This document provides a detailed overview of the proposed Combined Heat and Power Plant. The focus of this document is to provide information related to the utility infrastructure of the University and how the proposed Combined Heat and Power Plant will positively impact the energy component of Duke’s Climate Action Plan (CAP).
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Duke University is a large and diverse campus with energy intensive research and medical facilities that require the highest level of dependability from its utility systems. The University has committed to become a carbon neutral campus by 2024 and has developed a Climate Action Plan (CAP) to meet this ambitious goal. Much progress has been made since the commitment in 2007 to become climate neutral.

Duke is considering a proposal to partner with Duke Energy on a Combined Heat and Power (CHP) plant on campus to further reduce carbon emissions on campus and in North Carolina as well as increase the reliability of the University system.

Energy Profile of Duke University

The Duke University main campus has one of the largest utility networks in the southeastern U.S. The research and medical facilities need and expect the highest level of reliability from its utility systems and from the utility providers.

Unlike some U.S. states, under N.C. law, the electrical utilities are regulated and only grant a limited number of companies the license to operate as monopolies. They are investor-owned utilities (IOUs) and electric co-operatives (EMCs). No third-party energy sales are allowed. This dictates and limits what the University can do on its own.

The University buys nearly all of its electricity from the grid, yet produces its own steam, hot water and chilled water. All of these self-generated utilities supply the University and Medical Center buildings and rely on electricity in the production process. Steam and hot water are generated by burning natural gas in the two newly renovated plants on campus and account for nearly half of the energy needs.

The utility infrastructure on campus consists of several plants, substations and distribution that feeds over 18 million gross square feet of buildings for the university, school of medicine, school of nursing, hospitals, and clinics. The Facilities Replacement Value (FRV) of this infrastructure is approximately $800 million, requires an annual operating budget of over $80 million, and a staff of 60 engineers, technicians, and operators.

- Utility Infrastructure Includes:
  - 2 Chilled water plants
  - 2 Steam plants
  - 1 Solar hot water plant
  - 1 District hot water plant
  - 5 High voltage electrical substations
  - 3 Central emergency generator plants
  - 2 Stormwater “plants”
  - Hundreds of miles of underground pipes and wire
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Campus Energy Needs

- Duke University and Medical Center require very large amounts of energy to serve the needs of academic, research, and health care facilities, and to support the nearly 50,000 people on campus.
- Duke’s physical footprint on campus consists of over 300 buildings and 18 million gross square feet. On average, the campus has added 204,000 GSF per year and is projected to be over 20 million GSF in the next 3 to 5 years.
- Duke University uses annually about 1% of the electricity and about 3% of the natural gas sold to the entire N.C. commercial sector.
- Duke University is among the top 20 electrical consumers in the state of N.C.

To provide some context to the University’s energy needs, the following table compares each utility to the typical home in Durham:

<table>
<thead>
<tr>
<th>Duke Utilities</th>
<th>Annual Consumption (FY16)</th>
<th>Peak Demand</th>
<th>Equivalent Number of Typical* Homes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (MWh/MW)</td>
<td>450,000</td>
<td>81</td>
<td>16,200</td>
</tr>
<tr>
<td>Steam &amp; Hot Water (MMBtu/MBtu per hr)</td>
<td>1,650,000</td>
<td>363</td>
<td>18,100</td>
</tr>
<tr>
<td>Chilled Water (ton-hrs/tons of cooling)</td>
<td>127,301,000</td>
<td>41,000</td>
<td>20,500</td>
</tr>
</tbody>
</table>

* Assumptions of typical N.C. residence: Electrical Demand, 0.005MW; Heating Demand, 0.02 MMBtu/hr; Cooling Demand, 2 tons

Duke’s electrical demand is...

- Larger than that of Yale & Princeton...
- More than twice the peak demand of all 49 Durham County Public School sites.
The chart below demonstrates the scale of Duke University when compared to other Ivy League plus and ACC schools. Note that Duke’s peak electrical demand is highest of the 16 respondents which corresponds to Duke having the most space on its campus and that Duke’s facilities are 23% more energy intense than the average. This is a reflection of our greater density of research and medical facilities.

Duke’s Climate Action Plan

In 2007, Duke signed the American College & University Presidents’ Climate Commitment, committing the University to developing an institutional plan to achieve climate neutrality. The Campus Sustainability Committee (CSC), with student, faculty and staff representatives, was established immediately afterward to develop Duke’s Climate Action Plan (CAP).

The 2009 CAP primarily aims to reduce Duke’s carbon footprint, setting goals and creating strategies to achieve them in energy, transportation, and carbon offsets. In addition to making significant infrastructure and operational changes, the CAP also identified strategies to ensure students graduate with an understanding of sustainability and the importance of campus community engagement in this ambitious institutional effort.

This graph below illustrates the challenge and the components of our carbon footprint that must be reduced to achieve our goals:

- **Business as Usual Projection** – Duke’s CAP modeled the campus emissions trajectory if left to grow unchecked into the future. Assuming there were no reduction measures taken at Duke and no external factors such as carbon legislation or increased fuel economy standards were implemented, Duke’s emissions were expected to grow to 426,466 MTCO2e by 2050.
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Progress toward CAP Goals

To reduce emissions attributable to campus energy, the following actions were established in the CAP and are either complete or in progress.

