Analysis of and Alternatives to the Proposed Duke University Natural Gas-Fired CHP Plant

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Now in its 28th year, NC WARN is a member-based nonprofit tackling the climate crisis – and other hazards posed by electricity generation – by watch-dogging Duke Energy practices and building people power for a swift North Carolina transition to clean, renewable and affordable power generation and increased energy efficiency.

In partnership with other groups, and using sound scientific research, NC WARN informs and involves the public in key decisions regarding their health and economic well-being. Dedicated to climate and environmental justice, NC WARN seeks to address the needs of all of the public by intentionally including those often excluded from participation because of racism, sexism, classism, and other forms of oppression.

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Table of Contents

NC WARN

Building People Power for Climate & Energy Justice

October 24, 2016

Dr. Richard Brodhead, President
Duke University
Durham, North Carolina

Subject: Summary of our Report on an Alternate Path to the Duke Energy Gas-CHP Plant

Dear President Brodhead,

We appreciate the cooperative discussions University officials have shared with NC WARN in recent months regarding the campus energy system and the Duke Energy proposal. We look forward to continuing to assist you in finding a path that can be a source of pride and inspiration for members of the University, its neighbors and people across the nation.

I am pleased to submit to you the attached report as an initial assessment of the Duke Energy gas-CHP proposal and suggestions for an alternate approach that would serve the University's needs. This approach can also align you with leading universities adopting innovations that could become a critical step toward stemming what scientists variously refer to as a climate crisis, a planetary emergency, and a truly alarming situation.

It seems clear that climate change must serve as the backdrop for discussions over the University's energy choices. Based on our earlier exchanges, I believe that you share my deep concern over the unprecedented global heatwave that has continued – and worsened – for three years running, as documented by both NASA and NOAA. This year is on track to far surpass the all-time global average heat record set in 2015 even as a series of widespread floods have struck eastern North Carolina since Labor Day, and as weather extremes continue ravaging communities around the world.

Although there is an absence of data regarding whether the increased methane is causing the persistent heat, the record heat coincides with surging methane emissions from the US fracking boom in recent years.

Duke University's Drew Shindell has concluded that reductions in methane emissions will slow global warming quicker than reductions in carbon dioxide, and that we must exploit that opportunity. His colleague, Dr. Robert Howarth of Cornell University agrees, saying "*The climate* *system responds very quickly to changes in methane emissions; reducing methane emissions now will significantly slow the rate of global warming over the coming decades."*

In fact, as Dr. Howarth emphasized when speaking on your campus and at UNC-Chapel Hill in March, curbing methane is the only way to avoid irreversible harm to the climate. He and other leading scientists say these super-potent emissions – 100 times stronger than carbon dioxide at trapping heat over the first critical 10 years in the atmosphere – make the use of natural gas for electricity even worse than coal for the climate crisis. And they argue that we must overcome industry resistance to greatly reduce methane emissions while moving to ban fracking.

To be clear, the US electric power industry is driving the fracking boom through its fevered rush to build gas-fired power plants. That's despite the clear evidence that methane is deliberately vented and leaking in disturbing amounts during the drilling, processing and transportation of natural gas – from wellhead to power plant.

Amid the disturbing reality of climate change, the methane challenge points to your opportunity and duty. As I said to you earlier, the world badly needs bold leadership if humanity is to avert runaway climate chaos. You can provide such leadership by refusing to partner with Duke Energy in its effort to initiate a new national scheme to expand the burning of fracked gas on campuses. If Duke Energy's project is completed, Duke University would be joining those electric utilities that are driving the highly damaging US fracking boom and the increased spewing of methane into the air.

Below is a summary of key points from our report, prepared with technical assistance from Bill Powers, a San Diego-based engineer specializing in the electric power industry and clean, distributed energy solutions. (Bill is also an alumnus of the Duke University engineering program.)

A focus on profits, not climate

- *Duke Energy appears to be leading a power industry effort to create new revenue streams by building gas-fired CHP plants on the nation's campuses. Duke University is being sought as a partner in this shift from campus energy independence to corporate utility dependence.*

- *Until recently, Duke University leaders did not realize the gas-CHP plant would burn mostly shale gas from the fracking fields. They emphasized that this isn't what Duke University wants; this reason alone should be enough to end contract negotiations with Duke Energy for the plant.*

- *The amount of natural gas burned on campus – and associated greenhouse gas emissions – would increase by 61% over current practice. This is counter to the illogical claim that campus emissions would decrease merely because Duke Energy, rather than the University, would own the gas-CHP plant and burn the shale gas to power it.*

- *In addition, when methane emissions are included, the electricity generated by the gas-CHP plant* *could have a greenhouse gas profile up to 112% higher than power purchased from the Duke Energy system.*

Reliability issues

- *Reliable back-up power supply for critical facilities (emergency diesel generators totaling 13 MW) is fully functional and cannot be replaced by the gas-CHP plant, according to state law.*

- *The gas-CHP plant would add only marginal reliability at best. The plant would average up to 54 days per year of planned and unplanned outages, and its fuel source could be interrupted for numerous contractual or emergency reasons.*

- *Contrary to University statements, a fracked gas-powered CHP plant operating nearly full-time would emit far more air pollution than the emergency generators that run a few hours per year.*

False hopes and community impacts

- *Duke Energy indicates in its application to the NC Utilities Commission that it has chosen not to use the best available air pollution controls for the gas-CHP plant. Nitrous oxide emissions would be at least ten times greater, per kilowatt-hour, than those from a similar CHP plant at Cornell University. Staff, students and neighbors would be exposed to far higher emissions of NOx than is currently being emitted from the on-campus natural gas boilers.*

- *Hopes that a gas-fired CHP plant built on campus might someday be converted to burn biogas from swine waste remain highly speculative due to technical, economic and social justice challenges that are many years from being resolved, even after more than a decade of effort.*

- *Since Duke Energy and surrounding utilities own many power plants that sit idle much of the year – with excess capacity projected to continue for decades – it will be hard for the utility to honestly justify building the University gas-CHP plant based on need, an essential requirement.*

- *Duke Energy customers would bear the rate increases to pay for a new gas-CHP plant intended to serve a private university, raising regulatory challenges and concerns about economic justice.*

A better path

- *Leading universities that once relied on gas-CHP plants have been replacing them in favor of advanced clean energy programs including on- and off-campus solar installations, battery storage, aggressive energy-saving programs and electric heating and cooling systems.*

- *Duke University has a large amount of feasible solar photovoltaic potential. Market pricing at similar facilities in North Carolina is lower than the price which University officials indicate would make economic sense – and even lower than it is now paying Duke Energy for power.*

- *We recommend that the University conduct a comprehensive technical and economic assessment to optimize solar PV projects, with particular focus on rooftops and parking facilities, and with a goal of installing 4 MW per year. The 2009 Duke University Climate Action Plan target was 4 MW of solar PV installed by 2012 and none has been installed to date.*

- *The University's interest in the potential to convert on-campus steam usage to hot water systems should include a full evaluation of solar thermal systems instead of authorizing a large gas-CHP plant to serve this purpose.*

- *We recommend that the University build on energy efficiency achievements by committing to reduce energy consumption by 30% per square foot by 2024 and construct all new buildings to be LEED certified or zero net energy users.*

President Brodhead, Duke University is at an ideal crossroads. With your electricity and steam needs currently being met by existing resources without notable issues, the University should not commit to a single large project that would limit its options and squander its chance to help slow climate change. You are in a prime position to implement innovative projects to serve as a model for students, other universities and industry.

