Cornell University

CEE 5910 – Engineering Management Project

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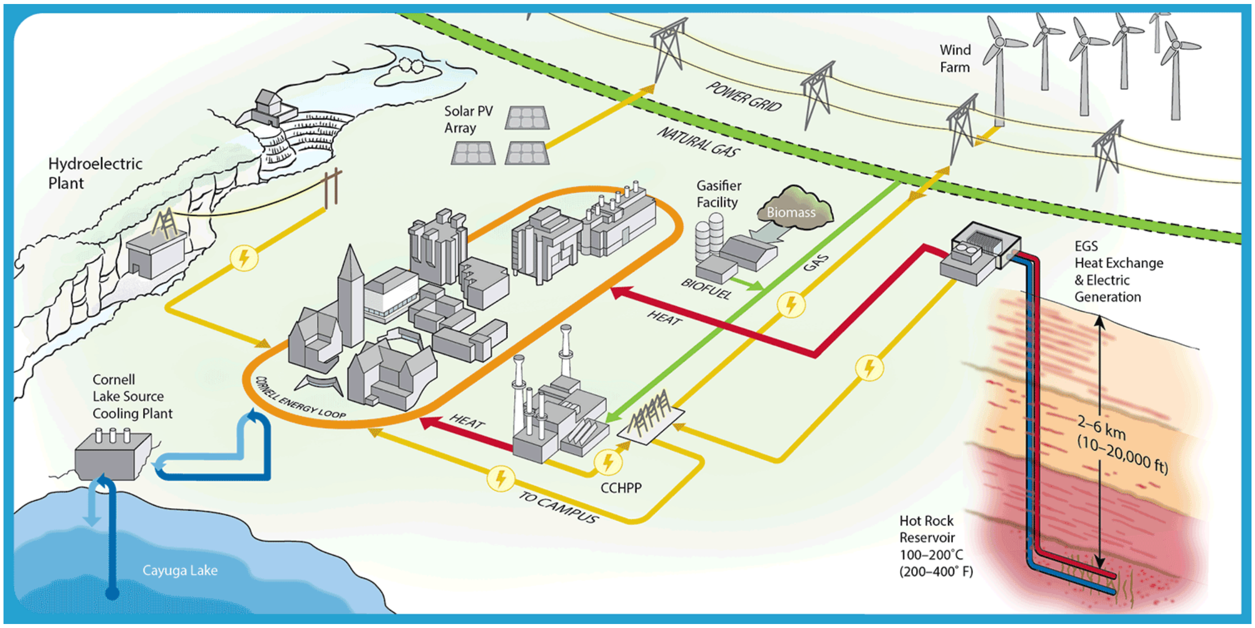
Cornell Ithaca Campus
Steam Distribution to Hot Water Conversion
Electrical Distribution Study



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1. Study Description and Scope

1.1. Scope

This study will include identifying and finding the existing process steam loads across multiple buildings on campus to determine the appropriate size of electrically powered steam generators required at each building to replace the campus steam distribution. Process steam is any use of steam in the building for anything other than heating, for example sterilization or humidification. The study will also determine the impacts the electric steam generators will have on the electrical distribution capacity at the building level as well as the medium voltage distribution level.

Financial impacts will be considered for adding the electric steam generation equipment as well as the upgrades to the existing electrical distribution system (transformers, medium voltage switches, cable, etc.). We will also investigate future costs associated with increased utility power usage.

Due to the large number of individual buildings, this study was able to gather data on most buildings identified having process steam but some are incomplete and are in progress. These buildings are noted and information that is still to be collected is marked as to be determined or "TBD".

1.2. Executive Summary

This report provides results of the Campus Process Steam Conversion Study performed over the previous four months to find where the process steam loads were located on campus. Once located, the study was also to determine the size of the steam loads and how large the equivalent electrical loads would be once the steam distribution on campus is removed.

Electrical boilers provide a highly efficient way to produce steam but at the same time require a large amount of power to operate. The electric boilers can produce the steam carbon free, granted it is receiving power from a carbon free generation source such as hydroelectric or solar. Due to the large power requirement, electrical capacity became a large concern during discussions on the transition to the new electrically generated steam at the buildings that need process steam.