**CAP Actions:**

1. **Establish green building energy consumption standards and an approval protocol for building energy consumption review -- implement, measure and report on energy use targets by Building Tech Rating**

2. **Beginning in 2010, implement energy conservation measures (ECMs) in existing buildings with the goal to realize a 15% reduction in energy use over a 20 year period (2010 – 2030)**

3. **Discontinue the use of coal as soon as possible. Duke should complete the gas-fired East Plant steam plant construction and start-up in 2010 and initiate the West Campus steam plant conversion from coal in 2012**

4. **Continue to urge, monitor and review Duke Energy’s progress towards emissions reductions while exploring on-campus electricity generation options. Additionally, Duke should install 4MW solar PV array by 2012**

5. **Leverage research into alternative technologies and explore and implement conversion to biogas, solar PV, solar thermal, combined heat and power or other technologies by 2030**

6. **Pursue plant efficiency improvements with tactics such as: distribution system upgrades, thermal storage, chilled water expansion and upgrade, and boiler plant heat recovery**

As a result of pursuing the above stated actions and despite an increase of 1.7 million gross square feet of buildings included in the CAP since 2007, Duke has decreased its overall CAP-related carbon emissions by 23%, and **energy-related emissions have dropped by 37%**.
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CAP Emissions Snapshot:
- CAP emissions from building-related energy has decreased 37%. However, transportation-related CAP emissions have increased 27% during the same period, resulting in a net reduction of 23% overall, as indicated in the above chart.
- Building energy accounts for nearly 2/3 of campus CAP emissions
- Purchased electricity from Duke Energy accounts for the 42% of CAP emissions

Energy Reduction in Existing Buildings (CAP Actions #2 & #6)

The university has worked diligently to meet this goal and has invested significantly in developing energy-efficiency and energy-conservation projects. As indicated in the chart below Duke has achieved a 13% reduction in energy usage through FY2016. These efforts have realized a cumulative 1.17 trillion Btu energy savings. In addition to energy conservation in existing buildings, Duke implemented a green building energy consumption standard and a protocol for building energy consumption review of new buildings.

![Energy Use in Buildings Constructed Pre-2008 CAP Plan Buildings](chart)

Elimination of Coal as a Fuel for Steam (CAP Action #3)

Duke discontinued the use of coal in 2011. Duke renovated and converted both the East Campus Steam Plant and West Campus Steam Plant. This resulted in a 12% reduction in CAP emissions.
Conversion from Steam to Hot Water Distribution (CAP Action #6)

A study conducted in 2012 determined that only 53% of the current space on campus required the higher temperatures of steam in its vaporous form. The remaining space could be served by a more energy-efficient and cost-effective hot water distribution system.

The advantages of converting from steam to hot water distribution:

- Increases energy efficiency by 4% or more
- Reduces total CAP emissions by 2%
- Lowers construction cost
- Requires 90% less space in buildings
- Costs 30% less to maintain

The proposed CHP would provide new hot water production to support the conversion away from steam for half the campus. Facilities Management is also studying solar hot water to supplement the system.
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Renewable Energy at Duke (CAP Action #4)
Duke has explored and invested in renewable energy projects as part of its strategy to reduce carbon emissions on campus. However, the scale of Duke’s operation and energy needs currently exceeds the capacity or feasibility of exclusive reliance on renewable sources.

Duke currently has 163KW of solar photovoltaics (PV) and hot water (shown as equivalent kW) installed as follows:

- Bryan Center – 80 kW solar hot water
- Smart House – 10 kW solar PV
- Environment Hall – 45 kW solar PV & 15kW solar hot water
- Marine Lab – 13kW solar PV

The goal established in the CAP is to have 4MW of solar energy for Duke. Although there is much to be done, once achieved it would be comparable to the largest systems among schools surveyed:

Summary of Recent Renewable Energy Studies

Duke has conducted many studies related to solar energy on campus since 2007 and continues to do so. The results of several studies indicates that the lowest cost of PV energy to date at 13¢/kwh, compared to the 6¢/kwh Duke University currently pays for grid power. We are currently engaged with a developer to study the potential of a larger (1MW or more) -off-campus solar PV installation. We expect to have those estimates back soon.

A high level scan of installing solar on the 300,000 sq. ft. of flat roofs at Duke resulted in an amount of solar power that would reduce Duke’s emissions by about 1%. A more detailed study will likely find that many of these roofs will not support a solar installation due to their design, age, orientation, etc.

A study for a ground-based solar PV in an open area of the Duke Forest was recently completed. The results were as follows:

- Studied two options: 350kW (4 acres) and 2.5 MW (13 acres), both self-financed development with PV power sold back to utility
- Electricity production rates
  - 350kW option - 25¢/kWh self-financed or 16¢ - 18¢/kWh with developer
  - 2.5MW option - 19¢/kWh self-financed or 11¢ - 13¢ /kWh with developer
- 2.5MW achieves better economy of scale, but would require Duke University to pay for upgrades to public electrical infrastructure to get power back to the grid

Potential Solar PV Area in Duke
The Research Drive Parking Garage structure was designed to accept solar canopies. Several studies have been conducted and the latest resulted in:

- ~700 kW parking canopy system with multiple financial models:
  - Tax-flip/lease-back to find investors able to take advantage of investment tax credit
  - Duke Energy GreenSource Rider program
  - Self-finance and build
- Electricity production rates ~13 - 17¢ cents/kWh

Summary of other recent studies:

