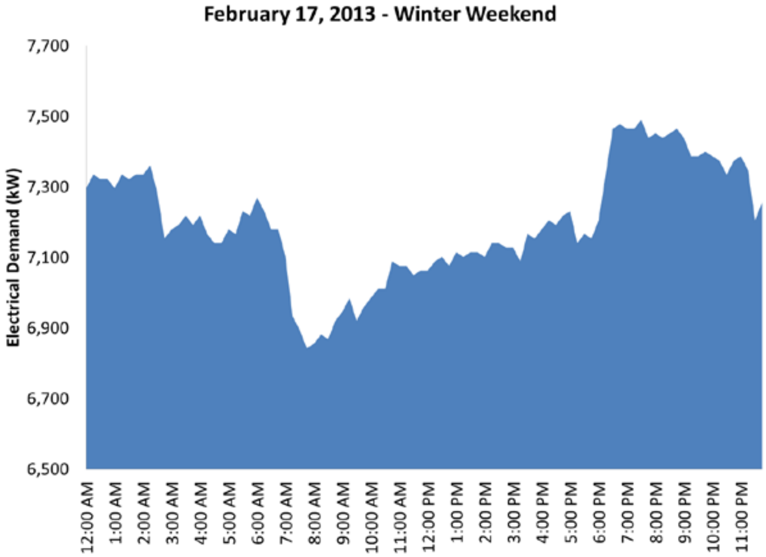
In addition to the seasonal trends discussed below, several annual trends are also worth noting. First, an approximate 2,000kW increase in electrical consumption from 8:00am to 9:00am during the weekday which occurs when systems turn on and the majority of building occupants arrive. After this initial peak, the increase in consumption is dependent on the season. Secondly, energy consumption during the weekends is generally flat. In each season the weekends experience a relatively small increase in energy consumption throughout the day as compared to the weekdays.

Winter

The two profiles to the right illustrate typical electrical demand for occupied winter days at Centennial Campus. During the weekday, the electrical demand on campus follows a standard peak that drops to a flat line as occupation levels decrease. During occupied periods, the electrical demand spikes initially and then experiences minor spikes through the remainder of the occupied timeframe. During unoccupied times, the electrical demand returns to a relatively flat line. A smart grid would aim to remove the minor peaks in demand.

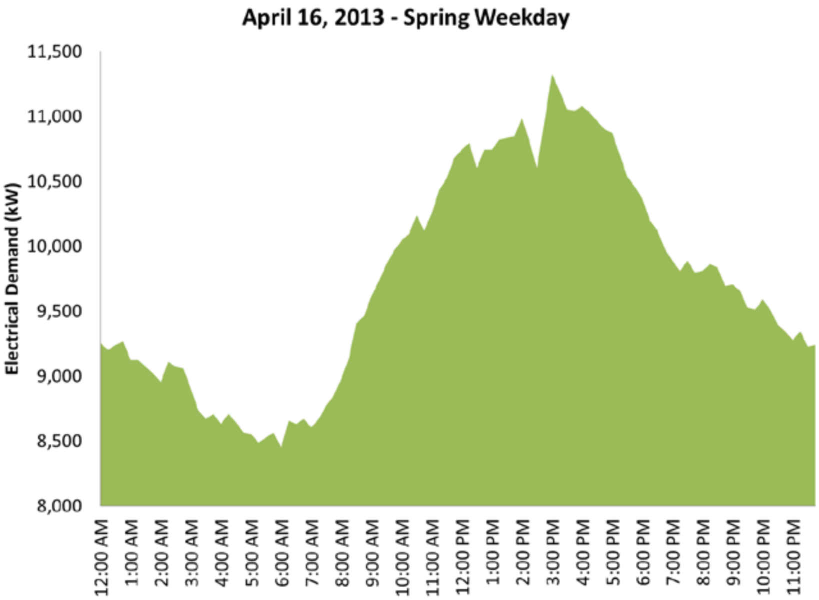


The weekend electrical demand profile has an inverse shape of the weekday demand. This is explained by two factors, occupancy and weather. During the weekends, there is a relatively constant plug load due to minimal occupancy on campus and the need for more energy to offset cooling temperatures. It is important to note that there are two load changes which occur at 7:00am and 7:00pm, rather than a slow increase. These changes are likely associated with scheduling issues that a smart grid would attempt to correct and/or minimize. A final note is that the differential over the weekend period is approximately 700kW versus the 2,000kW differential during the weekday.

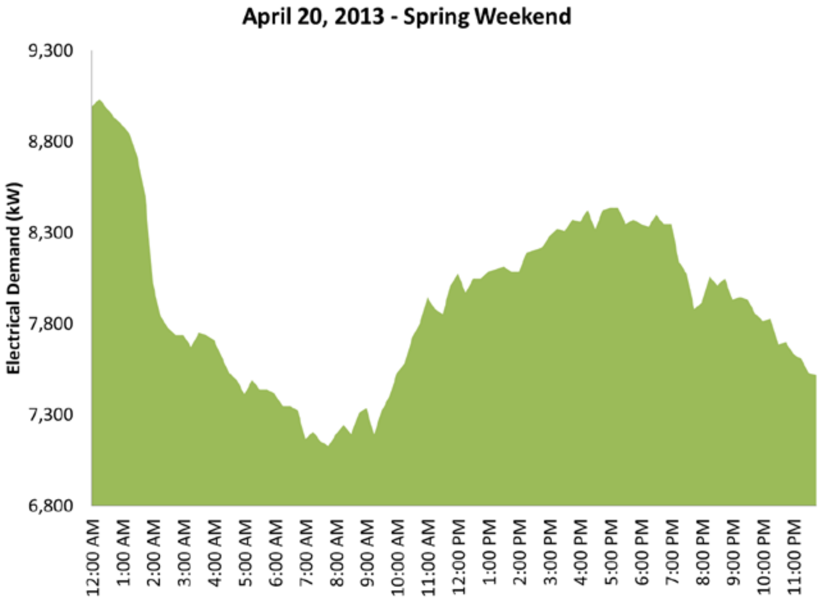


Spring

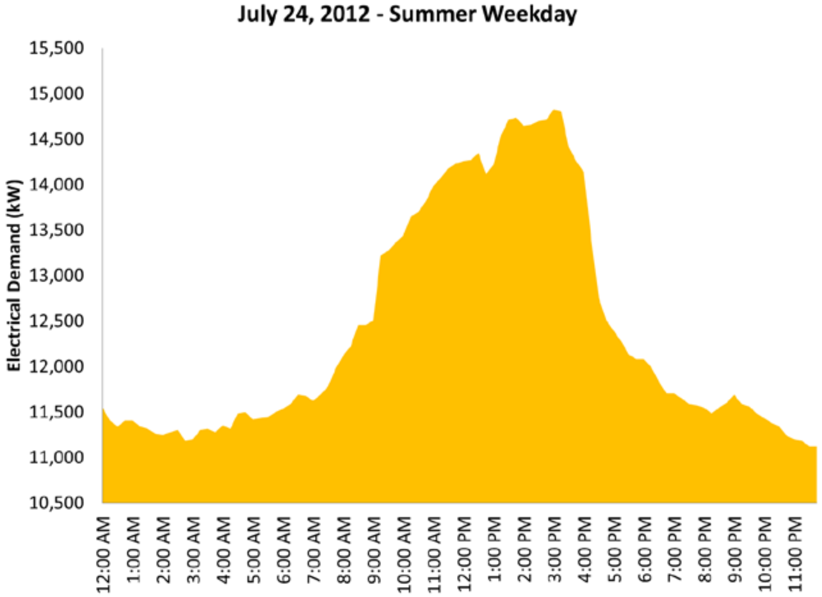
Two spring days were analyzed while school was still in session after spring break and before finals. The weekday electrical demand observed during those days follows as expected with an initial increase as occupants enter in the morning. Demand increases further as a result of a higher occupant/plug load and climbing temperatures over the course of a day.

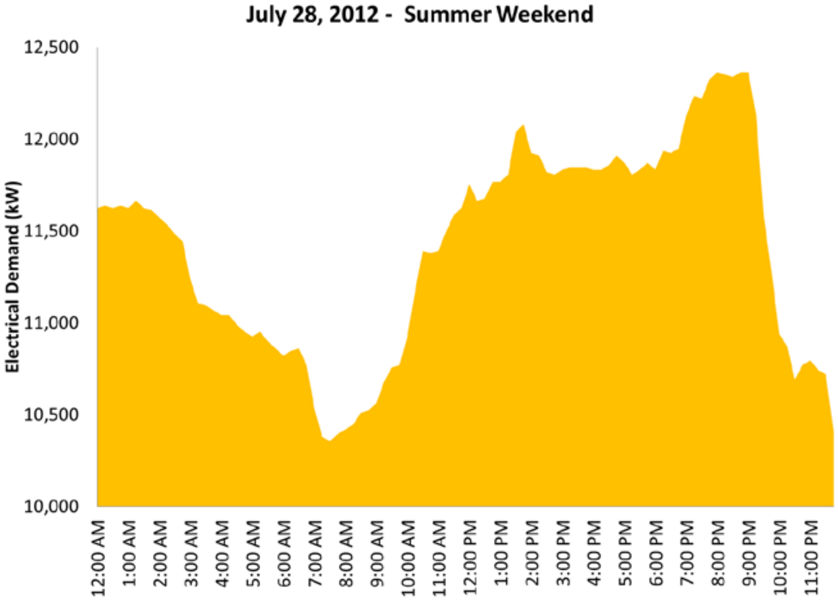


As campus occupancy decreases, the energy consumption decreases at an incremental pace. The peak in demand from the heat gain during the occupied period slowly drops, reaching its lowest level at 5:00am where it remains for only one or two hours. A smart grid would include developing a strategy to help the campus reach its minimum consumption faster and retain it for a longer period of time.



During the weekend in the spring, the electrical demand peaks at midnight. This is likely due to the BAS not switching over to a weekend mode until 12:00 am on Saturday. Following the operational mode change over the system still requires a couple of hours to react. Integrating the systems will allow for a smarter system that is able to fine tune the energy demand and remove excess consumption and optimize scheduling.





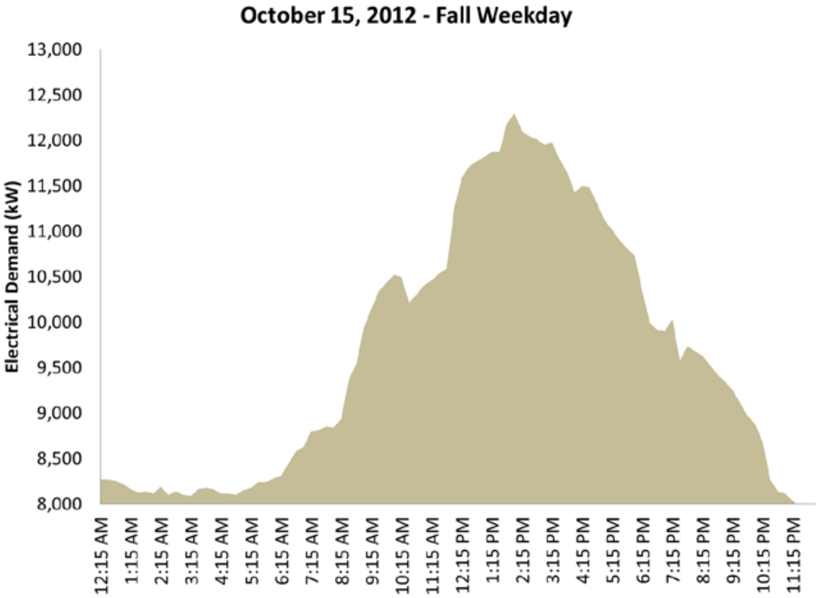
Summer

During a summer weekday, the campus experiences a relatively normal peak that flat lines during unoccupied hours. Peak demand lasts approximately 2-3 hours at a level approximately 30% higher than unoccupied periods. This peak versus unoccupied differential is relatively small for a campus which is not aggressively shaping its demand curve. A smart grid would strive to spread the peak over a longer period to reduce utility demand charges.

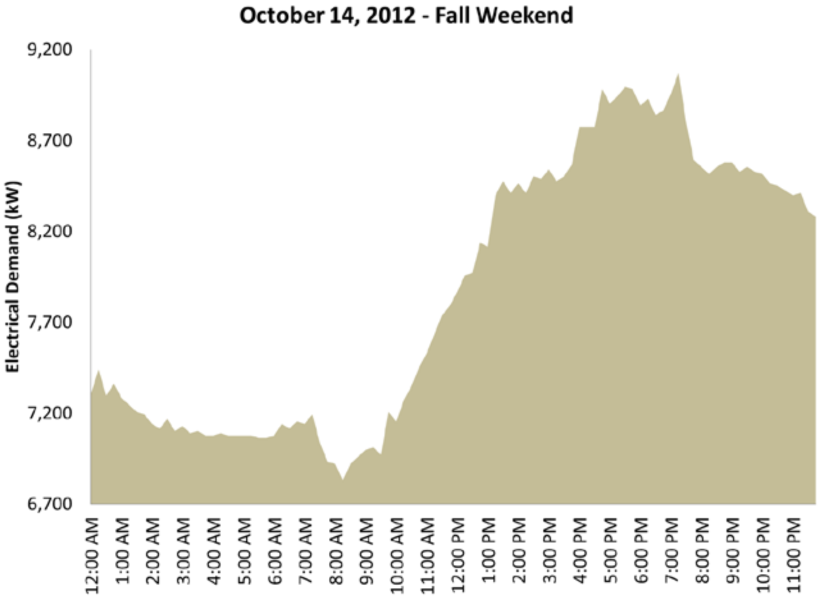
The effect of optimizing scheduling is evident when analyzing the summer weekend load profile. The highest energy demand on campus occurs at 9:00pm and rapidly decreases at 10:00pm. Implementation of a smart grid would lower this peak and level out overall energy consumption.

Fall

The electrical load profile of a fall weekday follows a similar pattern as the other seasons. The profile shows an initial peak in demand which is associated with the arrival of the occupants followed by another peak caused by increased cooling loads that occur in midafternoon. The load then slowly decreases until midnight. The load curtailment is relatively quick, but is rather high with a 4,000kW differential which is nearly double what is seen during the spring.



The fall weekend profile is for a Sunday and it appears the campus is utilizing a pre-cooling strategy at night in preparation for the weekday occupancy and increased cooling load. This strategy is very effective for hot days but may waste energy on days in the cooler months. Using a predictive energy model would concentrate on maximizing efficiency of operations such as pre-cooling.



Central Chilled Water

The Centennial Campus central utility plant is the largest user of energy on the campus and chilled water production comprises the majority of the electrical consumption at the plant. Reduction of the plant's existing energy consumption through the implementation of a smart grid was analyzed following a two part approach. First, benchmarking was used to verify that the chilled water production and usage on campus is at normal levels. Secondly, production data was normalized to the actual weather to understand the effects that the weather has upon the chilled water consumption on campus.

The analysis of the central chilled water system for Centennial Campus was conducted at the central utility plant level since individual building meter data is not currently available. Individual building data will be available when the smart metering project for the central utility loop is completed. The central utility plant does not serve all buildings on campus, some of which are served by local chillers or direct expansion (DX) cooling units. Refer to the chilled water distribution system map in the utility infrastructure section of this plan to see what buildings are served by the plant.

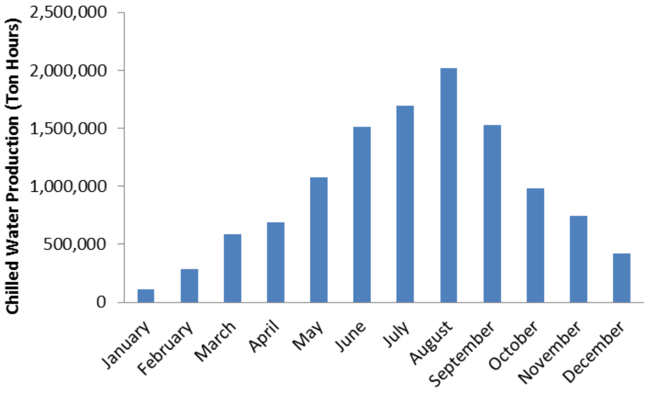


Figure 18 - 2011 CUP Chilled Water Production

Chilled Water Benchmark Analysis

The chilled water benchmark analysis gauges how campus buildings are currently performing compared to average buildings and identifies opportunities to optimize and reduce chilled water consumption. The benchmark analysis was prepared by calculating annual chilled water consumption data for each building based on typical consumption.

The individual building benchmark figures were developed using *Energy IQ,* a database produced by Berkley Lab and sponsored by the U.S. Energy Information Administration. The database uses data collected during the Commercial Building Energy Consumption Survey (CBECS) from 2003. The Energy IQ database provides consumption information for the buildings categorized by size, construction, configuration and climactic region.

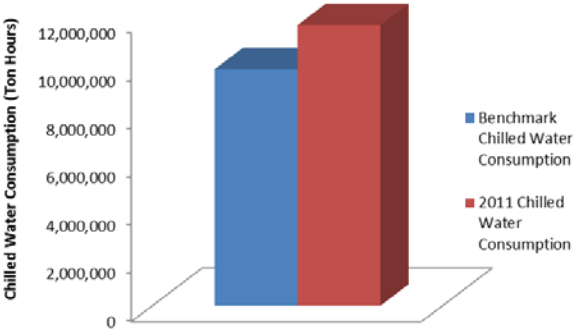


Figure 19 - Campus Chilled Water Consumption Benchmarking

The results of the benchmarking analysis indicate that the campus consumes approximately 20% more chilled water than the benchmarked buildings. This differential indicates there is potential for system improvement with the existing infrastructure.

Cooling Degree Day Analysis

A cooling degree day analysis of the chilled water production was also performed. This analysis assessed how the plant production is impacted by the weather. Production data from 2011 was used along with actual 2011 weather data.

A regression analysis was conducted to identify discrepancies that need further investigation. As illustrated in Figure 20 two major discrepancies were found.

The first discrepancy was the actual data was lower than the calculated data during the month with the highest number of cooling degree days. This was caused by the decrease in occupancy for that month as well as less reheat in the spaces.

The second discrepancy was the actual consumption data significantly exceeded the regression line for the spring and fall months. Since these months experienced between 100-300 cooling degree days, this indicates energy was being wasted. This may have been caused by a variety of factors including issues with simultaneous heating and cooling or the ineffective use of economizers. A smart grid would utilize a weather- based campus sequence of operations to lower fluctuations seen in months like October.

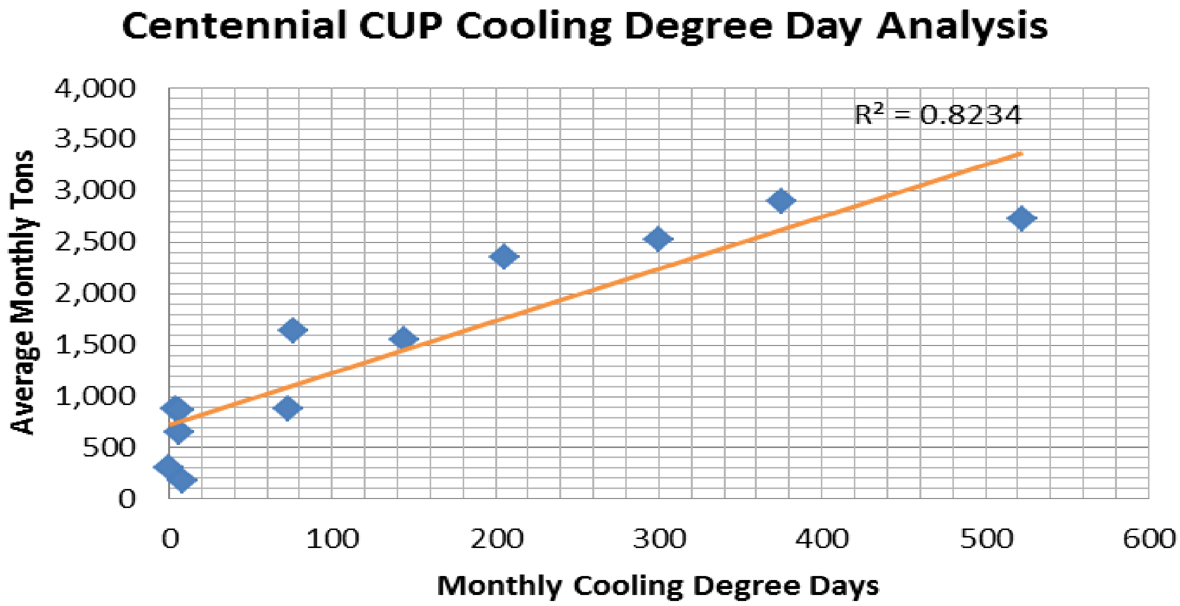


Figure 20 - Centennial CUP Cooling Degree Day Analysis

Steam

The central steam distribution system on campus is similar to the chilled water system and was analyzed utilizing the same methodology. Steam consumption was benchmarked against similar buildings then the monthly data was compared with 2013 weather data to identify any discrepancies or anomalies in need of further investigation.

The analysis of the steam system for Centennial Campus was conducted at the central utility plant level as individual building meter data is not currently available. Individual building meter data will be available when the smart metering project for the central utility loop is completed. The central utility plant does not serve all of campus with some buildings being served by local boilers or electric heat; refer to the steam distribution system map in the utility infrastructure section of this plan to see what buildings are served by the plant.

Benchmark Analysis

Similar to the chilled water, the campus steam consumption was evaluated using benchmarking. For each building the same *Energy IQ* database was applied. The primary focus was on the district heating energy consumption of the individual buildings.

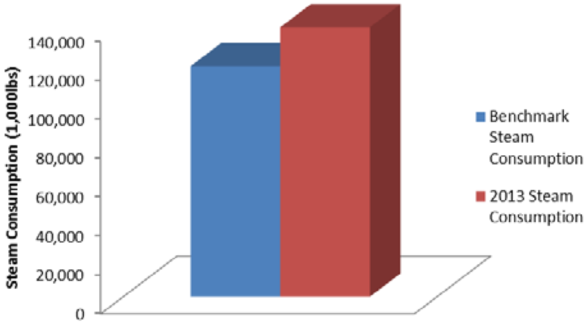


Figure 21 - Campus Steam Consumption Benchmarking

The results of the benchmarking indicated that the campus consumes approximately 15% more steam than comparable buildings. This differential indicates that there is opportunity for system efficiency improvements with the existing infrastructure.

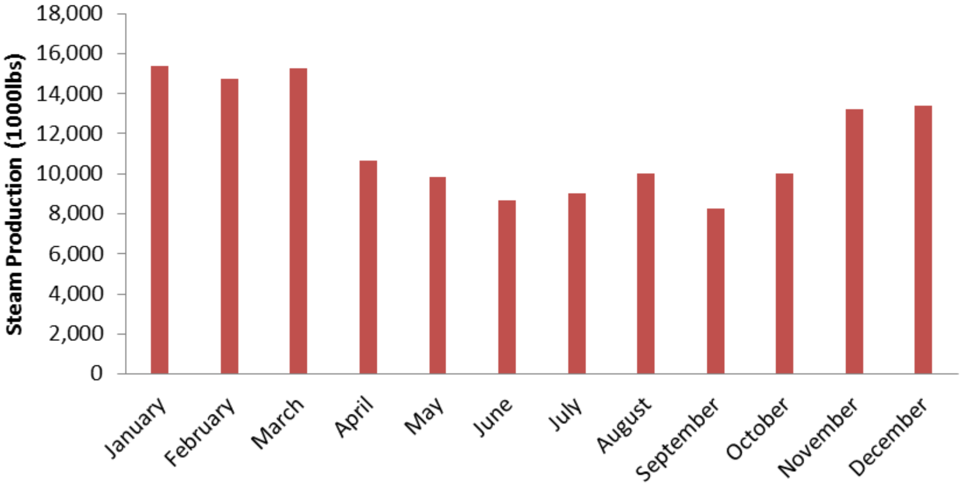


Figure 22 -2013 CUP Steam Production

Heating Degree Day Analysis

Like the chilled water production evaluation, a regression analysis of the steam production versus heating degree days was performed to provide a holistic picture of the campus steam consumption. Additionally, the regression helped validate concerns identified in the chilled water analysis. To maintain consistency, 2013 utility data was used.

The results of the analysis are depicted in Figure 23. Unlike the cooling degree day analysis, the steam consumption is closely correlated with the weather data. While the strong correlation is a positive indication the steam production is aligned well with weather-related needs, the clustering found at both ends of the analysis merits further examination.

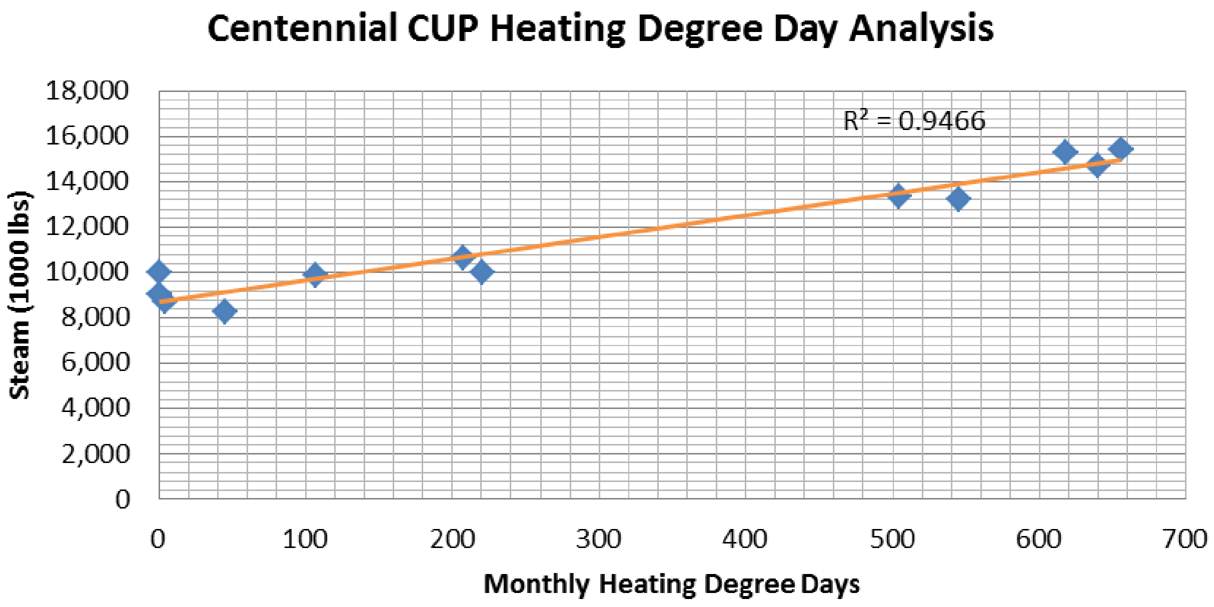


Figure 23 - Centennial CUP Heating Degree Day Analysis

Campus Smart Grid Expertise

A unique blend of knowledge from NC State researchers and private industry professionals is found at Centennial Campus. The collaborative effort between researchers and corporations is mutually beneficial. Below is a description of the collegiate and corporate knowledge base at Centennial Campus that a smart grid implementation would support.

Collegiate

There are more than 75 NC State research centers, institutes, laboratories, and department units located at Centennial Campus. Two currently dedicate their research toward the development of the smart grid and its associated technologies. These facilities are the FREEDM Center and the North Carolina Solar Center

FREEDM Center

The Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Center is an engineering research center dedicated to developing new technologies, hardware and software, for the smart grid. The FREEDM Center focuses on developing technology in energy storage and power semiconductor devices that connect scientific research with industry.

Figure 24 - Keystone Science Center

The FREEDM Center (Center) is a consortium of smart grid researchers and corporate partners engaged in a variety of ways that range from working with grade school students to partnering with corporations. The Center exposes research to pre-college students to cultivate their interest in the field. The Center also utilizes its partnerships with over 60 companies to develop electrical power technology.

The Center is located in the Keystone Science Center which contains office space, computer laboratories, a Real Time Digital Simulator lab, energy storage testing, and a 1MW Green Hub Demonstration Lab. The demonstration lab functions as a research facility and also showcases renewable energy technologies such as solar, wind, fuel cell, battery storage, flywheel storage, and plug-in vehicles.

North Carolina Solar Center

Located close to Centennial Campus, the North Carolina Solar Center (NCSC) is a leading alternative energy center. The NCSC began in 1981 to research and demonstrate the benefits of passive solar, solar water heating, and solar electricity. Since its founding, the Center has served as a major source for renewable energy research and the management of renewable energy programs, grants, and other funding.

A primary function of the Solar Center is to lead and maintain the Database of State Incentives for Renewables & Efficiency (DSIRE) that is funded by the U.S. Department of Energy. DSIRE is the leading resource for renewable energy and energy efficiency policy and incentives. Additionally, the Center has utilized its NC Solar House as a welcome center to educate visitors on a variety of renewable energy technologies. The Solar Center is staffed by nearly 40 professionals who cover all renewable energy areas. Staff members are dedicated to a plethora of areas including high performance buildings, clean transportation, clean distributed generation, and workforce training and economic development that revolves around renewable technologies.

Figure 25 - NC Solar House Center

NC State University Energy Controls Lab

The University is currently in the process of starting the NC State University Energy Controls Lab (Lab) on Centennial Campus to provide a living laboratory resource for cutting edge smart building research and academic programs. The Lab will look to address the need for engineers with practical, multi-disciplinary skills in the controls industry. The Lab's core function will be beta testing control systems for better integration and interoperability prior to implementation. The Lab will look to utilize building automation controls and systems integration of boilers, chillers, HVAC, CHP, etc... The Lab plans to work with the University Facilities department to compare actual data to modeled data to improve modeling software's predictive performance and better understand the numerous variables involved with the different systems.

University Partners

Today at Centennial Campus, there are over 60 partners across the corporate, government, and non-profit sectors. The partners range in size from startups to Fortune 500 entities. The primary focus of most partners is the development and application of technologies. For example, there are numerous companies including Duke Energy Progress and ABB Inc. that concentrate their smart grid research at Centennial Campus.