The primary goals of this project are to identify where our process steam loads are on campus, quantify those loads and find the correct size of the electrically powered steam generator necessary to produce the required process steam at each building. Once we determine the electrical demand necessary, we will know where we need to make building electrical service upgrades and distribution changes to accommodate loads. Another goal is to quantify the steam that is currently generated at individual buildings on campus by natural gas. Few buildings have their own boilers to produce steam with natural gas to allow them to be independent of the steam loop when necessary. These buildings have critical processes that creates the need to be independent from the campus steam distribution to avoid outages during the annual steam shut down for maintenance.

Other goals of the project include finding the financial impacts of producing steam locally at each building versus centrally (at our energy plant), the cost for campus electric load if it were entirely provided by public utility and costs for offsetting our increased load with remote photovoltaic installations. Also, another goal is to compare electric steam generation costs versus paying credits to continue using existing natural gas fired steam generators.

The study found that most of the buildings on campus that utilize the steam distribution will have electrical capacity on the existing building electric services. There are a few building services that will not be able to handle the additional electrical load and will need further considerations for upgrades prior to the transition to the new steam boilers.

Currently, the medium voltage distribution system can handle the additional electrical load of over 5MW that has been calculated to date for steam generation. This equates to approximately an 18% increase in peak load for the campus. The majority of this added load will be to the Campus Road Substation. This substation supplies power to the College of Agriculture and Life Sciences and Veterinary School Buildings, which is where most of the process steam loads are located on the campus steam distribution.

The study found that three of the buildings with natural gas steam loads have an equivalent to an additional 11MW if switched to electrically generated steam. At this time, it is infeasible to add the electrical equipment at the building level and to add the load to the medium voltage system. Future considerations and alternatives for these buildings will need to be discussed as we move towards carbon neutrality.

1.3. Background

1.3.1. Campus Electrical Distribution

The existing electrical distribution system for Cornell's Ithaca Campus originates from a local utility company, New York State Electric and Gas (NYSEG) which is a subsidiary of AVANGRID. NYSEG provides transmission power to Cornell from three different substations to provide redundancy. The power provided to Cornell's electric service point, Maple Avenue Substation, is 115 kilovolts (kV).

The incoming transmission voltage is stepped down to 13.2kV through Cornell owned transformers to provide the campus distribution voltage used across campus, in some areas of campus this distribution is dropped down to 2.4kV to provide power to older sections of campus that have not yet been upgraded to the newer 13.2kV system. There are a total of three transformers at Maple Ave Substation that provide the 13.2kV campus power to three separate buses at the substation, each capable of producing a base of 20 megavolt amperes (MVA). A diagram of this configuration is shown in Figure 1.3 below. With cooling, the transformers can increase to over 30MVA. Cornell's Ithaca Campus averages around the same load of 20 to 25MVA and has a peak power consumption reaching 30MVA. If we lost cooling from our Lake Source Cooling Plant during the summer, the peak could hypothetically reach a maximum of 35MVA. Historically, the peak has almost never exceeded 30MVA in the last five years.