<table>
<thead>
<tr>
<th>Description</th>
<th>Year</th>
<th>Type</th>
<th>Summary</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking Garage #9 Solar Lease</td>
<td>2009</td>
<td>Renewables - PV</td>
<td>Developed proposals for solar tax-flip lease-back PV installation. ~450kW system, Levelized Cost of Energy of 11-12¢/kWh, versus cost of grid energy at 6¢/kWh</td>
<td>Not pursued - Payback too high</td>
</tr>
<tr>
<td>West Campus Steam Plant Fuel Conversion</td>
<td>2010</td>
<td>Fuel Switch</td>
<td>high-level study to evaluate feasibility of converting previous coal burning boilers at WCSP to coal gasification. Renewal and Operating costs of coal handling equipment significantly higher than natural gas option, with much less impactful carbon footprint reduction</td>
<td>Not pursued - carbon reduction not significant enough</td>
</tr>
<tr>
<td>Pascal Field House PV study</td>
<td>2010</td>
<td>Renewables - PV</td>
<td>studied installation of PV system on roof of Pascal Field House. Cost estimates showed excessively high cost of installation/ LCOE</td>
<td>Not pursued - Payback too high</td>
</tr>
<tr>
<td>West Campus Steam Plant Fuel Conversion</td>
<td>2010</td>
<td>Renewables - Biomass</td>
<td>Feasibility study for biomass fuel option for WCSP. Studies indicated need for 25-30 tractor trailer loads of woody biomass coming to campus per day, approx. 3 acre material handling site. Lack of regional suppliers within 1 day delivery is major energy security risk, plus noise, traffic, and site area were concerning</td>
<td>Not pursued - transport and energy security too risky</td>
</tr>
<tr>
<td>West Campus Steam Plant Fuel Conversion</td>
<td>2011</td>
<td>Fuel Switch</td>
<td>converted West Campus Steam Plant from coal to natural gas fuel, reducing Duke's carbon footprint by 38%</td>
<td>Complete - in service</td>
</tr>
<tr>
<td>Duke Energy GreenSource - Parking Garage #9 PV</td>
<td>2014</td>
<td>Renewables - PV</td>
<td>Proposals for University owned and developer owned PV install at ~700kW, both through Duke Energy GS program. Costs proposed at 13-19¢/kWh, more than triple the cost of grid-purchased power.</td>
<td>Not pursued - Payback too high</td>
</tr>
<tr>
<td>Duke Energy GreenSource - renewable PPA</td>
<td>2014</td>
<td>Renewables - Wind</td>
<td>Feasibility proposal to purchase wind-generated power from midwest at 11-12 ¢/kWh. However, to qualify for GS rider, University needs to identify 1 MW new load coming online, which is difficult with our efficiency improvements</td>
<td>Not pursued - payback too high</td>
</tr>
<tr>
<td>Waste-to-Steam</td>
<td>2015</td>
<td>Renewables - waste fuel gasification</td>
<td>Feasibility study to gather municipal solid waste and regulated medical waste for pyrolysis/steam generation. Duke does not generate enough waste to be able to fully utilize this type of equipment. Site concerns for waste processing facility on campus were an issue</td>
<td>Not pursued - not enough waste available</td>
</tr>
<tr>
<td>Utility Scale PV</td>
<td>2016</td>
<td>Renewables - PV</td>
<td>Currently studying ground mount PV options to develop economics, carbon reduction potential, utility interconnect requirements.</td>
<td>Study in Progress</td>
</tr>
</tbody>
</table>
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Carbon Offset Initiatives

While Duke implements aggressive action toward on-campus carbon reduction, it accepts the reality that given its location in the southeastern U.S., carbon offsets will be a part of the overall climate neutrality plan. To meet its goal of climate neutrality by 2024, Duke University will need to offset approximately 185,000 tons of carbon dioxide equivalent-emissions per year, an amount expected to diminish over time as on-campus reductions continue.

To proactively address this need, the Office of the Executive Vice President established the Duke Carbon Offsets Initiative in June 2009. The Initiative is responsible for developing the University's strategy for meeting its offset goals in a way that provides significant local, state and regional environmental, economic, and societal co-benefits beyond the benefits of greenhouse gas emission reductions.

The Duke Carbon Offsets Initiative collaborates with students, staff, and faculty to conduct research and develop offset projects, such as:

- **Swine Waste-to-Energy**
- **2015 Solarize Duke Program**
- **Employee Energy Efficiency**
- **Urban Forestry**

The most successful offset initiative so far has been the Loyd Ray Farms Swine Waste-to-Energy project. This was a partnership between the University, Duke Energy and Google, Inc. The project captures and burns methane from the hog waste to generate ~350 MWhs of electricity and offsets ~2000 MTCO2e per year. The farm provides tours and research opportunities for students, staff, and faculty. This has pushed the envelope on waste-to-energy and has led to additional systems being built in N.C. and consideration of methane as a potential biofuel source for natural gas plants such as those at Duke.
Proposed Combined Heat & Power Plant

Duke University and Duke Energy have proposed to build a 21MW Combined Heat and Power (CHP) Plant on campus. The plant would be built by Duke Energy on Duke University property and will be owned and operated by Duke Energy.

The facility burns natural gas to produce electricity, but unlike traditional power plants, the heat generated by process is captured and put to productive use on campus to heat buildings and provide steam – reducing the demand from Duke’s two steam plants on campus.

According to the U.S. Environmental Protection Agency, “CHP is on-site electricity generation that captures the heat that would otherwise be wasted to provide useful thermal energy—such as steam or hot water—that can be used for space heating, ..., domestic hot water…”.

The typical power plant has an energy efficiency of 40-45% and rejects its waste heat to the atmosphere or to a body of water. With a CHP, the total energy cycle efficiency is projected to be 75-80% since the waste heat is converted to steam and/or hot water to be used in the adjacent buildings.