ABB Smart Grid Center of Excellence

ABB has invested substantially in smart grid research at Centennial Campus. The company recently launched the Smart Grid Center of Excellence:

In December 2011, ABB opened a state-of-the-art Smart Grid Center of Excellence (COE). The COE was created to demonstrate ABB's technology and investment in the smart grid industry. The COE has functional systems that display the end-to-end solution where information technologies and operational technologies connect to close the loop of automation, control, and data acquisition. In addition to the demonstration area, there is a Distribution Automation Verification Center where the interoperable testing of industry accepted products and development of advanced applications can take place. (ABB website)

Duke Envision Center

Duke Energy Progress constructed the Envision Center at Centennial Campus to help educate industry and legislative personnel on the capabilities of the smart grid. The Envision Center features a smart home complete with solar panels, an electric vehicle, smart meters, and a power delivery control center with real-time monitoring. At the Envision Center, visitors learn how smart grid technologies transform power distribution systems and utilize energy more efficiently.

Figure 26 - ABB Smart Grid Center of Excellence

Viable Smart Grid Technologies for Centennial Campus

The existing infrastructure, facilities, and knowledge at Centennial Campus are robust. To determine which smart grid technologies best compliment the campus, a wide array of smart grid technologies were assessed and grouped into three categories: Centennial Campus Smart Grid Proving Grounds (CCSGPG), Reliability, and Energy Optimization. The results of this assessment are presented in this section. Specific projects for the campus will be discussed in the *Implementing a Smart Grid at Centennial* section of the report.

Centennial Campus Smart Grid Proving Grounds

Overview

Centennial Campus encompasses a wide array of existing smart grid research and development capabilities. The CCSGPG intends to utilize the existing capabilities while developing new capabilities. By functioning as a virtual proving ground, the CCSGPG brands the University's smart grid capabilities without creating a new department or requiring additional management. This section describes the overall concept of the CCSGPG and the new and existing resources affiliated with it.

Goals

There are three major goals that the Proving Grounds strive to accomplish: serving as a smart eco system, fostering a culture of collaboration, and cultivating next generation thinking. These goals are intended to provide the University with unique research capabilities beyond what is found in a typical lab and research environment.

Smart Eco System

The CCSGPG aims to not only nurture ideas but also to develop them from concept to a commercially viable product without having to leave the campus. To accomplish this goal, the CCSGPG plans to first utilize the consortium of knowledge located on campus then develop and test prototype devices and concepts. With a working and lab-tested prototype, the system may be tested in a safe real world environment. All of these developments occur at the CCSGPG, developing from idea to reality all in one location.

Culture of Collaboration

While there is currently a large amount of collaboration occurring on campus, the CCSGPG seeks to encourage further collaboration. This alliance may happen in a variety of ways such as researchers working alongside a corporation through all stages of product development or facilitating a cooperative effort between two manufacturers. Ultimately, the CCSGPG seeks to house a culture of collaboration unlike any other in the smart grid realm.

Next Generation Thinking

In the field of research and development, the latest state-of-the-art commercially available technology is considered outdated. The CCSGPG aims to offer a test infrastructure that is ready for now and the future. The CCSGPG wants to be at the forefront of development for products that are 1-5 years and 6-10 years away from production. The test infrastructure is meant to adapt to the new requirements of developing technology and easily undergo upgrades if required.

Partnerships

One way Centennial Campus distinguishes itself from any other smart grid resource is its contributors. On a typical college research campus, the primary focus is graduate lab research with occasional external input from industry partners. Conversely, industry research is usually conducted in restricted corporate environment with limited consulting input from researchers. Centennial Campus is progressing beyond these limitations by actively integrating collegiate and corporate research. The smart grid intends to capitalize on the collaborative nature that already exists at Centennial and expand upon it.

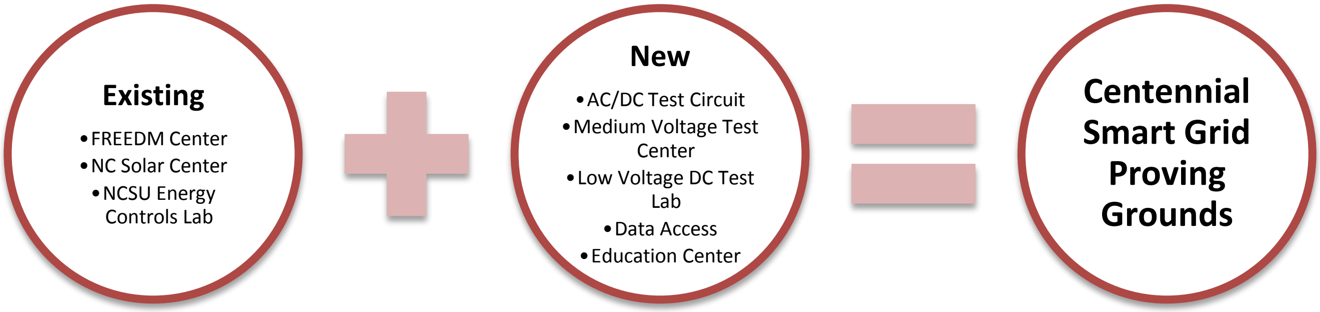
The CCSGPG provides a platform for developing a partnership relationship that is open to everyone including companies of all sizes. Various types of relationships ranging from single consultations to fully developed research teams integrated with the University are all supported by this platform.

The final aspect of partnership is the corporation-to-corporation partnership. At present, corporations work together on an as needed basis and rarely within a collaborative context. The CCSGPG plans to function as the foundation for a collaborative environment between corporations by developing technologies that align with each company's product or partnering to develop a concept or product. In fostering these partnerships, the CCSGPG strives to improve the development of smart grid concepts.

Figure 27 - Ribbon Cutting for ABB at Centennial Campus

Resources

A well-developed plan is vital to maximizing existing and new resources. This section outlines how these resources must complement each other while addressing industry needs for smart grid development to best position the University within the smart grid sector.



Existing Resources

FREEDM Center at the Keystone Science Center

The FREEDM Center conducts groundbreaking work in regards to smart grid innovation and integrates corporate partners very successfully. The FREEDM Center plans to continue current operations while enhancing partnerships with corporations of all sizes. The FREEDM Center intends to do the following in conjunction with the CCSGPG

- Serve as partner with industry partners of all sizes to develop smart grid technologies
- Overcome existing hardware and software limitations to smart grid technologies
- Develop new means of electrical production, distribution, and consumption
- Assist industry partners in developing cutting edge prototype hardware and software
- Conduct lab-based testing in the 1MW Demonstration Lab to ensure the safe operation of devices

New Smart Grid Proving Grounds Components

This section reviews the variety of new components that are affiliated with the development of the CCSGPG.

AC/DC Test Circuit

Centennial Campus researchers and corporate partners concur that a medium voltage AC/DC circuit connected to an operating grid for research and product testing is valuable. The loop will provide real world connection testing capabilities for AC and DC and is comprised of four key components: DC micro grid, medium voltage test lab, building connection, and a battery/renewables connection. The DC micro grid, medium voltage test lab, and low voltage DC test lab are described in more depth later in this section.

Overview

The new AC/DC test circuit is devoted to the testing of smart grid related hardware. The loop is connected to an existing circuit on campus, and power is converted and transformed to the desired voltage for the test circuit. Once the power is transformed, the circuit connects to a variety of components to provide the desired testing capabilities. A conceptual one line diagram of the AC/DC test circuit is shown in Figure 28. The diagram illustrates the capabilities that the AC/DC test circuit encompasses.

Throughout the circuit's run, there are various connection points to the test circuit. These connection points help distinguish the circuit from a normal test facility by offering a way to test solutions in a real world environment. The circuit provides AC and DC connections inside or outside a building, allowing any system whether it is battery storage or a PV solar array to be tested quickly. Additional information on a proposed AC/DC test circuit is included in the Implementation section of this plan.

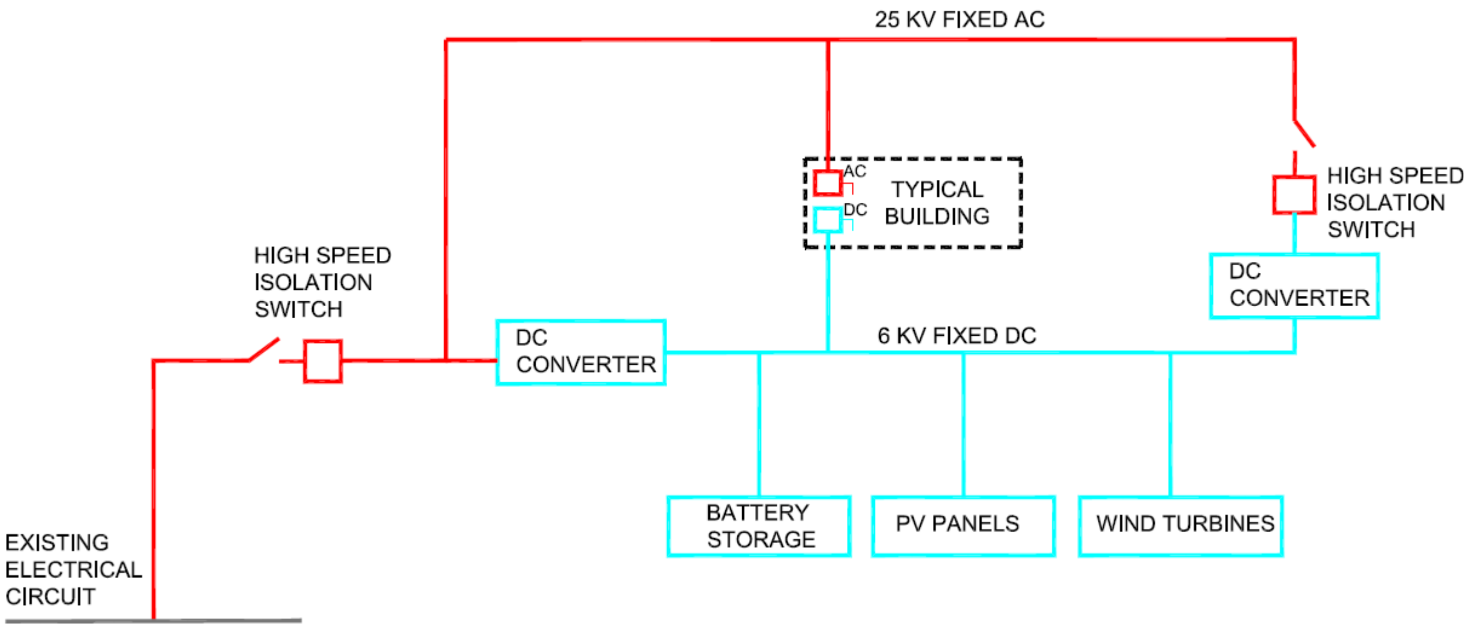


Figure 28 - Conceptual DC Loop One Line Diagram

Benefits

The AC/DC test circuit represents a major investment for the University. To justify such an investment, understanding the benefits and value associated with the loop is critical.

Innovation
Installing an AC/DC test circuit in a real world environment enables unique research and testing capabilities that establish the University as a leader in smart grid technology. From the design of the loop to the testing capabilities provided by the loop, it underscores the University's innovation.

Partnership
A major differentiator of the Centennial Campus in comparison to other campuses is its corporate/collegiate partnership environment. By expanding its research capabilities, the University becomes a larger player in smart grid world which in turn encourages further partnership development.

Future Proof
An additional component that makes the loop unique is its simplicity. The circuit is simply the backbone for all new technology. The system is intended to maintain the proper safety and monitoring equipment. The circuit utilizes minimal technology which safeguards it from becoming obsolete for the foreseeable future.

Direct Current Micro Grid

Installing a Direct Current Circuit at Centennial Campus offers numerous benefits for the University in regards to energy savings and enhanced research capabilities. This section reviews the benefits, protection requirements, code requirements, and implementation criteria for a DC micro grid at Centennial Campus.

Overview

While it is no longer the case, Direct Current (DC) was once the standard in electrical distribution in the United States. DC power was the main means of distribution until the late 1800s when the infamous "War of Currents" took place. The War of Currents was waged between Thomas Edison (DC) and George Westinghouse (AC), and highlighted the major advantages/disadvantages with the technology available at the time. The battle was won by Westinghouse and AC after several key exhibitions and deployments of AC in the 1890s were successful. From that period on, AC was accepted as the standard in electrical current.

As advancements are made in the technology and safety of DC systems and as energy efficiency becomes more important, DC distribution is being studied in earnest as DC- powered digital devices such as computers, televisions, and phones proliferate. Interest in DC systems to better serve these devices is being driven by the need to make them more efficient, integrated with renewable energy, and reliable. In addition, numerous hurdles must be overcome including circuit protection and transitioning from an Alternating Current distribution system which has been the standard for a century.

DC is not expected to eliminate AC power but rather provide a hybrid standard in which AC and DC systems are found in buildings. For this to occur, hybrid systems need to be proven safe and cost effective.

Benefits

Higher Efficiency – Each time power goes through a transformer, AC to DC converter, or other such devices, a small loss of energy occurs as these systems are not 100% efficient. While this loss is minimal on an individual occurrence basis, the loss is much greater and more costly when considering it happens on millions of computers and other devices. Figure 29 illustrates the efficiency benefits of DC power in a data center.

Renewable Energy Integration – As renewable energy production continues to rise across the world, increasing renewable energy efficiency becomes more important. There are many methods of accomplishing this, one of which is keeping the power in its native DC form rather than converting the power from DC to AC. Eliminating the conversion equipment is able to provide a notable efficiency improvement.

Reliability – Similar to other benefits, the DC system relies on its simplicity to increase reliability. By eliminating components, the likelihood of faults and shutdowns decreases along with overall maintenance costs.

Enhanced Research Capability – DC's origins are dated to the discovery of electricity, and a major amount of research continues to be conducted on low voltage and high voltage distribution DC. However, medium voltage DC lacks extensive physical research and testing. Installing a medium voltage DC circuit is anticipated to provide NC State with a unique academic and corporate research tool, helping NC State to serve as a leader in DC research.

Protection

To prevent the DC Loop from causing unintended interruption to the existing 23kV AC power system, a combination of protective functions is required. For example, a fast acting isolation relay is needed at the interface with the AC grid to limit disturbances. Functionality includes instantaneous overcurrent, inverse-time overcurrent, reverse power, under-voltage, overvoltage, and under-frequency. The University's standard SEL-351S relay is capable of providing this. This breaker needs to be installed adjacent to the step down 25kV to 12kV transformer in an outdoor enclosure. In addition, the circuit may be installed in its own concrete duct bank.

Besides the physical safety equipment associated with DC, there will need to be additional training for personnel. This need is driven by hazards associated with DC power. An example is arc flash which occurs when a fault releases a potentially harmful arc of electricity. This fault is dangerous, but the danger is limited due to the sine wave of an AC power which means the voltage crosses zero two times a cycle which shortens the arc. In a DC system this danger increases as the voltage never crosses zero as it is a steady state current. Training on how to safely work with DC power is essential to limiting any dangers associated with operating a Direct Current system.

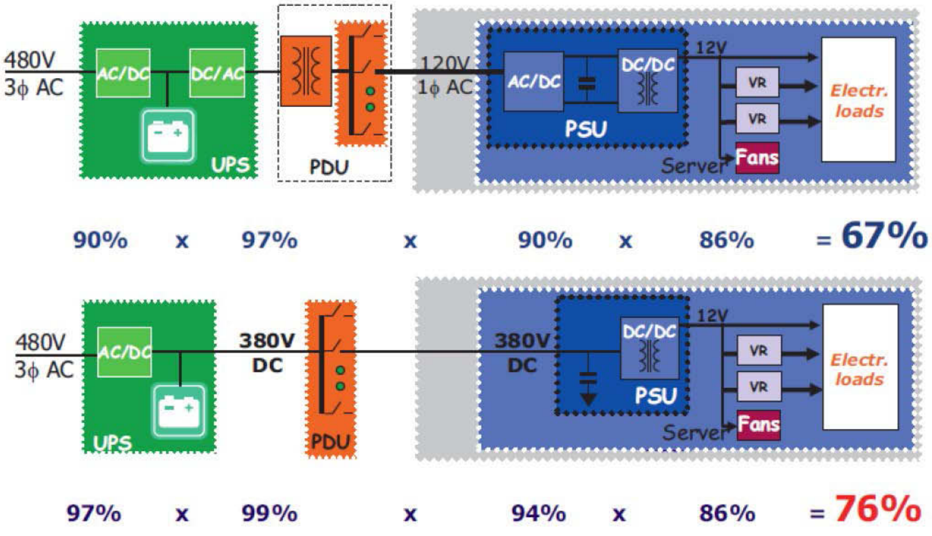


Figure 29 - Universal Electric Corporation Data Center DC Efficiency

Grounding

Grounding for DC systems is similar to AC systems in that there are a variety of grounding methods available to use. DC systems include several combinations of connecting-point positions for grounding, including positive, negative, and midpoint. There are also several options for connection to the earth including floating direct, restrictive, and voltage limit. There are many ways to deploy grounding solutions, and each solution offers unique benefits. The solution selected depends on the application.

The most common solution is the midpoint grounding option. Midpoint ground uses two hot lines with symmetrical voltages and protective earth to reduce the shock hazard if someone touches a conductor. While this is the recommended primary method of grounding a DC Power system on Centennial, a full investigation of the proper grounding system needs to be conducted during implementation.

Code

There are two national codes for the University to consider when implementing a DC system: the National Electric Code (NEC) and the National Electric Safety Code (NESC). The NEC focuses namely on AC power, but there are sections that address DC power systems as they relate to renewable energy. Aside from the renewable energy requirements, the DC requirements are very similar to AC requirements. The NEC specifically requires that all aspects of the system are clearly identified and that either a grounding system or a ground fault detection system is in place. Any AC or DC circuit under 1000V may also be run in the same conduit, provided all conductor insulation meets the requirements for the maximum voltage in the conduit.

The NESC is a code geared towards outdoor utility installation. As a result, NESC is generally more lenient and only applicable to electric utility companies. Similar to the NEC, there is minimal reference directly to DC. The DC specific portions discuss the grounding requirements associated with the system. Due to the experimental nature of the DC Loop, application of both codes is recommended.

Direct Current Micro Grid at Centennial Campus

It is recommended that the DC micro grid at Centennial Campus begin as part of the proposed AC/DC test circuit. If the University is successful with the test circuit implementation and discovers other applications for the system, it may be expanded to cover more of the campus. Expansion includes everything from renewable energy to a transportation system. A brief discussion of test facilities associated with the DC micro grid is found below. More detailed information on the facilities and the circuit is included in the Implementation section of this master plan.

Low Voltage Direct Current Test Lab

There is some low voltage DC testing currently conducted at the Keystone Science Center with the FREEDM Center. A new DC focused test lab is planned as part of the DC Micro Grid with installation in an existing building on campus. The lab provides an opportunity for researchers and corporations to connect into a DC power supply ranging from 24v – 380v. The DC test lab may be extremely useful in the data center industry where the use of DC is gaining traction. Additionally, the lab demonstrates how to use a DC distribution system for lighting and computers based on the Emerge Alliance Standards. The lab also offers a means to connect directly to renewable energy and battery storage in their native DC form.

Medium Voltage Test Lab

The University received a proposal to install a new medium voltage test lab on campus. The aim of this lab is to provide capabilities that are currently unavailable in the industry. Two key differentiators make this lab ideal for innovation: collaboration and real world testing.

The medium voltage test lab aims to allow researchers and corporations to connect a variety of different devices to a live medium voltage grid. This facility would offer a safe way to test AC devices at medium voltage and medium voltage DC devices. Funding options for the lab include a “pay to play” structure and renting the facility to a variety of corporate or academic partners.

Beyond serving as a physical test resource, the lab represents a great method for collaboration. Consultation or partnering services with corporate partners offered by the University is one method of providing benefits beyond a typical test lab. Additional funding from corporate partners may also be sought depending on the revenue stream of the test lab.

Data Access

The smart grid is a data driven technology. To further develop the smart grid, researchers require access to real world data. The CCSGPG offers the large volumes of data ranging from electrical distribution monitoring to building HVAC consumption and manipulation abilities necessary to improve smart grid technology. The data is necessary to supply researchers with a clear picture of not just a building or electrical switchgear but of an entire campus environment.

Central Utilities

The ability to providing a complete data set of how a utility infrastructure powers a university campus is a useful tool. It is recommended that the University give researchers access to the utility data for the central utility system from the smart meters back to the substation and central utility plant. The data is relevant to creating effective energy strategies for any campus setting.

The data is useful for offering information on the electrical infrastructure and identifying what actual loads and stresses are put on the electrical equipment on campus. The development of campus energy modeling software is another way to help test strategies for central utility systems to realize their effect on energy consumption.

Test Facilities

A variety of test facilities at CCSGPG are planned. These facilities are able to test in a real world environment with access to sophisticated monitoring devices for tracking critical data points. All data associated with the equipment being tested is accessible upon agreement with the test administrator.

Commercial Facility

There is a copious amount of data available on overall building energy consumption and the typical breakdown of energy for a commercial building. Energy modeling to simulate real world conditions is applied to collect this data and perform associated calculations. Energy modeling is likewise used to analyze energy conservation measures and calculate estimated savings. Estimated cost savings calculations are fairly correct but may be honed for greater accuracy.

Another proposed data access action is to enhance the metering and sub metering capabilities of one of the typical office buildings on Centennial Campus. This exercise is anticipated to help researchers gain a better understanding of exactly what the benefits of a conservation measure are and how to fine-tune them. The development of an energy optimization testing procedure would need to be developed by the University.

The optimization procedure would be broken out into two parts: energy modeling and real world testing. The energy modeling software would develop savings estimates as well as prove that the measure could be implemented successful without effecting occupants. The second part, real world testing, tests and monitors the measure in a real world setting with precise metering to calculate accurate energy savings data related specifically to that measure.

Commercial Housing Test Facility

The existing NC Solar Center is a showcase of technology that includes some testing abilities. The Solar Center encompasses a wealth of knowledge that ranges from technology to renewable energy and energy efficiency policy. The CCSGPG intends to build upon this existing foundation.

Two primary options for enhancing testing capabilities are under consideration. One opportunity is to create a new commercial test facility for the research and development of new projects as well as the testing of new products. The focus areas of the new facility are concept testing and prototype development. This would serve as a place to not only develop new smart grid and energy saving concepts but also test them in a lab setting. Similar to other portions of the CCSGPG, the main purpose of the facility is to encourage collaboration between the University and its corporate partners.

The other option for improving testing capabilities is to develop a real world test facility that is part of an existing housing facility located on Centennial Campus that is up fit to meet testing requirements. This option allows manufacturers to prove that their technology works and to provide accurate data on how much energy their device saves in a real world application. The facility would help foster a relationship between the University and corporate partners, serving as a way to enhance the testing capabilities of the University.

Education Center

The highly technical knowledge and equipment which is planned for the NC State Smart Grid is very important to the University and society as a whole, but can be difficult for a person without a technical background to comprehend. An Education Center located on Centennial Campus focused on educating students and visitors on the smart grid technology and research on campus would be beneficial to the University and community. The Education Center would serve as a place for individuals new to the campus to visit to recognize that Centennial Campus is not an ordinary campus. The Education Center would provide a visually appealing and potentially interactive way for visitors to see what has been implemented on campus, current research, and the smart grid's impact on people's homes. Further investigation will need to be completed to understand how an education center would serve the campus and how it would fit in the campus master plan.

Figure 30 - Solar Panel Installation at the Current Solar Center

Reliability

A major component of a smart grid is ensuring that a reliable source of energy is provided with a minimal amount of downtime. The grid on Centennial Campus has already proven to be reliable. The smart grid looks to complement the existing components to further enhance the system's reliability.

Self-Healing Grid

A self-healing grid works by constantly monitoring the electrical grid to identify any actual or potential problems. Upon detection of an actual or potential problem, the smart grid reacts within a fraction of a second. By reacting immediately, the event is localized or possibly prevented. This additional reliability is valuable when accounting for all the potential research that could be saved by preventing a power outage. There are four major components that would be used for the self-healing grid at Centennial Campus: High Speed Switching, Protective Relays, Fault Indicators, and Controls.

Automated High Speed Switching

The high speed switches are what put the intelligence of a self-healing grid to work. The switches are located throughout the distribution system and rely on a signal from the control system or protective relays. Upon a detection of a fault, the switch opens to isolate the fault and allow the electrical service to continue to parts of the grid not directly affected by the fault. When the fault is repaired, the system recloses the switch to allow for normal operation.

Protective Relays

The protective relays act as the brains of the high speed switching. The relays monitor the current, voltage, and frequency at the switches. If there is a failure detected by the protective relay in conjunction with the SCADA system, an alarm is sent, and the switch operates as commanded by the control system. Protective relays need to be installed everywhere a high speed switch is located and tied into the smart grid system.

Fault Indicators

A fault indicator monitors the conductors and constantly senses voltage, current, and fault conditions. If they detect an existing or impending fault, they relay that information immediately to the control system. If there is a power failure on the grid, the indicators pinpoint the location, reducing the time required to repair the fault.

Controls

The self-healing grid is controlled by switches and breakers with automatic operators installed. These operators enable the remote smart grid system to open and close the circuits and ways as required to isolate any faults present on the system. The same controllers are applicable for controlling manual operations during switching events on campus. The system would rely on a SCADA system to communicate between the central control system and the switches, relays, and fault indicators throughout the distribution system.

Self-Regulating Grid

Voltage Regulation

To provide stable voltage control to all end user loads on campus, the system needs to be designed with an automatic voltage regulation system. This is accomplished by providing a substation transformer with a Load Tap Changer (LTC). This device automatically adjusts the voltage ratio of the transformer by changing the tap position of the secondary winding. This can be done under load so there is no outage experienced by the end user. The feedback for the setting is provided within the substation yard via a bus Potential Transformer (PT) and is fully automatic once given initial operating parameters.

Security

The smart grid infrastructure covers a variety of critical components across campus. It is very important that access and control of the system is managed properly. To do this, a layered approach is recommended with a description of each layer provided below. This layered approach involves numerous departments and requires a well-developed plan that clearly assigns responsibilities to assure access points are properly controlled.

Software Security and Access Control

The smart grid needs to be secure such that access to it requires a user name and password. Each individual user will have limited access based on their functional role and/or informational needs. For example, limiting access will prevent building personnel from accidentally altering substation control set points. Additionally, all access to the smart grid system is monitored and logged by user to allow for troubleshooting when a problem arises. There will be additional security enhancements, an example of such security would be limiting the number of incorrect password attempts in a set period; this security will assist in thwarting computerized attacks utilizing mass password entry.

Network Firewall

To assist against external security threats a well-developed firewall that carefully monitors internal and external access to the system is necessary. The threat defense will utilize the existing University network and firewall protection as the first defense to prevent outside infiltration. Additionally, it would be recommended that a separate network firewall be setup for the system inside the University network.

Physical

A component of the smart grid is the deployment of physical devices throughout the campus. It is important that these access points are physically secured to prevent any tampering or undesired access. Small items like smart grid controllers and large components like switchgear must be properly secured from outside threats. Appropriate physical security actions also need to be taken such as installing fencing or other physical barriers at all major grid access points.

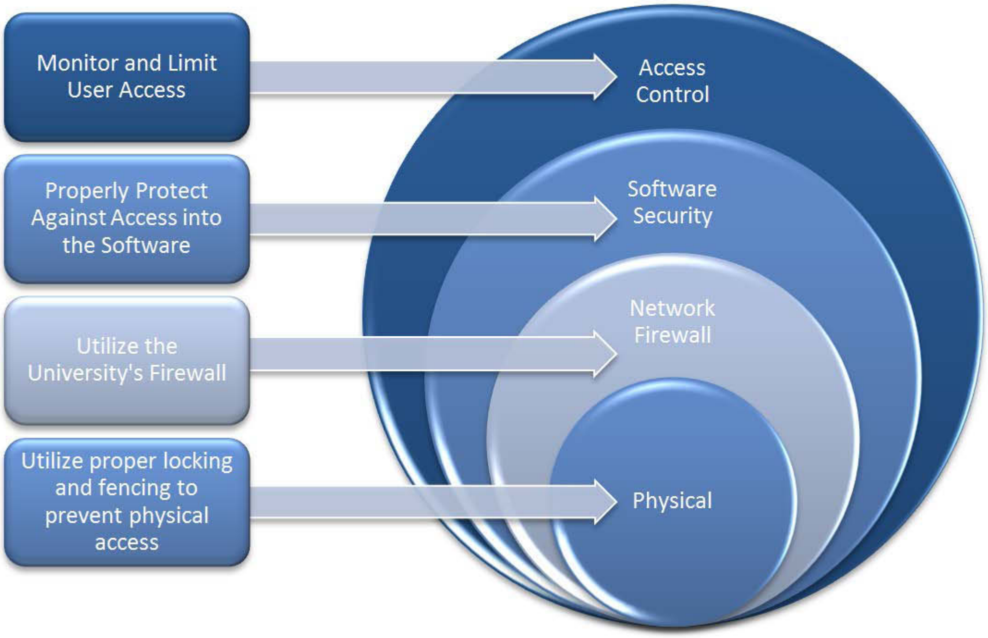


Figure 31 - Smart Grid Layered Security Diagram

Grid Isolation

In a well-developed and stable grid, like those found in most cities today, grid isolation was not seen as being important. In light of several recent natural disasters and increased threat to grid security, however, grid isolation is becoming an increasingly critical issue. Being able to provide a reliable grid that is not affected by outside utility outages is helpful not just to the University but also to the entire community as it could serve as a place of refuge.

Generation

There are numerous emergency generators located throughout the campus to support the partial electrical load of select buildings. If the University were to isolate its grid, a centralized generation system needs to be installed. The University's current electrical peak demand is around 18MW, and it is expected to expand to around 30MW with future growth. This means that if the University wants to isolate its grid at any time, approximately 20-30MW of generation needs to be installed. The full isolation ability would benefit the University if there is an extreme spike in the price of electricity or there are constant issues with grid reliability. Since the University is not confronting either of those problems, providing the full generation capability is not recommended.