NC WARN recommends careful and open consideration of your energy options. As detailed in our report, we believe you've been misled by Duke Energy on a number of important aspects of this proposal in ways that run counter to the University's values and intentions.

We therefore urge you to suspend contract negotiations with Duke Energy, and commit to a truly open process and discussion with the campus – and with the community that would bear the decades of air pollution and economic burdens if Duke Energy's fracking gas plant were built in Durham. To continue forward under the non-transparent, pro-Duke Energy auspices of the NC Utilities Commission would, I believe, ensure escalating controversy for years to come.

Most of all, it would deflate the public hope that someone in your position will rise above fossil fuel intransigence and obfuscation, and raise a call for assertive action to avert one of the greatest and most urgent challenges facing humanity.

Every week and month that pass, more natural gas industry methane is pouring into the atmosphere, trapping more heat and pushing humanity ever closer to a point of no return. I sincerely hope you will embrace this opportunity.

Sincerely,

Jim Warren

Jim Warren
Executive Director

About This Report

News of Duke Energy's proposal to build a natural gas-fired power plant at Duke University induced a backlash from students, faculty and alumni concerned by the expansion of fossil fuels on campus. This report is based on a series of meetings between climate justice nonprofit NC WARN and University officials, on our independent research, and on technical assistance from Powers Engineering. We believe the proposed combined heat and power (CHP) plant, which would burn fracked gas, would run counter to the University's climate goals and would negatively impact members of the University and the greater community in multiple ways. We urge President Brodhead to end contract negotiations with Duke Energy and conduct a holistic, transparent assessment of the economically superior clean energy options that other universities are developing. That process should include genuine participation by the University community and its neighbors.

Duke University's Stated Goals

There appears to be no pressing need to upgrade or expand the energy system at Duke University in the short term, so NC WARN recommends careful and open assessment and discussion of various options amid a rapidly evolving energy marketplace. The electricity and steam loads of the University campus and medical center are being met adequately on a day-to-day basis and there are backup systems in place to serve critical loads in case of an emergency grid outage. However, over the course of a number of meetings with NC WARN and in communications to the public, University officials have identified two primary goals they hope to achieve as they seek to upgrade the existing energy system:

1. Ensuring that the campus and, most significantly, the medical center and other uses deemed "critical loads" have access to reliable backup power in the event of a grid outage or other emergency situation and
2. Reducing greenhouse gas emissions in order to make progress toward Duke University's goal, set forth in its 2009 Climate Action Plan (CAP), of becoming carbon neutral by 2024.

A Power Industry Scheme to Move onto Campuses

In August NC WARN discovered that the US electric power industry is exploring the construction and operation of gas-fired combined heat and power (CHP) plants on college and university campuses as a previously untapped revenue source as they saturate their existing markets with new utility-scale natural gas-fired power plants.[1]

Colleges and universities have generally been bastions of energy independence in the US, owning and operating their own heat or power generation systems. Duke Energy hopes to begin an era of college and university dependence with the Duke University project. The University is being sought as a willing partner in this shift from campus energy independence to utility dependence.

Concerns arise that utilities might seek to leverage university investments in the power industry, for example, Duke University's status as a major institutional investor, with about $70 million of Duke Endowment assets invested in Duke Energy Corporation.[2] If it completes this groundbreaking and controversial project, Duke University would effectively be serving as a business development agent for Duke Energy by offering its campus as a national "proof of concept" for this new revenue generation scheme being pursued by the electric power industry.

Reliability Not Enhanced by Gas-CHP

Duke University officials have emphasized that they are seeking "the best way to ensure that Duke has reliable backup power to serve the University hospitals and research labs in the event of a power outage," and the need for "an immediate and uninterruptible source of backup power in the event of a massive disruption." However, the CHP plant Duke Energy has proposed to build on campus, with a single 21 megawatt (MW) turbine fired by natural gas, would not be the reliable source of backup power the University is looking for.

Inherent challenges

The University's energy system is complex. Duke University operates five substations that connect to one another in a loop across the campus. The University's transmission loop connects to Duke Energy's distribution grid at a single substation.[3]

University officials indicate that if Duke Energy's closest substation goes down in an outage, the campus also loses power. At the first meeting between NC WARN and the University, officials indicated that grid power has been lost, thus requiring use of the emergency diesel generators (EDGs), on very few occasions in the last few decades.

A key benefit cited by proponents of the gas-CHP plant is that it would serve campus and medical center power needs by operating in "island mode" in the event of a grid outage, i.e., with the campus separated from Duke Energy customers in areas surrounding the campus. Construction of the gas-CHP plant would be accompanied by a new transmission line connecting the plant to one of the five substations on the Duke University campus.[4] Reportedly, Duke University will pay up to $7 million to connect the gas-fired CHP plant to its distribution system, plus an unidentified amount to be able to "island" the campus.[5]

University officials indicate that the peak electricity load of the campus is up to 80 MW. In the event of a grid outage during times of peak demand, even with the presence of the 21 MW CHP plant, there would still be a need to immediately shed about 75% of the total campus load. Duke University officials have explained that, in the event of a loss of grid power, the CHP plant would immediately shut down if it is online at the time of the outage. The campus would lose all electric power with the exception of critical campus loads that are supported by the existing EDGs. The gas-CHP plant would then be brought back online manually to serve loads not handled by the emergency backup system. In a short-duration loss of power, the gas-CHP plant may play no role at all. In a longer-duration loss of power, it could serve some of the campus load such as dormitories and research labs not already being served by the backup generators.

The existing EDG system automatically comes online when grid voltage drops below a preset level, signaling an outage. The EDG system shuts down when the grid voltage returns to the preset "normal" level. Grid power does not operate concurrently with the backup emergency power provided by the EDGs.