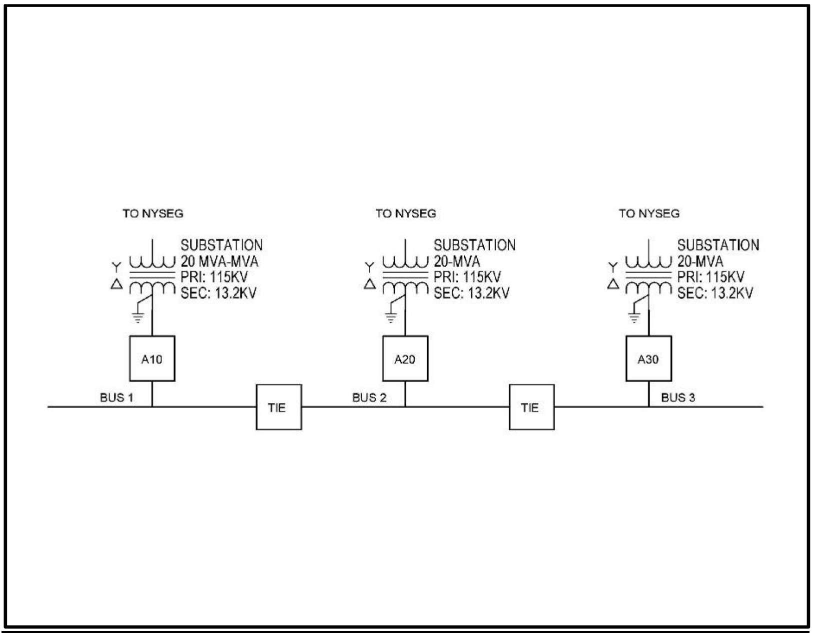

Figure 1.3 Campus Substation Configuration

1.3.2. Campus Central Energy Plant

For the most part, Cornell can operate on one transformer most days out of the year but only imports power from the utility grid about 50 days a year. The rest of the time, the power for campus distribution is produced at the Cornell's Combined Heat and Power Plant (CCHPP). The CCHPP utilizes a combined heat and power system, also known as cogeneration, to produce power using two 15 megawatt (MW) natural gas combustion turbines with heat recovery steam generators for the campus steam distribution. The byproduct heat created from the electrical generation is used to pre-heat the water that is eventually turned to steam (Jim Ciolek, Cornell University Utilities Electrical Engineer, personal communication, October 2019). The steam is produced at the CCHPP by further heating the water using natural gas and is distributed around the Ithaca campus via multiple steam distribution loops.

1.3.3. Carbon Neutrality

Cornell has set a goal to become carbon neutral by 2035. Parts of achieving this goal include replacing the existing steam distribution and installing a new heating distribution system for campus as well as with using a new source to provide the heat.

Cornell plans to install a new hot water system to provide heat to the buildings on campus. The new system will greatly improve the efficiency of use the by reducing heat loss in the distribution. When compared, hot water only has a 3 percent loss in distribution vs 20 percent losses using steam. If Cornell was to replace the system and continue to produce hot water with natural gas, the benefits in cost and efficiency would alone be worth the transition. With the 2035 carbon neutrality goal on the horizon, Cornell plans to get the heat from a more sustainable source. Plans have already begun to drill into the earth's crust, into the deep hot rock approximately 3-5 kilometers below the surface (Mark Howe, Cornell University Director of Utilities Distribution and Energy Management, personal communication, October 2019).

The temperature of the earth at that depth will range from 200 to 300 degrees. By installing an encased line to the hot rock reservoir and using the heat exchange with the earth source, Cornell will heat the hot water system for distribution on campus. Earth Source Heat would replace the burning off approximately 300,000 dekatherms of natural gas per year which is currently used to produce steam. Cornell averages three million dekatherm of natural gas usage per year to produce electricity and steam. Roughly 90% of that usage is for electricity, the rest is consumed by the boilers to produce the steam (David Frostclapp, Cornell University Engineer, personal communication, December 2019).

2. Market Analysis

2.1. Electric Steam Generation

Electric steam generators are packaged boiler systems that use electrical elements which heat water to create steam. When the power supply is connected to the element, the electrical element creates heat through the resistance. Water is passed over the elements to bring the water to a high temperature making it hot enough to create steam which is then transported to the steam piping that exit the boiler to the desired steam loads. Because there is no combustion the steam generators are 100% emission free and are nearly 100% efficient. The water used to create steam is usually treated before entering the generator to prevent premature failure and corrosion of the elements and equipment. There are existing electric steam generators on Cornell's campus in the form of small point of use type steam generators located in laboratory bench tops and in autoclaves. In the case of this project, the electric steam generator would be large enough to handle the entire building process loads and would be located near the existing campus steam line entrance to the building as a central building steam generator for the autoclaves and/or humidification.