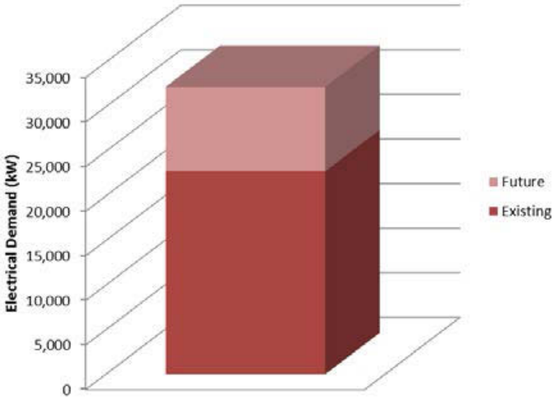


Figure 32 - Centennial Campus Estimated Existing and Future Electrical Demand

The second option is to install a generation system that allows the campus to be fully operational during emergency situations. Implementing a system like this supports University operations without having to provide generation capability to meet the peak demand. The system relies on the smart grid to implement an energy reduction strategy to ensure only critical components are operating and items like HVAC systems are in full demand reduction mode. With an emergency grid isolation system, the University would be able to greatly reduce its generation needs to approximately 5-20MW.

The generation needs given are approximations. A comprehensive study of the electrical needs would need to be conducted before undertaking implementation of a central generation system. Also of note, a cogeneration system may be used as part of either grid isolation generation system.

Controls

In addition to the generation capability, the University needs to install an enhanced power and energy control system. Depending on the desires of the University and the utility, the control system could allow for the unidirectional or bidirectional flow of energy between the University and the utility. Furthermore, the implementation of a sophisticated monitoring and control system is needed to ensure that no damage is done to the generation, distribution, or consumption systems.

Energy Optimization

In light of key global problems related to energy including climate change, energy cost, air pollution, and energy security, reducing usage is increasingly important in industrialized countries. The University acknowledges this problem and has acted accordingly. NC State signed the American College and University Presidents Climate Commitment (ACUPCC) which is a national pledge for universities to take action against global warming. As part of that commitment, the University established a goal to achieve climate neutrality by 2050. This is an ambitious goal that requires every energy consuming device to be evaluated for energy reduction. The smart grid at Centennial Campus may play a major role in achieving this goal.

Smart Metering

Smart meters are devices that communicate the energy usage data of a system to a central database according to short time intervals. By installing smart meters, the University may better track energy consumption and employ data analytics to examine the building's energy consumption. To obtain a full picture of energy consumption in a building, a smart meter should be utilized on all incoming utilities including electricity, steam, and chilled water. The smart grid is capable of using the meters for enhanced load forecasting, optimization of distributed renewable generation, and monitoring of building energy consumption.

Energy Engagement Dashboard

An energy engagement dashboard aims to bring energy to the forefront of discussion at the University. The concept of an energy engagement dashboard is to provide energy consumption data directly to the occupants in a visually interesting way. Once the smart metering project is complete, the infrastructure for the dashboard will be in place, and a software overlay is the only additional item required for the engagement dashboard to be implemented.

The dashboard is intended to show real-time energy usage and encourage energy conservation. The dashboard allows the entire campus to view the energy consumption of each building and compare the use to previous weeks, years, and other buildings. In addition, the dashboard may be successfully used to encourage an energy conservation competition between buildings, departments, or other universities. It has been found in several campus case studies that by providing energy awareness through the dashboards, the campuses have reduced consumption by 2-5%.

Photovoltaics (PV)
PV is a method of creating electrical power by converting the sun's radiation into direct current electricity. The panels are comprised of numerous photovoltaic cells.

Figure 33 - Energy Engagement Dashboard

Building Benchmarking

Building benchmarking monitors a building's entire energy consumption continuously in small time increments to help identify degradation in building energy performance. Benchmarking the building is completed using a baseline, either from historic data or typical building consumption data, and comparing it to the actual data. For an effective comparison, variables such as weather and occupancy are factored into the analysis. If there is a discrepancy between the benchmark data and the actual data, the building is flagged for further review. This almost instant analysis provides feedback that in a standard university energy tracking system could take years to notice.

Building benchmarking also allows for the monitoring of elements that are not connected to the BAS. For example, if a large amount of electric space heaters are used during the winter, the benchmarking tool highlights the building for excessive electrical consumption. Facilities personnel are then able to take corrective actions as needed. A major advantage of building benchmarking is that the capital investment required - smart meters and monitoring software – is small.

The benchmarking also assists with central utility system management. The system helps track the efficiency of the central utility equipment as well as monitor the distribution system for potential leaks or faults in the system. This is done by comparing the real time building consumption data to the central plant production data then highlighting when the differential is outside of normal operating conditions.

There are two downsides to the building benchmarking: utilizing the "as found" baseline and fault detection. Building benchmarking assumes that the initial benchmark is made when the building is operating efficiently and correctly which may not be the case. Benchmarking is limited in regards to fault detection. For example, the system may not necessarily detect if one VAV box is constantly reheating, it would need a group of VAV boxes to fail before the problem is flagged. The final shortcoming is that if a building is identified as having a problem there is no way to know exactly where the problem is, it could be any of the major energy consuming devices in the building. To determine the source would require facilities personnel to go through the entire building.

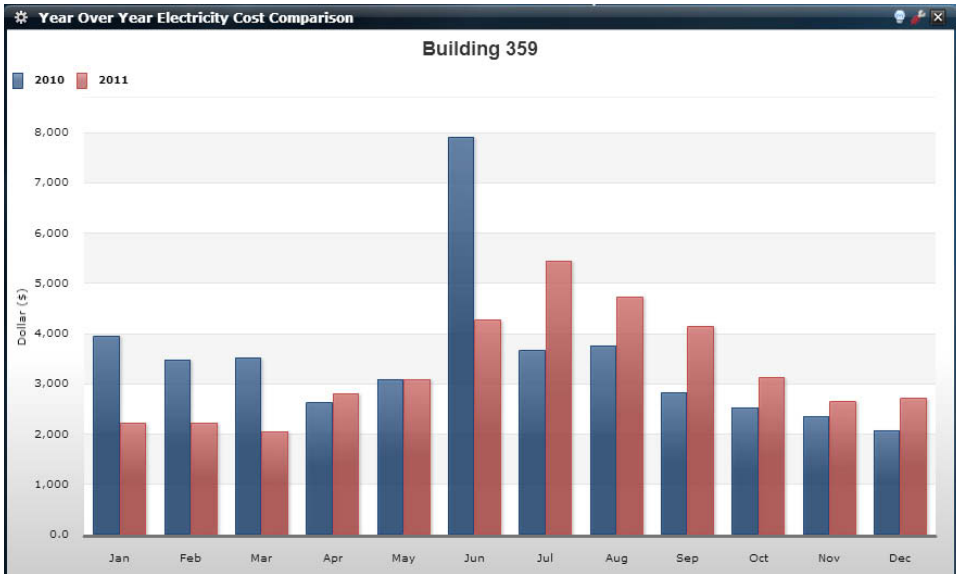
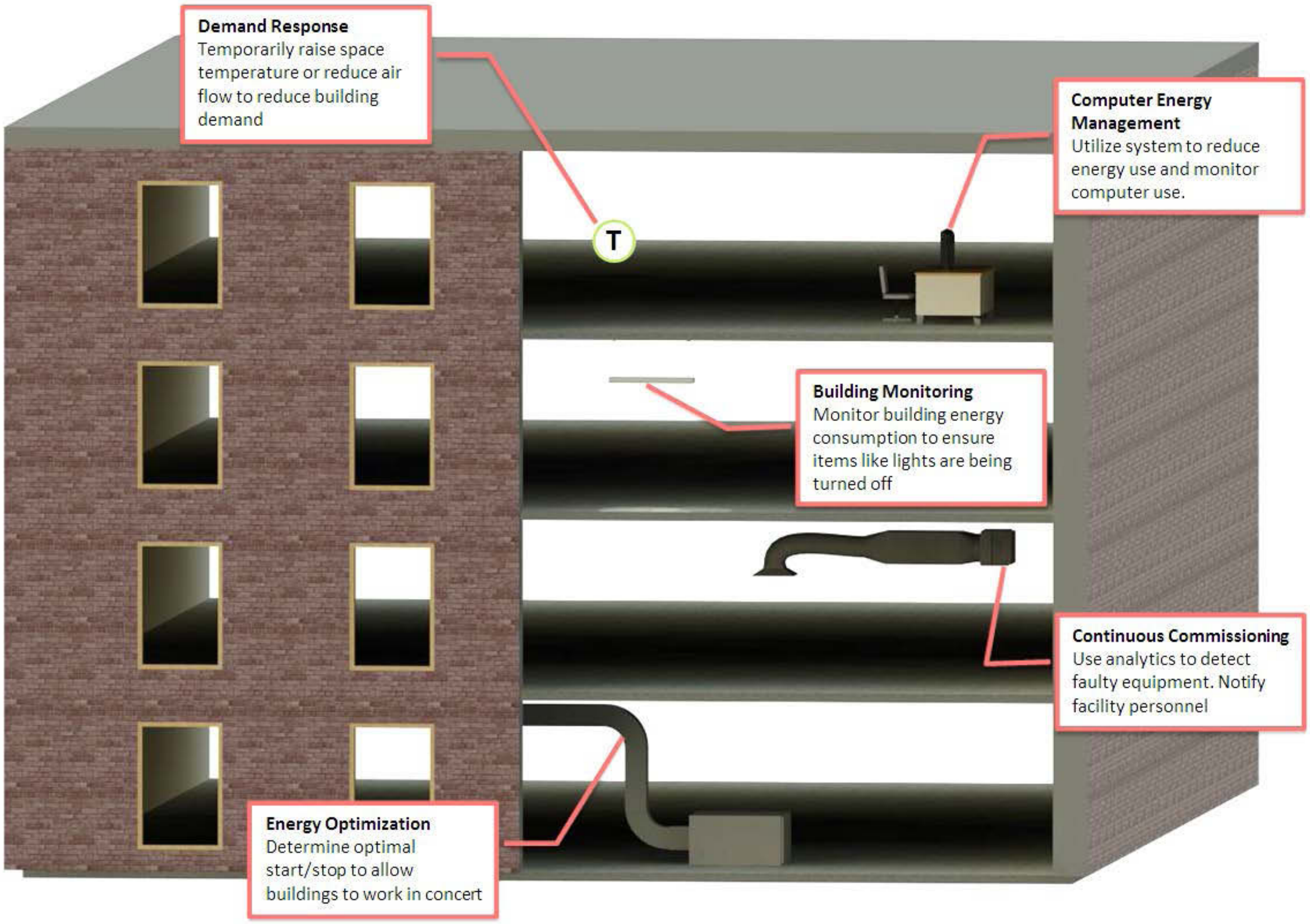


Figure 34 - Building Year over Year Analysis

Smart Buildings

Over the past decades, significant progress in reducing fossil fuel generated energy consumption and increasing renewable energy production with items such as solar PV panels and variable frequency drives (VFDs) occurred globally. These advances are substantial and saved countless kilowatt hours. There is another technological advancement that has occurred in the last couple of decades where the energy savings has not reached its full potential: **DATA**. Building automation systems monitor and log a large number of important data points related to energy consumption. These points are monitored and controlled to a certain extent, but the potential energy savings if this data is properly analyzed is substantial.

The key aspects to energy efficient smart buildings are: continuous commissioning, energy optimization, automated demand response, automated lighting control, and computer energy management. These items are outlined in greater detail later in this section.



Demand Response
Temporarily raise space temperature or reduce air flow to reduce building demand

Computer Energy Management
Utilize system to reduce energy use and monitor computer use.

Building Monitoring
Monitor building energy consumption to ensure items like lights are being turned off

Continuous Commissioning
Use analytics to detect faulty equipment. Notify facility personnel

Energy Optimization
Determine optimal start/stop to allow buildings to work in concert

Figure 35 - Smart Building Diagram

Continuous Commissioning

No matter how energy efficient a building is designed to be, operational disruptions and/or component breaks prevent the building from achieving the desired efficiency. For facility personnel to ensure that components of an HVAC system are operating correctly by either physical inspection or trend analysis, requires a substantial investment of labor hours and would not make fiscal sense. The current system relies on alarms when a major component fails, hot/cold calls by occupants, and energy audits/retro commissioning to detect problems. These current fault detection methods are often expensive, slow to react, or unable to detect the fault.

A smart building replaces the existing detection system with intelligent and automated fault detection. The smart building uses a refined set of algorithms and rules to constantly evaluate the components of the system and detect operational anomalies. In addition, the continuous commissioning solution calculates the energy wasted by each deficiency and develops a prioritized list of deficiencies.

By providing a prioritized list that identifies the problem, repair of major energy issues can be done immediately. The increased speed is beneficial beyond the energy savings, quickly identifying the problem allows for facility personnel to repair the problem swiftly, sometimes preventing a major failure. Additionally, the system may monitor the component and verify that a repair is effective.

How Does it Work?

Continuous commissioning works by monitoring the major points in a system. The major components usually include air handling units, VAV boxes, fan coil units, pumps, chillers, and boilers. The points associated with these pieces of equipment are mapped. For example, a VAV box may have the space temperature, temperature set point, damper position, and discharge air temperature mapped to the system. The system will monitor these points and poll them every 1-15 minutes. If there is a change, the point information is sent to the smart building controller. The controller then evaluates the pieces of equipment utilizing a set of rules specific to that piece of equipment. If the component passes the rules, then normal operation continues. If the system fails, then the piece of equipment is added to the prioritized list of faults.

Summary

A smart building that utilizes continuous commissioning is able to achieve reduced energy consumption by identifying and prioritizing deficiencies quickly. This identification reduces energy wasted as well as the cost of investigation and repair as the system is automated and capable of quickly identifying the component which is not operating correctly. It has been observed that a building will reduce energy consumption by 5-15% based strictly on the addition of continuous commissioning. While 5-15% seems like a modest goal, if it were applied to the Centennial Campus utility bill it would in over $750,000 in savings annually. This does not include savings associated with reduced demand on facility personnel or outside contracts to retro commission the buildings.

Energy Optimization

A building HVAC system is designed to handle the peak load conditions that happen less than 1% of operational time. A HVAC control system is designed to react to a building's requirements based on programmed rules that respond. By reacting to a need rather than predicting, the system utilizes all of its resources to meet the building demand. This immediate reaction usually causes the system to overact, wasting energy. In addition, buildings experience peaks around the same time. This unintelligent and untimely reaction of all of the HVAC systems may unnecessarily inflate the peak demand.

A smart building that is optimizing energy consumption, evaluates energy consumption, pricing, human comfort, and other variables. The smart building develops a predictive energy model based on numerous energy based variables. From the baseline energy model, the system evaluates operational sequences to develop the optimal building operating sequence. The optimal operational model is selected based on the forecasted weather, energy cost, and baseline model. The model looks to shape the buildings' electrical demand curve to reduce energy consumption and cost.

How Does it Work?

A baseline predictive model for the building is developed based on historic and recent energy consumption data and variables including occupancy schedule, day of the week, and outdoor air temperature. The model is developed using normalized data to ensure any outliers or previous energy conservation measures do not affect the baseline model.

The system then runs numerous simulations of the building's energy consumption. A large component of the energy optimization evaluation is allowing the HVAC system to utilize the building's existing thermal storage to permit the system to float. The system may do this by either allowing temperature set points (zone or ahu) to float or reducing air flow through the space temporarily. These fluctuations are analyzed to ensure that the zone temperatures stay within a temperature range that is ideal for the occupants. The optimum solution is then relayed to the Building Automation System (BAS). The smart building relies on the BAS to achieve the set points as efficiently as possible.

Summary

The building energy optimization system capitalizes on building data and transforms the data into building knowledge. The system does this by first developing a predictive energy model based on previous energy consumption and forecasted variables. From the predicted baseline, the system develops an optimized operational sequence that allows the building to run as efficiently and economically as possible for the next 24 hours

Automated Demand Response

Demand response is simply limiting or shifting the power consumption of a building over a short period of time. A demand response event may be triggered by a variety of factors. For example, the building owner setting demand limits or the utility company sending a demand reduction signal to an owner who is enrolled in a demand response program may initiate a demand response.

Demand response programs created by the building owner vary significantly. The owner created program is defined by the aggressiveness of the demand reduction and the goals of the program. An owner demand response event may occur daily or only a handful times a year. No matter how aggressive the program is, the end goal is always the same: to reduce energy consumption during peak demand periods.

The utility demand response program is a joint effort between the utility company and the customer who collaborate to set a reduction goal and a limit on the number of demand response events the utility may request. The utility company then pays the owner for participating in the program. A utility company demand response event usually occurs during high electrical peak times such as a summer afternoon.

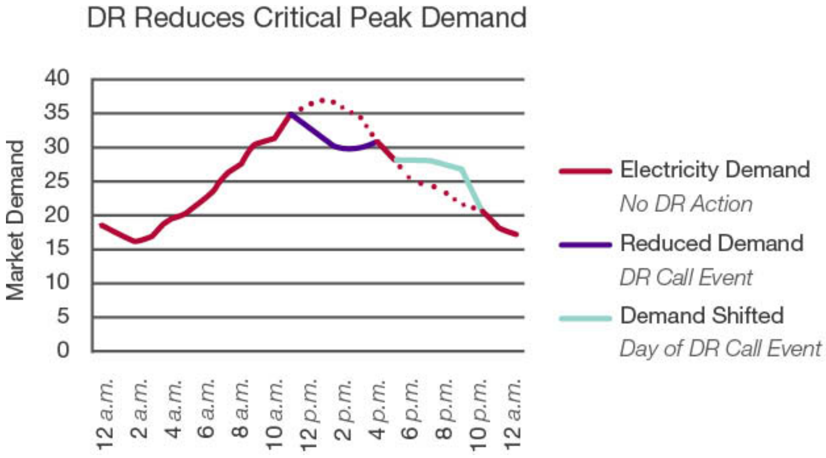


Figure 36 - Example Demand Response Curve

How Does It Work?

The system works by receiving a demand response goal for the system. If the goal is from the utility, it is sent via email or through a communication protocol language, OPENADR. OPENADR allows utility companies to communicate utility pricing and demand response signals to their customers quickly and effectively. If the goal is from the system, it is based on the predictive energy model or user inputs.

Once a demand reduction goal is set, the system begins a reduction sequence typically involving adjustments to the central utility plant and individual buildings. The program utilizes a previously developed and approved list of reductions, then estimates the reduction associated with each load shedding action. The system first evaluates the least evasive measure and continues forward until the demand response goal is met. Examples of these measures include raising temperature set points, reducing air flows, and dimming lights.

Summary

A demand response program reduces campus energy consumption during peak periods for a short period of time. By enrolling in a demand response program or developing its own program, the University is able to reduce the overall cost of energy. For example, if the campus agreed to shed 1MW of load over 10 periods throughout the year, it would receive over $50,000 in reimbursements from the utility company for that year.

Enhanced Lighting Control

Historically, commercial lighting control was based on a manual switch that controlled the lights. The industry now uses occupancy sensors and daylight controls to control lighting. Occupancy sensors provide great energy savings in spaces with varying occupancy schedules. While occupancy sensors are effective in conserving energy, there are several weaknesses in the system. Sensors must be laid out properly to ensure that the lights are on whenever a space is in use. Ensuring the sensors are operating correctly and tying the sensors into other systems such as HVAC or security may be costly. Also, the sensors need to control numerous lights to be cost effective, but this increases the possibility of wasting energy if lighting is operating unnecessarily.

Daylighting controls may also provide considerable energy savings. The sensors dim lights during the day to ensure that desired light levels are maintained. To maximize effectiveness, the system needs to be designed properly to ensure proper lighting levels are maintained and that the occupants are comfortable. There are numerous cases of an ineffective design that caused occupants to complain and the system to be neglected.

Newer solutions that align these technologies and enhance the capabilities of the system are now available. Automated lighting solutions seek to improve the customization of the lighting system for individual occupants and provide two way communications to a wide variety of systems.

How Does It Work?

The system increases the ability for individual control by increasing the number of sensors and controllers available as well as providing greater user access to the system. A communication system is also implemented that allows for constant communication between the lighting system and other building systems. An example is controlling HVAC set points based on lighting occupancy sensors or dimming lighting levels based upon a campus wide demand response signal.

One of the more advanced solutions is Power over Ethernet (PoE) lighting which utilizes typical network cable to power the lighting and provide enhanced control and monitoring to occupants and the BAS. The PoE lighting solution offers occupancy, dimming, and temperature monitoring and control for each individual light fixture. The system also limits the additional power and control wiring by supplying it through network cable. In addition to providing lighting control the system limits the additional power and control wiring as network cable is used to provide both power and control.

Summary

Lighting control has seen significant enhancement in recent years with occupancy sensors and daylight control systems becoming standard design practice. These controls are a good starting point, but can be enhanced further with lighting solutions such as PoE which offer enhanced control that is used not only for the individual light fixtures, but also HVAC and security systems.

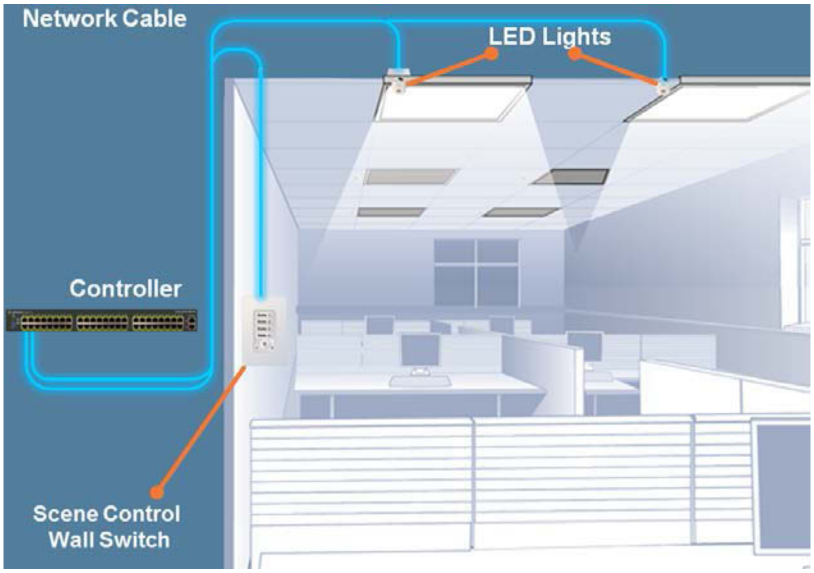


Figure 37 – Power over Ethernet Lighting Diagram

Computer Energy Management

Computers and other related electronic devices are major consumers of energy on campus. A smart grid is able to implement a solution on top of the current IT and energy management system for remote device control. Through enhanced monitoring and control, the system reports and optimizes energy consumption as well as acting in a demand response program. The system utilizes power policies to control a defined group of devices. The power policies determine how quickly a device goes to sleep, hibernates, or goes to standby. This enhanced timing control varies based on the user group and time of day, and it is imperative to reducing energy use as a system in standby uses 80% less energy.

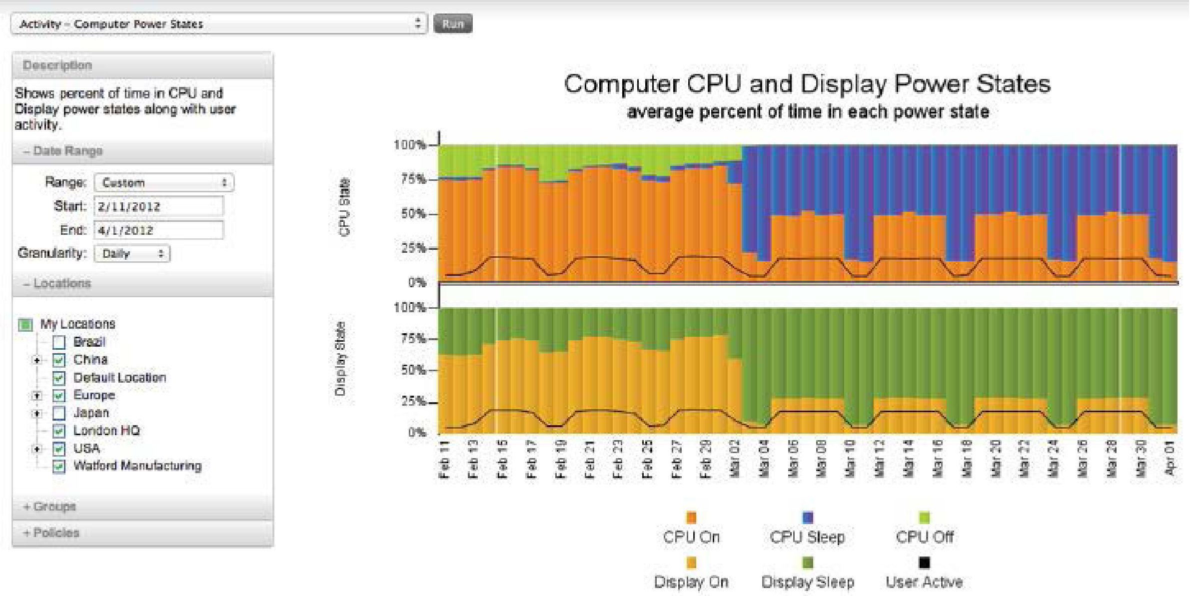
How Does It Work?

The initial startup inventories all connected devices that the University wishes to control and monitor. The devices are then grouped together based on type, operating system, user group, etc.

After inventorying and grouping the network devices, the system implements power policies for each group. The power policies are unique to each group and are customized to meet the desires of the end user. The power policies also limit interference with users. Facilities management and IT agree in advance on which policy to apply to each device group to ensure energy savings are balanced with end user productivity. For example, the power policy during normal business hours remains unchanged, but on the weekends the system goes to standby 50% sooner than it would otherwise. The system is also capable of responding to a campus demand reduction signal. For instance, a demand response signal is sent, and all computers are adjusted to go into standby mode 70% quicker.

Summary

Computers and other network electronics are major consumers of energy even when they are not in use. A computer energy management control system ties all of the systems together to allow for the monitoring of energy consumption and the implementation of power policies that reduce energy consumption when devices are not in use. Significant energy can be saved when implementing aggressive power policies during periods of reduced use.



Shows percent of time in CPU and Display power states along with user activity.

Range: Custom
Start: 2/11/2012
End: 4/1/2012
Granularity: Daily

My Locations
- ☐ Brazil
- ☑ China
- ☑ Default Location
- ☑ Europe
- ☐ Japan
- ☑ London HQ
- ☑ USA
- ☑ Watford Manufacturing

Figure 38 – Example Computer Energy Management Software Dashboard

Distributed Energy Generation

Solar Photovoltaic

The commercial deployment of solar photovoltaic (PV) have been on the rise in the last several years, due to a continuous decrease in the cost of installation occurred because of improved technology, reduced manufacturing cost, increased number of installations, and utility/government rebates. The reduction of the installed cost in the US over time is shown in Figure 39 as reported by the Lawrence Berkeley National Lab.

Due to this reduced cost, solar PV is a more viable option for installation at universities like NC State. With a current median installed cost for large systems in North Carolina of $4 per watt as reported by the Lawrence Berkeley National Lab, a system installed on campus is still expected to have a long payback period. The provided installed cost excludes any incentives or equipment donations that the University may obtain.

Solar PV is a good energy generation fit for the University due to the electrical load profile on campus. Both systems are at their peak production/consumption at approximately the same time. It is recommended that NC State investigate all solar PV opportunities at Centennial Campus. It is also recommended that the University utilize its current renewable energy generation limit, 10% of the campus peak electrical demand, as the goal for the amount of renewable energy installed on the campus.

With a low level of renewable energy generation at present, a sophisticated monitoring and forecasting of power production is not recommended. When the renewable generation capacity of campus grows considerably, a forecasting solution is recommended for implementation and integration into the smart grid. The forecasting tool allows for the optimization of energy generation and consumption while enabling NC State to increase its renewable energy generation via increased monitoring and control.