According to Duke University officials, the University has 13 MW of EDG capacity. The CHP plant would produce 21 MW of power. Assuming all 13 MW of EDGs are operating in an outage, unless the architecture of the current EDG control system is modified, as the CHP plant ramps up (with the Duke University internal distribution grid isolated from the external Duke Energy grid) and reaches 13 MW, the EDGs would shut down and the CHP

NC WARN Position on Combined Heat and Power

NC WARN has been a longtime advocate for implementing more combined heat and power (CHP) into North Carolina's energy mix as a key efficiency resource. For many years, we have sought to educate the general public about CHP technologies through published reports, and we have repeatedly urged the NC Utilities Commission to require open discussion and debate over CHP, and to require that CHP be incorporated into the long-term planning of North Carolina utilities. Both the Commission and Duke Energy refused to openly consider implementation of CHP until 2016, even as newer technologies have somewhat decreased the overall viability and benefits of CHP in the marketplace.

NC WARN still supports CHP as an energy efficiency addition to some existing, distributed gas-fired power generators. However, the evolution of the energy industry in recent years has provided more distributed energy options that are economically feasible and must be taken into consideration ahead of making commitments to increased reliance on natural gas.

Most importantly, the gas-fired CHP plant proposed for the Duke University campus does not represent the kind of implementation of CHP that NC WARN has ever promoted. Instead of being an energy efficiency measure that captures and uses waste heat from existing natural gas generation facilities, the Duke University gas-fired CHP plant would contribute to an increased burning of natural gas on campus and serve as an excuse for Duke Energy to build yet another unneeded power plant. Therefore, NC WARN cannot support this particular CHP initiative.

plant would carry the critical loads previously carried by the EDGs. The CHP plant could continue to ramp up to 21 MW, and add another 8 MW of priority loads beyond the 13 MW previously carried by the EDG system.

With this sequence, Duke University would gain 8 MW of additional internal generating capacity during an extended outage, or about one-tenth of its peak load of 80 MW. However, in the case of reliance on the CHP plant, the critical loads would then be dependent on a single-turbine power plant with a modest projected availability of as low as 85% on an interruptible natural gas fuel supply that is more likely to be interrupted when Duke University needs it most – during weather events such as hurricanes or polar vortexes. If the CHP plant fails because of any of the inherent weaknesses that limit its reliability, the campus is back where it started – in the dark except for critical loads being carried by the existing backup EDGs.

Likely plant outages

The typical 21 MW natural gas-fired CHP plant, similar to the facility proposed for Duke University, operates at an availability of about 93.5%, although University officials and Duke Energy indicate the campus plant operation could be as low as 85% of the hours in a year. This means the CHP plant could experience planned and unplanned outages averaging one day per week. In addition, its fuel source may be interrupted for several reasons including lack of supply, a spike in the price of natural gas and high demand elsewhere, as explained more below.

Other college campuses that once relied on gas-CHP plants, such as Stanford University, are already moving past this technology. Stanford has cited mechanical complications and a lack of adequate reliability benefits as reasons for closing its gas-fired CHP plant in favor of an electricity-powered combined heating and cooling plant, plus considerable investments in on- and off-campus solar installations. Stanford officials state that the University's gas-fired CHP plant experienced unscheduled outages one to three times per year for several hours at a time. [6]

Interruption of natural gas supply

The potential for gas supply interruption to the proposed gas-CHP plant further calls into question whether the project would actually enhance reliability for the medical and research facilities. The plant would be operated by Duke Energy and would burn natural gas exclusively. The power would be produced to serve the greater electricity grid, including off-campus demand, similar to any other natural gas plant in Duke Energy's fleet.

The gas-fired CHP plant would likely be fueled by interruptible gas. Natural gas-burning power plants operated by the electric utilities typically have an interruptible supply clause in the contract with the gas supplier, in return for lower prices, and are therefore subject to curtailments in the event of a supply shortage or high demand. As an interruptible gas customer, Duke Energy's CHP plant – and therefore Duke University – would need to be prepared for the plant to shut down when regional gas supplies are tight, thus the plant might not be available in the case of an emergency. If Duke Energy were to choose to operate the plant on an uninterruptible gas supply, it would result in premium fuel rates that would make the plant less economical to operate for Duke Energy and its retail customers.

Duke officials admit they have no control over whether the CHP plant would have an uninterruptible gas supply; they say that would be up to Duke Energy. Data from Duke Energy indicate that interruptible gas customers can expect interruptions a few times a year due to supply issues, not including equipment failures or security challenges.[7]

Diesel backup required by state rules

The implication that the CHP plant would be used as the preferred source of backup power to the 13 MW of diesel generators that already exist on campus during a grid power outage is contrary to the North Carolina administrative code that requires hospital emergency power systems to have an on-site, dedicated fuel source.

As a selling point for the gas-fired CHP project, University officials have stated that existing emergency diesel generators are inconvenient to maintain. That may be true, but constructing a CHP plant will not help because the EDGs must remain as the primary backup in case of an emergency.

Even if the University believes that Duke Energy's gas-fired CHP plant could serve as a reliable source of backup power, North Carolina code does not allow it to replace the existing emergency diesel generators as the sole backup power source for the University Hospital. North Carolina code states, *"An emergency power generating set, including the prime mover and generator, shall be located on the premises and shall be reserved exclusively for supplying the essential electrical system."*

In addition, the code states, *"Sufficient fuel shall be stored for the operation of the emergency power generator for a period not less than 72 hours, on a 24-hour per day operational basis with on-site fuel storage."*[8] In other words, backup power sources for hospitals must be located on the hospital premises and fuel for the backup power source must be stored on site. The proposed gas-CHP plant meets neither of these standards.

There is no available information that suggests that the University needs a secondary backup power source, a "backup to the backup." The EDGs have been used only on rare occasions to address grid power outages. University officials have cited no instance where the generators failed when called upon during an outage. However, if the University is interested in reinforcing its backup power capability, there are better options to consider such as: additional emergency diesel generators, reconfiguration of existing diesel generators in relation to each other and the facilities they serve, a solar-powered battery storage system or a stand-alone battery storage system powered by the grid. Creative solutions are being evaluated on other campuses around the nation. For example, Stanford University is investigating the augmentation of its emergency diesel generators with battery storage.[9]

The gas-fired CHP plant could potentially serve as backup for other campus needs in "island mode," such as dorms and administrative facilities. However, that is not the reason for the new plant as stated by the University. Using the CHP plant to provide power only for Duke University in an outage, when neighboring Duke Energy customers are without power, raises basic issues of fairness, considering that the entire Duke Energy customer base will pay for the plant.