The sizes of the electric steam generators will vary depending on the necessary steam requirements. Recent quotes received from Chromalox offer systems with electrical requirements ranging from 6kW to 180kW; the relative heat energy output at 15psi (which is the operating pressure for our campus steam) is around 20,000 BTU up to 630,000 BTU, respectively. The cost range for these start at $5,000 and go up to $20,000 for the largest. Larger models are available from Cleverbrooks ranging from 12kW to 400kW in 208V models. They also offer 480V models available from 12kW up to a maximum of 3360 kW. This maximum output could produce up to almost 11.7 million BTU, but the electrical requirement at 480V would be 3,469 amps which is larger than most of our electric services at our buildings. For reference, a single steam generator operating at 2,880kW would consume almost as much electrical power as 10% of the entire campus during normal operating conditions. There are a few buildings on campus that have large natural gas steam generators that are close to 10 million BTU. These buildings are addressed in this report under the Findings and Recommendations sections.

On a similar note, the increase in electric usage for steam generation will increase electric demand across campus. In order to meet this higher electrical demand and still reach the goal of carbon neutrality, Cornell will need purchase renewable energy credits once the campus power is 100% provided from the public utility grid.

2.2. Peer Institution Examples

University of California Berkeley

UC Berkeley's existing power is mostly generated by an on-site cogeneration plant similar to the plant that the Cornell Ithaca Campus uses to generate power and steam. The remaining power used at Berkeley comes from the local utility, PG&E. The future plans to purchase power from the utility include procuring 100% renewable or carbon-free generated power by 2025. The campus also utilizes auxiliary boilers for backup steam production throughout campus in addition to the cogeneration plant. The University's plan to replace some of the natural gas usage includes using biogas as a fuel through the natural gas pipeline. [1]

Massachusetts Institute of Technology (MIT)

Similar to Cornell, MIT replaced its coal burning plant with a co-generation plant which it currently uses to supply power and steam to its campus, so MIT faces the same issue that we are facing at Cornell. Having recently installed co-generation and lacking on site energy options at the moment, the largest opportunities for renewable energy are off campus through offshore wind and hydroelectric power imported from Canada. The plan for the near future is to continue using natural gas at the plant (and adding additional load in the future), and looking into purchasing offsets and purchase solar energy equivalent of up to 40% of its current electrical usage. [2]

University of British Columbia (UBC)

The University of British Columbia has implemented many different initiatives over the last decade. Carbon based fuel reduction has been achieved through use of wood waste to produce thermal energy. The campus has also replaced its steam system and steam plant with a more efficient hot water system, similar to the future plans for Cornell University. Electric steam generators were installed in buildings that required process steam loads under 100kW. Larger process loads were provided with natural gas steam generation. [3]

Northwestern University (NU)

Northwestern University is in the middle of transitioning from a central steam plant to distributed hot water boiler plants on campus with dedicated steam for process loads at necessary buildings. Realizing the inefficiencies of centrally located steam, NU decided to replace the heating system with a decentralized hot water system similar to Cornell's plans for Earth Source Heat, only with natural gas hot water heaters. Natural gas will still be used for steam but on a smaller level and only where needed to reduce the overall inefficiencies. The system was to help reduce carbon based fuel usage to get to net zero emissions by 2050. [4]

2.3. Approach

The first steps in this study were to identify what qualifies as process steam. We met with the Cornell Utilities group to discuss the uses for process steam and determined if any steam used on campus for humidification and autoclaves it would classify as campus steam use. The autoclave and steam to steam generated loads were calculated based on a pound per hour (lb/hr) basis and then converted to peak boiler horsepower (BHP), peak British thermal units (BTU) and finally peak kilowatt (kW).

2.4. Meetings/Field Surveys

The kickoff meeting for the project was on August 16th with Mark Howe to identify the process steam loads that we needed to locate and establish the initial contact list for the buildings that had known process loads. Subsequent meetings and phone conferences were held with building coordinators Wayne Davenport (Veterinary College Buildings), Libby Foust (CALS Buildings), Brian Flannigan (Bradfield Hall, Emerson Hall and Plant Science), Tim Dodge (Greenhouses), John Dawson (Uris Hall), Matt Stratton (Stocking Hall), Todd Pfeifer (Weill Hall, Biotech and PSB), and Scott Albrecht (Duffield Hall) throughout September and October. Further information was gathered through phone calls, emails and conversations during field visits.