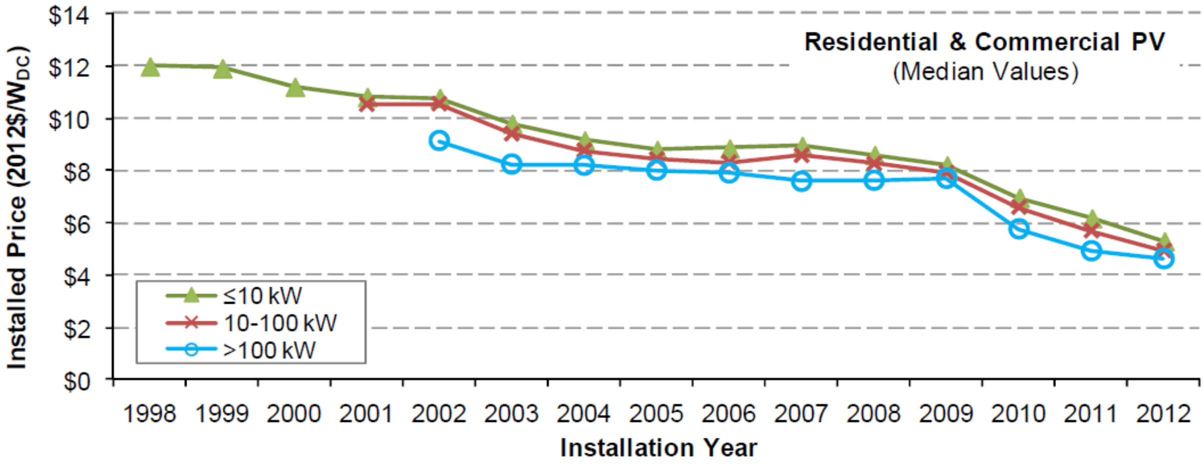


Figure 39 – Department of Energy National Installed Cost of Solar PV

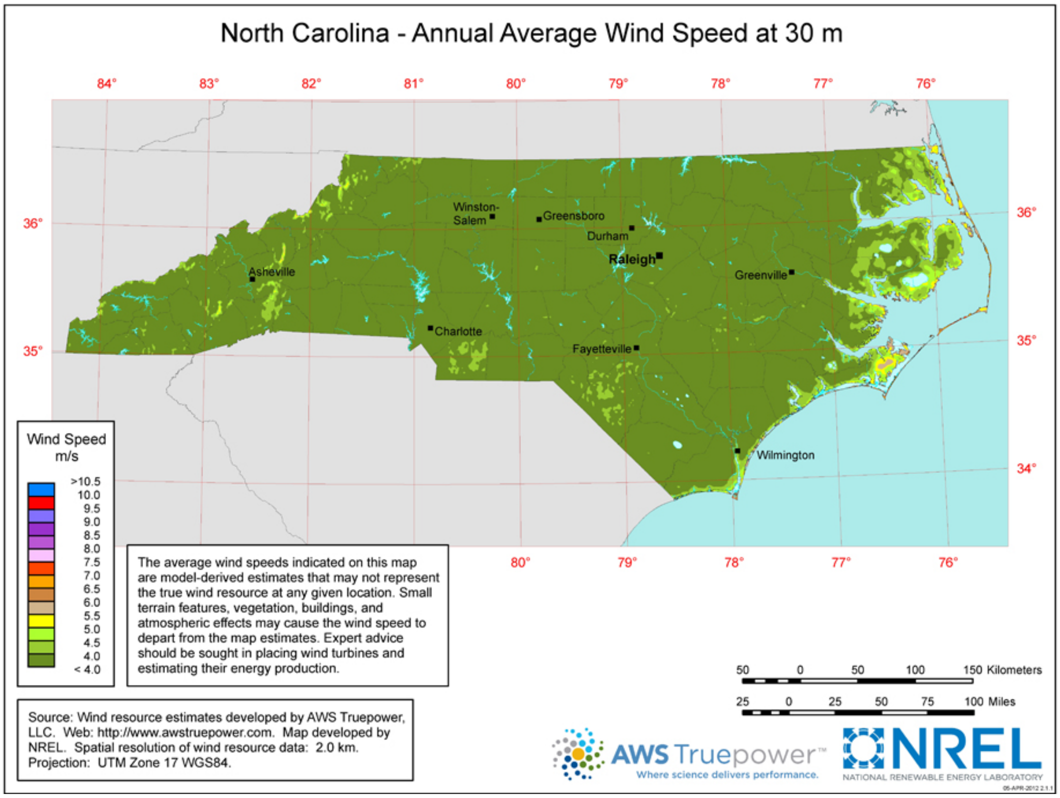
Solar Thermal

Solar thermal energy is able to harness two types of energy: hot water or energy generation. Currently, hot water is the most common type of solar thermal technology, but energy generation has seen recent improvements in technology and lower implementation costs. Solar thermal energy generation is still very much in its early stages and needs to be located in high solar areas such as Florida or Arizona to attain an acceptable payback. Below is a brief description of solar hot water technologies and their potential application on Centennial Campus.

Solar thermal heating works by circulating cold water through solar collection panels that utilizes the sun's energy to heat the water. Solar thermal technology at a university is usually used to heat domestic hot water but may also be used for building heating systems. The buildings at Centennial are made up of mostly office, classroom, and lab space. Those occupancy types are not large domestic hot water consumers, and this drives up the payback for a solar water heating retrofit. If new residential buildings utilize a central domestic hot water system, solar thermal should be investigated further.

Wind Turbines

The use of wind turbines in North Carolina to date is not very successful. There are a few areas near the mountains and the coast where there is enough wind for a turbine to be feasible. Raleigh is not located in one of the high wind locations as shown in Figure 40, so a wind turbine would not have a desirable payback for the University. It is therefore not recommended that wind turbine technology be investigated until the installation cost/kw is reduced significantly.



The average wind speeds indicated on this map are model-derived estimates that may not represent the true wind resource at any given location. Small terrain features, vegetation, buildings, and atmospheric effects may cause the wind speed to depart from the map estimates. Expert advice should be sought in placing wind turbines and estimating their energy production.

Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: UTM Zone 17 WGS84.

Figure 40 - North Carolina Wind Speed Map

Micro Steam Turbines

A micro steam turbine replaces a pressure reducing station at the building level. The turbine makes use of the steam pressure reduction by using the high pressure steam to spin a turbine to generate electricity. At present, the technology is capable of operating with a steam flow of 4,000 lbs/hr or higher. With a 100 psi reduction, the turbines are capable of producing 125kW with 7,000lbs/hr of steam. While the system efficiency is not exceptional, it is a vast improvement on the 0% efficiency of a standard reducing station.

The central utility plant at Centennial Campus currently distributes steam throughout the campus at 150psi. This pressure is necessary to meet certain campus requirements, but the majority of the buildings only utilize 15psi or less due to the safety concerns associated with utilizing high pressure steam inside a building. The pressure differential at Centennial Campus is ideal for a micro steam turbine application, but there is no one building with a constant steam load of 4,000lbs/hr or more. To achieve an acceptable payback period, the turbines must be operating the majority of the year. Unless the University finds a new high demand for steam or is able to group buildings into a low pressure area the micro steam turbines are not recommended.

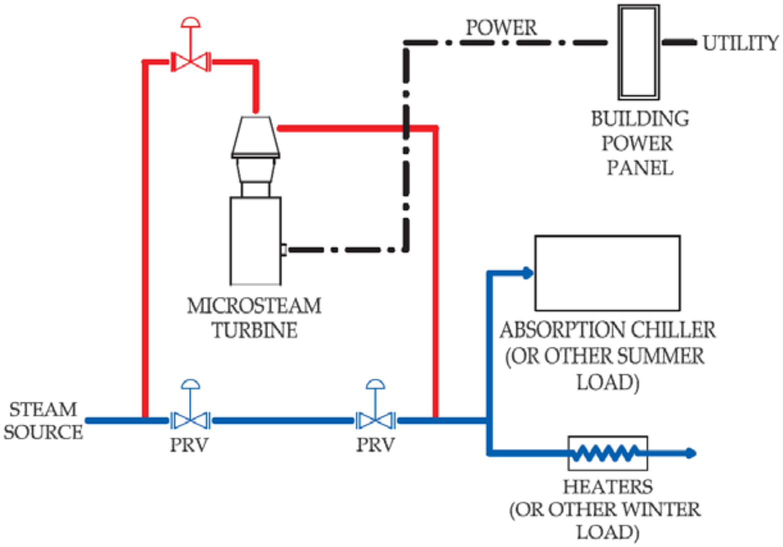


Figure 41 - Micro Steam Turbine Diagram

Distributed Cogeneration

Microturbines and Fuel Cells are two combined heat and power (CHP) technologies that can be used to complement a centralized system. Both technologies allow interconnection with the utility grid. In addition, an existing building boiler may be used as backup or provide additional peak capacity.

Natural Gas Microturbines

Natural gas microturbines are ideal for sites or buildings with high coincident electrical and hot water loads throughout the entire year. The capture of waste heat for hot water or steam loads can yield microturbine efficiencies above 80%. Microturbines are typically available in sizes as low as 30 kW. Several microturbines may be configured together for capacities as high as 10 MW. Microturbines may also be used in trigeneration applications, where the waste heat off the turbine is used to drive an absorption chiller(s) for building cooling as well.

Due to the existing infrastructure at Centennial Campus and the high cost of equipment, the installation of microturbines at Centennial Campus is not recommended. It is suggested that a life cycle cost analysis be completed on all new buildings on campus that will have standby generation and will not be connected to the central steam loop to determine if they are a good fit for a microturbine application.

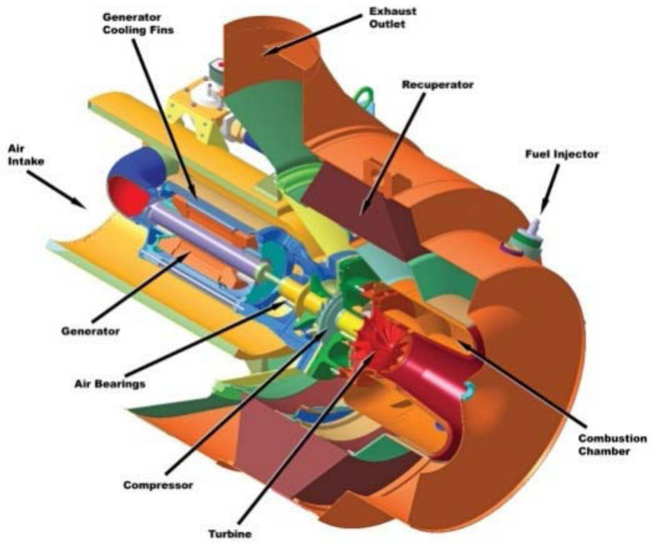


Figure 42 - Capstone C200 Microturbine

Fuel Cells

Fuel cells contain electrochemical devices that combine fuel with oxygen from ambient air to produce electricity, heat, and water. The entire non-combustion process is a direct form of fuel-to-energy conversion. Most of the fuel cells in use today are operated with natural gas. A chemical reforming process produces hydrogen that is used in an electrochemical reaction to produce electricity.

A distinct advantage of the fuel cell technology is that the waste heat produced during the generation of electricity can be used in CHP. The CHP configuration can raise the fuel cell efficiency from 47% to as much as 80%. Phosphoric Acid and Molten Carbonate fuel cells are the two most common types available today. Phosphoric Acid machines have been available for almost 20 years and are typically 200 kW in size. Molten Carbonate machines are available between 300 kW and 1200 kW. Molten Carbonate fuel cells operate at higher temperatures, and the high grade waste heat allows for the production of either steam or hot water. The electric conversion efficiency of this fuel cell is anticipated to be 55%. Conversely, the efficiency of a typical utility power plant is around 33%.

Currently the cost of installing a fuel cell is approximately $10,000/kW. Due to this high cost, further investigation of this technology is not currently recommended. It is suggested that fuel cell technology be reinvestigated if an additional funding source is used, a dramatic increase in cost of electricity occurs, or the cost of the equipment and installation is substantially lowered.

Emergency Generator Load Curtailment

Peak shaving is a technique that is used to reduce electrical power consumption during periods of maximum demand on the power utility. Duke Energy Progress offers two programs which could benefit from the use of the existing emergency generators: a *Generator Curtailment Program and a Demand Response Program*. NC State is allowed to enroll in only one of these programs. The generator curtailment program offers a credit for the operation of the generators during curtailment periods and testing. The demand response program can use the generators in addition to a demand response reduction program implemented at the buildings to reduce load. The ideal program for NC State to enroll in is the demand response program. This program allows the University to obtain the most credit for other demand reduction undertakings. In addition, this program does not rely on the generators for load shedding and only require them if it is deemed necessary.

Generator Load Curtailment at Centennial Campus

There are numerous generators located throughout the Centennial Campus that range from 33kW to 1000kW. Most of the generators are fueled by diesel and have storage tanks that allow the generators to operate at full load for an average of 12 hours. Information on all of the generators located at Centennial Campus is found in Table 3.

For the curtailment program to be successful at Centennial, it is recommended that only generators 500kW and above be examined. Using this size criteria, there are five (5) generators with a total capacity of 3500kW that are available for use in the program. There are three major items in need of investigation for the eligible generators: controls, transfer switches, and air permit requirements.

Controls

The controls that need to be evaluated include automation controls and pollution controls. Tying the generators into the smart grid control system is required for seamless and efficient operation. The smart grid controls allow for the automation of the startup and shutdown of the generators as required by Duke Energy Progress. The controls also include the proper monitoring and metering required to meet all regulations. The existing pollution controls need to be assessed to ensure they meet all of the environmental regulations.

Table 3 - Centennial Campus Emergency Generators

Building Name	Generator Size (kW)	Manufacturer	Fuel Type	Tank Size (Gallons)	Production with Full Tank (kWh)	Estimated Full Load Hours with Full Tank (Hrs)
COLLEGE OF TEXTILES	500	Caterpillar	Diesel	300	3558	7
PARTNERS BUILDING II	700	Caterpillar	Diesel	600	7116	10
TOXICOLOGY BUILDING	150	Onan	Natural gas	-	0	0
PARTNERS BUILDING III	400	Onan	Diesel	700	8302	21
RESEARCH BUILDING I	350	Caterpillar	Diesel	250	2965	8
RESEARCH BUILDING II	455	Caterpillar	Diesel	800	9488	21
RESEARCH BUILDING III	33	Kohler	Diesel	100	1186	36
PARTNERS BUILDING I	125	Olympian	Diesel	115	1364	11
CENTENNIAL CAMPUS CUP	250	Onan	Diesel	500	5930	24
MONTEITH ENGINEERING RES.CTR. (MRC)	1000	Caterpillar	Diesel	150	1779	2
ENGINEERING BUILDING I (EB1)	800	Onan	Natural gas	-	0	0
ENGINEERING BUILDING II(EB2)	500	Caterpillar	Diesel	0	3558	7
Total	**5263**	**-**	**-**	**3515**	**45244**	**-**

Existing Transfer Switches

The existing automatic transfer switches need to be investigated to ensure that the switches meet the operational requirements and are connected to serve the entire building load. It is recommended that automatic transfer switches are closed transition type with a peak shaving or curtailment function built into the switch. With the proposed switching configuration, NC State can only expect to shave the load associated with the building which may not be the full capacity of the generator. If the full capacity of the generator is desired, paralleling equipment needs to be installed. It is recommended that a full economic analysis of both options be conducted.

Air Permit

Environmental regulations require that the University file a Title V air permit with the North Carolina Department of Environment and Natural Resources (NCDENR). The Title V air permit is required for all facilities or campuses that meet certain emissions levels.

The current Title V air permit for NC State does not allow for the operation of the generators in a load shed or demand response mode. The permit needs to be updated to allow this option. There are several universities in North Carolina that have successfully updated their air permit to allow emergency generators to operate in a load shed mode.

Figure 43 - Emergency Generator Located on Centennial Campus

Cogeneration

Cogeneration is a system that sequentially produces electricity and heat that is used for steam and/or hot water. In most conventional methods of producing electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put to use, and waste heat is reduced. Cogeneration is a thermodynamically efficient use of fuel with an average overall efficiency of 80% or higher.

Centennial requires high pressure steam which has two options for cogeneration, a combustion or steam turbine. In the Southeastern United States, a cogeneration system is usually sized based on the lowest heating demand throughout the year. This sizing methodology is used to allow the system to operate as much as possible throughout the year.

Combustion Turbine

A combustion turbine system works by burning fuel in a turbine which drives a generator to produce electricity. High temperature gas turbine exhaust flow with optional supplementary firing feeds a heat recovery system. The heat recovery system then produces steam or hot water. Combustion turbine CHP systems have an equipment life of approximately 30 years. The system runs on high pressure natural gas and has an average run time of 97%.

Figure 44 - Cates Cogeneration Plant at NCSU

Steam Turbine

Unlike a combustion turbine, in a steam turbine cogeneration system heat is produced first and electricity is the by-product. The system works by producing superheated steam at a higher pressure and running it through a steam turbine which generates electricity and lower pressure steam. The reduced pressure and temperature steam is then distributed throughout the campus. A steam turbine CHP system also has an equipment life of approximately 30 years and an average run time of 97%.

Cogeneration at Centennial Campus

Cogeneration is a familiar concept to NC State. In 2012, the University installed two (2) 5.5MW gas turbines with heat recovery steam generators that produce 100,000 lbs of steam an hour on the main campus. This system reduced energy consumption, improved reliability, and cut annual operating costs. The installation was so successful that the University commissioned a study to implement a cogeneration system at Centennial Campus. The study calculated that a 5.7MW gas turbine cogeneration system at Centennial would require a payback period of over 15 years. This analysis was based on a general service flat rate.

Thermal Storage

Thermal Energy Storage (TES) is an attractive strategy for efficient chilled water production when the price of electricity varies during the day. Depending on the local utility rates, the cost of cooling generated with electric chillers using electrical off-peak power may be half the cost of producing the same chilled water during the on-peak period. As such, the operational savings potential of thermal energy storage is substantial.

The most cost-effective TES technology for large-scale university style cooling is stratified liquid storage. This variety of TES requires the most space but is capable of being seamlessly integrated into an existing chilled water system. The chillers continue to operate as they always have at the same efficiency if the system temperature differential is maintained.

Ice storage is another possibility. While it requires less physical space, this approach adversely affects the overall efficiency of the plant as there is a substantial energy penalty for making ice versus chilled water. Additionally, this approach requires the installation of chillers that are capable of driving a brine solution down to temperatures required for ice-making.

There are three fundamental ways to operate stratified chilled water TES. The first is full load shed which is the avoidance of any chilled water production during the target period. Full load shed requires the largest physical tank and the most chiller capacity of any TES scenario. In many cases, it requires more chiller capacity than a system without storage.

The next option is known as load leveling. During this mode of operation, no consideration is given to avoiding chilled water production during a specific window of time. Instead, the objective is to enable the chillers to operate at a constant production value all day long. Load leveling requires the smallest tank size of any TES scenario and enables the lowest possible amount of installed chilled water capacity.

Figure 45 - DFW Airport Thermal Storage Tank

The final TES scenario falls in between the first two and is referred to as partial load shedding. In this scenario, the tank is optimized to avoid at least some cooling during a specified time period this option is generally selected to optimize energy savings relative to the capital cost of the TES installation. The partial load shed option yields a smaller tank than the full load shed option while decreasing the amount of chiller capacity required and the monthly electric demand value.

Thermal Storage at Centennial Campus

The University recently commissioned a study of thermal storage at Centennial Campus. The study determined that with a time of use rate schedule the system would have a 16 year payback period. With a flat rate schedule, a thermal storage tank would have a 25 year payback period.

Energy Storage

Grid connected energy storage covers a broad range of products and applications. Energy storage could mean a large amount of lithium ion batteries that last for hours or a flywheel that supports load changes for a few minutes. It is important that the proper application to support the desired outcome of the system is used. An energy storage system is not going to save the University energy or a significant amount of money on its own. An energy storage system could enable the University to improve reliability and save money. An energy storage system enables the University to add more renewable energy, implement more aggressive demand reduction strategies, and provide higher quality power to the grid.

Demand Response

Energy storage assists a demand response program. The system works by charging the batteries during off peak hours and discharging during a demand response event. Depending on the size of the energy storage solution and the amount of load that is attempted to be curtailed, the batteries are used for rapid load curtailment before other load curtailment strategies are implemented. Alternatively, they may be used for a longer load curtailment period to reduce a smaller amount of load over a longer period.

Frequency Regulation

Frequency regulation works by constantly adjusting its charging/ discharging state to offset effects from fluctuating renewable energy production and demand to keep the grid frequency constant. An energy storage system is able to respond quickly and is able to adjust to power swings within milliseconds. This frequency regulation is especially important for systems with large renewable energy generation capacity where power output can go from 0 to 100% within a second. Currently, the most popular form of frequency regulation with energy storage is a flywheel system.

Back Up Power

An energy storage system may be used as back-up power for critical loads to ensure power is never interrupted to the facility. This is done with the energy storage system maintaining a set charge. When an outage occurs, the system responds quickly to maintain power to the facility while the back-up generation is brought online.

Energy Storage at Centennial Campus

Due to the current high price of battery storage and relatively low price of peak electricity, battery storage cannot be justified based on energy cost savings. In addition, Centennial Campus has a minimal amount of renewable energy which makes frequency regulation difficult to justify. A future evaluation of energy storage is recommended when additional renewable energy generation is added to the campus.

Smart Electric Vehicle Charging Stations

Electric vehicles (EV) continue to gain traction in the United States. As the EV market continues to grow, so does the need for an adequate EV charging infrastructure. It is standard for an electric vehicle to be charged to full capacity without regard to the price of energy. At the current growth projection of electric vehicles, this unintelligent charging could cause major problems for the utility companies as well as the utility customers. New smart chargers will interact with the grid to prevent charging during high demand or demand reduction periods. The smart grid will evaluate the EV charging needs as well as grid consumption, renewable energy production, utility cost, and other factors to determine the optimal charging scenario for all vehicles connected to the grid.

A more sophisticated system may be implemented that not only charges the vehicles at optimal times but also uses them for energy storage. For example, a user may indicate that they want a full charge by 5 pm when they leave for the day. The system guarantees a full charge by 5 pm, but it may use the car battery as a means of peak shaving during a peak occurring at 12 pm.

Smart EV Charging Stations at Centennial Campus

As NC State continues to grow and modernize, its EV charging infrastructure at Centennial Campus and the charging system must be integrated into the smart grid to enhance control. If the charging system is not intelligently controlled, the University may experience an increase in electrical demand cost. The demand cost is likely to increase as the majority of the charging is done during "On Peak" hours.

Figure 46 - Electric Car Parking Sign at Centennial

Smart Campus Control System

The University may possess the most sophisticated building automation systems with a thermal storage tank, peak shaving generators, and a large battery storage facility, but unless these systems are aligned, substantial energy saving opportunities may be lost. A smart campus control system allows all of the parts and pieces from the electric vehicle charger to the cogeneration plant to work together to provide the most energy efficient and cost effective campus. The smart campus control system works by connecting the various energy control systems into an integrated network. The network is controlled by the smart grid control system which analyzes the numerous variables to determine the optimal energy equilibrium for the campus. The following is a diagram highlighting how a smart campus communicates and interacts.

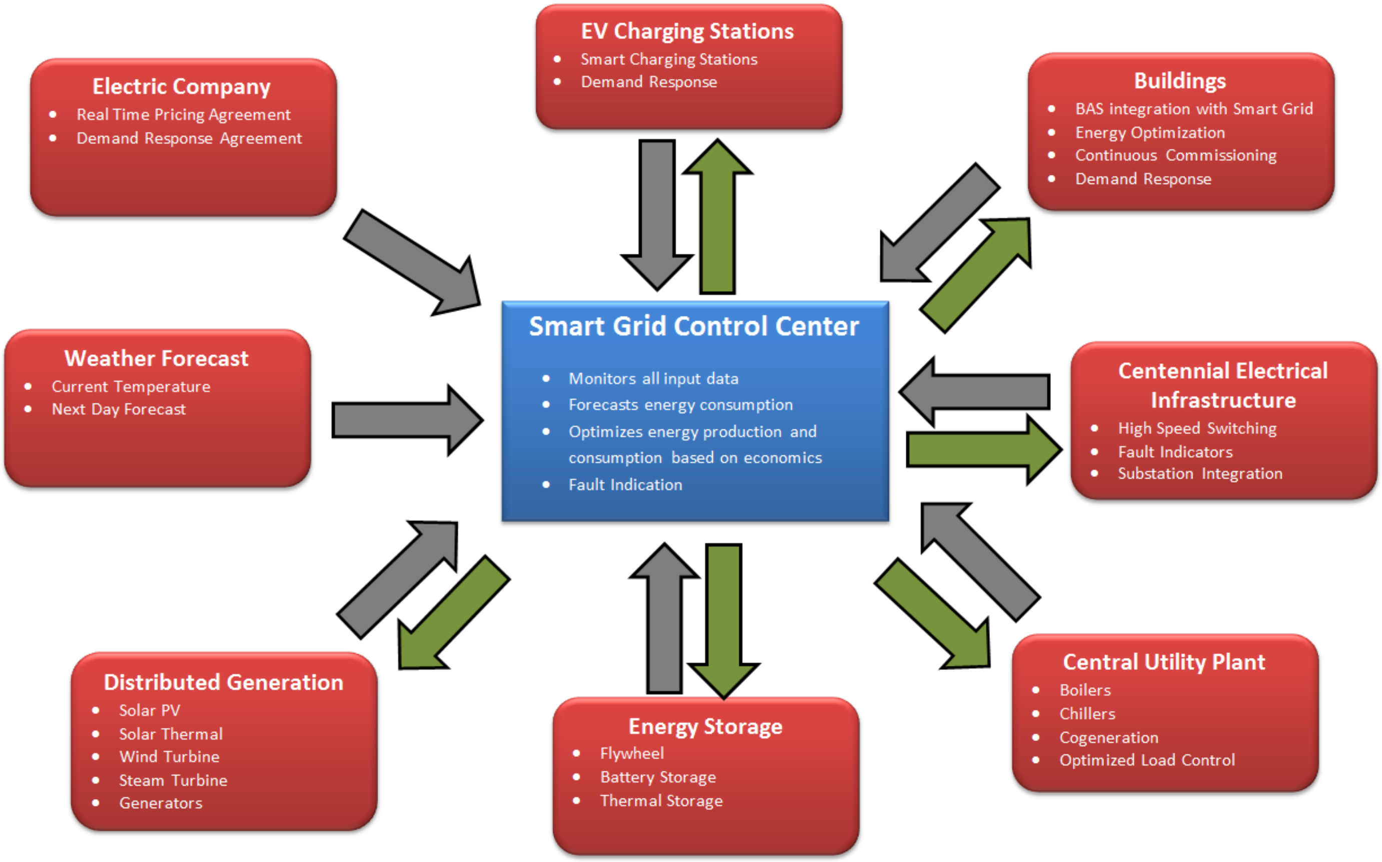


Figure 47 - Smart Campus Diagram

A smart campus control system uses constant two way communication and controls with the energy consuming/producing entities on campus. Outside inputs such as the weather forecast and electric rates are also applied to develop an optimized energy solution for the campus that is constantly monitored and able to adapt there are three critical components to a smart campus control system: monitoring, modeling, and optimizing. The importance of each component and how they work together is described in this section.

Monitoring

A goal of the smart campus control system is to integrate the various energy monitoring and control systems into one central system. The smart campus control system integrates monitoring of campus components from the smart switches and relays of a self-healing grid to the continuous commissioning of building HVAC systems. The system provides easy campus wide access for facility personnel. Facility personnel no longer need to consult the BAS for the building, followed by the smart meter energy management program, and then the central utility system to understand what is occurring within one building. Instead, the smart campus control system combines all of these systems together for all of the buildings to allow for an easy operational overview of a building in one central location. The monitoring ability also allows for the development of a strategy for facility maintenance. The smart campus control system will highlight the buildings and systems across campus where the facility personnel need to focus their attention.

Power System Modeling

Monitoring data and detecting problems are the first steps in developing a smart grid on campus. The next step is predicting the data. Predicting the energy consumption and production gives the University the power to shape its future energy consumption.

A smart campus control system utilizes existing data to develop a predictive energy model for the next 24 hour period. The model is developed based on data gathered from weather data, calendar, building automation systems, central utilities, and smart meters. The smart campus control system utilizes the gathered data and applies analytics to develop a predictive model. The predictive model predicts building energy consumption and incorporates any energy production from sources such as solar PV arrays or combined heat and power systems.

Energy Consumption and Production Strategy

Knowing the future energy consumption and production is useful information, but if this information is not acted upon, the data is useless. Putting this data to work is where the smart campus control system excels. The control system uses analytics to develop an ideal operating strategy. A smart campus control system capitalizes on the smart buildings by coordinating the buildings to ensure that they do not create an unnecessary demand. For example, during the winter the smart campus control system might spread out the start times of buildings to prevent having to start an additional boiler to cover the morning warm up period.