Although it is counter intuitive, this natural gas driven plant will actually reduce the burning of fossil fuels in North Carolina. This is due to the utilization of the generator’s waste heat on campus to offset natural gas use in University steam plants and the reduction of electricity transmission losses. One of the greatest benefits is the one we hope we never have to use: the additional on-campus generation could be used in “island” mode in case of a grid outage due to a major weather event or system failure. Princeton University’s CHP and micro-grid is credited with keeping their facilities operational in the wake of the widespread electrical outages caused by Superstorm Sandy in 2012.

Duke would benefit with an approximate 18% reduction in the University’s CAP carbon footprint due to burning less natural gas in our steam plants as well as lower-cost steam and hot water produced from the CHP Plant’s waste heat.

The long range goal is for both the CHP and Duke’s steam plants to be sourced with biogas.
Proposed Combined Heat & Power - Building a More Sustainable Duke

Proposal Overview

- Duke Energy will build, own and operate a Combined Heat and Power (CHP) plant on property leased from Duke University.
- Duke Energy will send electricity back onto N.C. grid and the University would continue to purchase electricity as we always have.
- The University will buy the “waste” heat generated in the process at a rate that is significantly less than it costs us to generate steam and hot water at our plants.
- The system will be constructed to allow Duke University to “island” in cases of a power grid outage.
- If another technology with lower (or zero) emissions factor becomes economically feasible, the University will have the ability to exit the CHP contract.

How the CHP would Work on Campus

There are over 8,000 CHP’s across the US
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Summary of Benefits of CHP to Duke University

As currently proposed, the University sees many benefits from having the CHP on campus, including environmental, economic, and energy security. These are subject to change as the N.C. Utility Commission has not yet approved the project and the final contract terms between the two parties have not been finalized:

- **Emissions**
  - Reduces CAP-tracked emissions by cutting Duke University’s use of natural gas by 50%
  - Overall less fossil fuels will be burned in N.C.

- **Return on Investment**
  - University is projected to have a 2 – 3 year payback on its investment
  - University avoids a $2.5M capital investment in a 2nd hot water plant on campus

- **Future Renewables**
  - Duke Energy is investigating existing biogas sources to run the CHP plant
  - The University can pursue new biogas sources to eventually power campus steam plants – as called out in CAP – but will need 50% less due to the CHP

- **Resiliency**
  - Ability to island in the event of regional power outage
  - Flexibility to shift power around campus grid as needed
  - Does not rely on diesel fuel supply chain in the event of natural disaster (transportation problematic in ice/snow, flood, hurricane events)
  - Provides for 3rd source of steam on campus

University CAP Emissions Impact

The CHP facility would be operated by Duke Energy and electricity from the CHP is connected to their grid. Therefore the emissions from the CHP facility would be counted as part of the University’s purchased electricity and as such it is included in the overall emissions factor for Duke Energy’s total generation fleet. Also the fuel-consuming piece of equipment is the turbine/generator, which can technically operate without heat recovery should only the electricity is needed (it will not, however, operate as an electrical-only plant).

This proposed method accounts for total fuel consumption for all delivered energy. The waste heat from the CHP is enough to allow the University’s heating plants to ramp down production, reducing by 50% the annual amount of natural gas burned at the plants. This reduced gas consumption will result in an **18% reduction** in CAP emissions for the campus.

The following graph is used to track the progress of reducing CAP emissions versus the original CAP forecast. During the time of the plan’s development, Duke Energy had expectations of adding more nuclear generation as a way to reduce their emissions. With the decision on adding nuclear plants being delayed, the expected drop in campus emissions will not occur as hoped.
Existing campus steam infrastructure is arranged such that all of the steam and hot water production from the CHP will be used by University CAP buildings. The CHP can supply nearly all (94%) of the heating needs to the CAP buildings, meaning that the remainder of the annual emissions from University steam plants is attributed to the non-CAP building portfolio (hospitals & clinics). This accounting is the most conservative methodology, actually understating the benefit of the CHP when compared to the emissions of marginal electrical generation technologies in the Duke Energy fleet.

Impact to Emissions in North Carolina

In order to evaluate the impact to emissions to North Carolina, the total source energy emissions must be taken into consideration:

- Total source energy emissions is defined as the emissions from both Duke Energy’s production of 20MW of power plus Duke University’s production of steam equivalent to the CHP heat output and compared to the CHP’s emissions.

The generation is an offset since this electricity generation is not for any new demand, so there will be a corresponding reduction at one or more of Duke Energy’s current generation stations. The most likely scenario is that a gas-fired or coal-fired power plant or a combination of the two would need to produce 20MW less as a result of the CHP. Duke Energy, Duke University Facilities Management and an outside consultant have evaluated the impact. In addition, the calculations performed by Facilities Management were reviewed by Nicholas School faculty. The consultant, Affiliated Engineers Inc. (AEI), performed independent emissions calculations under several scenarios.
Emissions estimates were performed or reviewed by:

- Duke Facilities Management: Estimated a 26% reduction
- Duke Faculty: Timothy L. Johnson, Associate Professor of the Practice in Energy & the Environment, EE Program Chair: Reviewed and concurs with Facilities Management’s estimate
- Duke Energy Carolinas: Estimated a 30% reduction
- Affiliated Engineers Inc., engineering consultant firm estimated 3 scenarios:
  1. Compared to Duke Energy’s entire generation mix – a 23% reduction
  2. Compared to Duke Energy’s natural gas generation mix – a 39% reduction
  3. Compared to Duke Energy’s fossil fuel generation mix – a 49% reduction