Gas-CHP Would be Far More Polluting than Current Backup

University officials have several times reflected a misunderstanding of the project by writing and stating that, compared to the gas-fired CHP plant, the existing emergency backup diesel generators are "the least desirable approach for the environment." We appreciate that they later acknowledged to us that the statement was incorrect, as EDGs that typically run only a few hours of the year cannot possibly compare from an air emissions standpoint with a fracked gas-powered CHP plant on campus that runs at least 85% of the time.

In the past, the University participated in Duke Energy's Power Share program, which allowed the utility to operate a number of the campus EDGs during times of peak usage across the Duke Energy system, in return for a fee. We were pleased to learn that the University has not participated in the program for the past three years and does not plan to participate in the future, as operating the EDGs creates a significant local air quality impact.

Duke Energy Would Not Use Best Technology to Control Air Emissions

Duke Energy indicates the gas-CHP plant would not be subject to Best Available Control Technology requirements for air pollution emissions, and proposes that the CHP plant turbine would achieve a nitrogen oxide (NO_x) limit of 25 parts per million (ppm) at or near full load and 150 ppm when the unit is operating below 75% of full load.[10]

NOx is a lung irritant and precursor to the formation of ground-level ozone. The proposed turbine, known by its model name as a "Titan" turbine, is manufactured by Solar Turbines, Inc. of San Diego. In contrast to the high NOx emission levels proposed for the Duke University CHP plant, the CHP plant at Cornell University, which has operated with Titan turbines since 2009, has a NOx limit of 2.5 ppm across its entire useful load range.[11] The NOx emissions from the Duke University CHP plant will be at least ten times greater, on a per kilowatt-hour basis, than those from the Cornell CHP plant that uses the same type of turbine.

Duke Energy is aware, given that the Titan turbine manufacturer has operating installations with very low NOx emissions like the Cornell CHP plant, that far lower NOx emission levels than proposed for the Duke University CHP plant have been achieved in practice. Duke Energy is apparently choosing to minimize cost by failing to add proven and readily available air emission control systems to the Duke University CHP plant. The losers in this case would be Duke University staff and students, who would be exposed to far higher emissions of NOx than they would be if Duke Energy added what, under normal circumstances, would be a standard emission control system for the turbine.

Greenhouse Gas Emissions Would Increase 61% with the Gas-CHP Plant

Proponents of the proposed gas-fired CHP facility claim it would reduce the campus's overall consumption of natural gas and, as a result would cut carbon emissions by 25%.[12] This characterization only takes into account natural gas burned directly by the University, as if the added emissions should be ignored simply because Duke Energy would be burning the gas for the campus.

There are currently two natural gas-fired boiler plants operated by the University that provide steam for space heating and hot water needs across campus and at the medical center. If the gas-fired CHP plant were constructed, the two existing steam plants would be used less, and the University would purchase steam produced from waste heat at the gas-fired CHP plant to meet some of its needs. While Duke University would be buying less natural gas to meet its steam needs, it would also be allowing Duke Energy to burn much more natural gas on campus to produce 21 MW of grid power and the associated steam.

It is irrational to claim that Duke Energy burning gas on University property – primarily for the University – should somehow allow the University to claim it is cutting emissions. NC WARN's technical analysis shows that the amount of natural gas burned on Duke University's campus would actually increase by 61% over current practice if the proposed CHP plant is constructed and operated as planned.[13]

The increase in the total amount of natural gas burned on campus is critical. It means that greenhouse gas emissions emitted on campus would also increase by 61% if the CHP plant is built. In addition to increased CO_2 emissions from fuel burned on campus, the campus would also be responsible for methane leakage and venting occurring from fracking wells that supply natural gas in growing quantities to customers in North Carolina. Recent research shows such methane emissions could be 12% or more of all gas produced at the wellhead, with most of it occurring near the point of production.[14] Climate scientists indicate that methane emissions must be below 3.2% in order for natural gas to provide any climate benefit over burning coal for electricity.[15] A 2013 report from the Intergovernmental Panel on Climate Change stated that methane in the atmosphere is 100 times more effective at trapping heat than carbon dioxide over a 10-year period, and 86 times more effective over 20 years.[16]

Methane is unintentionally leaked and deliberately vented constantly and in dangerous quantities during the drilling, storage, transportation and burning of natural gas, with the highest rates coming from shale wells. The gas industry and Duke Energy ignore methane emissions from the wellhead to the power plant and do not count these emissions toward the climate impacts of natural gas when compared to the CO_2 emissions from coal. The US EPA has improperly gone along with this omission to date. As a result, the greenhouse gas implications of burning natural gas for electricity have been substantially underestimated.

Duke University's Dr. Drew Shindell, a prominent climate scientist, has concluded that reductions in methane emissions will slow global warming more quickly than reductions in carbon dioxide. Dr. Robert Howarth of Cornell University agrees: *"The climate system responds very quickly to changes in methane emissions; reducing methane emissions now will significantly slow the rate of global warming over the coming decades."*[17] Howarth also states that *"Natural gas systems are the single largest source of anthropogenic methane emissions in the United States."*[18] As he emphasized when he spoke at a forum on the Duke campus in March, curbing methane is the only way to avoid irreversible harm to the climate.[19]

The gas-fired CHP plant would be worse for the climate than Duke Energy's grid power

Duke University officials say that having a natural gas-fired CHP plant on campus would be better for the climate than purchasing electricity from Duke Energy's broader system, which includes coal-fired power plants. In fact, NC WARN's analysis shows that the electricity produced on campus by the gas-CHP facility would have a higher greenhouse gas profile than power purchased from the Duke Energy grid.

Technically, the University will continue to buy all of its electricity from Duke Energy regardless of whether or not the proposed gas-fired CHP plant is constructed. The plant would be owned and operated by Duke Energy and supply the utility's electric grid. However, if Duke University plans to claim that the electricity from the gas-fired CHP plant is going to be predominantly used to power its campus, the University would be better off continuing to buy its electricity from the Duke Energy grid and not authorize construction of the CHP plant.