The smart campus control system will also develop an ideal operating strategy for the next 24 hours. For instance, based on the predictive model the smart campus control system will develop a strategy that ensures the most efficient chilled water production at 2 pm is occurring. The selection would account for the various equipment load curves, predicted load, and other variables to determine the optimal operating points for each piece of equipment. By developing an operating strategy based on energy efficiency with accurate calculations the system is able to optimize energy use at every building. In addition to developing an operating strategy based on the predictive model it will also adapt to the various unforeseen load changes. If the peak load is going to be exceeded, the system evaluates options such as temporarily changing

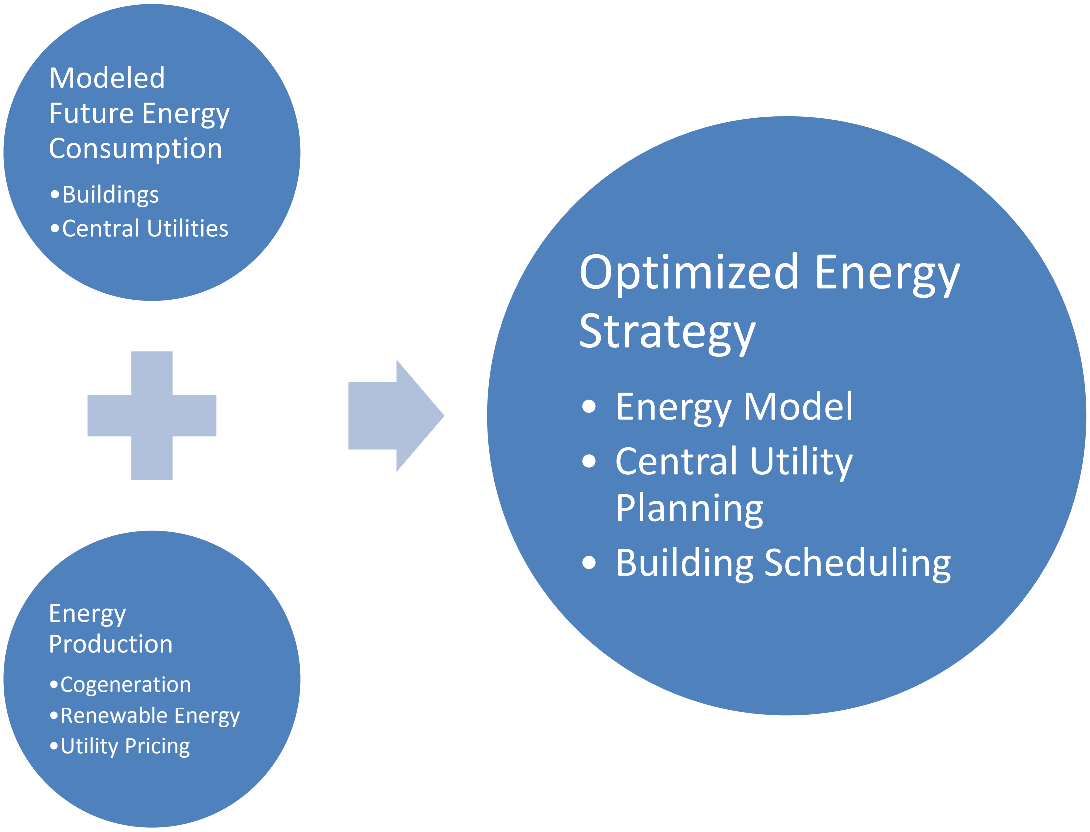
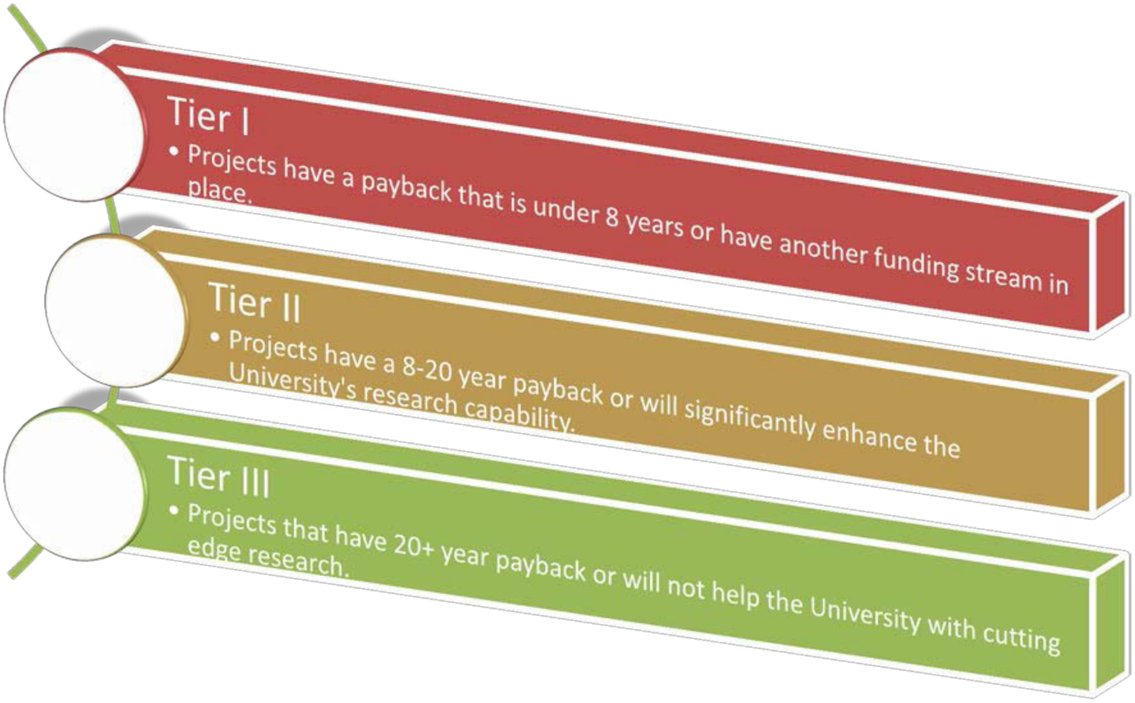


Figure 48 - Energy Strategy Development Diagram

Implementing a Smart Grid at Centennial

With a review of the various smart grid technologies that are applicable to the Centennial Campus completed, the next step is to determine how to apply these technologies to the campus. This section develops specific projects for consideration as part of a successful smart grid implementation at Centennial Campus.



Tier I
- Projects have a payback that is under 8 years or have another funding stream in place.

Tier II
- Projects have a 8-20 year payback or will significantly enhance the University's research capability.

Tier III
- Projects that have 20+ year payback or will not help the University with cutting edge research.

The projects are divided into three tiers based on economic feasibility and enhancement of University research capabilities. The tiers provide guidance for the University as to what projects should be implemented first. The University can implement these projects in the order they choose as there may be justifications outside what this plan considered. This section includes the description of specific projects with an economic analysis including savings, cost, and payback estimates. Further information on the cost estimate development can be found in the cost estimate supplement. In addition, each project was evaluated using four key divisions related to the smart grid implementation at Centennial Campus. A breakdown of the evaluation criteria is found below.

Essential to the Smart Grid

Red – An auxiliary component that is not essential for smart grid operation.
Yellow – A key part of the smart grid, but only has minor interaction
Green – A component that is necessary for the successful implementation of the smart grid.

Research Benefits

Red – Does not provide any benefits to new smart grid research.
Yellow – Will assist NC State in furthering smart grid development on campus.
Green – Will support NC State becoming a leader in smart grid research.

Energy Savings

Red – Does not provide any energy savings.
Yellow – Provides decent energy savings relative to the investment.
Green – Provides significant energy savings relative to the project cost or the overall energy consumption of the campus.

Smart Grid Demonstration

Red – An auxiliary component that is not essential for smart grid operation.
Yellow – Demonstrates aspects of a smart grid and the potential applications.
Green – Demonstrates key components of the smart grid in a substantial way.

North Carolina State
Smart Grid

2.2 YEAR

PAYBACK

$3,600,000

SAVINGS

$7,810,000

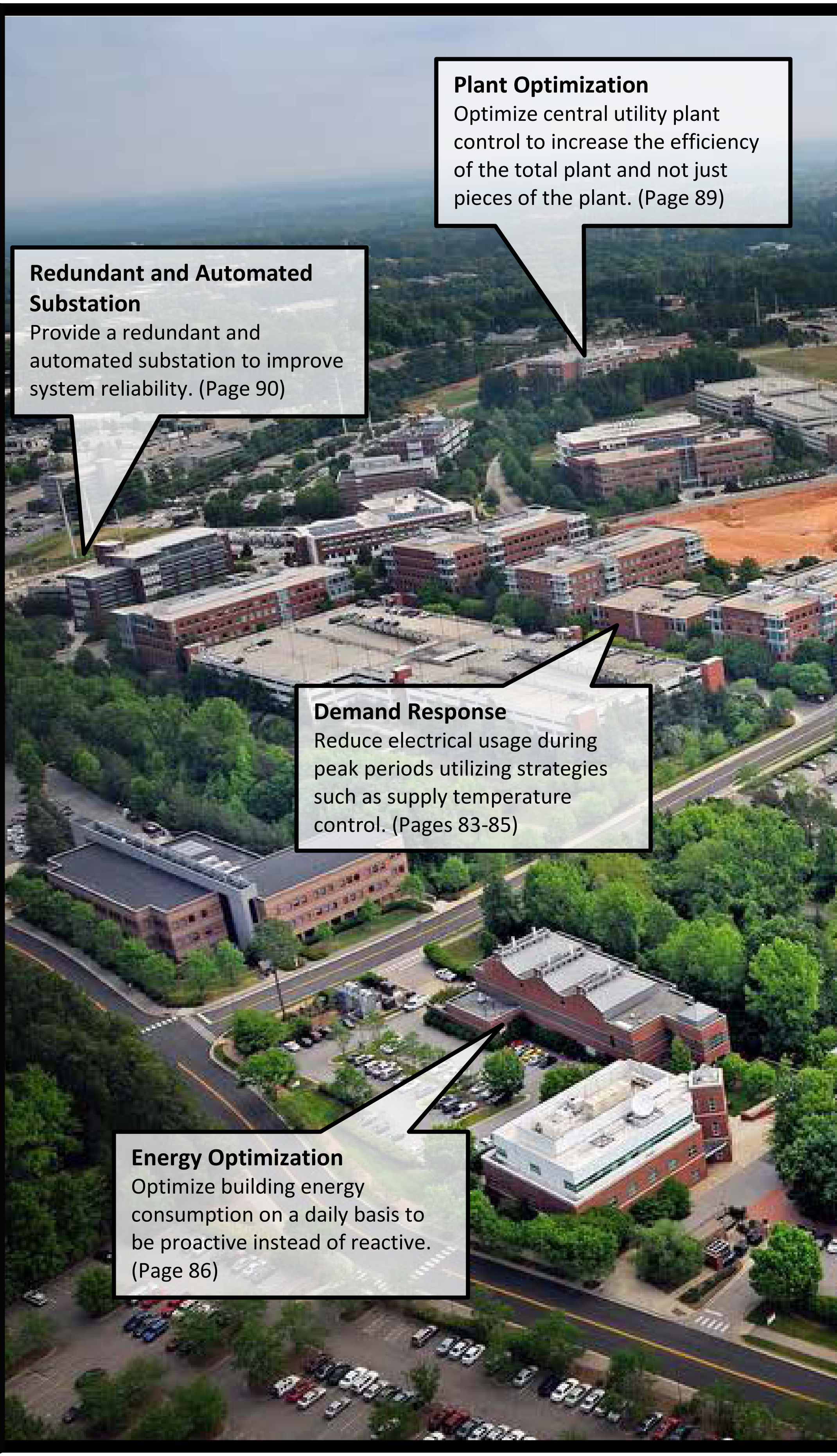
INVESTMENT

The projects found in the Tier I section are items that the University should pursue immediately.

These projects have a payback that is financially beneficial to the University and will provide attractive savings.

It should be noted that some projects are contingent upon the completion of other projects. This contingency is especially important to the smart campus control system projects which are priced assuming a complete system installation.

Further information on each Tier I project including a description, savings, and cost for the individual projects can be found in this section.



Plant Optimization
Optimize central utility plant control to increase the efficiency of the total plant and not just pieces of the plant. (Page 89)

Redundant and Automated Substation
Provide a redundant and automated substation to improve system reliability. (Page 90)

Demand Response
Reduce electrical usage during peak periods utilizing strategies such as supply temperature control. (Pages 83-85)

Energy Optimization
Optimize building energy consumption on a daily basis to be proactive instead of reactive. (Page 86)

University Centennial Campus

Tier I Projects

Automated Set Point Control
Monitor system set points to ensure they are within the University's operational guidelines. (Page 87)

Continuous Commissioning
Constantly monitor building equipment to ensure all systems are operating properly. (Pages 81-82)

Energy Monitoring
Provide infrastructure to allow for enhanced energy monitoring and engagement students in energy reduction. (Pages 79-80)

Self-Healing Grid
Install the proper fault detection, controls, and switching to increase grid reliability. (Page 91)

Campus Integration
Connect mechanical system controls to allow for the disparate systems to work as one. (Page 88)

Smart Metering Infrastructure

The University has put an emphasis on developing a smart metering infrastructure at Centennial Campus. The primary focus of the existing smart metering project is on the larger buildings and those buildings connected to the central utility plant. At present there are still several buildings that need to be upgraded.

The proposed smart metering project will complete the smart metering infrastructure on Centennial Campus for all utilities including steam, chilled water, electricity, and natural gas for all buildings.

By completing the infrastructure the University will have part of the base required for a smart grid completed. A table of the buildings requiring additional smart metering is found below.

Building	Electric
LPGC Pump House	X
Chancelors Residence	
LPGC Maintenance Facility	X
Keystone Energy Center	
Research II	X
Poulton Innovation Center	
Research III	X
Research IV	X
Alumni Bldg.	
Research I	
Toxicology	
Partners II	X
College of Textiles	
MERC	
Central Utility Plant	
Constructed Facilities Lab	X
Total	**7**

In addition it is recommended that the University's construction guidelines be updated to include both the requirement of smart metering on all utilities and to be properly integrated into the campus wide system.

N/A Year Payback

The completed smart metering infrastructure will not immediately provide benefits to the University. The benefits will only come if the University acts on the real time data provided by the smart metering devices.

$N/A Annual Savings

The smart metering infrastructure will reduce the time necessary to read meters, but no savings will be accounted for as part of this project. Additionally, it is anticipated the University will be able to save energy if the data from a smart metering system is used properly.

$30,000 Investment

The cost provided is for the complete installation and start-up for every smart meter. These costs were developed based on the University's experience with previous smart meter installations utilizing the University's standard smart meter.

🟢 **Essential to the Smart Grid**
Smart meters are part of the base infrastructure required for a smart grid.

🟡 **Research Benefits**
Can provide enhanced data for research on building energy consumption.

🟡 **Energy Savings**
Enables other energy saving opportunities, but without action on the data there will be no energy saved.

🟢 **Smart Grid Demonstration**
Will provide the data to identify how a smart grid reduces energy consumption.

Figure 49 - Hunt Library

Smart Campus Control System

The smart campus control system is the command center for the reliability and energy optimization components of the smart grid at Centennial Campus. Due to the complexity of the smart campus control system the project was broken down into system elements. The project breakdown validates the total cost of the smart campus control system and identifies where the energy savings are coming from. All of the projects that are part of the smart campus control system below and a full description of each project can be found on the proceeding pages.

- Campus Energy Engagement
- Building Benchmarking
- Continuous Commissioning (Partial)
- Continuous Commissioning (Full)
- Supply Air Temperature Demand Response
- Space Temperature Demand Response
- Energy Optimization
- Automated Set Point Control
- Campus Integration
- Central Plant Optimization
- Chilled Water Demand Response

Along with a review of the individual components of the smart campus control system a market research of the different solutions available was completed. The results of the smart grid market research are located the Appendix.

In addition to the project list, each project that is part of the smart campus control system is designated with the SCCS tag in the heading before the project name.

2.6 Year Payback

The payback is extremely favorable to the University due to the low capital cost and far reaching potential of this project. Each component of the smart campus control system was carefully evaluated specifically for Centennial Campus. The components found in the SCCS section are projects that are recommended for implementation as soon as possible.

$970,000 Annual Savings

The annual savings were calculated using a mixture of utility data, as built drawings, case studies, and engineering assumptions. The calculations were completed following the order in the project list to the left. This was done to show project interaction and to prevent the overstatement of savings.

$2,500,000 Investment

The initial cost shown is for the full implementation of the recommended smart campus control system. Due to the complexity of the system, it cannot be assumed that if a project is not selected that the implementation cost would decrease by the cost associated with the project. The costs associated with other systems are in the smart grid market research section. Wolf Ridge Student Housing and any new/recent construction were not included in the cost or savings estimate.

Essential to the Smart Grid

A centralized monitoring and control system is essential to the smart grid.

Energy Savings

The system will optimize energy consumption on the entire campus.

Research Benefits

The data gathered by the smart grid control system can be used to help develop the smart grid even further.

Smart Grid Demonstration

This will demonstrate how a smart grid can be used to optimize energy consumption.

SCCS - Campus Energy Engagement

The students at NC State are driven to better our future environment. This was proven again during a recent drought that was of major concern for the local community. The students took part in the water reduction effort and saved countless gallons of water. While there is no concern of an energy shortage today, the threat of global warming is real and is a concern of the students. The University can assist the students in understanding the energy consumption problem and show them that they can make a real difference.

To engage the students, the University needs to implement a software solution that encourages the students to reduce energy. To do this, it is recommended that a software solution with proven university energy dashboard deployment be used as the energy dashboard at Centennial Campus. It is recommended that the University provide a web presence for the energy consumption that is visible and easily accessible to the students. This should include a connection to the "Change Your State" website as well as utilizing social media. In addition to the web presence it is recommended that "energy kiosks" be placed in highly visible locations throughout the campus. The University could host energy saving competitions locally and nationally to further encourage students.

<1 Year Payback

The payback is extremely favorable to the University due to the low capital cost and far reaching potential of this project. Even if savings are well below the target savings the project will still have a payback of less than a year. The University may consider including the smart metering infrastructure as part of this project to overcome the sunk cost of the smart metering project.

$143,000 Annual Savings

The exact savings will be dependent on how engaged the students are in saving energy. There are numerous case studies at universities that show savings between 2-5%. For this project, a conservative estimated savings of 2% was used.

$60,000 Investment

The cost provided is for installation of standalone software focused on displaying energy consumption data by building in an interactive and intuitive interface. It is expected the University will have some additional expenses associated with their IT department, which is not included. This cost also does not include energy dashboard kiosks. If the University decides to use kiosks from the vendor, the kiosks are estimated to cost $10,000 each.

🟢 **Essential to the Smart Grid**
An important tool for educating end users about energy and the smart grid.

🔴 **Research Benefits**
This project will not provide additional benefits to smart grid research.

🟢 **Energy Savings**
Estimated savings between 2-5% across the entire campus can prove to be significant.

🟢 **Smart Grid Demonstration**
This will demonstrate to students and faculty how a smart grid can save energy.

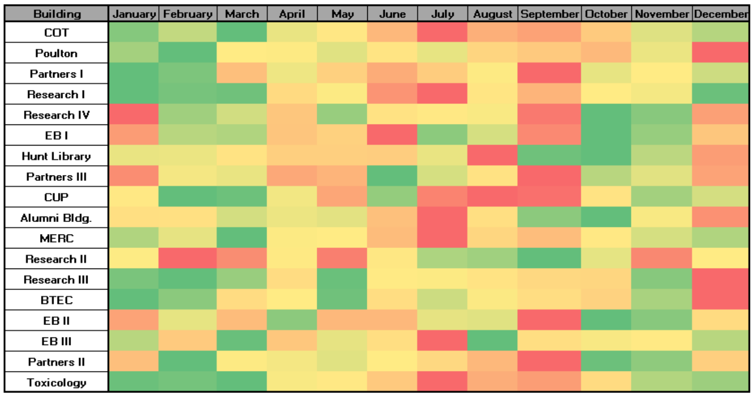
SCCS -Building Benchmarking

Benchmarking software provides the University with a visual and analytical view of campus energy use. The benchmarking software aggregates the large amount of data from the meters and consolidates it into an easily understood format. Building benchmarking provides energy and facility managers with a quick and effective way to analyze systems for each building and the entire campus.

To offer the best insight into the campus energy consumption, it is recommended that the building benchmarking software include the following abilities:

- **Trend Analysis** - Review data over different timescales and compare data with temperature, Heating Degree Days, and Cooling Degree Days overlaid.
- **Load Profiling** - Overlay multiple load profiles for a single facility to identify scheduling inefficiencies.
- **Heat Map** - Visually analyze trends to detect scheduling problems.
- **Regression Analysis –** Normalize weather data to better compare year to year changes.

A building benchmarking software solution should be a module of another software solution, whether it is the campus energy engagement dashboard or smart campus control system.



<1 Year Payback

With a low initial investment cost and good energy savings a short payback is expected. The estimated payback period assumes the facilities department at the University has the staff available to take action on the discovered problems.

$70,000 Annual Savings

It is estimated that with the deficiencies discovered by the facilities personnel the University will be able to save a minimum of 1% of the energy costs annually. This savings estimate is conservative and could be higher.

$30,000 Investment

The cost provided is assuming that an energy engagement software or smart campus solution is already in place and a benchmarking tool is an add-on. There would be additional cost for including additional sub metering or building automation systems.

🟡 **Essential to the Smart Grid**
Provides a high level analysis of data, but is not essential to the operation of a smart grid.

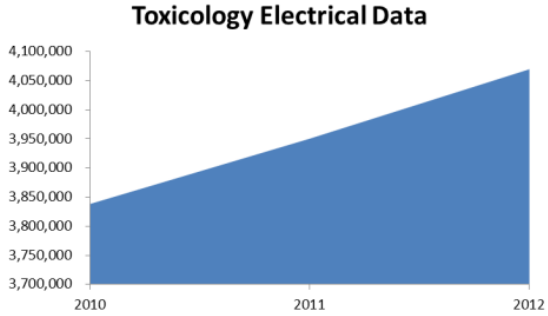
🔴 **Research Benefits**
There are no expected research benefits from this project.

🟢 **Energy Savings**
Estimated savings of 1% across the entire campus.

🟢 **Smart Grid Demonstration**
Demonstrates how analytics of energy data can be used to save energy at a campus setting.

SCCS – Continuous Commissioning (Partial)

Over years of operation, buildings become less efficient as items stop functioning as designed. This is evident in buildings such as the Toxicology Building which has seen a 5% increase in electrical consumption over the last three years. Continuous commissioning helps eliminate this problem by providing system alarms and prioritizing the faults detected based on calculated energy wasted.



This is done by mapping key points to monitor equipment performance. The equipment performance is evaluated against a set of rules and baseline parameters. If the equipment does not meet the standards the system will alert the maintenance personnel of the problem.

Installation of a partial continuous commissioning system would only examine the major pieces of equipment such as central AHUs, chillers, pumps, and boilers. Specific items which are examined for air handling units include the following:

- Chilled/hot water valve position
- Supply/return/ mixed air temperatures
- Damper positions
- Airflow
- Airside economizer
- Status and set points

Chillers and boiler systems are evaluated based on published equipment data and equipment performance testing. Specific items which are monitored for chillers and boilers include the following:

- Supply and return temperatures
- System Efficiency
- Valve Position
- Fluid Flow
- Status and set points
- Pump Status

3 Year Payback

The payback period of the project will depend on the number of problems located and the action facility personnel takes.

$130,000 Annual Savings

The annual savings are based on calculations using utility data, as built drawings, and engineering assumptions. It was assumed that on average 1% of the equipment fails annually. In addition, these figures were supported with case studies which have seen a range of 5-10% in energy reduction.

$340,000 Investment

The above cost assumes this project is part of a full implementation of a smart campus control system which is owned and operated by the University. The actual cost will be dependent on the solution the University selects.

🟢 **Essential to the Smart Grid**
Is a major part of the information gathering aspect of the smart grid inside the buildings.

🔴 **Research Benefits**
There are no real research benefits associated with this project.

🟢 **Energy Savings**
As the system is optimizing energy consuming equipment, energy savings is a major portion of the project.

🟢 **Smart Grid Demonstration**
This project will demonstrate the energy saving abilities of processing and analytic analysis of BAS data.

SCCS – Continuous Commissioning (Full)

Building upon the partial implementation of continuous commissioning is a full employment of the solution. A full implementation is focused on the smaller devices and terminal units such as VAV boxes, fan coil units, and small packaged air handling units.

While these smaller devices use less energy per point monitored than the larger items, these systems can waste more energy. The reason for the high energy waste is the neglect associated with the devices. Due to the sheer number and the typical location, inside an occupied space, it is challenging to properly monitor the smaller equipment. In addition, a malfunction at the device is hard to locate in normal day to day operations because of its ability to overcome faults in the system. As this is the case, a system can remain unrepaired until a space occupant complains or a major investigation of the building energy consuming systems is completed.

Continuous commissioning would help eliminate these unnoticed deficiencies by alerting facility personnel as a problem develops. The enhanced monitoring capability for the smaller devices will be more expensive, but will also provide larger savings.

It is to be noted that this project and the partial continuous commissioning project assume that the existing building automation systems are in good working order and can connect to the smart campus control system.

Specific items which are examined for VAVs and FCUs include the following:

- Chilled/hot water valve position
- Supply/return/ mixed air temperatures
- Damper positions
- Air flow
- Space temperature
- Supply fan operation
- Status and set points

3 Year Payback

The payback period of the project will depend on the number of problems located and the action facility personnel takes.

$330,000 Annual Savings

The annual savings are based on calculations using utility data, as built drawings, and engineering assumptions. It was assumed that on average 1% of the equipment fails annually. In addition, these figures were supported with case studies which have seen a range of 8-15% in energy reduction for a full implementation. The savings estimate includes the partial continuous commissioning savings and not in addition to.

$940,000 Investment

The above cost assumes this project is part of a full implementation of a smart campus control system which is owned and operated by the University. The actual cost will be dependent on what solution the University selects. This cost does include the costs associated with the implementation of the partial continuous commissioning project.

🟢 **Essential to the Smart Grid**
Is a major part of the information gathering aspect of the smart grid inside the buildings.

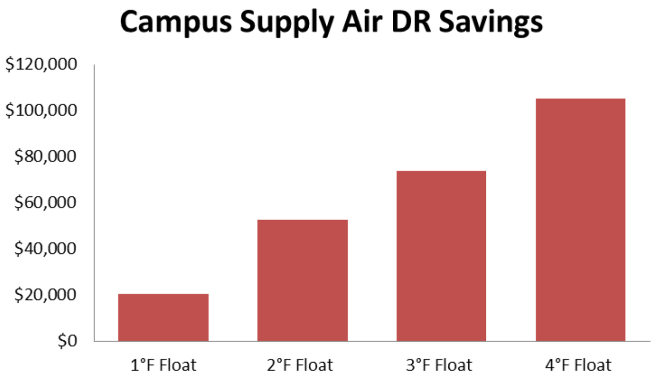
🔴 **Research Benefits**
There are no real research benefits associated with this project.

🟢 **Energy Savings**
As the system is optimizing energy consuming equipment, energy savings is a major portion of the project.

🟢 **Smart Grid Demonstration**
This project will demonstrate the energy saving abilities of processing and analytic analysis of BAS data.

SCCS - Supply Air Temperature Demand Response

This project aims to control the supply air temperature during a demand response period. Raising the supply air temperature reduces demand while minimizing the impact on the occupant. In spaces where maintaining a precise temperature within +/- 1°F is required, this system will not be utilized. A variety of increases in supply air temperature float temperatures were modeled, (1˚F, 2˚F, and 3˚F) and it was determined that a 2˚F rise in supply temperature provides the best blend of economics and comfort.



The economics were also evaluated using variations of demand reduction allotments to utility and campus developed response program. Through the evaluation it was determined that a University controlled demand response program would be best. There are multiple drivers for this recommendation including the University's ability to self-control the system and other incentive programs the University is part of that would be affected by this program.

Ideally the demand response program would be part of a full smart campus control system as that would limit the project cost to programming.

2 Year Payback

The major benefit of this project is a reduction in the energy cost. The actual energy reduction is anticipated to be minimal as a pre-cool and post cool strategy will need to be implemented to meet the thermal demands of the buildings.

$50,000 Annual Savings

The savings is based on a 2˚F temperature rise with a University run demand respond program. It is assumed the program will be utilized four months of the year. The program could be used year round and increase the savings associated with this project. The calculation was completed using actual design air flows with a diversity factor of 70%. Actual savings depend on what kind of strategy the University is willing to take part in and the aggressiveness of the strategy.

$110,000 Investment

The above cost assumes this project is part of a full implementation of a smart campus control system which is owned and operated by the University. The actual cost is dependent on the solution the University selects. If the University implements a standalone demand response system the cost will be higher.

🟢 **Essential to the Smart Grid**
Demand response and load leveling is a key component to a smart grid.

🔴 **Research Benefits**
There are no research benefits associated with this project.

🟡 **Energy Savings**
There will be some energy savings associated with this project, but most savings will be from an energy cost reduction.

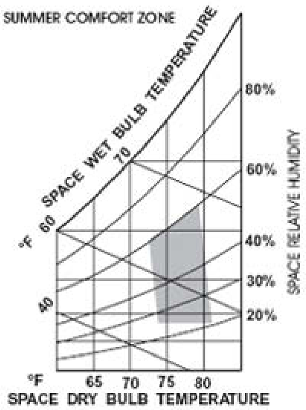
🟢 **Smart Grid Demonstration**
This project will demonstrate the demand response capabilities of a smart grid

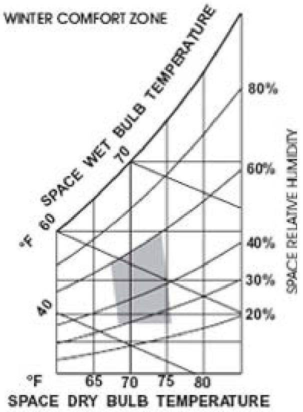
SCCS– Space Temperature Demand Response

Similar to the supply air temperature demand response program, the space temperature demand response program is used to reduce peak demand. The buildings are pre-cooled approximately 1-2 ˚F then the spaces are allowed to float 1-2˚F above their set point. In spaces where maintaining a precise temperature within +/- 1°F is required, this system will not be utilized.

A variety of increases in space temperatures were modeled (1˚F, 2˚F, and 3˚F) using energy modeling software. It was determined that a 2˚F rise in space temperature will provide the best blend of economics and comfort.

A 2˚F change is minimal and should be undetectable by most occupants. This minor change will maintain space temperatures which are well within the summer and winter thermal comfort guidelines as determined by ASHRAE and shown in the graphs below.





For this demand response program, it was determined that an internally monitored and controlled program provides the University with the flexibility needed to adjust space temperatures instead of a utility program.

5 Year Payback

The major benefit of this project is a reduction in the energy cost. The actual energy reduction is minimal as a pre-cool and post-cool strategy needs to be implemented to meet the thermal demands of the buildings.

$30,000 Annual Savings

The savings estimate is based on a 2˚F space temperature in a University run demand response program. It also assumes that 60% of building area will participate in the program. Actual savings depends on what kind of strategy the University is willing to take part in and the aggressiveness of the strategy.

$140,000 Investment

There is a wide variety of cost that could be associated with the demand response program. The cost shown above assumes this project is completed as part of a smart campus control system. If the project is completed independently, a dramatic increase in cost is expected.

🟢

Essential to the Smart Grid

Demand response and load leveling is a key component to a smart grid.

🟡

Energy Savings

There will be some energy savings associated with this project, but most savings will be from an energy cost reduction.

🔴

Research Benefits

There are no research benefits associated with this project.

🟢

Smart Grid Demonstration

This project will demonstrate the demand response capabilities of a smart grid.

SCCS – Chilled Water Demand Response

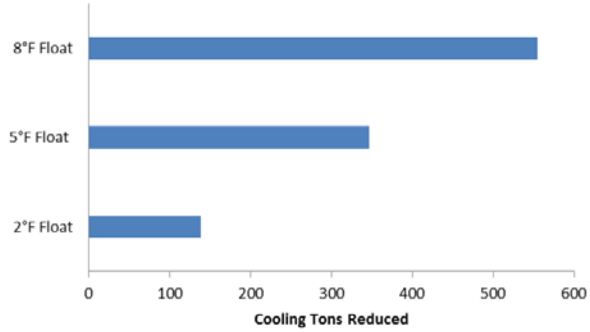
The Centennial Campus Central Utility Plant experiences the largest energy demand on campus. Peak electrical demand may exceed 5,000kW, with the majority of that demand coming from the production of chilled water. With demand making up approximately 25% of the campus electric bill, it is important to reduce demand as much as possible.

A low cost scheme for chilled water demand reduction is utilizing the inertia associated with the distribution system and allowing the chilled water supply temperature to float a couple of degrees. To accomplish this without seeing an effect at the building level the chilled water must first be pre-cooled several degrees and then floated to an increased temperature that will not cause major issues with building cooling demands.