**Graphical Representation of AEI’s Scenario #1**

**Total Source Energy Emissions – Considering All DE Generation**

Without CHP

- Electrical Output (net): 20,213 kw
- Thermal Output: 87.1 mmbtu
- NG Input: 191.94 mmbtu

With CHP

- Electrical Output (net): 15,800 kw
- Thermal Output: 72.8 mmbtu
- NG Input: 151.3 mmbtu

**AEI Scenario #1 – All Duke Energy Generation**

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Output (net)</td>
<td>20,213 kw</td>
<td>Predicted runtime at full load</td>
</tr>
<tr>
<td>Thermal Output</td>
<td>87.1 mmbtu</td>
<td>Delivered steam and hot water</td>
</tr>
<tr>
<td>NG Input</td>
<td>191.94 mmbtu</td>
<td>Predicted turbine fuel consumption</td>
</tr>
<tr>
<td>Electrical Transmission Losses</td>
<td>15,800 kw</td>
<td>Duke Energy all generation sources</td>
</tr>
<tr>
<td>DU Steam Generation</td>
<td>72.8 mmbtu</td>
<td>Reported 9% grid losses to deliver power</td>
</tr>
</tbody>
</table>

**Business as Usual (BAU) Emissions**

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Generation</td>
<td>168,777,506 kwh/yr</td>
<td>Duke Energy all generation sources</td>
</tr>
<tr>
<td>Elec. Transmission Losses</td>
<td>15,189,976 kwh/yr</td>
<td>Reported 9% grid losses to deliver power</td>
</tr>
<tr>
<td>DU Steam Generation</td>
<td>727,123 mmbtu/yr</td>
<td>Equivalent DU steam plant production</td>
</tr>
</tbody>
</table>

**BAU TOTAL**

- 110,424 MT CO2e

**CHP Emissions**

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
<th>Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine</td>
<td>1,602,723 mmbtu/yr</td>
<td>Total useful energy output</td>
</tr>
</tbody>
</table>

**NET SAVINGS**

- 25,188 MT CO2e
- 23% reduction
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AEI Scenario #2 – Only Duke Energy’s natural gas generation mix

<table>
<thead>
<tr>
<th>Based on First Year Full Operation</th>
<th>Assumptions</th>
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</thead>
<tbody>
<tr>
<td>Electrical Output (net) 20,213 kw</td>
<td>Predicted runtime at full load</td>
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<tr>
<td>Thermal Output 87.1 mmbtu</td>
<td>Delivered steam and hot water</td>
</tr>
<tr>
<td>Generator Efficiency 35.9%</td>
<td>Turbine Higher Heating Value efficiency</td>
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<tr>
<td>NG Input 191.94 mmbtu</td>
<td>Predicted turbine fuel consumption</td>
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<tr>
<td>Business as Usual (BAU) Emissions</td>
<td></td>
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<tr>
<td>Electrical Generation 168,777,506 kWh/yr</td>
<td>Offset only 35% efficient NG plants (1.14 lbs/kwh)</td>
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<tr>
<td>Elec. Transmission Losses 15,189,976 kWh/yr</td>
<td>Reported 9% grid losses to deliver power</td>
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<tr>
<td>DU Steam Generation 727,123 mmbtu/yr</td>
<td>Equivalent DU steam plant production</td>
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<td></td>
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</tr>
<tr>
<td>BAU TOTAL</td>
<td>138,809 MTCO2e</td>
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<tr>
<td></td>
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<tr>
<td>CHP Emissions</td>
<td></td>
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<tr>
<td>Turbine 1,602,723 mmbtu/yr x 117 lb/mmbtu = 85,236 MTCO2e</td>
<td>Total useful energy output</td>
</tr>
</tbody>
</table>

NET SAVINGS 53,574 MTCO2e 39% reduction

% Savings vs BAU

AEI Scenario #3 – Only Duke Energy’s natural gas generation mix

<table>
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<tr>
<th>Based on First Year Full Operation</th>
<th>Assumptions</th>
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</thead>
<tbody>
<tr>
<td>Electrical Output (net) 20,213 kw</td>
<td>Predicted runtime at full load</td>
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<td>Thermal Output 87.1 mmbtu</td>
<td>Delivered steam and hot water</td>
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<td>Generator Efficiency 35.9%</td>
<td>Turbine Higher Heating Value efficiency</td>
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<tr>
<td>NG Input 191.94 mmbtu</td>
<td>Predicted turbine fuel consumption</td>
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<tr>
<td>Business as Usual (BAU) Emissions</td>
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</tr>
<tr>
<td>Electrical Generation 168,777,506 kWh/yr</td>
<td>Duke Energy fossil fuel plants (coal and NG)</td>
</tr>
<tr>
<td>Elec. Transmission Losses 15,189,976 kWh/yr</td>
<td>Reported 9% grid losses to deliver power</td>
</tr>
<tr>
<td>DU Steam Generation 727,123 mmbtu/yr</td>
<td>Equivalent DU steam plant production</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>BAU TOTAL</td>
<td>167,578 MTCO2e</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>CHP Emissions</td>
<td></td>
</tr>
<tr>
<td>Turbine 1,602,723 mmbtu/yr x 117 lb/mmbtu = 85,236 MTCO2e</td>
<td>Total useful energy output</td>
</tr>
</tbody>
</table>

NET SAVINGS 82,342 MTCO2e 49% reduction

% Savings vs BAU

Since the most likely scenario for the generation offset from the CHP will be a Duke Energy fossil fuel plant(s), total source energy emissions are expected to be reduced by 39% - 49% versus separately produced power and steam. Although the University uses Duke Energy’s entire fleet to calculate our CAP emissions from purchased electricity, if we were to use the CHP’s emissions and expected net emissions, our emissions for electricity would be reduced.