2.5. Existing Systems

2.5.1. Steam Distribution

The original steam distribution system was wood-encased and installed in 1889. After many changes over the years, the lines today are concrete encased. Currently, the steam system consists of about 13 miles of steam line, 12 miles of condensate line, and 165 vaults/manholes. The average age of steam line in the steam distribution system is 15 years for the large mains, 50 years for the small mains and 60 years for the laterals.[5] Along with the inefficiency of the system as stated previously, the age of the steam system is an additional reason for moving to a new hot water system.

Steam enters each building through piping that splits depending on the different uses and distribution in the building. Process steam is part of this steam delivery and is used in two different ways inside the buildings, as explained in the following paragraph.

2.5.2. Building Process Steam Usage

The buildings targeted in this study utilize the campus distributed steam to provide process steam in two ways. One ways is a direct use, which means the steam that enters the building is routed to the load and fed into a piece of equipment, such as an autoclave. The other way is through a steam to steam generator, also called clean steam generator. This is an exchanger which uses the campus steam to make building steam but keeps the campus steam loop separated from the steam distributed throughout the building. This is done to keep the steam pure and not introduce any of the campus steam impurities or chemicals into the building processes.

2.5.3. Building Electric

At the building level, the electric distribution voltages (13.2kV or 2.4kV) are stepped down through a building service transformer to a usable voltage of either 480 Volt (V) or 208V, both three phase wye configurations. The wye configuration utilizes a neutral which is to provide a single phase, 277V for the 480V system and 120V for the 208V system. The 480V distribution is used for larger electrical loads, as in research buildings for heating, cooling, ventilation, older lighting and other processes. These buildings also utilize 208V through the use of smaller step down transformers inside the building. The 208V is used to supply much of the 120V general single phase loads such as receptacles, special systems, control power, benchtop equipment, newer LED lighting to name a few. Some buildings with smaller electrical consumption like offices and dormitories only utilize a 208V distribution system. These service transformers are designed to have spare capacity when they are installed for the building in case future loads are added to the system.

Some of the larger building electrical services on campus have a combination of two transformers and two switchboards that are connected in a configuration noted as a “main-tie-main” arrangement. This term comes from the two switchboards, fed from separate transformers, each switchboard having their own main breaker. There is a tie breaker in between the switchboards that is normally open, which will allow an electrical connection between the two. This configuration is used in many buildings that have a large amount of research and processes that would benefit from having redundancy with electrical services. Transformers and medium voltage equipment can fail, causing the service to lose power. The main-tie-main setup allows for opening one main breaker and closing the tie breaker to power the switchboards from one transformer until the failure is corrected. An example of this configuration is shown in the Figure 2.4.5 below. The “Main” and “Tie” breakers are shown as described previously, the “FDR 1” and “FDR 2” labels are to denote the feeder breakers that serve the building loads.

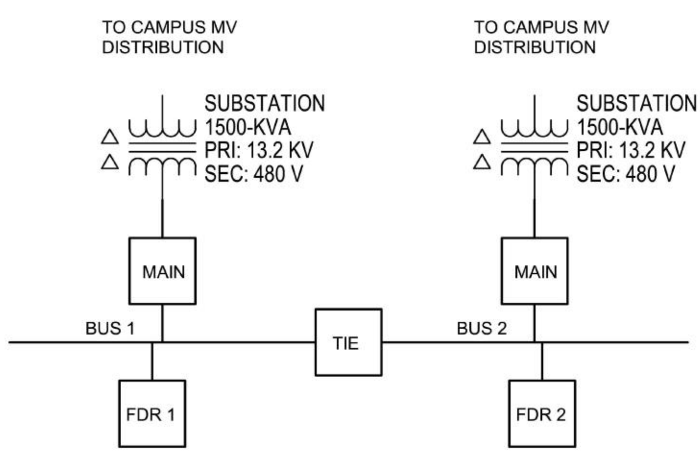

Figure 2.4.3 – Typical Building Distribution
with Main-Tie-Main Configuration

3. Findings

3.1. Buildings with Process Steam

The existing buildings that have process steam loads that are served from the campus steam loop are the following:

- Bradfield Hall
- Duffield Hall
- Emerson Hall
- Guterman Lab
- Federal Nematode Lab
- Morrison Hall
- Physical Sciences Building
- Plant Science Building
- Riley Robb
- Stocking Hall
- Tower Road Greenhouses
- Uris Hall
- Vet Research Tower
- Wing Hall
- Wing Hall Wing

Aside from these buildings, a separate list of buildings that use natural gas powered process steam were identified and listed below:

- East Campus Research Facility (ECRF)
- Vet Medical Center (VMC)
- Schurman Hall
- Weill Hall
- Biotech Hall

These two lists of buildings are addressed separately in this report. The buildings using process steam generated by the campus steam distribution are assessed in this section followed by their electrical service assessments in Section 3.2. The natural gas generated steam loads and their electrical service assessments are in Section 3.3.

A building summary showing the process steam loads at each building along with the conversions to Peak kW is in the Table 3.1 below.

Building	Other process loads	Humidification Load	Autoclave Load	Total Process Load	Peak BTU/hr	Peak KW
	lb/hr	lb/hr	lb/hr	lb/hr	BTU/hr	KW
VRT			1140	1140	1,106,263	324.16
Wing Wing			540	540	524,019	153.55
Wing			1080	1080	1,048,038	307.10
Riley Robb			540	540	524,019	153.55
Morrison			180	180	174,673	51.18
Stocking	155		795	950	921,886	270.13
Stocking West	10		360	370	359,050	105.21
Stocking East	1486			1486	1,442,023	422.54
Stocking East Addition	4825			4825	4,682,208	1371.98
Bradfield			720	720	698,692	204.73
Emerson			720	720	698,692	204.73
Plant Science			1080	1080	1,048,038	307.10
Federal Nematode Lab			180	180	174,673	51.18
Tower Road Greenhouses			1000	1000	970,406	284.35
Guterman			360	360	349,346	102.37
Phys Sci Bldg				0	0	0.00
Uris Hall	723	836		1559	1,512,863	443.30
Duffield				0	0	0.00

Table 3.1 – Process Steam Summary by Building

Bradfield & Emerson Hall

Bradfield Hall and Emerson Hall are separate buildings and each building houses their own process steam usages in the form of autoclaves. These two buildings are grouped together in this study because the electric service for Emerson Hall originates from the secondary electrical distribution in Bradfield Hall. Therefore, any electrical load increase for Emerson Hall is a load increase on the main electrical service for Bradfield Hall.

Duffield Hall

The final steam loads have yet to be determined for Duffield Hall.

Federal Nematode Lab

The final steam loads have yet to be determined for Duffield Hall.

Guterman Lab

The two autoclaves in Guterman Lab have a steam load that was not estimated under this study. Instead, the autoclaves will be addressed in a new project to renovate the building and replace the autoclaves with their own unit-mounted electric steam generation. The plan in design has currently estimated the electrical load for the autoclaves at 240 kW each, which is 480 kW total added electrical load in autoclaves alone.

Morrison Hall

Morrison Hall has only one autoclave in the building that utilizes process steam from the campus distribution. The total process steam load for the building is 180 lb/hr which equates to 51.18 kW.

Physical Sciences Building

The final steam loads have yet to be determined for Physical Sciences Building.

Plant Science Building

Plant Science has six autoclaves that use process steam that comes from the campus distribution. The demand is estimated at 180 lb/hr for each autoclave. This makes a total of 1080 lbs/hr, 307.1 kW after conversion.