A kilowatt-hour (kWh) of energy from the Duke Energy Carolinas system is currently produced by a combination of resources that includes nuclear power (61%), coal (27%), natural gas (11%) and small amounts of hydro power and renewable energy, although Duke Energy plans to increase the percentage of natural gas it burns.[20] By contrast, a kWh of energy produced by the proposed CHP plant would be 100% natural gas power. The relatively low percentage of natural gas in Duke Energy Carolina's power mix lessens the greenhouse gas impact from methane leakage and venting associated with natural gas production on the overall Duke Energy Carolinas grid. With methane leakage impacts included, the greenhouse gas impact of a kWh of energy produced by the proposed gas-fired CHP plant would be about 7% higher than a kWh of energy from Duke Energy Carolinas' system in a low methane emissions scenario, 39% higher in a mid-range methane emissions scenario, and 112% higher in a high methane emissions scenario.[21]

The plant would burn fracked gas

University officials say their intention is to avoid burning shale gas, but they understand the point-of-origin issue is not transparent and acknowledge that they would have no control over where the gas comes from. The US Energy Information Administration (EIA) reported in May 2016 that two-thirds of all natural gas burned in the US in 2015 was from fracked wells, a percentage that continues to increase rapidly nationwide.[22]

Duke Energy has downplayed its use of shale gas – as in the ongoing fight over its Asheville natural gas-fired power plant project – but its primary source is the Transco pipeline from the Gulf region. Last June, two persistent reporters for the *Mountain Xpress* in Asheville interviewed an official with the Oklahoma-based Williams Company, which owns and operates the Transco pipeline. The gas comes from various sources, including offshore drilling platforms in the Gulf of Mexico. As the *Mountain Xpress* reported, ***"the vast majority is produced through hydraulic fracturing."***[23]

In addition, Duke Energy is half-owner of the proposed Atlantic Coast Pipeline. This pipeline, if built, would bring shale gas from fracking wells in Pennsylvania and West Virginia, primarily for use in power plants in Virginia and North Carolina.

Above all, natural gas is a fungible commodity. For this reason it is impossible to separate shale gas from conventional gas in the marketplace. Because nearly all new US gas developments are in shale fields, all use of gas drives the highly destructive fracking industry. The only option open to University officials committed to avoiding fracked gas burning in the proposed CHP plant is to not allow the project to proceed.

Duke Energy's business model is to build plants, not use excess regional supply

It is not reasonable to expect that construction of a new 21 MW CHP plant would help to reduce emissions or environmental impact elsewhere on Duke Energy's system. Duke Energy's business model depends on construction of new power plants and related infrastructure like transmission lines to raise customer rates and make a considerable profit – a guaranteed 10.5% return on capital investments due to its monopoly status.

The utility pushes for construction of these new plants even when electricity demand does not require it and regardless of the fact that large amounts of excess power are available across the region for years to come, according to industry projections.[24] Increased demand, if it develops, could be purchased from neighboring utilities and existing merchant plants. Such regional sharing of resources has been encouraged, but not formally required, by the Federal Energy Regulatory Commission (FERC). To date Duke Energy and other southeastern utilities have declined to participate, electing to keep building power plants.[25]

Duke Energy itself sits on a glut of supply resources and continues to build more plants.

Duke Energy Carolinas currently operates a 19% reserve margin – meaning it has 19% more supply than needed to serve the demand of its customers even during peak usage. Over the next 15 years, Duke Energy Carolinas projects its reserve margin will reach as high as 25%.[26] The FERC-mandated minimum reserve margin is 7% and the North American Electric Reliability Corporation target reserve margin is 15%.[27]

Over the next 15 years, Duke Energy Carolinas plans to build over 2300 MW of natural gas plants while closing 585 MW of barely-used coal-fired units by 2024 and another 542 MW by 2028.[28] So the Duke University gas-fired CHP plant would not displace natural gas or coal power plants elsewhere; it would be built on top of Duke Energy's existing resources and contribute to an even greater overall excess of capacity throughout the Southeast region.

The gas-fired CHP plant was not proposed by Duke Energy for the benefit of the University; it was proposed because it would bring in more profits for the utility. As noted earlier, NC WARN discovered that this is a tactic that monopoly utilities across the country are pursuing in order to justify building new power plants and raising customer rates – despite the fact that distributed resources are advancing, national demand for electricity is down and there is a large excess of generating-capacity supply across most regions.[29] It is unfortunate that Duke Energy is trying to make Duke University the guinea pig for its new money-making initiative.

Biogas from Hog Farms is Not a Viable Option

University officials hope that, should a natural gas-fired CHP plant be built on campus, it might someday be converted to burn biogas as a more sustainable option. However, technical, economic and social justice challenges for that process have not been resolved – even after more than a decade of effort. Biogas, the use of animal and landfill waste to generate methane for fuel, has remained an elusive and highly speculative source of electricity for at least 15 years.

According to a 2013 Duke University study, biogas could possibly be produced at a cost of 6 to 11 cents per kWh if and when longstanding technical barriers are resolved: *"Because the analysis contemplates electricity generation but not business costs (e.g., profits that would motivate investment in development of new systems, payments to swine producers to secure long-term biogas production, or other incentives), it does not represent retail or final costs. Rather, the analysis reflects the costs that researchers estimate would be incurred to supply the market."*[30] The gas generated by animal waste is a combination of various chemicals, and requires energy-intensive processing before use.

Factory farms are highly controversial, with multiple negative impacts on air and water quality in many communities across eastern North Carolina.[31] In 2007, NC Senate Bill 3 established set-asides in the State's renewable energy portfolio standard (REPS) for electricity generated by swine and poultry wastes.[32] Year after year, the utilities have come to the NC Utilities Commission and requested to modify and delay the requirements due to failure of technology advances.[33]

In an August 11, 2016, filing, the utilities reiterated their arguments from past years and stated that *"procurement efforts with respect to swine and poultry waste-to-energy resources have been challenging from the outset, due to the small numbers of existing market participants in the United States and the fact that few, if any, of those market participants have direct experience developing or operating those biomass technologies."*[34] We also emphasize that the biogas technologies being pursued would do very little to reduce the air and water pollution that have plagued communities near hog farms for so long.

Only a few small pilot facilities are presently being considered in North Carolina, and every year the forecast for viable commercial facilities is set back another year. It is clear that the University should not be hedging its bets on biogas due to the contentious nature and lack of current viability of this fuel.

A Better Path for Duke University and Neighbors

Duke University and everyone impacted by its energy choices would benefit from a proactive, open evaluation process. The University should collaborate with students, faculty, staff and the Durham community to implement a methodology for reviewing potential projects based on a priority list of preferred resources that can be deployed ahead of fossil fuels to match the University's desire to become sustainable based on economically superior technologies. NC WARN has developed some recommendations for incremental steps the University could take. However, we believe there are many voices that need to be heard in order to determine the best path for the University to pursue.