Even when comparing the CHP to Duke Energy’s published anticipated emissions (which include projections for new nuclear generation) over the next 20 years, Duke Energy is not expected to have fleet emissions factors lower than the proposed CHP (refer to graph on next page).
Energy Security at Duke

Energy, in all its delivered forms, is critical for University and Medical Center facilities to execute their mission – saving lives, delivering transformative medicine and research, and promoting education and scholarship. The interruption of that energy service is damaging and disruptive to that mission, with the possibility of negatively impacting health care outcomes, long-term research efforts, classroom instruction, and daily campus life. Both Duke University and Duke Energy have built very reliable systems to support campus needs, but the possibility of a power disruption is real.
Duke’s hospital buildings have 100% diesel-powered backup generators as required by law but these can also fail, either the mechanical components themselves, or the fuel supply chain that delivers diesel fuel to campus. Yet several of the facilities that contain support operations for the hospitals do not have a 100% back-up generation. This is also the case for most of Duke’s critical research buildings that only have enough on-site back up power to take care of life-safety systems and a limited portion of process equipment. Thus few buildings would be able to be open and be occupied on campus during a major blackout. The following table is a sample of critical buildings on campus and the percent of backup power they have:

<table>
<thead>
<tr>
<th>Medical Center Buildings</th>
<th>% Backup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Science Research Building #1</td>
<td>0%</td>
</tr>
<tr>
<td>Surgical Oncology Research</td>
<td>0%</td>
</tr>
<tr>
<td>School of Nursing</td>
<td>6%</td>
</tr>
<tr>
<td>Research Park 1</td>
<td>7%</td>
</tr>
<tr>
<td>Jones</td>
<td>14%</td>
</tr>
<tr>
<td>AERI/Wadsworth</td>
<td>29%</td>
</tr>
<tr>
<td>Research Park 2</td>
<td>31%</td>
</tr>
<tr>
<td>Dialysis</td>
<td>33%</td>
</tr>
<tr>
<td>Global Health Research Building</td>
<td>33%</td>
</tr>
<tr>
<td>Global Science Research Building #2</td>
<td>37%</td>
</tr>
<tr>
<td>Surgical Research Pavilion</td>
<td>40%</td>
</tr>
<tr>
<td>Medical Science Research Building #1</td>
<td>47%</td>
</tr>
<tr>
<td>Vivarium</td>
<td>48%</td>
</tr>
<tr>
<td>Duke North Pavilion</td>
<td>50%</td>
</tr>
<tr>
<td>Medical Science Research Building #2</td>
<td>56%</td>
</tr>
<tr>
<td>ALIF Cancer Center Isolation Facility</td>
<td>61%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>University Building</th>
<th>% Backup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio Science / Greenhouses</td>
<td>0%</td>
</tr>
<tr>
<td>Triangle Universities Nuclear Lab</td>
<td>0%</td>
</tr>
<tr>
<td>Free Electron Laser Lab</td>
<td>1%</td>
</tr>
<tr>
<td>Cameron Indoor Stadium</td>
<td>4%</td>
</tr>
<tr>
<td>Nasher Art Museum</td>
<td>7%</td>
</tr>
<tr>
<td>Fitzpatrick/CIEMAS</td>
<td>10%</td>
</tr>
<tr>
<td>Fugua School of Business</td>
<td>18%</td>
</tr>
<tr>
<td>Bryan Center</td>
<td>20%</td>
</tr>
<tr>
<td>Perkins Library</td>
<td>25%</td>
</tr>
<tr>
<td>Gross Hall</td>
<td>27%</td>
</tr>
<tr>
<td>Levine Science Research Center</td>
<td>29%</td>
</tr>
<tr>
<td>French Family Science Center</td>
<td>40%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Utility Plants</th>
<th>% Backup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilled Water Plant #1</td>
<td>29%</td>
</tr>
<tr>
<td>Chilled Water Plant #2</td>
<td>55%</td>
</tr>
</tbody>
</table>

The 20MW of CHP-provided generation capacity represent 25% of the peak electrical demand of the campus. Along with the generators on campus, the CHP would provide Duke with enough power to fully operate the campus for 8 out of 12 months a year. Only during the peak cooling season would a portion of the campus would be without power. Moreover, the existing electrical infrastructure on campus, operated as a microgrid, would allow power from the CHP to be moved to the priority sites, something that cannot be done with stand-alone diesel generation.

Planning for disaster situations, which could include widespread energy outages, is not taken lightly by the administration. We do not plan for the “typical” disaster, we plan for worst-case scenarios in which this campus would be relied upon not by just students, faculty, and staff, but also the City of Durham, and perhaps the County and region.