An analysis of the savings associated with chilled water demand reduction was conducted. The calculations were based on the over half million gallons of chilled water in the distribution system for inertia and supply temperature changes of 2, 5, and 8°F.

The analysis was conducted based on the peak load of the plant with that load being sustained over a 5 hour period. The saving calculations were completed based on a University run program and not in cooperation with the utility.

Based on financial savings and practicality, it is recommended that a 5°F temperature float be utilized as the demand reduction set point for this evaluation.



1 Year Payback

The payback period is short due to the relatively minimal cost associated with programming a demand response program using the smart campus control system.

$30,000 Annual Savings

The annual savings is based on the reduction of the electric bill during the warmer months. There could be additional savings during the cooler months, but they were not accounted for.

$40,000 Investment

The project utilizes the existing equipment and controls for the system. There will simply be an additional programming over top of the existing system to provide intelligent control. Due to the simplistic nature there will be minimal cost

🟢 **Essential to the Smart Grid**
Demand reduction is a major financial driver of the smart grid.

🔴 **Research Benefits**
There are no research benefits from this project.

🟡 **Energy Savings**
Most savings from this project will be from reduction in energy cost.

🟡 **Smart Grid Demonstration**
This will demonstrate the value of controls and modeling in a smart grid.

SCCS – Energy Optimization

Energy optimization relies on a set of algorithms to learn a building's operation and develop an ideal daily operational strategy based on a range of variables. An example of this learning capability is pre-cooling. Instead of utilizing a default pre-cooling sequence when cooling, the building will pre-cool based on the forecasted weather and occupancy. By doing this the building is able to prevent overcooling and wasting energy. Listed below are several common strategies that may be part of an initial energy optimization sequence with additional sophistication of the system increasing as the system evolves.

Hot Water/Chilled Water Pump Control

- Turn off pumps at specified outside temperature and humidity levels.

Unoccupied mode optimization

- Adjust unoccupied mode set points and time to reflect current and expected conditions.

Chilled/Hot Water Reset

- Implement a more aggressive chilled/hot water reset strategy in the buildings.

Supply Air Temperature Control

- Implement a more aggressive supply air temperature reset strategy in the buildings.

Optimized Stop/Start

- Start and stop the buildings based on historic data and forecasted weather to reduce start up time.

The ability of the University to implement these strategies depends on the initial investment into the smart campus control system. If the University integrates all major equipment (pumps, AHUs, chillers) and minor equipment (FCUs, VAVs, thermostats) into the system, the energy optimization strategies are vast. The strategies may also be more aggressive in energy reduction with more points integrated and monitored in the system.

2 Year Payback

The payback is advantageous for the University due to the far reaching potential of this project. The payback period will be dependent on how aggressive the University is with the strategies they implement.

$130,000 Annual Savings

It is estimated that by improving the operational sequences, equipment control, and set points that the buildings on average will save 2% of their total energy consumption.

$310,000 Investment

There is a wide variety of cost that could be associated with energy optimization. The cost depends on what amount of the smart campus control system is already in place from other projects, as well as how sophisticated the installed system is.

🟢 **Essential to the Smart Grid**
Energy optimization is a key idea of the smart grid concept.

🔴 **Research Benefits**
There are no real research benefits associated with this project.

🟢 **Energy Savings**
Saving energy in each building is the main focus of this project.

🟢 **Smart Grid Demonstration**
Demonstrates how the smart grid can take input from a variety of sources to optimize energy consumption.

SCCS – Automated Set Point Control

The wide variety of usage and occupants on a University campus means that system set points are being constantly changed. Set points are most commonly changed for occupant comfort or temporarily repairing a problem. Managing all of the set points to ensure they stay within the required range is a nearly impossible task, but this lack of oversight can create a substantial cost for the University.

These set point adjustments may be extremely costly as it not only directly affects a system or room, but also the systems and rooms surrounding it. In addition, as these adjustments are input directly into the BAS, the system will not alarm, which means these costly adjustments can go unnoticed for years.

The smart campus control system utilizes automated set point control to manage set points and prevent energy waste. The smart campus control system uses rules for each set point to make sure it is permissible within the rules. If the set point is outside the range of the rules for a prescribed period the system will change the set point back to the default or alarm facility personnel.

Using automated set point control will not only make sure that the equipment is controlled properly during occupied periods, but also during unoccupied periods where the majority of its benefits will occur. This is due to systems either being overridden to keep occupants temporarily satisfied or a system never going into an unoccupied mode.

A concern that must be addressed as part of the automated set point control is critical spaces, which need a constant temperature. It is proposed that the University implement a procedure which requires occupants to submit a request at the beginning of the year that prevents a zone from entering an unoccupied mode. To prevent excess paperwork and administrative work this will only occur at the beginning of the year or semester.

2 Year Payback

A short payback period is expected due to the use of existing smart campus control system infrastructure and which means minimal additional programming is required.

$60,000 Annual Savings

The annual savings is based on an estimate on an assumption that 10% of the spaces are not going into a normal unoccupied mode. Additional savings are likely as the calculation is only accounting for unoccupied faults, but the system will monitor both occupied and unoccupied set points.

$110,000 Investment

The investment will be small as it is reliant on the smart building infrastructure already being in place. The cost associated with this project is for the analysis and implementation of the control system.

🔴 **Essential to the Smart Grid**
This project is not essential to a smart grid operation.

🔴 **Research Benefits**
There are no research benefits associated this project.

🟢 **Energy Savings**
For the small investment required the energy savings will be considerable.

🟡 **Smart Grid Demonstration**
This project demonstrates the advance capabilities of a smart grid.

SCCS – Campus Integration

The goal of a smart campus control system is to utilize one scheme that works seamlessly to integrate all of the programs into one fluid system. The campus integration not only optimizes the campus energy consumption but also improves facility productivity. The system will provide easy access to vital information that a variety of facility personnel need, as well as being the backbone for an energy management and demand response program.

The smart campus control system models campus energy consumption and predict future consumption. The predicted energy consumption is used for developing an energy strategy for the next 24 hour period. The system will first evaluate the estimated energy consumption and determine if a demand response event will need to be implemented based on a baseline set of parameters. If it is determined to be necessary the smart campus control system will calculate how much energy should be shed and at what time.

During normal demand periods, the system can also be used to communicate with buildings in shaping the load curve. This is done by putting hourly values on campus utilities. The building will then take those values and optimize energy consumption based on cost using methods described in the smart campus control system energy optimization project.

In addition the smart campus control system will serve as a central monitoring point that can be used by each facilities department. To assist in providing useful information to each user a dashboard will be provided for each user or user group. This dashboard is customized to provide a view into specific systems. For example, the chiller plant operator may see chilled water consumption by building, as well as the distribution system, and be able to monitor the chilled water plant operation.

As part of the campus integration it is recommended that a central command center be installed. The center could serve two roles: a central location to monitor the campus 24/7 and to display the vast amount of data gathered in the smart campus control system. It is recommended that the system be installed in a central utility plant or facilities occupied building.

7 Year Payback

The payback claimed is only utilizing energy savings. It is expected that the University will also see savings in facility operations.

$60,000 Annual Savings

The annual energy savings is based on improved efficiencies due to the various disparate systems working as one. It is estimated that it will reduce campus energy consumption by 1%.

$410,000 Investment

As the campus integration is a backbone to the system a large capital investment is required compared to the payback period. The cost associated with a new control room is not included.

Essential to the Smart Grid

The central control system is what allows all of the various components to act as one system.

Research Benefits

Will provide a large amount of useful real world data for use in academic and corporate research.

Energy Savings

Will optimize energy consumption over all the energy consuming and producing systems.

Smart Grid Demonstration

Demonstrates the smart grid's ability to integrate all systems into one fluid system.

SCCS – Central Plant Optimization

The central utility plant accounts for over 25% of the energy consumption on campus. Due to the high energy use it is important to optimize it as much as possible. Utilizing plant optimization software will provide definite solutions for running the plant efficiently.

The plant optimization integrates every component of the chilled water and steam systems to allow them to work together and reduce energy consumption. The solution will not only integrate all the components inside the plant but also connect to the buildings utilizing chilled water and steam.

Integrating the components inside the plant ensures that the systems work together to reduce energy consumption. Instead of sacrificing one component's efficiency to improve another's efficiency, the system will find the proper operational setting to provide the best overall efficiency. This optimization will include everything from chilled and condenser water pumps to the chiller and cooling tower. The solution will also operate to minimize energy wasting equipment "hunting" that can be caused by improper control sequences.

Additionally, the system will utilize the data and knowledge from the smart campus control system to further optimize the system. The plant will take the predicted chilled water consumption for the day and develop an optimal operation strategy. The strategy will be based on equipment performance curves, historical data, and other data.

2 Year Payback

It is expected that the plant optimization generates a strong payback as part of a smart campus solution. Even if the entire smart campus solution is not implemented, a stand-alone optimized plant control system will provide a good payback.

$50,000 Annual Savings

It is estimated the system would improve the average chilled water system efficiency by approximately 0.05kw/ton and the steam system is estimated to improve efficiency by 0.5% over the existing efficiency of 68% with enhanced operating control sequences.

$80,000 Investment

The cost shown is part of a smart campus control system installation. If the smart campus installation is not completed, a plant optimization software can still be implemented but at a higher cost.

🟡 **Essential to the Smart Grid**
The project is not essential, but is part of a smart grid system integration.

🔴 **Research Benefits**
There are no major benefits associated with this project.

🟢 **Energy Savings**
Will save energy at the central utility plant.

🟡 **Smart Grid Demonstration**
Demonstrates how monitoring and controlling various systems can optimize energy consumption.

Redundant and Automated Substation

Maintaining a constant supply of energy to University buildings to allow for cutting edge research and institutional education is the goal of the utilities department at NC State.

At present, all of Centennial Campus electricity is funneled through one transformer and switchgear line up before it is distributed to the buildings on campus. If only one component fails, the campus may be without power for an extended period of time. Depending on the component that fails, the outage could last from just a few hours to several days. Any outage, especially one over an extended period, would have a dramatic impact on the operations of the University.

Installing a redundant and automated substation will reduce the risk to the University of experiencing any such problems. The new substation would be configured to run electricity through both parallel transformer/switchgear line ups with automated throw over switches.

In addition, it is recommended that the distribution system is fed such that each loop has one circuit fed by each switchgear lineup. Configuring the system in this fashion will allow for the campus to be fed from either switchgear lineup. With this automated and redundant substation configuration, outage periods will be reduced.

2 Year Payback

The payback period is based on the avoided cost from the increased reliability of the substation and reduction in potential outage time. It is possible the existing substation equipment will never fail before it is taken out of service. The University must evaluate the risks and understand a redundant system may never be necessary.

$2,600,000 Avoided Cost

The annual avoided cost figure is based on the calculated reliability improvement and downtime associated with a potential substation outage with no spare. The hourly cost associated with Centennial Campus operations was provided by the University.

$5,100,000 Investment

The cost provided is for the installation of a 30/40/50MVa transformer and switchgear as well as reconfiguring the circuiting to feed distribution loops from both switchgear line ups. The cost also includes the switching and controls required for the system.

🟡 **Essential to the Smart Grid**
Improves the reliability of the distribution system, a major goal of the smart gird.

🟢 **Research Benefits**
Will help ensure that all academic activities and research will be unaffected by a potential equipment failure.

🔴 **Energy Savings**
There are no energy savings associated with this project.

🟢 **Smart Grid Demonstration**
Will demonstrate the improved reliability that a smart grid can provide.

Self-Healing Grid

A self-healing grid aims to reduce or prevent power outages on an electrical distribution system. This outage reduction is very important when trying to maintain a large distribution system that has a large number of vulnerabilities. The Centennial Campus electrical distribution is relatively small and was designed with minimal vulnerabilities. This is evident with the small amount of power interruptions that have occurred from faults inside the fence.

Due to the robustness of the current system the amount of downtime reduction will be minimal. Thus, a payback period would be long for a full self-healing grid. To optimize the payback period three self-healing grid concepts were evaluated: open points, sectionalized, and full campus. The work and benefits associated with each concept are described below.

Open Points

This scenario would automate the switching at the existing open points. Automating the open points will not prevent a fault from occurring on a circuit, but it will reduce the system downtime after the fault is isolated or repaired. **Cost: $240,000**
Campus Downtime Avoided: $39,000

Sectionalized

This option would sectionalize the grid and provide fault isolation and self-healing capabilities at select buildings based on the University priorities. The reduction in downtime is minimal due to the shortened repair time and the small chance of a fault occurrence. **Cost: $580,000**
Campus Downtime Avoided: $40,800

Entire Campus

Providing self-healing capabilities to isolate each building would ensure that any fault in the system would be isolated to that section or building. The system would then open and close switches as necessary to ensure as many buildings stay on line as possible. This system is very effective in maintaining electrical distribution throughout the campus, but has a high initial cost. **Cost: $1,730,000**
Campus Downtime Avoided: $43,500

6 Year Payback

The payback period is for the self-healing grid at the open points only; this scenario provides the optimum avoided cost to investment ratio.

$40,000 Avoided Cost

The calculated avoided cost is based on a reliability calculation and a reduction in estimated downtime. The hourly cost associated with Centennial Campus operations were provided by the University.

$240,000 Investment

The cost is to replace existing manual switches at the open point for each circuit (4 circuits) with automated switching, install fault detection and smart relays for each circuit open point, and add fiber optic backbone for each switch.

🟢 **Essential to the Smart Grid**
Improves the reliability of the electrical distribution system.

🟢 **Research Benefits**
Will help ensure that all academic activities and research will be unaffected by a potential equipment failure.

🔴 **Energy Savings**
There are no energy savings associated with this project.

🟢 **Smart Grid Demonstration**
Will demonstrate the improved reliability that a smart grid can provide

North Carolina State
Smart Grid

20 YEAR

PAYBACK

$1,560,000

SAVINGS

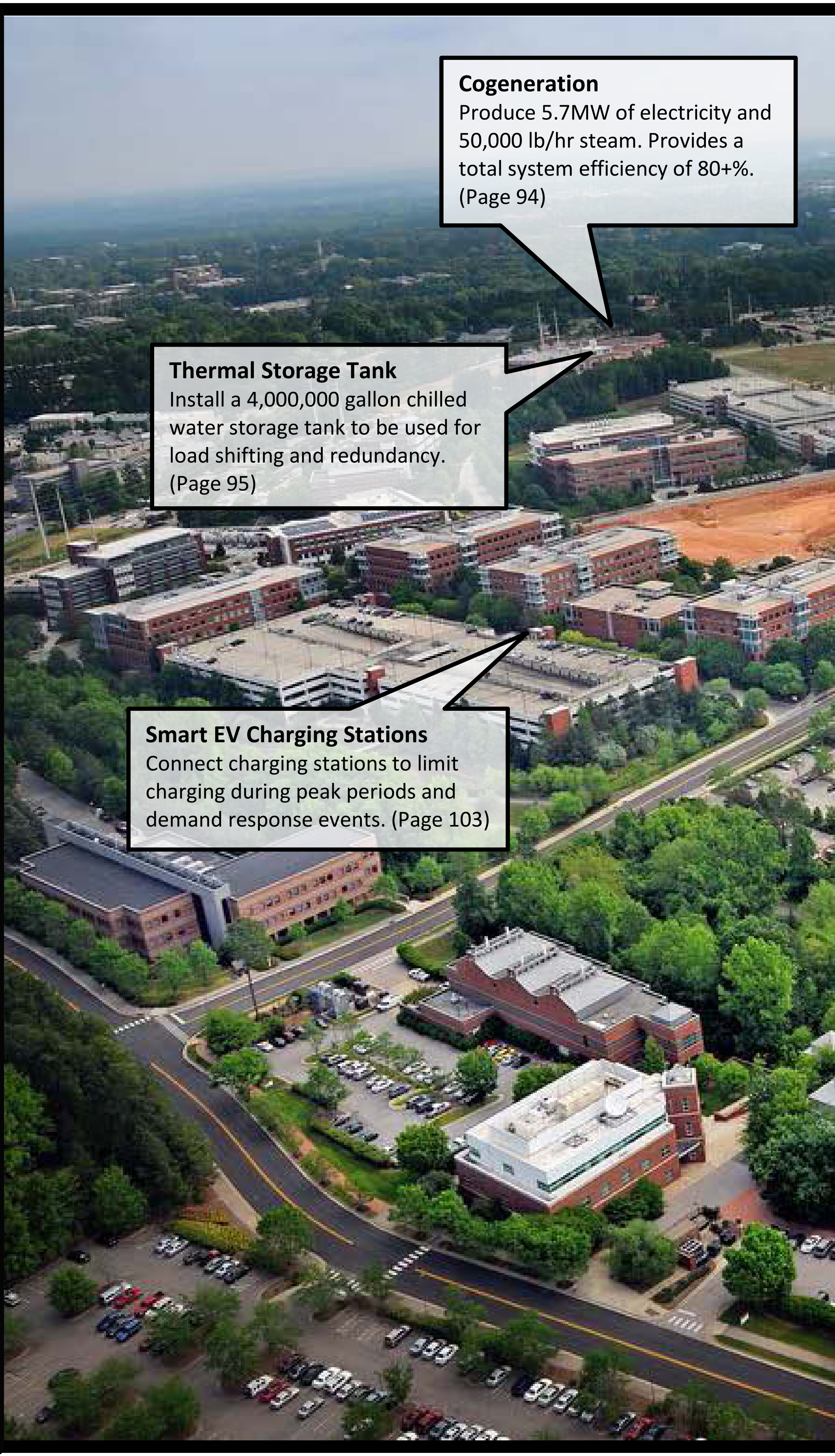
$31,770,000

INVESTMENT

The projects found in the Tier II section are items that currently do not have a desirable payback, but may in the future. There are some projects that still may be desirable due to other factors.

On average these projects have a payback of ten years or longer. It is to be noted that some projects are related to smart grid research and don't have any savings associated with them, however they will greatly enhance the University's smart grid research capabilities.

Further information on each Tier II project including a description, savings, and cost for the individual projects can be found in this section.



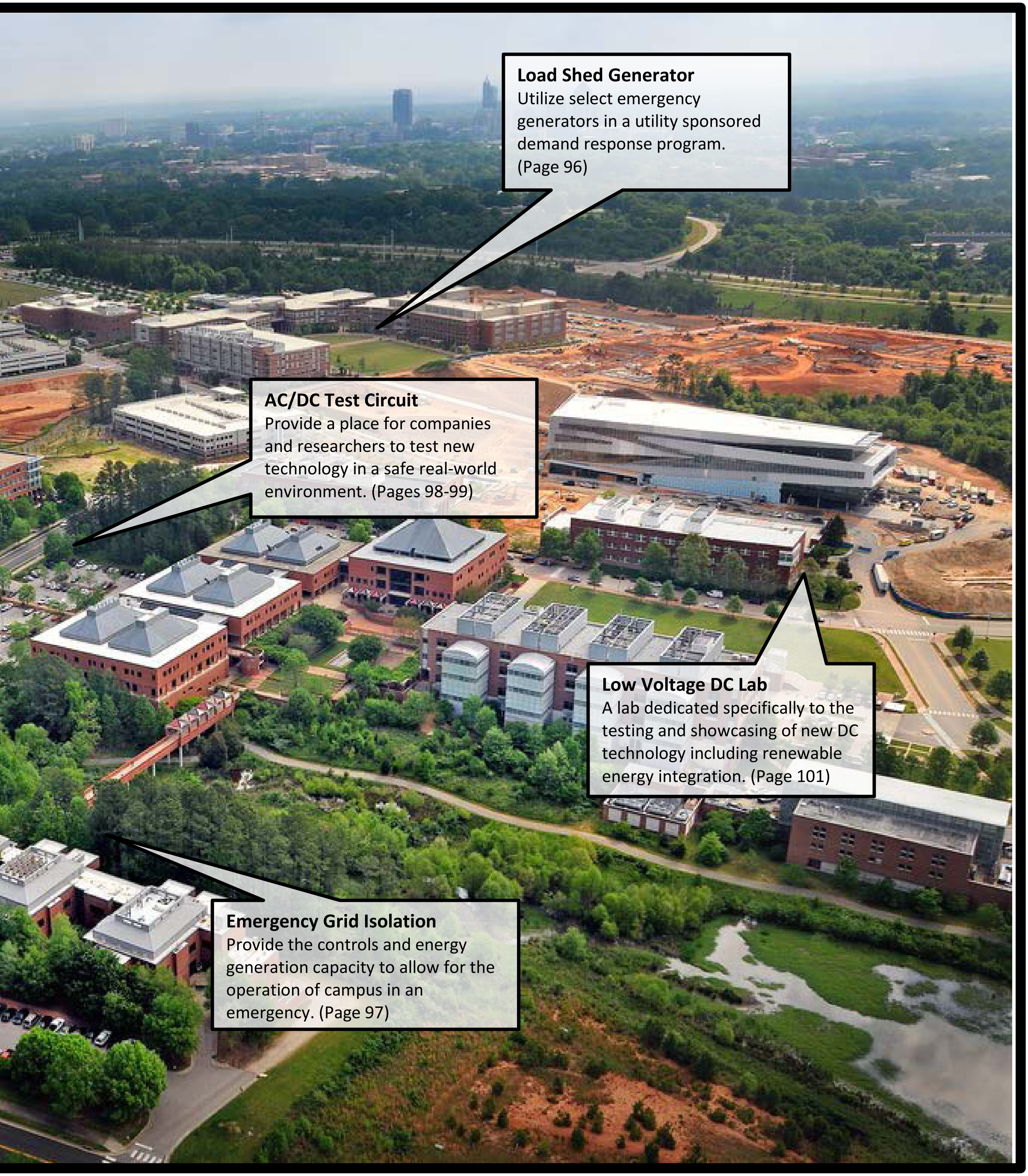
Cogeneration
Produce 5.7MW of electricity and 50,000 lb/hr steam. Provides a total system efficiency of 80+%. (Page 94)

Thermal Storage Tank
Install a 4,000,000 gallon chilled water storage tank to be used for load shifting and redundancy. (Page 95)

Smart EV Charging Stations
Connect charging stations to limit charging during peak periods and demand response events. (Page 103)

University Centennial Campus

Tier II Projects



Load Shed Generator
Utilize select emergency generators in a utility sponsored demand response program. (Page 96)

AC/DC Test Circuit
Provide a place for companies and researchers to test new technology in a safe real-world environment. (Pages 98-99)

Low Voltage DC Lab
A lab dedicated specifically to the testing and showcasing of new DC technology including renewable energy integration. (Page 101)

Emergency Grid Isolation
Provide the controls and energy generation capacity to allow for the operation of campus in an emergency. (Page 97)

Cogeneration

The Centennial Campus has a significant steam load which it maintains throughout the entire year. The existing steam and electric loads plus the additional load anticipated in the future means the campus is a good fit for a combined heat and power system.

The University commissioned a preliminary study of cogeneration at the campus. The study examined a variety of existing and future load scenarios. Based on various scenarios, it was determined that a cogeneration system which produces 5.7MW of electricity and 60,000 lbs/hr of 125psi steam would best fit the University's needs now and in the future.

Due to the heat load requirements of the campus and the University's positive experience with a natural gas turbine and heat recovery steam generator (HRSG), it is recommended that this solution be used as the prime mover. A natural gas turbine produces electricity efficiently while outputting exhaust at approximately 950 °F which is ideal for producing high pressure steam.

The current layout of the plant does not allow for an ideal location of a long term operation and maintenance of a cogeneration system. It is recommended a building addition house the cogeneration equipment.

17 Year Payback

This payback period is based on using a flat electric rate at the current prices. It is important to note that the Energy Information Administration (EIA) forecasted that in the next 30 years the cost of natural gas will double while electricity will increase approximately 25%. Utilizing the EIA's projected numbers, the cogeneration system has a payback period of 28 years.

$1,070,000 Annual Savings

The annual savings are based on the future load predicted for 2017. The annual savings does account for additional operation and maintenance costs associated with a cogeneration system. Beyond the benefit of increasing overall system efficiency a cogeneration plant would also be a base for emergency grid isolation.

$18,450,000 Investment

The cost provided is for the complete installation and start-up for a 5.7MW gas turbine with a 30,000 lb/hr heat recovery steam generator, and a duct burner. The cost includes the building addition, connection costs, controls, and commissioning of the system. The cost assumes the plant does not need to increase the capacity of the deareator, feedwater pumps, and water treatment.

🟢 **Essential to the Smart Grid**
Will provide distributed generation that could also be used in emergency micro grid scenarios.

🟡 **Research Benefits**
Will help understand how to use distributed generation in a smart grid.

🟢 **Energy Savings**
Will provide a 15-20% overall efficiency improvement over the existing electrical/steam production equipment.

🟢 **Smart Grid Demonstration**
Will demonstrate the distributed generation concept and can be used as a base for a micro grid demonstration.

Chilled Water Thermal Storage

As previously discussed there are a variety of uses for a chilled water storage tank. For Centennial Campus it is recommended that Thermal Energy Storage (TES) be used for two purposes: load shifting and providing additional redundant capacity. Utilizing TES for load shedding and redundancy will provide benefits with reduction in utility costs as well as reduced capital costs associated with installing an additional redundant chiller.

Load shifting will move the majority of chilled water production to off peak periods. It is beneficial to produce during off peak periods to reduce demand charges and energy cost.

As more buildings are connected to the chilled water loop, production demand increases. At the current pace of expansion it will not be long before additional capacity will be required at the plant. The University could use the TES to provide an additional 2,500 tons of redundant cooling capacity for 12 hours during peak periods. Removing the additional capital cost and O&M associated with a 2,500 ton chiller could provide significant savings to the University.

Based on the current and future campus load, it is recommended that a 35,000 ton hour tank be installed. A 35,000 ton hour tank will provide the ideal amount of savings now and in the future as well as provide the redundancy desired by the University. Utilizing an estimated temperature differential at peak periods of 12°F, the tank needs to hold approximately 4 million gallons of chilled water.

18 Year Payback

The payback is based on the annual electric savings from a time of use rate structure. Additional savings from potential reduced capital and O&M costs were not included in the payback period.

$340,000 Annual Savings

Savings above are calculated based on reduced demand and energy costs. The savings are based on a time of use electric rate and the current chilled water load. As additional buildings are connected to the loop there will be additional savings.

$6,270,000 Investment

The cost is for a 4 million gallon concrete tank including the tank, site work, piping and controls associated with the thermal storage tank. If the University selected a steel tank the cost could be reduced by 25%.

🟢 **Essential to the Smart Grid**

Provides the ability to shift load to off peak periods and respond to high demand.

🟡 **Energy Savings**

The TES will provide a little improvement on system efficiency, but the focus is energy cost reduction.

🟡 **Research Benefits**

There are minimal research benefits with thermal storage. Additional research could be conducted on optimal operation.

🟢 **Smart Grid Demonstration**

The TES will demonstrate the load shifting abilities of a smart grid.

Load Shed Generators

Due to the critical nature of the research and life safety concerns on campus, the University invested heavily in building emergency generators. At present, the University has over 5,000kW of emergency generation capacity at Centennial Campus. The majority of these units are diesel, with two being natural gas. These generators receive minimal use; it would be advantageous for the University to take advantage of this underutilized resource by enrolling a utility sponsored load shed program.

All of the generators at Centennial Campus were evaluated for use as load shed generators during peak periods. It was determined for the program to be effective long term, natural gas engines are to be used. Due to this requirement, most buildings would require a new generator. The evaluation determined that buildings with large natural gas generators or facilities which have not been constructed are the only scenarios which will provide a viable payback.

In addition to using natural gas, the engines must have increased controls and monitoring as well as improved pollution control. Also, the University would have to update their Title V Air Permit.

Taking all of these variables under consideration, it was determined that the University should only look at existing natural gas generators or new construction. With this criterion, there are two buildings which have been targeted: Engineering Building I (EB I) and the Central Utility Plant (CUP).

The work on EB I would include upgrading controls, switching, and pollution controls. For the central utility plant the system would be based on the installation of a new 1MW black-start generator required for a future cogeneration system. Instead of a 1MW system, it is recommended that a slight increase in generator size to 1.5MW be considered as well as upgrading the generator and controls as necessary for a load shed operation. To limit the changes to the Title V Air Permit, these projects should be completed at the same time.

9 Year Payback

The payback period is based on the Duke Energy Progress demand response program. Major changes to the program are not expected, but if they occurred it could dramatically change the payback.

$70,000 Annual Savings

Annual savings are based on the utility company load shed credit of $5.90/kW/month. The additional cost of running the generators for up to 400 hours including natural gas and O&M costs are subtracted from the savings.

$600,000 Investment

The cost provided is for new controls and switching for the generator at EB I and 500kW size increase plus upgraded controls and switching for the new black start generator at the CUP when a combined heat and power system is installed.

🟡 **Essential to the Smart Grid**

Providing distributed demand response is essential to a smart grid.

🔴 **Research Benefits**

There are no research benefits associated with this project.

🟡 **Energy Savings**

There will be no energy savings, but there will be an energy cost reduction.

🟡 **Smart Grid Demonstration**

This project will demonstrate the ability for demand response as well as distributed generation.

Grid Isolation- Emergency Loads

Being able to maintain campus operations during weather related emergencies such as hurricanes and ice storms is a major benefit to the University, the City of Raleigh, and the surrounding communities. Providing an emergency system for the entire campus ensures priority loads are maintained during long and short power outages.

The emergency grid isolation relies on the proposed smart campus control system and cogeneration system. The smart campus control system implements a demand response program to limit.