Energy efficiency

Duke University has demonstrated an admirable commitment to energy efficiency. The University's 2009 Climate Action Plan (CAP) set a goal of reducing energy consumption 15% in existing buildings by 2030, which has already been reached.[35] We encourage the University to set new, aggressive benchmarks that build on its success. Duke University goals and accomplishments should at least match those of neighboring universities. The University of North Carolina at Chapel Hill has reduced energy consumption 29% per square foot since 2003.[36] North Carolina State University has reduced energy consumption 28% per square foot since 2002.[37]

We recommend that Duke University reduce energy consumption by 30% per square foot from early 2000s levels by 2024. Since its existing CAP energy efficiency goal only addressed existing buildings, a priority as the campus grows should be to ensure that all new buildings are as efficient as possible. Therefore, the University should set a goal for all new buildings on campus to be LEED certified and/or zero net energy users. The

University of California Davis' West Village complex serves as a good model for implementing zero net energy buildings on campus.[38]

Solar photovoltaic assessment

Our analysis indicates that the University has a large amount of feasible solar photovoltaic (PV) potential, that PV pricing is lower than the level that the University indicated would make economic sense and that solar power costs are lower than what the University is paying Duke Energy for electricity. Thus, we recommend the University conduct a comprehensive technical and economic assessment to optimize the build-out of solar projects on campus with particular focus on rooftops and parking facilities.

The solar PV industry has experienced a tremendous boom in recent years in North Carolina and nationwide. Although recent policy challenges within the state have posed new challenges for local solar companies, solar still has become more accessible and economic than ever. NC WARN's research of the current market in North Carolina has shown that solar PV installations similar in scale to what would be appropriate for the Duke University campus are being installed in North Carolina at a cost of $1.75 to $2.00 per watt for rooftop installations and $2.50 to $3.00 per watt for installations on parking lots.[39] With no fuel costs and little maintenance, solar power is an investment that pays for itself and becomes more valuable as the price of grid power increases year after year.

Conditions and pricing vary at different sites, but actual installations at several similar institutions indicate that solar PV should be a substantial part of Duke University's energy mix. Clearly, the most economically feasible sites on or off campus should be developed first, and others added as the price of solar continues to drop.

Duke University is a nonprofit institution with a substantial endowment valued at $3.35 billion.[40] As a tax-exempt institution, Duke University has multiple options for financing a major solar construction program to support its power needs.[41] It could opt to finance solar projects on a "pay as you go" cash basis to eliminate finance charges that would otherwise increase the cost of solar PV. For example, if the University were to invest $12 million per year of its assets in solar projects, sufficient to add 6 MW of rooftop or parking capacity per year, the estimated levelized cost of this solar energy would be approximately 4.5 to 5 cents per kWh.[42]

The University can also opt to finance the solar with tax exempt bonds.[43] Assuming use of this financing approach, the levelized cost over 30 years would be in the range of 7 cents per kWh for rooftop solar.[44] The University could also opt to blend the two financing approaches, paying cash for a portion of the solar buildout and financing the rest with low-interest, tax exempt bonds.

There is clearly a pathway available today to install solar PV at Duke University at a large scale for significantly less than the price that University officials have identified as economic, and even less than the 6.5 cents per kilowatt-hour the University is now paying Duke Energy.

The Duke University campus has a great deal of space suitable for solar PV. A rough analysis of the campus by NC WARN suggests there may be as much as 20 MW of solar PV potential on rooftops, parking decks and surface parking lots. Additional solar PV investments would be similarly beneficial on Duke University's many off-campus medical facilities and other properties located across the Triangle. However, at this time the University lacks a comprehensive assessment of what the true solar PV potential of its property might be.

Because of Duke University's particular internal transmission system, solar PV power generated on University buildings and parking facilities can be used in those or adjacent facilities, thus avoiding having to deal with net metering or avoided cost issues with Duke Energy.

An added benefit of solar PV is that most of the energy is produced during times of peak demand. Solar used by the campus would reduce both the University's demand charge (a Duke Energy fee that increases at times of high usage) and demand on the Duke Energy grid. This would financially benefit the University while easing the strain on Duke Energy's system at times of peak demand.

NC WARN recommends that the University utilize its research capabilities through the Nicholas School for the Environment and the Pratt School of Engineering to do a full technical assessment of potential solar PV projects throughout the campus and an assessment of the economic feasibility of potential projects.

Such a PV potential study was performed by students for the University of North Carolina at Chapel Hill in 2010.[45] While UNC's study only evaluated potential for rooftop installations, Duke University's study should evaluate the potential for all types of solar PV projects, including rooftop, surface parking lots, parking decks, large-scale ground mounted installations on campus and investments in remote solar installations off campus in the surrounding community.

Once it has conducted a solar potential study, the University can work with members of the faculty, staff and student body to set a total installation target and annual benchmarks. It is worth noting that, in the 2009 CAP, the University set a goal to install 4 MW of solar PV by 2012.[46] The University has yet to install any solar PV on campus. Therefore, NC WARN recommends that Duke University immediately develop a concrete plan of action to meet the 4 MW benchmark, then add more solar capacity each year.

The potential for economically reducing the University's overall energy usage – and reducing carbon emissions – needs to be quantified. But it seems clear that solar PV power should be a key part of the University's present and future energy path.

NC WARN is committed to continue assisting the University in identifying and advancing solar opportunities and resources.

Solar thermal assessment

University officials have stated that they are interested in examining the potential to switch on-campus buildings that currently rely on steam produced by natural gas to on-site solar thermal systems. Such a transition could greatly reduce the University's natural gas-fired steam load. This option should be fully evaluated before authorizing a large gas-CHP plant that is intended to be a new source of steam. A critical first step is a formal analysis of campus buildings to determine which are good candidates for solar thermal systems and what impact switching these buildings to solar thermal would have on the University's natural gas requirements.

Cutting edge energy technology

As renewable energy and storage technologies continue to evolve, university campuses are in a prime position to implement innovative projects to serve as a model for students, the broader community and industry. Advanced technologies to consider include solar chillers, solar-plus-battery storage systems and stand-alone battery storage systems. In particular, implementing battery storage as a form of cleaner, more reliable backup power would be an ideal consideration for a campus like Duke University. These types of systems would accommodate some of the campus's energy requirements and simultaneously serve as a learning tool for students in environmental and engineering programs. As an example, the University of California San Diego has been a leader in experimenting with innovative technologies, having recently installed a 2.5 MW battery storage system on campus.[47]

Long-Term Strategy in Dynamic Times

The energy industry is in the midst of a major transition in the United States and across the globe. Distributed renewable energy technologies have evolved and dropped dramatically in cost, making them economically superior to centralized power plants and fossil fuels when all costs and subsidies are considered. This shift will continue as battery storage is further refined. By allowing Duke Energy to construct a large fossil fuel power plant on campus, Duke University would be taking an approach that inhibits its ability to adopt currently available and emerging energy supply options, and which would undermine the University's carbon neutral goal. The University acknowledged as much in its 2009 CAP.[48]

We were glad to hear that University officials are determined to invest in clean solutions over time, and that they fully intend to retain an option to demolish the gas-fired CHP plant – if it is built – well before the end of its expected 35-year life. However, Duke Energy would own the plant and is not likely to give that option to the University. Even assuming the University bargains hard and successfully to include that option in a contract with Duke Energy, it is unlikely to gain approval by the Utilities Commission. Even if closing the plant early were going to happen, how fair would it be to Duke Energy customers to pay for a fracked gas plant only to have it dismantled when it fulfills the needs of the University? In all likelihood, if Duke Energy obtains a lease from Duke University for the CHP plant site for 35 years, it will attempt to operate the plant for at least 35 years.