There are over 8,000 CHP’s across North America including at 160 universities. In total universities are producing nearly 3,000MW of highly reliable and efficient electricity and heat. This chart summarizes the results from a survey of Ivy + and ACC schools regarding their CHP’s:
Energy security is cited by President Obama’s Department of Energy as one of the key advantages of CHP’s to businesses and the U.S.:

Energy security is cited by President Obama’s Department of Energy as one of the key advantages of CHP’s to businesses and the U.S.:

The Argonne, Berkley, Brookhaven, and Sandia National Labs, and even Pew Charitable Trusts have also highlighted resiliency benefits of microgrids in publications and video production. We encourage further reading and discussion on this topic.
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Equivalent Alternatives to the CHP

Even though the CHP is not an either/or proposal, the following were evaluated to illustrate and provide perspective on what other energy supply technology options might look like:

- **Solar**
  - To provide equivalent carbon footprint reduction as CHP, would need over 400 acres of solar PV – an area equivalent to 2/3 of West Campus
  - Such an installation would only provide fractional amount of electrical needs, and at a very high comparative cost

  ![Duke's West Campus](image)

  - **Solar PV:**
    - 430 acres
    - 47,000 MTCO2e/yr saved
    - $100M+ cost (DU)
    - $4.2-$4.5 M/yr saved
    - 20% uptime

- **Biomass Plant**
  - This alternative was studied. Although it can technically work, it was deemed that there was a negative impact to doing so on campus.
  - Would require 3-5 acres of on-site storage and 20 to 40 tractor trailer trucks per day to deliver biomass
  - Ideally, the plant would be a third-party-owned facility located offsite with the bio-gas piped to the gas infrastructure that currently supplies campus

  - **CHP:**
    - 1 acre
    - 47,000 MTCO2e/yr saved
    - $55M cost (DE)
    - $5M connection (DU)
    - $2M-$3M/yr saved
    - 95% uptime
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- Energy Storage
  - Large-capacity energy storage currently exists for grid voltage regulation, not hours-long charge and discharge cycles
  - If a feasible site were located, it would likely be the largest energy storage project ever attempted in U.S., and would be the largest solar PV project on the east coast
  - To provide Duke with a large-scale battery energy storage and coupled solar PV system would cost several hundred million dollars

The following analysis is conducted to provide a level of context for various options to reduce our carbon footprint. The chart below compares, at a high level, the greenhouse gas reductions that can be achieved with two solar PV scenarios, with building demand-side energy conservation measures, and with the proposed combined heat and power project. We reiterate that the CHP does not affect a decision for or against implementation of renewable energy systems, but to provide perspective on costs and achievable GHG reductions with each option.

<table>
<thead>
<tr>
<th>Carbon Reduction (MT CO2e)</th>
<th>2,300</th>
<th>11,500</th>
<th>15,000</th>
<th>47,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV</td>
<td>4MW</td>
<td>20MW</td>
<td>Proposed 20MW CHP</td>
<td></td>
</tr>
<tr>
<td>% CAP Reduction</td>
<td>0.9%</td>
<td>4.4%</td>
<td>5.7%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Space Required</td>
<td>20 acres</td>
<td>100 acres</td>
<td>None</td>
<td>1 acre</td>
</tr>
<tr>
<td>Estimated Capital Cost</td>
<td>$6M to $8M</td>
<td>$30 to $40M</td>
<td>$1.5M to $5M</td>
<td>$5M to $7M</td>
</tr>
<tr>
<td>Annual Net Savings</td>
<td>$350k to $400k</td>
<td>$1.3M to $1.4M</td>
<td>$2M to $3M</td>
<td>$2M to $3M</td>
</tr>
<tr>
<td>Simple Payback</td>
<td>15 - 23 years</td>
<td>21 - 31 years</td>
<td>0.5 - 2.5 years</td>
<td>1.7 - 2.3 years</td>
</tr>
</tbody>
</table>

First, CHP and building demand-side energy efficiency provide the best return on investment for the University, in terms of simple economic payback and dollars spent for each ton of GHG reduction. Secondly, solar PV, either at the building scale (multiple rooftop installations would add up to 4 MW) or at the utility scale (20 MW would have to be a remotely-sited ground-mount installation), do not make as significant of a GHG impact, nor is the economic return as attractive. A literature review of both academic and industry publications regarding different strategies for mitigating greenhouse gas emissions will uncover similar findings as those we demonstrate above.
Conclusions

As currently proposed, the University views the CHP as having a positive impact on our emissions, North Carolina’s emissions and the campus’ energy security. However, since this project is contingent on N.C. Utilities Commission approval and agreement of both parties on acceptable contract terms, much could change before a deal is finalized.

- University CAP emissions: **Reduced by 18%**
- Total source energy in NC: **Reduced by 23% - 49%**
- University energy security: **Increased by 20MW**

Duke University infrastructure needs are complex and widespread. The university has commitment to become climate neutral. The CHP coupled with the ability to burn biogas will further reduce CAP emissions and total energy source emissions. The CHP has the potential to be one of the major steps in Duke's goal to become carbon neutral by 2024. But even with its positive impact, the University has substantial work to do to meet the CAP goal of climate neutrality.
Proposed Combined Heat & Power - Building a More Sustainable Duke

References & Other Resources

- Duke Facilities Management – Office of Energy Management Services
  ▪ http://fmd.duke.edu/about/energy/index.php

- Duke Sustainability Office
  ▪ http://sustainability.duke.edu/

- President Obama CHP Executive Order

- NC Clean Energy Technology Center
  ▪ https://nccleantech.ncsu.edu/

- US Environmental Protection Agency CHP Partnership
  ▪ https://www.epa.gov/chp

- NC Warn – Combined Heat & Power in NC

- International District Energy Association (IDEA)
  ▪ http://www.districtenergy.org/

- US Department of Energy
  ▪ http://energy.gov/

- National Renewable Energy Laboratory
  ▪ http://www.nrel.gov/

- US Energy Information Administration
  ▪ http://www.eia.gov/

- Database of State Incentives for Renewables & Efficiency
  ▪ http://www.dsireusa.org/

- Duke Energy Integrated Resource Plan (most current filed 1 September 2016)
  ▪ http://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=0707e812-b29f-4d0e-8974-d215cb3a6e87

- Princeton University’s CHP & Microgrid performance during Superstorm Sandy

- Pew Charitable Trusts “How Microgrids Improve Resiliency in Power Outages” video:

- Microgrid Resources Coalition
  ▪ http://www.microgridresources.com/
Why is Duke University interested Combined Heat & Power (CHP)?