Table 4 - Conceptual Emergency Load Analysis

Building	On Centralized Emergency Power	Emergency Demand (kW)
College of Textiles	Yes	742
Poulton Innovation Center	Yes	87
Partners I	Yes	669
Research I	Yes	219
Research IV	Yes	227
Engineering Building I	Building Generator	0
James B. Hunt Library	Yes	325
Keystone Energy Center	Yes	243
Partners III	Building Generator	0
Central Utility Plant	Yes	2250
MERC	Yes	1021
Research II	Building Generator	0
Research III	Building Generator	0
BTEC	Yes	233
Engineering Building II	Yes	386
Engineering Building III	Yes	350
Partners II	Building Generator	0
Toxicology	Yes	169
Total Emergency Demand		**6919**
Centralized Generation Capacity (kW)		**7700**

The system utilizes the proposed cogeneration plant with 5.7MW gas turbine and the 1.5MW black start generator for the centralized generation. To utilize only the cogeneration system for emergency central generation, several buildings must utilize their local generation capacity. For this, each building's generation capacity and electrical demands were evaluated. Buildings with lower electrical demand that was handled by the local generator were not put on the central generation. A table of each building, its estimated emergency demand, and emergency generation source is found to the left.

N/A Year Payback

There will be no payback period associated with this project. The project is an improvement in system reliability and is not expected to provide a reduction in energy consumption.

N/A Annual Savings

There are no savings accounted for in this project. The ability to be used as a place for refuge serves as a benefit to the community.

$350,000 Investment

The cost provided is assuming the cogeneration plant is constructed and the smart campus control system is put into place. The cost associated is for additional switching and controls as well as programming required for implementing the emergency load sequence.

🟡 **Essential to the Smart Grid**
Takes advantage of the enhanced controls and distributed generation that is part of a smart grid.

🟡 **Research Benefits**
Will help maintain any critical loads that are necessary for academics and research on campus.

🔴 **Energy Savings**
There is no energy savings associated with this project.

🟢 **Smart Grid Demonstration**
Demonstrates the advantages of enhanced controls and distributed generation.

Smart Grid Proving Grounds - AC/DC Test Circuit

The centerpiece of the Centennial Campus Smart Grid Proving Grounds is the AC/DC test loop which would be devoted to the testing of smart grid related hardware. The loop is intended to be connected to an existing circuit located on the campus and capable of providing both AC and DC power at a fixed voltage.

As this is a test circuit, extra consideration needs to be given to the safety of the circuit. This includes the installation of the proper safety devices including high speed switching and fault detection to ensure the connections are quickly disconnected from the circuit upon detection of a fault. It is recommended as part of the installation that the test circuit be installed in a new ductbank to prevent potential issues that may arise with the testing of new components. As for the testing abilities of the circuit, it is recommended that the infrastructure provide an easy connection method for the following items: batteries, renewable energy sources, buildings, and other future technologies.

The AC/DC infrastructure will be key to the success of the test circuit. The circuit must be flexible as to allow for testing components now and unknown components that will exist in the future. A conceptual layout was developed which will allow the system to connect to a wide variety of components for now and the future is shown to the right. The layout is only to illustrate system design concepts and components and not a design.

To make the project more financially feasible it is recommended that the test circuit be completed in three phases. A description of each phase can be found below.

Phase I

This phase would involve the initial development of the test circuit including the electrical equipment which is required to energize both currents of the circuit safely. The circuit would tap off an existing distribution circuit, with the proper safety equipment to prevent disruption to the rest of campus, near the Keystone Science Center and run to Alliance I, both facilities would have testing abilities.

Phase II

The second phase of the loop would run from the Keystone Science Center to the Poulton Innovation Center. The Poulton Innovation Center houses ABB which already has some DC testing and the additional circuit would enhance the Center's abilities. This phase would also include various connection points to allow for connecting to renewable energy, batteries, and other energy devices.

Phase III

The final phase of the test circuit would run from the Keystone Science Center to the Centennial Central Utility Plant. This final phase would allow for the test circuit to connect into a large power generation source such as a gas turbine used for combined heat and power or a diesel generator. This would provide the opportunity to test devices on a larger commercial scale.

🟢

Essential to the Smart Grid

Will greatly enhance the smart grid research capabilities of the University.

🔴

Energy Savings

There are no energy savings accounted for as part of this project.

🟢

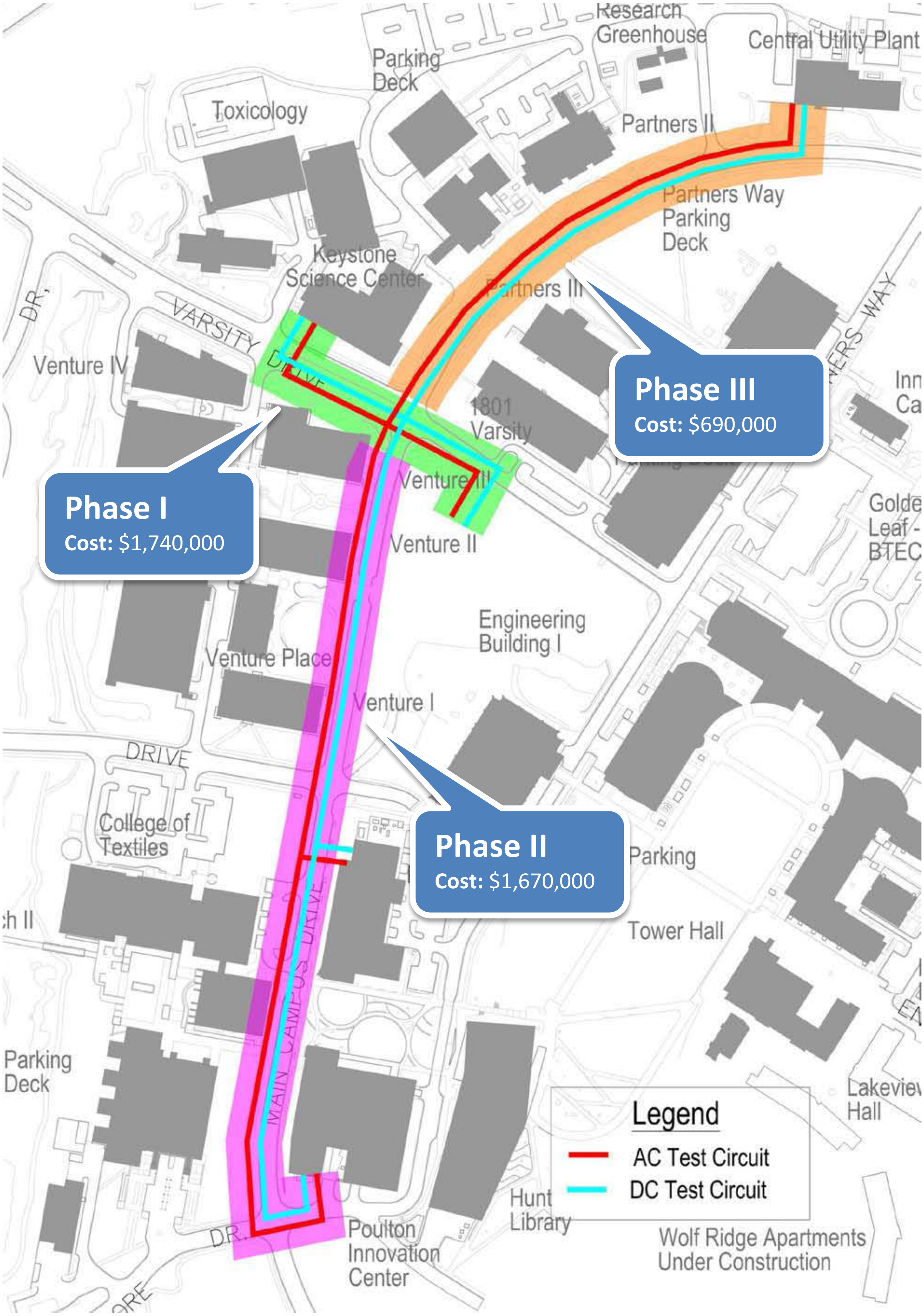
Research Benefits

Will serve as a cutting edge smart grid test circuit that will allow corporations and the University to collaborate on new developments.

🟢

Smart Grid Demonstration

The circuit will be used to test and demonstrate the latest smart grid technology.



Phase I
Cost: $1,740,000

Phase II
Cost: $1,670,000

Phase III
Cost: $690,000

Smart Grid Proving Grounds - Medium Voltage Test Lab

A key to the success of the AC/DC test circuit is to provide quick and safe access to the circuit for real world testing. It is proposed that the University create a medium voltage test lab to offer this quick connection access.

The lab needs to be designed to simulate real world conditions to determine how equipment interacts and integrates with other energy sources such as solar PV or battery storage. The lab serves only as a place to conduct functionality and verification testing and is not intended to be used for destructive testing.

The test facility would be set up for a “pay to play” type arrangement. This arrangement benefits the University and corporations. Corporations contract with the University to rent out the lab for a period of time. The corporation may use the facility strictly for the physical resource or it could also utilize the knowledge resource at the University and collaborate under a research partnership. The facility may also help with the development of the proper strategy for integrating a large percentage of renewables onto the grid.

It is recommended that the University start with a smaller lab with a single test bay. This allows for researchers and corporations to test products quickly with minimal space and financial requirements. Expansion of the lab would be recommended as there are two concerns with a single lab space however which are privacy and long term testing.

Corporations are concerned about maintaining their competitive edge and not leaking any potential technological advantages. With a single lab space, it may be harder to guarantee the privacy of the testing. The other concern is the potential high demand of the lab for extended periods. A corporation may want to verify the equipment works under a variety of conditions which could take months. It is likely that this would not be possible as other corporations or researchers may need access to the lab.

$340,000 Investment

The cost provided is for the up fit of a portion of an existing high bay lab. For a single bay lab, it is estimated that approximately 1,500 ft^2 of space is required. It is assumed that the majority of the cost is for electrical equipment, controls, and minimal updating to the physical structure. This cost is only for reference, and the exact location of the test lab is to be determined by the University.

🟢 **Essential to the Smart Grid**
Will serve as a key for developing new smart grid technology.

🟢 **Research Benefits**
Will serve as a cutting edge smart grid test facility that will allow corporations and the University to collaborate on new developments.

🔴 **Energy Savings**
There are no energy savings as part of this project.

🟢 **Smart Grid Demonstration**
The lab will test and demonstrate new smart grid technology.

Smart Grid Proving Grounds – DC Lab

As Direct Current electric power becomes more prominent in use with applications such as data centers, research needs to be conducted to understand what other applications are enhanced by using DC power.

A low voltage DC lab enables research on the usage of the electricity inside a facility and the integration with renewable energy and DC distribution. The DC Lab is focused on utilizing a variety of different test environments. A prototype low voltage DC lab is pictured above, and descriptions of each test environment are as follows:

1. **Consumer Electronics** – Provide an area for the testing of consumer electronics powered by DC as well as the testing of new connection configurations.
2. **Lighting** – Provide a grid support system for the showcasing and testing of a variety of DC powered lighting applications.
3. **Renewable Energy Connection -** Provide a safe direct connection to solar PV array located on the roof of the facility. Offers ability to investigate how to better manage renewable energy.
4. **Battery -** Test various uses of battery storage in a DC system and different battery storage systems.
5. **Server -** Used for the investigation of directly using DC power in computer servers.

$190,000 Investment

The cost provided is for the completion of an up fit of a 1500ft^2 DC Test Lab that provides all components discussed above in an existing building.

🟢 **Essential to the Smart Grid**
Will be used to investigate new DC technologies on a smart grid.

🟢 **Research Benefits**
Can provide enhanced data for research on low voltage DC

🔴 **Energy Savings**
As this is a testing facility there are no anticipated energy savings from the installation of the lab.

🟢 **Smart Grid Demonstration**
Will be used to evaluate how the smart grid can control various sources and improve system efficiency.

Smart Grid Proving Grounds – Commercial Housing Test Facility

The University took a sustainable approach to developing student housing on Centennial Campus. The Wolf Ridge housing complex currently under construction is evidence of this. The complex is LEED Silver Certified with numerous sustainable features ranging from lighting to landscaping.

Using this as a test facility offers a sound baseline for the testing of commercial building products. To do this, it is recommended that the metering and monitoring abilities of 1-3 apartments be enhanced. This includes increased monitoring of temperatures, equipment usage, and occupancy.

With the increased monitoring, companies are able to attain accurate energy savings in a real world environment. In addition, companies may evaluate energy consumption to understand where other energy saving opportunities exist.

It is recommended that a testing schedule be implemented which coincides with the academic semester schedule. This ensures that there is minimal disruption to the space occupants. To get the occupants agreement for the enhanced monitoring and equipment testing, it is recommended that an incentive program is offered to the students. The program includes a modest discount on rent which would be covered by equipment testing fees.

This testing ability is not expected to be a main attraction for companies to come to Centennial. Rather, the facility is an additional feature that the University may offer to companies at a minimal cost.

TBD Year Payback

The payback period is expected to be relatively short but depends on what the University determines is the proper testing fee.

$10,000 Annual Income

It is recommended that the testing fees are high enough to recover the initial capital cost, administrative costs, and housing incentive discount. The above income is an estimate and does not include administrative cost or a housing incentive discount.

$50,000 Investment

The cost provided is for additional monitoring and metering of three apartments as well as providing a gateway for the test companies and researchers to access the data.

Essential to the Smart Grid
Demonstrate the capabilities of a smart grid for housing applications.

Research Benefits
Can provide research and development opportunities with new smart grid housing technologies.

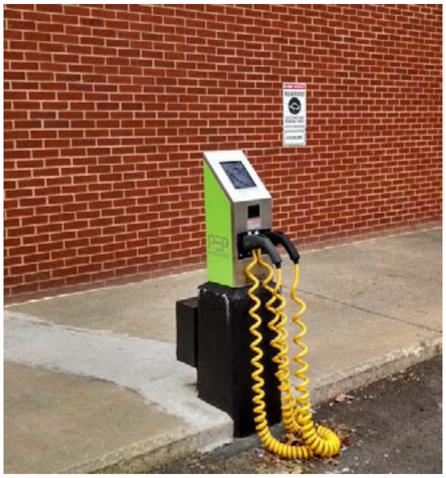
Energy Savings
The program will likely reduce the energy consumption of the facility with no cost to the University.

Smart Grid Demonstration
Demonstrate the capabilities of a smart grid for housing applications.

Smart Electric Vehicle Charging Stations

The existing electric vehicle charging stations on campus have the ability to draw a significant amount of power during peak electrical demand periods. Utilizing a system that integrates the electric vehicle charging stations will assist in lowering the demand charges the University incurs.

This is done by continuously monitoring the campus electrical demand and the electrical demand of the smart chargers. If it is calculated that the campus will reach a peak or near peak demand for the month, the smart campus will send a signal to the EV charging station. The charging station will then either reduce power output or suspend power to the unit for an hour or two during the peak window. This short window of no charging is small enough that a driver who plugged in their car in in the morning will never know charging was suspended. The University will need to provide a notification or warning to the users that the charger is involved in a demand response program.



10 Year Payback

The payback is relatively short due to the existing infrastructure currently in place. It is expected with increased usage of electric vehicles that this number would go down.

$2,000 Annual Savings

The savings is based on an estimate of 25% of the charging stations being used during peak periods. The usage rate is expected to increase in the next several years and should increase the annual savings.

$20,000 Investment

The cost is for the retrofit of ten (10) smart EV charging stations and integration into the smart campus. The retrofit technology is currently in its infancy and will need a couple years to develop into a commercially viable solution.

🟡 **Essential to the Smart Grid**

Provides additional demand response capabilities to the grid.

🟡 **Energy Savings**

There will be no energy savings associated with this project, savings will be from an energy cost reduction.

🟢 **Research Benefits**

The integrated and responsive charging stations can help with the current EV charging research being conducted at NC State.

🟡 **Smart Grid Demonstration**

This will demonstrate the value of controls and modeling in a smart grid and the connection to all grid components.

North Carolina State
Smart Grid

90 YEAR PAYBACK

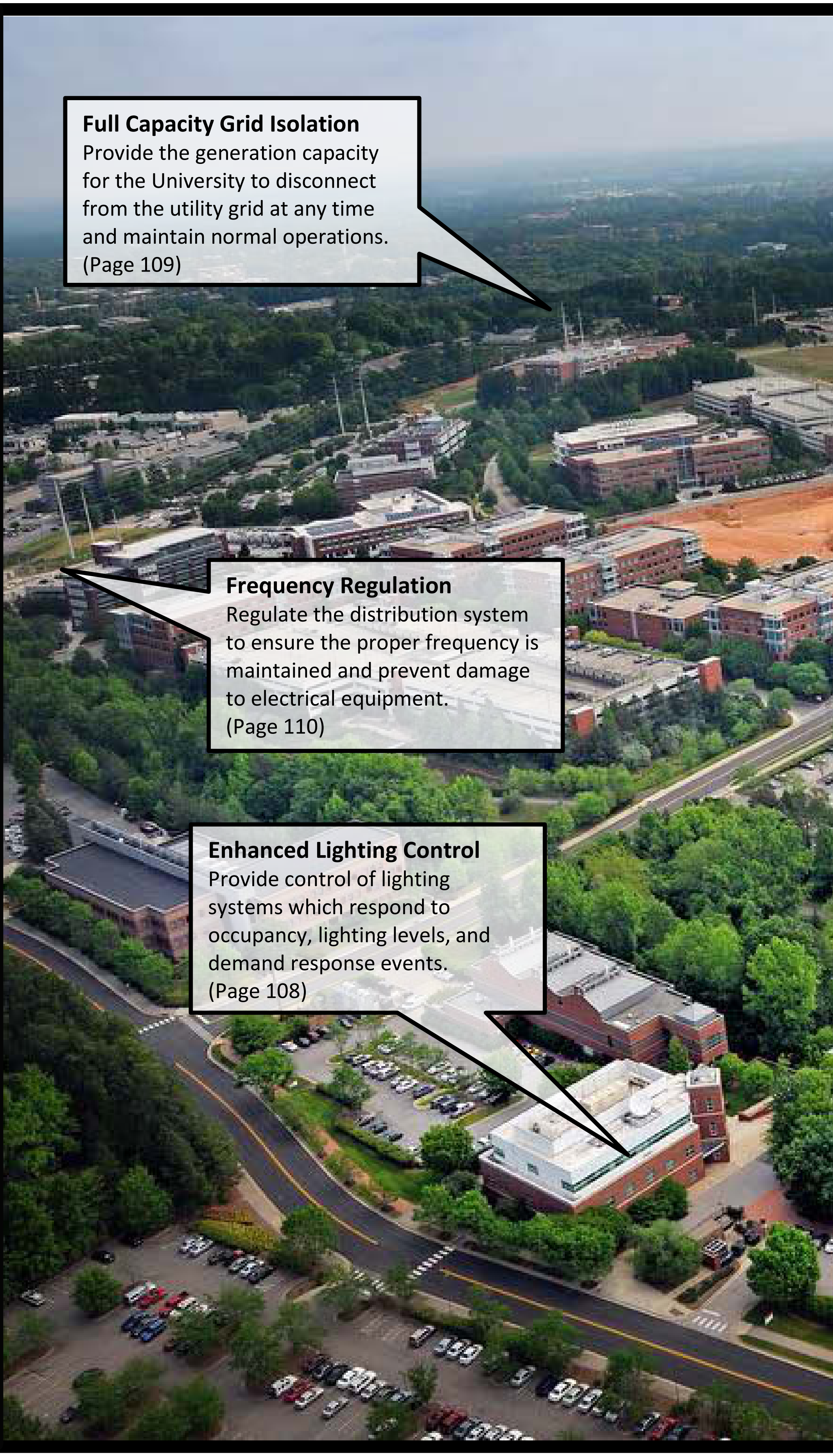
$340,000 SAVINGS

$30,390,000 INVESTMENT

The projects found in the Tier III section are items that the University should only consider if there is a major change in economics or policies.

These projects have paybacks that are not within the University's guidelines for an acceptable payback.

Further information on each Tier III project including a description, savings, and cost for the individual projects can be found in this section.



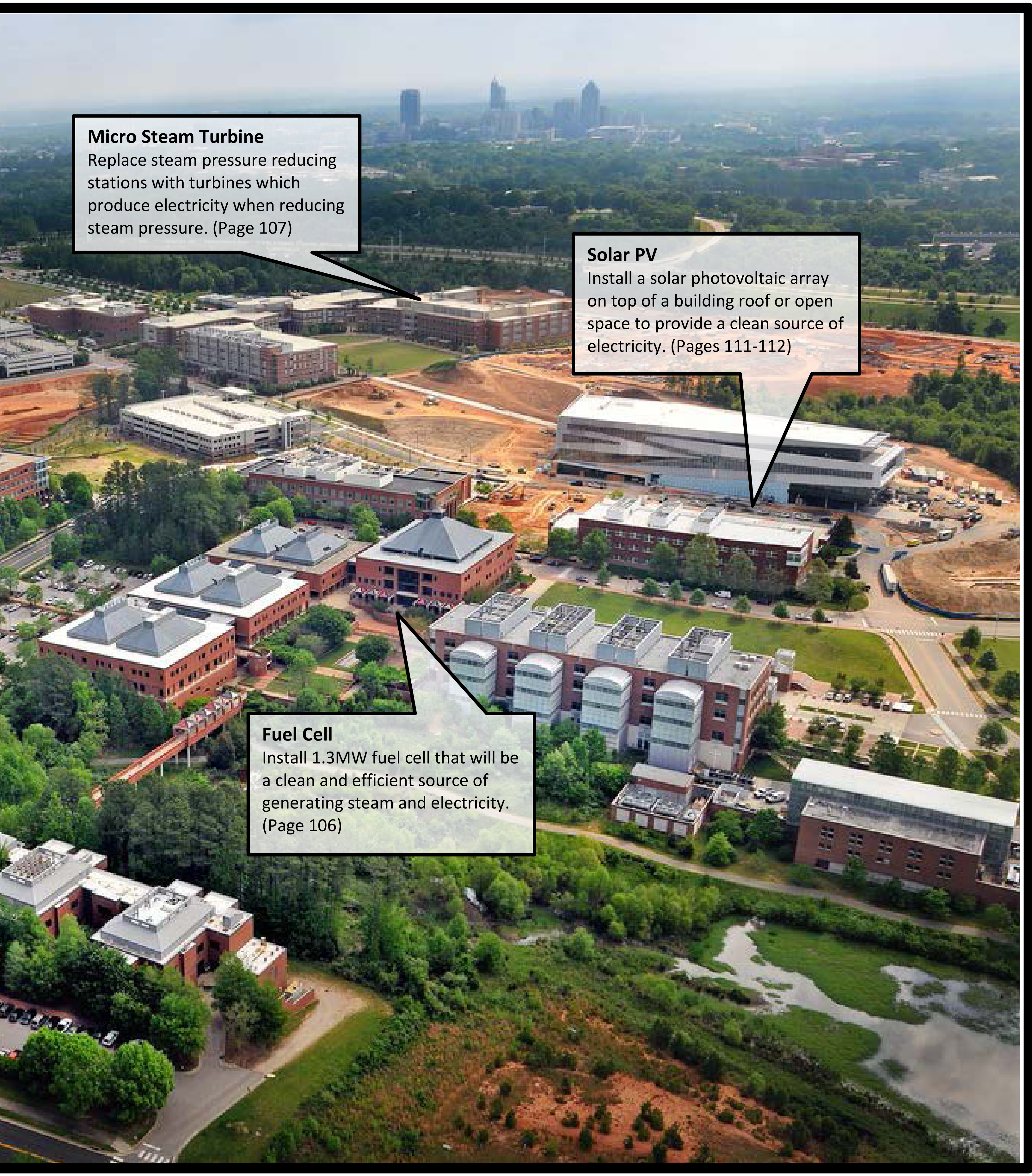
Full Capacity Grid Isolation
Provide the generation capacity for the University to disconnect from the utility grid at any time and maintain normal operations.
(Page 109)

Frequency Regulation
Regulate the distribution system to ensure the proper frequency is maintained and prevent damage to electrical equipment.
(Page 110)

Enhanced Lighting Control
Provide control of lighting systems which respond to occupancy, lighting levels, and demand response events.
(Page 108)

University Centennial Campus

Tier III Projects



Micro Steam Turbine
Replace steam pressure reducing stations with turbines which produce electricity when reducing steam pressure. (Page 107)

Solar PV
Install a solar photovoltaic array on top of a building roof or open space to provide a clean source of electricity. (Pages 111-112)

Fuel Cell
Install 1.3MW fuel cell that will be a clean and efficient source of generating steam and electricity. (Page 106)

Fuel Cell

The installation of a 1.4MW fuel cell to provide combined heating and power to a portion of the campus was examined. The exact location of the fuel cell in a location that serves a portion of the three existing Engineering Buildings needs to be determined.

While the system is extremely clean and relatively efficient, it requires a high capital investment and operating and maintenance cost. The installed cost of the system is approximately two to four times the cost of a similarly sized cogeneration system.

A fuel cell is one of the cleanest burning sources of combined heat and power available today and one of the most expensive. This high cost is difficult to overcome in comparison to an existing and functional central utility system. If a fuel cell installation is to be completed at the University, either an additional source of funding or reasons beyond energy economics need to be developed.

In addition to the high initial cost, there are high operation and maintenance costs associated with the fuel cell. On average, it costs between $0.02 to $0.04/kWh to maintain. These high operation and maintenance costs make up approximately half of what the University is paying for electricity which makes justification challenging when including fuel costs.

190 Year Payback

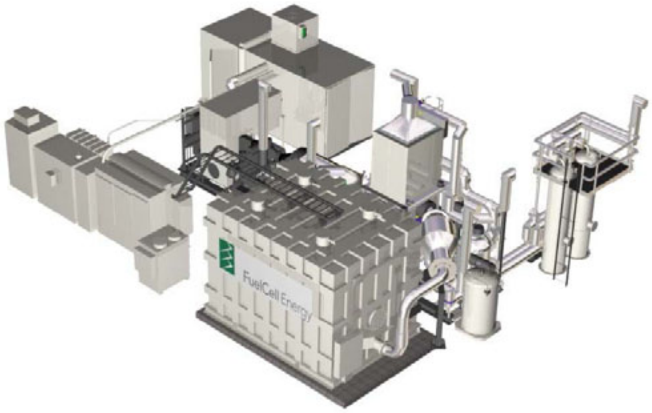
The payback period for a fuel cell is extremely high and extends beyond the life of the equipment. This technology only provides savings with additional funding or other non-financial drivers.

$60,000 Annual Savings

The annual savings is based on the current electrical and natural gas rates. It also includes the increased cost of operating and maintaining the plant.

$11,370,000 Investment

The cost provided is for a new plant as well as new piping and controls to connect to the existing system. The price of the fuel cells is expected to decrease in the future but not substantially enough to make these systems financially viable in the immediate future.



Essential to the Smart Grid

Provides an additional source of distributed generation of heat and power.

Research Benefits

The system could be used to study the relatively new fuel cell technology and other possible applications.

Energy Savings

There will be energy savings due to the improved efficiency of the system. There will be an even further drop of Greenhouse Gas emissions.

Smart Grid Demonstration

Provides an additional source of distributed generation of heat and power.

Micro Steam Turbine

A micro steam turbine replaces a building pressure reducing valve with a turbine that converts the pressure reduction into energy. For a micro steam turbine to be cost effective, it must be installed where high steam flow for a long period of time occurs. Due to lack of steam data for individual buildings, a building was selected based on electrical consumption. It is estimated that presently one of the three Engineering Buildings would provide the best load for the turbine.

Due to minimal available steam consumption data, the analysis of the system was completed based on several assumptions. These assumptions included a building steam load of approximately 6,000lbs/hr for 1,000 hrs per year and approximately 7,000lbs/hr for 1,500 hrs. The remainder of the year it was assumed to have a load below the ideal operation point for the system.

It is recommended that after the completion of the smart metering project on all utilities is complete that the system is reevaluated.

An alternative to installing at an individual building is installing it at the central utility plant if a cogeneration system is implemented. It could be advantageous to use a micro steam turbine in series with an absorption chiller to increase the campus summer steam demand. This option should be evaluated as part of the central utility plant expansion.

42 Year Payback

Due to the low estimated savings and high cost of the installation the payback for the installation is not favorable. It is recommended that a micro steam turbine installation be investigated with the installation of a large building such as the proposed Engineering Building Oval or a cogeneration plant.

$20,000 Annual Savings

The annual savings is a based on an estimated number of hours based on the central utility plant load profile and the buildings which it serves. This is strictly an estimate and actual load data should be evaluated when it becomes available.

$840,000 Investment

The cost provided is for the complete installation of a 250kW micro steam turbine and utilizing the existing pressure reducing station as a backup. The cost will be reduced if it is part of new construction or installed at the central utility plant.

🟢 **Essential to the Smart Grid**
This project is not essential, but does provide a small amount of distributed generation.

🟡 **Energy Savings**
This project is focused on reducing energy. The amount of energy savings increases as steam consumption increases.

🔴 **Research Benefits**
There are no research benefit associated with this project.

🟢 **Smart Grid Demonstration**
This project demonstrates the distributed generation of smart grid and the management of the distributed generation.

SCCS – Enhanced Lighting Control

There are two options for enhancing the lighting control for the University. The first option is to utilize the existing lighting fixtures and add enhanced controls as well as provide the ability to dim the lighting fixtures. The second option is to replace the existing fixtures with new high efficiency technology and integrated lighting control.

While retrofitting the existing light fixtures is an option, it is not the recommended path. Fluorescent fixtures are beginning the phase out process with T12 and some T8 fixtures ending production in 2014. It is therefore recommended the University invest in a complete lighting upgrade.

It is recommended that fixtures are replaced with an integrated system of LED light fixtures with dimming, daylighting, and occupancy control in the fixture. The system is then to be connected into the smart campus for centralized monitoring and control. While the first priority is to control the lights, there are numerous benefits that would reduce initial capital costs as well as save energy. The data provided by the enhanced lighting control may be used for HVAC control, security monitoring and other automated control systems.

For the replacement to be cost effective, the University must systematically upgrade their lighting fixtures. This is done by ensuring the proper lighting and controls are added when major renovations or new construction occur. If there are no major projects the recommended strategy is to first update the buildings with older fixtures and then move to buildings which do not have automated and integrated control systems.

Before an enhanced lighting system program is rolled out at the University it is recommended that a pilot program be created. A space identified for this was the first floor corridor at EB I due to its daylighting, varying occupancy, and high visibility. The figures below are based on this pilot.