Duke University has already seen the start of the controversy surrounding this proposal. Students, faculty and members of the community have voiced concerns to University officials and the media regarding the impact the project would have on the climate crisis and the lack of transparency that has taken place in the initial planning phases. The controversy is likely to increase should the project move forward. While concerns over climate continue to grow, other issues are sure to arise with a proposal this complex. Although the plant has been promoted as meeting the electricity and steam needs of the University, Duke Energy would be charging the $55 million in construction costs, plus a large and guaranteed rate of return to its customers.[49] North Carolina communities would bear the cost of this new power plant that would serve the needs of a private university. This is likely to be a contentious issue.

To be in the best position to prioritize its own needs and goals, Duke University should deploy energy solutions that it can own as an investment and operate at its discretion. The gas-fired CHP plant would be entirely under Duke Energy's control – leaving the corporate utility to make all major decisions about how frequently the plant runs and how far into the future it operates. The clear influence Duke Energy would have on energy operations on campus is likely to spur public discussion about corporate influence over the University.

A Measured Approach to Energy Decisions

Duke University officials have expressed a desire to find a "silver bullet" to achieving the campus's sustainability and reliability goals. Realistically, there is no single, turnkey solution for achieving all of the University's goals. It is our understanding that the University's current energy system is fully functional and reliable.

Duke University is at an ideal crossroads; with its electricity and steam needs currently being met by existing resources without notable issues, there is no operational need for the University to commit to a large, controversial project that would limit its options and squander its chance to help slow climate change.

Instead, the University should take a measured approach – analyzing how to meet its needs in a way that is both reliable and sustainable with the help of the University and the community, rather than relying on Duke Energy's assessment of campus needs. The steps to meet those goals now and in the future should be based on a full evaluation of resources currently available and those that will become available as technology inevitably progresses. Such a measured approach will give Duke University a chance to join Stanford and other universities as leaders in modelling sustainability and innovation.

The regulatory review process of the proposed plant's application (called a Certificate of Public Convenience and Necessity) at the NC Utilities Commission is not the transparent and constructive forum the people of the University and its neighboring communities need and deserve.

Conclusion

The implementation by the University of a preferred resource list for its campus energy system would presumably relegate the use of fossil fuels on campus to a last resort. Duke University is lacking crucial analysis that must be performed before settling for increased and continued burning of natural gas on campus that would result in detrimental impacts to the climate and the community at a critical time.

Duke University invests many millions of dollars each year to enhance its campus. The University is considering an investment of more than $7 million to bring a fracked gas-burning power plant to the campus that might only run for several years.

Now is the time for the University to join the clean energy revolution by aggressively developing solar PV, solar thermal and battery storage – which are already viable and economically superior technologies. Consideration of a new gas-fired CHP plant on campus should be shelved until proven alternatives have been fully and openly explored.

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[17] Dr. Robert W. Howarth, Cornell University, "Methane emissions: The greenhouse gas footprint of natural gas," September 2016: http://www.eeb.cornell.edu/howarth/summaries_CH4_2016.php
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Attachment A

Case Study: Stanford Energy Systems Innovation (SESI)[i]

Stanford University has a campus profile similar to that of Duke University. The latter has a campus of about 8,500 acres, 36,000 employees and 15,000 students. Stanford has an 8,180-acre campus, 20,500 employees and 16,000 students. Both campuses are host to massive research and medical facilities and major hospitals.

Stanford was host to a 50 MW natural gas-fired combined heat and power (CHP) plant from 1987 to 2015. The CHP plant was operated and maintained by a third-party company on Stanford property in a similar arrangement to the proposed Duke University-Duke Energy CHP plant. Before the existing contract for the CHP operation was set to expire in 2015, Stanford staff began doing intensive research about what options were available to move the campus beyond the CHP plant toward a more sustainable path. The result was a decision to close down the CHP plant and make a massive transition to an electricity-powered combined heat and cooling plant that began operating in early 2015.

The transition has been a huge success. Among the benefits the University has experienced are:

- *Increased reliability:* Stanford staff has said that, due to the complex and high-heat operations of their CHP plant, there were notable issues with reliability. The plant encountered unplanned outages one to three times per year for several hours at a time. By contrast, Stanford staff says their new system has had no outages since it was put online 18 months ago.
- *Increased efficiency and sustainability:* Stanford officials say that the new combined heat and cooling facility is 50% more efficient than its natural gas-fired CHP predecessor. Natural gas imports to the University have been reduced by 95% since the CHP plant was shut down. The campus has continued to purchase grid power from the local utility to meets its electricity needs, but has built on the momentum of its newfound efficiency by making large, incremental investments in renewable energy projects to lower its energy needs even further.
- *Reduced operating struggles:* Stanford has been able to take advantage of the fact that its new electric system is less complex and dangerous than a natural gas-fired turbine. Stanford is able to operate the combined heat and cooling plant itself with just two of its staff Instead of requiring a third party to operate a CHP plant at the added cost to the University that goes toward the company's profits.

Stanford's new energy system did require an investment of $400 million – mostly in order to convert their existing campus steam system to hot water. However, the transition from steam to hot water has contributed to greater efficiency and given the University the opportunity to preemptively upgrade steam infrastructure that was quickly becoming outdated. The process took about two and a half years and caused minimal disruption to campus-wide operations. Most importantly, Stanford officials firmly believe the expense, time and effort have been entirely worthwhile to achieve the efficiency, sustainability and stability that are now in place for decades to come.

Stanford University officials are confident that the transition implemented on campus in 2015 is transferrable to other campuses across the country. And they are encouraging other schools to consider following their approach by offering their expertise, and making the computer tools and data that they utilized to map their transition openly available. NC WARN encourages Duke University to consider Stanford's approach and not settle for adopting a new CHP system that other universities are already abandoning as obsolete without full analysis of potential alternatives. Stanford saw a crossroads in the school's energy future, researched all the available paths and made a decision to be forward-thinking. If other universities have an honest desire to become more sustainable and innovative, they can – as long as they are willing to put in the effort.