Duke University & Medical Center require many forms of energy to execute our mission. For two main reasons, Combined Heat and Power suits our application. First, CHP is a form of distributed generation that greatly contributes to the resiliency of both the University electric grid and that of the central North Carolina region. On-site power generation provides Duke University and Duke University Medical Center the ability to continue operating critical campus facilities in the event of a major grid outage, such as one caused by natural disaster. Secondly, CHP is a very energy efficient (and less carbon-intense) way to deliver the heat and power that the campus requires. In the traditional electric generation cycle, where a large, rurally-sited central station power plant generates only useful electricity, typically 55%-65% of the total input heat is wasted – rejected to the atmosphere through a cooling tower or put into a body of water. A CHP facility, makes use of up to 40% of that otherwise-wasted heat, generating steam and hot water that can then be piped through the University’s utility systems to campus buildings. This significant increase in efficiency means that the campus steam plants burn less natural gas to provide heat to the university, and the power utility burns less natural gas in other power plants to provide the same amount of power.

Why is Duke University Interested in letting Duke Energy build a combined heat and power facility on our campus?

The partnership is an economical and energy efficient way for Duke University to increase the reliability of energy systems on campus, while simultaneously supporting a reduction in fossil fuels burned in the Carolinas. The University has studied several methods of executing a CHP project, but the regulated-monopoly framework on which North Carolina allows utility companies to operate makes self-ownership unattractive to the University. If we were to build, own, and operate the CHP plant ourselves, it would cost the University more money than it would save, particularly on the electrical generation side of energy delivery. Next, Duke University recognizes that we are pushing the boundaries of the traditional North Carolina electric utility business model. We think there is value in demonstrating to Duke Energy, North Carolina, and peer institutions that there is a more resilient, more energy efficient, lower-carbon-footprint option for delivering energy to campuses.

What kind of fuel does the CHP Plant burn? How much energy does it make?

This plant will burn natural gas to generate about 20 megawatts of electrical power, and about 85,000 pounds per hour of steam and hot water. Natural gas is the same fuel that the University already uses, having eliminated the use of highly-polluting coal in 2011. We are currently studying the ability to procure renewably-sourced biogas as a fuel source for this plant, and for campus steam plants as well. The turbine will generate about 20 Megawatts of electrical power – this represents about 25% of the campus summer peak or about the same amount needed to support the core hospital, clinical, and critical research facilities should the regional grid become unable to deliver power.
Does this CHP plant mean that more fossil fuels will be burned?
No, in fact the CHP would reduce the amount of fossil fuels burned in North Carolina. The CHP plant provides 20 MW of power that would otherwise be generated by burning coal or natural gas in other, less efficient, more GHG-intense plants in North and South Carolina. Additionally, the CHP reduces the amount of fuel burned to make up for energy lost in getting that power to campus over long-distance transmission lines. Most directly, recovered heat from the CHP will offset the amount of natural gas that the campus steam plants would otherwise have to burn. We estimate a reduction in on-campus heating-related fuel of nearly 50% per year – over 700 million cubic feet of natural gas that we don’t have to burn to provide heat to our growing campus.

How does the CHP align with Duke’s Climate Action Plan Goals?
The 2009 Climate Action Plan specifically referenced Combined Heat & Power Plant in the six main goals in the Energy section. The CHP plant is projected to reduce the campus energy-related carbon footprint by 18% or campus total by 12%, as well as reducing the fossil fuel use required to deliver electric power (see above). We recognize that this CHP plant is not, however, a form of carbon-free energy, and so we continue to pursue the other goals outlined in the CAP, continuously evaluating other energy generation and demand reduction technologies for application on campus.

What about renewable energy sources?
CHP and renewables provide complimentary, but not equivalent benefits, so by choosing CHP we are not excluding renewables. The University requires electrical power around the clock, and unfortunately, solar photovoltaic systems can’t generate at night, nor is it steady in output, nor is energy storage technology advanced enough to make up the balance of energy needs. The Facilities Management Department has studied, and continues to study, options for integrating renewable energy into the campus supply mix. The reality is that even if we deployed 4 MW of solar PV across several building rooftops, it would only result in a carbon footprint reduction of about 1%. Outside of University’s on-campus actions, we continue to monitor Duke Energy’s efforts to reduce the GHG impact of their delivered electricity, and to push them to include more opportunities to deploy renewable technologies, both locally and regionally.

What about energy efficiency?
Helping our buildings and people use less energy is the fastest, most cost-effective and simplest-to-achieve method of carbon footprint reduction. Duke University has made significant progress in reducing the energy needs of campus, even as it grows with major renovations and new construction – CHP would be another large step in increasing energy efficiency. From our Climate Action Plan baseline year of 2008, Duke has reduced energy consumption by 13% in existing buildings, and total campus energy use has remained flat even as the University & School of Medicine has grown by over 1.7 million square feet (note that the Hospital has grown an additional 1M square feet, but is not included in the CAP). That avoided energy, if tallied up (342,329 MWh), would be enough to power about 31,000 typical American homes for a year.

End of Document