Riley Robb Hall

Riley Robb has three autoclaves that use process steam that comes from the campus distribution. The demand is estimated at 180 lb/hr for each autoclave. This makes a total of 540 lbs/hr, 153.6 kW after conversion.

Stocking Hall

Stocking Hall is the largest single consumer of campus steam for process loads. In order to better understand the uses, this study addressed the process steam loads as they applied to the building in its four different pieces. The building is made up of four different sections, which each have their own building codes.

The four different sections are Stocking Hall, Stocking Hall East, Stocking Hall East Addition and Stocking Hall West. Stocking Hall contains the winery which includes a still, a clean steam generator and its own autoclaves. Stocking Hall West houses the autoclaves and a glass washer. Stocking Hall East process load is comprised of the pilot plant sterilization, cleaning and pasteurization equipment. Lastly and most notable, the dairy is located inside the East Addition which contains heat exchangers, cleaning tanks and a cage washer.

The winery in Stocking Hall accounts for 950 lb/hr of steam or 270.13 peak kW. Stocking Hall West demand is estimated at 370 lb/hr of steam which is 105.21 peak kW. Stocking Hall East is estimated to use 1486 lb/hr of steam or 422.54 peak kW. The dairy in Stocking Hall East Addition is the largest single load in the entire campus, estimated at 4825 lb/hr of steam, the equivalent of 1,371.98 peak kW.

Tower Road Greenhouses

The two greenhouses that currently house autoclaves are the Yellow Greenhouse and the Green Greenhouse. Each greenhouse has an estimated demand of 500 lb/hr, which equates to an additional load of 142.17 peak kW.

Uris Hall

The process steam load for Uris Hall is all located in the lower levels of the building for research.

Veterinary Research Tower (VRT)

Veterinary Research Tower has three autoclaves and a couple bottle sterilizers that use process steam that comes from the campus distribution. The demand is estimated at 180 lb/hr for each autoclave and 300 lb/hr for each bottle sterilizer. This makes a total of 1140 lbs/hr. This converts to 324.16 peak kW.

Wing Hall

Wing Hall has six autoclaves that use process steam that comes from the campus distribution. The demand is estimated at 180 lb/hr for each autoclave. This makes a total of 1080 lbs/hr, 307.1 kW after conversion.

Wing Hall Wing

Wing Hall Wing has six autoclaves that use process steam that comes from the campus distribution. The demand is estimated at 180 lb/hr for each autoclave. This makes a total of 540 lbs/hr, 153.55 kW after conversion.

3.2. Existing Electrical Services and Loads

The loads for all buildings are estimated based on the peak kW loads identified above. The peak load was then compared to a list of available electric steam boilers. The next size larger than the peak kW load was used for estimating additional load on the buildings.

Bradfield & Emerson Hall

As stated previously, Emerson Hall gets power from Bradfield Hall. While both buildings have the same steam load at 210 kW peak, the entire electrical load of 420 kW will be added to the existing service in Bradfield Hall, which is currently loaded at 735 kVA. This leaves a total capacity of approximately 23% after adding the proposed steam generation. With a building upgrade project coming in the near future, the facility will need to identify other future needs in the building in case additional electrical capacity is needed.

Duffield Hall

Duffield Hall has a 2,500 kVA transformer that is currently loaded to a 1,325 kVA peak. This leaves approximately a 47% spare capacity to add electrically powered steam.

The steam load has yet to be determined but it is anticipated that the loads will be most likely within the capacity of the existing service.

Federal Nematode Lab

The Nematode Lab service size is a 1000 amp service served by a 300 kVa transformer. The existing load on the service is only 30 kVA, leaving plenty of capacity with 90% to spare. The proposed additional load on the service by adding the steam generation is only 60 kW and would leave 70% for future loads to be added to the service.

Guterman Lab

As stated in the steam load estimate, the design in progress has estimated the electrical load for the autoclaves at 480 kW total added electrical load. While the added load exceeds the existing service size, the design in progress will address this issue.