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[i] Information about SESI was acquired from discussions with Stanford University Department of Sustainability and Energy Management. More information about SESI can be found at: http://sustainable.stanford.edu/sites/default/files/documents/Stanford_SESI_General_Information_Brochure.pdf

Attachment B

Technical Analysis: Emissions on Duke University Campus

Prepared by Bill Powers, Powers Engineering

Duke University CHP Plant: Increases Duke University Natural Gas Consumption

Case 1: Business-As-Usual (BAU), No CHP Plant:			
A. Avg. natural gas consumption for steam production:	1,600,000	MMBtu[i]	
B. Heat content of steam:			
1. Enthalpy of 60 of water =	28	Btu/lb[ii]	
2. Enthalpy of 150 psi saturated steam =	1,111	Btu/lb[iii]	
3. Heat addition per lb of steam =	1,083	Btu/lb	
C. Boiler efficiency, Miura LX-300 SG [newest Duke U. steam boiler type]:			
1. Boiler efficiency =	85%[iv]		
D. Avg. annual Duke U natural gas consumption for steam production:	**183**	**MMBtu/hr**	
E. Avg. annual Duke U steam production rate:	143,353	lb/hr steam	
Case II: CHP Plant 21.7 MW, 77,600 lb/hr Steam Production:			
A. Turbine is assumed to be Solar Titan 250, 21.7 MW, with no supplemental firing and steam production of 77,600 lb/hr			
1a. Heat input of unfired Titan 250, low heating value (LHV), 939 Btu/cubic foot[v] =	190.8	MMBtu/hr	
1b. Heat input of unfired Titan 250, high heating value (HHV), 1,035 Btu/cubic foot[vi] =	210	MMBtu/hr	
2. Steam production of unfired Titan 250 =	77,600	lb/hr	
B. Residual heat input needed to meet Duke U average steam load:			
1. Ave hr steam load - CHP steam output =	65,753	lb/hr	
C. Natural gas requirement of residual steam need:			
1. (residual steam production x heat addition per lb steam) ÷ boiler efficiency =	84	MMBtu/hr	
D. Total natural gas heat input, 21.7 MW CHP + residual steam production:	**294**	**MMBtu/hr**	
Increase in On-Campus Natural Gas Usage with CHP:	natural gas consumption		increase (%)
Case I: Business-As-Usual (no CHP)	183	MMBtu/hr	**0**
Case II: 21.7 MW CHP	294	MMBtu/hr	**61**

[i] Duke University staff, Sept. 8, 2016 meeting with NC WARN
[ii] Thermodynamic tables
[iii] Thermodynamic tables & Miura LX-300 SG O&M manual, March 2000 (150 psi operating pressure)
[iv] Miura LX-300 SG O&M manual, March 2000
[v] Titan 250 high heating value (HHV), assume HHV
[vi] Solar Turbines, Inc. assumes LHV

Carbon Dioxide and Methane Emission Rate

Duke Energy Carolinas 2015 grid power mix versus proposed Duke University CHP plant

I. 2015 Duke Energy Carolinas Power Mix, GHG Emission Rate with Methane Leakage Associated with Natural Gas Combustion

source	fraction	GHG EF, lb/MWh	Case 1: methane leak rate = 1.8% gas usage	Case 2: methane leak rate = 4.2% gas usage	Case 3: methane leak rate = 12.0% gas usage
nuclear	0.61	0	0	0	0
coal	0.27	2,070[i]	559	559	559
natural gas	0.11	999[ii]	110	110	110
methane		24975	49	115	330
Total GHG emissions, 2015 DEC grid power, lb/MWh:			**718**	**784**	**998**

II. Duke University CHP Plant, GHG Emission Rate with Methane Leakage Associated with Natural Gas Combustion

source	fraction	GHG EF, lb/MWh	Case 1: methane leak rate = 1.8% gas usage	Case 2: methane leak rate = 4.2% gas usage	Case 3: methane leak rate = 12.0% gas usage
natural gas	1.00	530[iii]	530	530	530
methane		13250	239	557	1590
Total GHG emissions, Duke University CHP, lb/MWh:			**769**	**1087**	**2120**

Assumptions:

1. Duke Energy Carolinas power mix, 2015: nuclear = 61%, coal = 27%, natural gas = 11%, 1% = renewable & other[iv]
2. Bituminous coal CO2 emission factor: 2,070 lb CO2/MWh
3. Composite (CC & CT) natural gas combustion emission factor: 999 lb CO2/MWh
4. Methane global warming potential compared to CO2: 25x natural gas EF[v]
5. Natural gas (methane) leakage rate as % of natural gas combustion: 1.8% (EPA), 4.2% (Howarth average), 12% (Howarth high)

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[i] EIA, Frequently Asked Questions, Feb. 29, 2016: https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11

[ii] California Energy Commission, Thermal Efficiency of Gas-Fired Generation in California: 2014 Update, September 2014, Table 1, p. 1. (Note: no similar document found for NC gas-fired generation.)
Composite California 2013 natural gas-fired combustion heat rate = 8,537 Btu/kWh.
Therefore, 8,537 Btu/kWh × 1000 kW/MW × 117 lb CO2/106 Btu = 999 lb/MWh.

[iii] See calculations below, "CO2 Emission Rate of Duke University 21.7 MW CHP Plant."

[iv] DEC 2016 IRP Annual Report, Sept 1, 2016, p. 80.

[v] EPA 2014, Emission Factors for Greenhouse Gas Inventories

CO_2 Emission Rate of Duke University 21. 7 MW CHP Plant

Titan 250 natural gas consumption, low heating value (LHV)	190.8 MMBtu/hr
Ratio of LHV to high heating value (HHV)	0.907
Titan 250 natural gas fuel consumption, HHV	210 MMBtu/hr
Heat addition per lb steam produced	1,083 Btu/lb
Unfired Titan 250 steam production rate	77,600 lb/hr
Unfired Titan 250 heat absorbed by steam	84 MMBtu/hr
Conversion	3,412 Btu = 1 kWh
Megawatts of thermal energy produced per hour	24.6 MWht
Megawatts electric produced by Titan 250	21.7 MWhe
Megawatts thermal + electric per hour	46.3 lb/MWhtotal
Natural gas CO_2 emission factor, HHV	117 lb/MMBtu
Total lb CO_2 per hour	24570 lb CO_2/hr
CO_2 emission rate	**530 lb CO_2/MWhtotal**