30 Year Payback

The pilot program will have a long payback period. The system is anticipated to have a sound payback as part of a major renovation or new construction effort.

$900 Annual Savings

The annual savings is based strictly on the estimated savings for the lighting control. The savings does include any benefit associated with security or an HVAC system.

$27,000 Investment

The investment is for a complete replacement of the fixtures and update connection into the smart campus of a corridor of Engineering Building I. The cost per square foot is lower when an entire building is complete.

🔴 **Essential to the Smart Grid**
It is not essential to a smart grid operation.

🔴 **Research Benefits**
There are no research benefits associated this project.

🟡 **Energy Savings**
The energy savings related to the investment for the system is small.

🟡 **Smart Grid Demonstration**
This project demonstrates the advance capabilities of a smart grid.

Grid Isolation- Full Capacity

Providing the capability to completely isolate the campus from DEP during normal operations requires a substantial investment. In addition to being a capital intensive project, there is minimal benefit to the University as DEP provides power at a rate that is cheaper than what the University generates with no major reliability issues at this time.

If complete grid isolation is desired, it needs to utilize a central generation facility. It is recommended that the facility be located as part of the central utility plant complex. The system would utilize the proposed cogeneration system, a 5.7MW gas turbine with an additional 1.5MW capacity from a black start generator, the base generation source.

Through an analysis of the peak electrical demands now and in the future at the Centennial Campus, the system needs to generate approximately 20MW and 30-35MW for the future. Due to the rapid expansion of the Centennial Campus, it is recommended that at least 20MW of generation with expansion capabilities be installed. Before the project can be seriously considered, the natural gas company must be contacted to determine if the natural gas infrastructure supports the increased consumption.

This increased reliability may not only be beneficial to the University and its students but also as a marketing tool. Providing a reliable source of power is important on a research campus.

101 Year Payback

The payback is based on the reduction of lost downtime due to power outages. There needs to be a major change in grid reliability or pricing for this project to be a viable solution.

$140,000 Avoided Costs

The annual savings associated with this project is based on overall major outage history with DEP and the estimated loss of productivity that occurs during a power outage.

$14,200,000 Investment

The cost provided is for the complete installation of 12MW of natural gas generation as well as the controls required for proper system operation. The cost assumes that 7MW of generation would come from a cogeneration system.

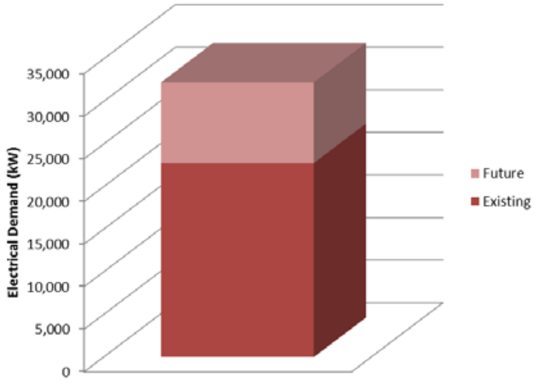


Figure 50 - Campus Peak Electrical Demand

🟡 **Essential to the Smart Grid**
This project would be essential if a completely isolated smart micro grid is desired.

🔴 **Energy Savings**
There are no energy savings associated with this project.

🟢 **Research Benefits**
Will maintain normal campus operation and remove any potential long or short term utility power outages which could affect research projects.

🟢 **Smart Grid Demonstration**
Would demonstrate what an isolated smart micro grid would look like and how it operates.

Self-Regulating Grid

Due to the large amount of expensive electronic devices connected to the Centennial Campus electrical distribution system, it is important that the proper protection be implemented to prevent any potentially harmful changes in the power delivered. To do this, there are two central devices that provide additional protection to the electronic devices on campus: a load tap changer and flywheel energy storage. Those items and their application on campus are discussed below.

Load Tap Changer

A load tap changer is a device used to regulate the output voltage of the substation transformer. For Centennial Campus, a load tap changer is being installed as part of the substation expansion. The system allows for the University to automatically or manually change the voltage output of the substation.

The power distribution of Duke Energy Progress overall is very consistent which means there are minimal occasions where a load tap changer is needed.

By installing a load tap changer during the expansion of the substation, the University is provided with a relatively low cost, reliability improvement feature that could become important in the future if voltage from the utility fluctuates.

Flywheel Storage

A flywheel storage system provides frequency regulation for an electrical distribution system. When a system receives the majority of its power from a utility, frequency regulation is not necessary as the utility provides the frequency regulation. If the University were to consider putting a large amount of renewable energy onto its grid, the University should install a frequency regulation system like a flywheel system to regulate the power.

N/A Year Payback

There is no payback period associated with this project.

N/A Annual Savings

There are no energy savings being accounted for as part of these projects.

$825,000 Investment

The cost provided above is for frequency and voltage regulation. The cost of the voltage regulation was estimated at $25,000, assuming it is being completed in conjunction with a substation upgrade. If the project is a retrofit, the price is going to be higher.

🟡 **Essential to the Smart Grid**
Is essential if there is a large amount of renewable energy connected to the grid.

🔴 **Research Benefits**
There are no research benefits associated with this project.

🔴 **Energy Savings**
Enables other energy saving opportunities, but will not save energy alone.

🟡 **Smart Grid Demonstration**
Will assist in demonstrating how you can connect a large amount of renewable energy.

Solar Photovoltaic – Small Scale

The University is very familiar with building level solar photovoltaic installations and has several currently in place on campus. It is recommended the University enhance its solar portfolio and increase its notoriety by connecting solar to the proposed DC circuit.

With the installation to a DC circuit, the losses associated with an inverter will no longer exist. As this is still a relatively new concept, there is likely to be interest in research in this area. It is recommended that the connection to the DC circuit includes additional safety equipment and a quick connection for testing the equipment.

It is recommended the University install a 50kW solar PV array on the roof of one the buildings or parking decks on the proposed AC/DC test circuit. A 50kW array is large enough to provide a solar presence that allows for testing, but is still small enough to be affordable.

The exact location of the solar array is to be determined. There are several solar specific items that must be considered when evaluating a site including ease of access, visibility, constructability, and sun exposure. At present, a leading candidate for the panels is Research II.

33 Year Payback

The payback period is based on the University providing 100% of the funding for the project. Due to the nature of the project it is likely that the University will be able to receive grants or donations to reduce the cost of the project.

$6,000 Annual Savings

The annual savings was based on typical weather in Raleigh, NC. The installed panels were assumed to be south facing, tilted at Raleigh’s latitude, and mounted in a fixed position.

$200,000 Investment

The cost provided is for the complete installation and start-up. It is assumed that the array would be contracted in a design-build fashion as is typical with a small scale Solar PV installation. The cost does not include any grants or donations.

🟢 **Essential to the Smart Grid**
Will provide distributed generation to the grid.

🟡 **Research Benefits**
Can provide enhanced data for research on building energy consumption.

🟢 **Energy Savings**
System will provide clean energy for the campus.

🟢 **Smart Grid Demonstration**
A key component to a smart grid and providing clean distributed generation.

Solar Photovoltaic – Public/Private Partnership

The installation of a large solar array on campus provides an additional source of distributed generation and demonstrates the University's commitment to a sustainable future. The only way for a large solar project to be successful in a University setting is a public/private partnership. The partnership mitigates the significant capital investment associated with a large solar array.

For a public/private partnership to be successful, it is recommended that at least 3MW of generation capacity be installed. This is due to the large fixed costs associated with a public/private partnership. In North Carolina, a typical solar system requires 5 acres to produce 1MW. This indicates that an effective public private partnership requires at least 15 acres. At present, the University doesn't have 15 acres of land on Centennial Campus which they would like to devote to a solar array.

Figure 51 - Cary Public/Private Partnership Solar Array

If the land is found for solar development, the University needs to enter an agreement with an investor. The agreement is for the investor to install a solar array on the site for a specified period of time that is usually 20 years, and then pay the University for using the land. The power generated from the solar array would then be directly connected for use on Centennial Campus through a DC bus.

This connection of renewable energy benefits the University in three ways. The first benefit is reducing its greenhouse gas emissions and taking another step towards the goal of being greenhouse gas neutral by 2050. Secondly, it serves as a source of income as the investor pays to lease the land. Finally, the renewable energy connection may be used for research of integrating a large percentage of renewable energy into a distribution system.

0 Year Payback

As the University is not investing any capital funds and the lease will be covered by the partnership agreement, the project will payback immediately.

\$400-600/Acre Annual Savings

The University will see some additional revenue with this project, but the major driver is a reduction in greenhouse gas emissions and potential research associated with the solar array.

\$0 Investment

In a public/private partnership the University does not have to invest any capital funds into the project.

🟡 **Essential to the Smart Grid**
A clean distributed energy source is an important component of the smart grid.

🟢 **Research Benefits**
Can be used to research how to properly integrate a large percentage of solar onto a grid.

🟡 **Energy Savings**
Will provide some energy cost savings, but will mainly reduce the University's greenhouse gas emissions.

🟢 **Smart Grid Demonstration**
Demonstrate the potential of a DC bus and how controls can allow for the integration of a high amount of renewable energy.

Appendix

Smart Grid Market Research

The heart of the energy saving portion of the smart grid at Centennial Campus is the smart campus control system. The control system integrates all of the disparate systems together to allow them to work as one fluid system. The main focus of the control system is monitoring and controlling energy consuming building, distribution, and central utility equipment. Due to the importance of the control system to the smart grid, a market research analysis was conducted to determine what solution is best for the Centennial Campus at North Carolina State University. The complete evaluation was based on ten categories that are important to a successful smart grid implementation at Centennial Campus. Shown in the table below is an overview of each solution with an “X” indicating the system is capable of performing that task.

	System A	System B	System C	System D	System E	System F	System G	System H
Smart Meter Integration	X	X	X	X	X	X	X	X
BAS Integration (Read)	X	X	X	X	X	X	X	X
BAS Integration (Write)	X		X	X	X		X	X
Demand Response	X		X	X	X		X	
Continuous Commissioning			X		X		X	X
Energy Optimization	X		X				X	
Electrical Distribution System		X	X	X	X	X	X	
Central Utility Plant		X	X	X	X	X	X	X
Weather	X		X				X	
Real Time Pricing	X		X				X	
Space Optimization		X						

Example Implementation Strategy

An example implementation strategy was developed to help provide the University with guidance on a fiscally responsible implementation of the smart grid at Centennial Campus. This strategy is only preliminary and due to the ever changing variables, such as funding and occupant needs, should only be used as a guideline. Found below are the projects with the suggested start of construction as well as their construction period and financing period. The results of the implementation plan can be found in the graphs and tables on the proceeding pages. Any projects with a start year of 9999 are not recommended for implementation or are already funded and being implemented.

Table 5 – Example Implementation Strategy

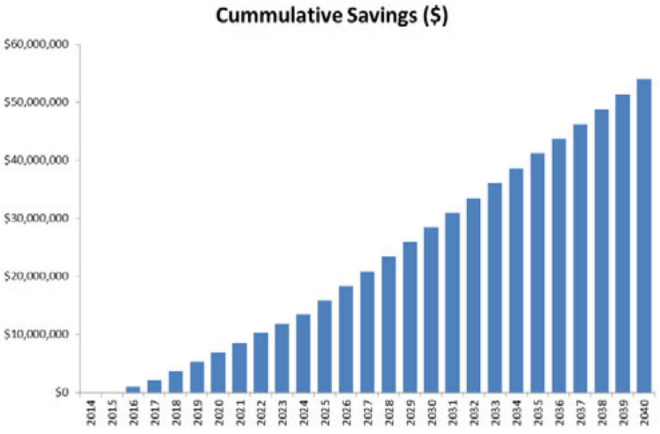
Category	Project	Construction Start (Year)	Construction Period (Years)	Savings Start (Year)	Financing Period (Years)
Smart Metering	Smart Infrastructure	2014	1	2015	1
	Energy Engagement	2015	1	2016	1
	Building Benchmarking	2015	1	2016	1
Smart Buildings	Supply Air Demand Response	2015	1	2016	3
	Space Temperature Demand Response	2015	1	2016	3
	Continuous Commissioning (Partial)	2015	1	2016	3
	Continuous Commissioning (Full)	2015	1	2016	3
	Energy Optimization	2015	1	2016	3
	Automated Set Point Control	2015	1	2016	3
	Enhanced Lighting Control	2025	1	2026	3
Cogeneration	Cogeneration Plant - 5.7MW	2022	3	2025	15
Thermal Storage	Thermal Storage	2016	2	2018	10
Micro Steam Turbine	Micro Steam Turbine	9999		9999	5
Load Shed Generator	Engineering Building I	2025	1	2026	2
	Partners II	9999		9999	2
	Research II	9999		9999	2
	Cogeneration Plant	2025	2	2027	2
Smart Campus	Campus Integration	2015	2	2017	3
	Plant Optimization	2015	2	2017	3
	Real Time Pricing	2015	2	2017	3
	Chilled Water Demand Response	2015	2	2017	3
Solar PV	Building Level	2020	1	2021	1
	Public Private Partnership	2025	1	2026	1
Fuel Cell	Fuel Cell	9999	1	10000	
Electric Vehicle Charging Stations	Electric Vehicle Charging Stations	2020	1	2021	1
Grid Isolation	Emergency	2030	1	2031	2
	Full Capacity	9999		9999	10
Self Healing Grid	Redudant and Automated Substation	9999	2	10001	5
	Self Healing Grid (Open Points)	2020	1	2021	1
	Self Healing Grid (Sectionalized)	2025	1	2026	2
	Self Healing Grid (Campus)	2030	2	2032	3
Self Regulating Grid	Voltage Regulation	2014	2	2016	1
	Frequency Regulation	2025	1	2026	2
AC/DC Test Circuit	AC/DC Test Circuit	9999	2	10001	3
	AC/DC Test Circuit	9999	2	10001	1
	AC/DC Test Circuit	9999	2	10001	1
Test Facilities	Low Voltage DC Lab	9999	1	10000	1
	Medium Voltage Test Lab	9999	2	10001	2
Commercial Housing Test Facility	Wolf Ridge	9999	1	10000	2

Financial Analysis

As part of the implementation strategy development, a simple financial analysis was performed to provide an accurate financial picture for the University's facilities department. The financial analysis is based on the schedule indicated in Table 4. Along with the preliminary schedule, several assumptions were made to simplify the calculation:

- The Energy Information Agency (EIA) published projections for the cost increase of electricity and natural gas for the industrial sector of the southeastern United States for the time period examined was used.
- The increase of operation and maintenance was estimated to occur at an average rate of 0.5% per year.
- The investment cost of a project was estimated to increase 1% annually until the project is paid in full.
- The investment of each project was spread equally across the years in the financing period.
- There are no savings associated with the project until the project is complete.

The results of the financial analysis indicate that under the suggested implementation plan the University may expect to receive continuous positive cash flow starting in 2027. The results of the analysis are shown below and on the proceeding pages.



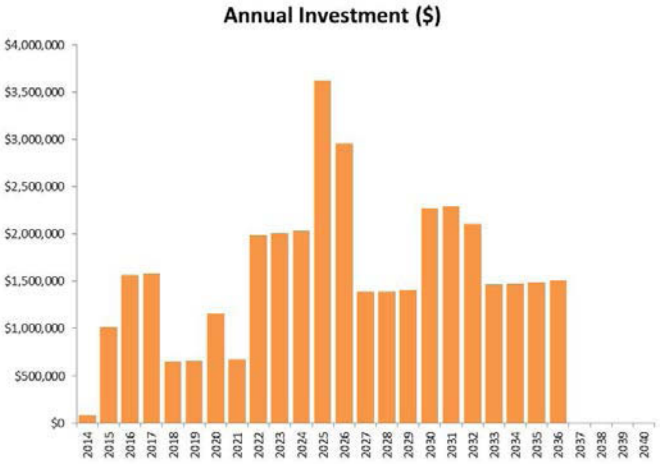
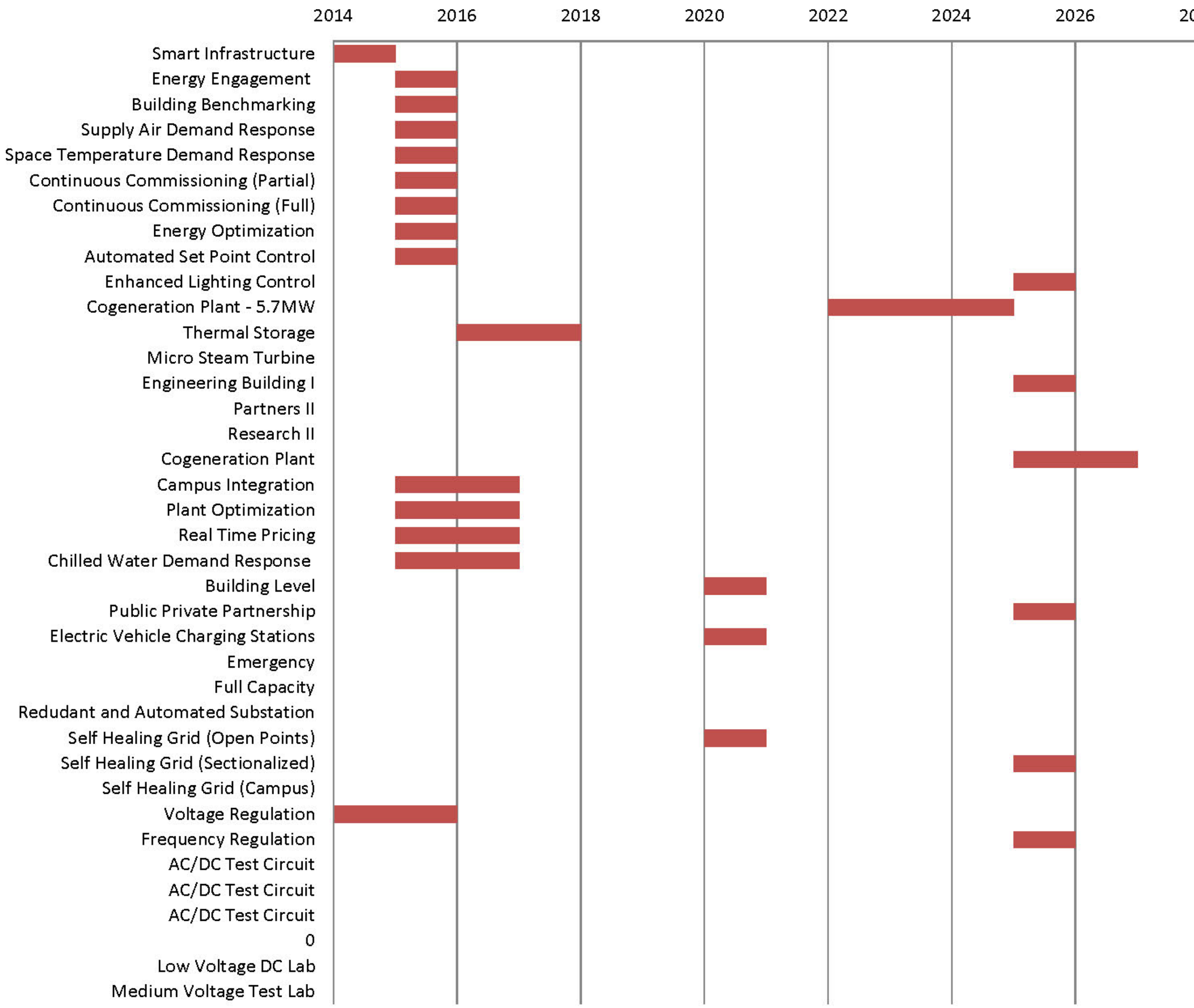


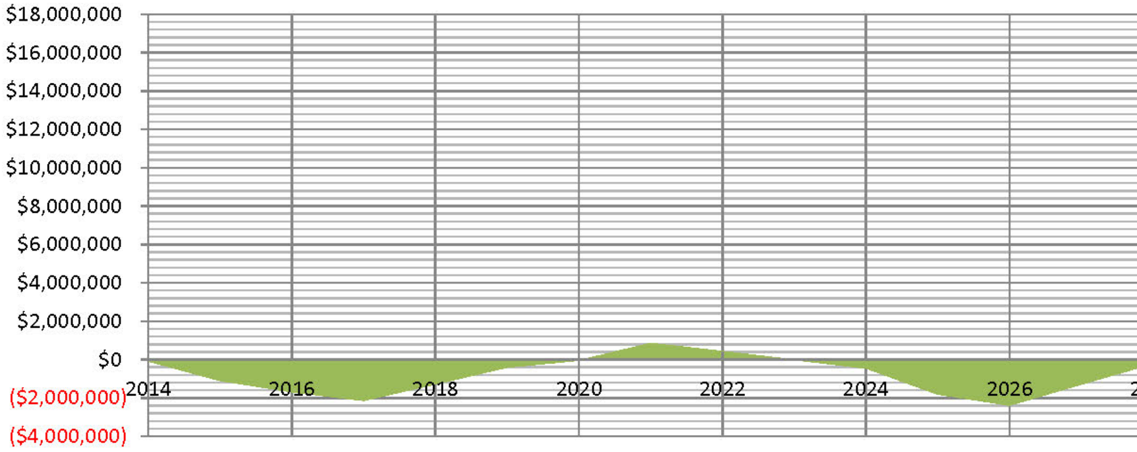
Table 6 – Example Implementation Plan Cash Flow

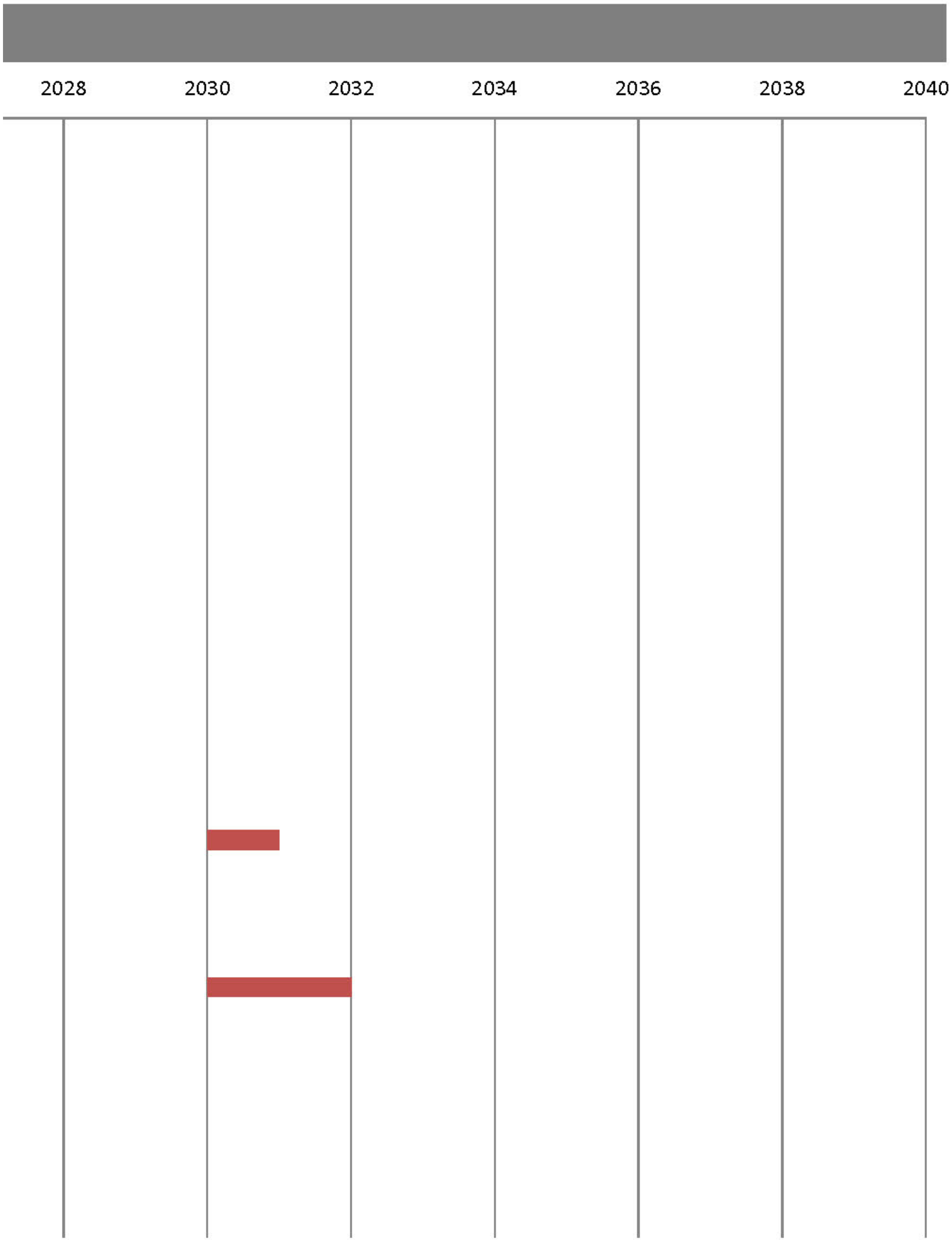
Year	Annual Savings	Cummulative Savings ($)	Annual Investment ($)	Cummulative Investment($)	Net ($)
2014	$0	$0	$85,000	$85,000	($85,000)
2015	$0	$0	$1,016,733	$1,101,733	($1,101,733)
2016	$976,298	$976,298	$1,564,493	$2,666,227	($1,689,928)
2017	$1,131,527	$2,107,825	$1,580,138	$4,246,365	($2,138,540)
2018	$1,510,228	$3,618,053	$652,459	$4,898,824	($1,280,770)
2019	$1,531,117	$5,149,170	$658,983	$5,557,807	($408,637)
2020	$1,518,148	$6,667,318	$1,153,872	$6,711,679	($44,361)
2021	$1,567,640	$8,234,958	$672,229	$7,383,908	$851,050
2022	$1,563,040	$9,797,998	$1,989,930	$9,373,838	$424,160
2023	$1,568,580	$11,366,578	$2,009,829	$11,383,667	($17,089)
2024	$1,594,242	$12,960,821	$2,029,927	$13,413,594	($452,773)
2025	$2,263,747	$15,224,567	$3,622,203	$17,035,797	($1,811,230)
2026	$2,380,450	$17,605,018	$2,951,906	$19,987,703	($2,382,686)
2027	$2,477,059	$20,082,076	$1,388,094	$21,375,798	($1,293,721)
2028	$2,474,993	$22,557,070	$1,391,630	$22,767,428	($210,358)
2029	$2,452,072	$25,009,142	$1,405,546	$24,172,974	$836,168
2030	$2,437,087	$27,446,229	$2,269,721	$26,442,696	$1,003,533
2031	$2,457,599	$29,903,828	$2,292,419	$28,735,114	$1,168,714
2032	$2,494,589	$32,398,417	$2,106,017	$30,841,131	$1,557,286
2033	$2,462,186	$34,860,603	$1,462,617	$32,303,749	$2,556,855
2034	$2,466,625	$37,327,228	$1,477,243	$33,780,992	$3,546,236
2035	$2,470,925	$39,798,153	$1,492,016	$35,273,008	$4,525,145
2036	$2,453,789	$42,251,942	$1,506,936	$36,779,944	$5,471,998
2037	$2,484,545	$44,736,487	$0	$36,779,944	$7,956,543
2038	$2,497,132	$47,233,619	$0	$36,779,944	$10,453,675
2039	$2,492,595	$49,726,214	$0	$36,779,944	$12,946,271
2040	$2,485,021	$52,211,236	$0	$36,779,944	$15,431,292
2041	$2,511,374	$54,722,610	$0	$36,779,944	$17,942,666
2042	$2,537,998	$57,260,608	$0	$36,779,944	$20,480,664
2043	$2,564,896	$59,825,504	$0	$36,779,944	$23,045,560
2044	$2,592,070	$62,417,574	$0	$36,779,944	$25,637,630
2045	$2,619,524	$65,037,098	$0	$36,779,944	$28,257,154
2046	$2,647,260	$67,684,358	$0	$36,779,944	$30,904,414
2047	$2,675,281	$70,359,638	$0	$36,779,944	$33,579,694
2048	$2,703,589	$73,063,228	$0	$36,779,944	$36,283,284
2049	$2,703,589	$75,766,817	$0	$36,779,944	$38,986,873
2050	$2,703,589	$78,470,406	$0	$36,779,944	$41,690,463

Smart Grid Project Implementation Schedule



Smart Grid Project Cashflow

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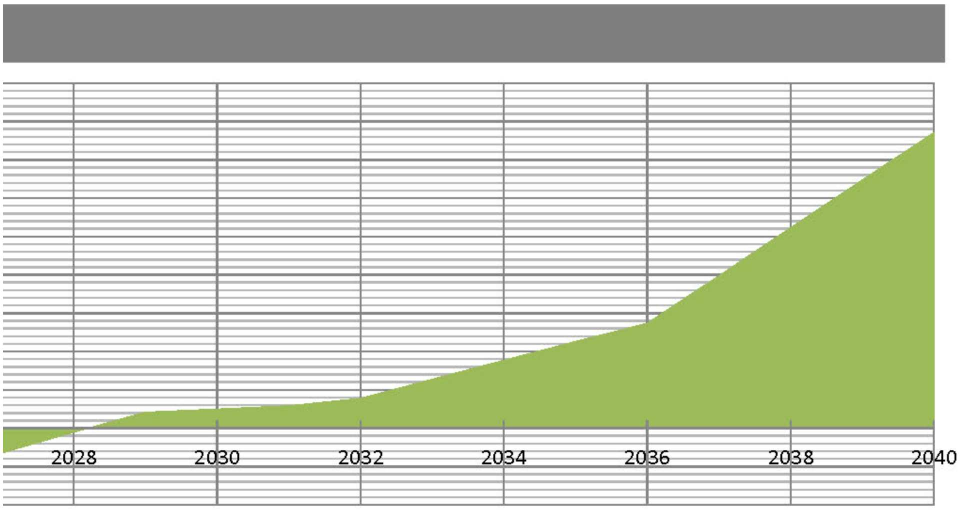
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