Morrison Hall

Morrison Hall is a combination of two transformers and two switchboards that are connected in a main-tie-main arrangement. The two 208V switchboards in Morrison are 2,500 amps each, served by 750 kVA transformers. Each transformer has approximately a 70% spare capacity. The estimated steam generator size is 60 kW. With only one autoclave in the building, the load can be added to one of the spaces on either switchboard and only reduce the capacity by about 8%.

Physical Sciences Building

The service for PSB is similar to Morrison Hall as it has a main-tie-main configuration. The service consists of two 480V switchboards that are powered from 1500kVA transformers. The steam load has yet to be determined for PSB but it is anticipated that the loads will be most likely within the capacity of the existing service.

Plant Science Building

The service size at Plant Science is a 3,000A, 480V service served by a 2,000 kVa transformer. The existing load on the service is only 470kVA, leaving 76% spare capacity. The proposed additional load on the service by adding the steam generation is only 320 kW. Adding the electrical steam generation to the service would still leave a little over 60% capacity for future loads to be added to the service.

Riley Robb Hall

Riley Robb has an existing 1,200 A, 480 V service size provide by a 1,000 kVa transformer. The existing electrical peak load on the service is 389 kVA, leaving approximately 60% spare capacity. The proposed additional load on the service from adding the steam generation is 160 kW. Adding the electrical steam generation to the service would still leave about 45% spare capacity to the building service for future loads to be added.

Stocking Hall

The existing electrical service at Stocking Hall is a 3,000A service fed from a 2,000 kVA, 480V transformer. The service is currently loaded to a peak of 812 kVA. The total proposed load for the additional electric steam generation totals over 2,240 kW. This is the largest single load found in this study. This exceeds the service capacity by over 50%. Dividing up the loads by building section will help with accommodating the electrical steam generation. Planning will be required to decide the proper path forward, possible solutions and additional information is included in the Recommendations section of this report.

Tower Road Greenhouses

Both have recently been upgraded for transition from the 2.4 kV distribution system to the 13.2 kV distribution system. The Yellow Greenhouse has a 2,000 amp rated switchboard provided from a 500kVA transformer that were both recently installed during an electrical service and distribution upgrade project. Adding the proposed 160 kW of load for steam generation will leave a 63% spare capacity on the transformer for future loads to be added to the electrical system.

The Green Greenhouse has a 1,000 amp service provided from a 300 kVA transformer. The transformer is currently loaded to only approximately 25%. However, adding the proposed 160 kW load for steam generation reduces the spare capacity to approximately 22%. While this leaves some capacity, discussions regarding future loading will need to occur with the facility to ensure we are not going to need additional capacity in the future aside from the steam generation.

Uris Hall

The existing electrical service at Uris Hall is a combination of a 500 kVA, 13.2 kV primary, 208 Volt secondary transformer and switchboard along with a 150 kVA, 480 Volt transformer and switchboard. This service is in the process of being installed and upgraded from a 1,500 kVA, 208 volt service. The service size was reduced based on meter data and providing a safer installation. Reducing the transformer size has reduced the short circuit availability and arc flash hazard level. The proposed additional electrically powered steam generation will bring the total load to 480 kW. This is close to the entire service size of the new 208V service. Planning will be required to decide the proper path forward, possible solutions and additional information is included in the Recommendations section of this report.

Veterinary Research Tower (VRT)

The existing electrical service at VRT is a 1,500 kVA, 13.2 kV primary, 208 Volt secondary transformer. The service size currently has an existing peak load of 625 kVA, which equates to a 58 percent spare capacity.

The proposed additional electrically powered steam generation will bring the building load up to 340 kW. This proposed load will leave 35% spare capacity on the service.

Wing Hall

Wing Hall has an existing 1,000 amp service which is served from a 300kVA transformer. The existing service has a spare capacity of approximately 53%. The proposed additional electrical steam generation will bring the total load to 315 kW, which will exceed the service by over 50%. Planning will be required to decide the proper path forward, possible solutions and additional information is included in the Recommendations section of this report.

Wing Hall Wing

The service size at Wing Hall Wing is a 2,000A, 208V service served by a 500 kVa transformer. The existing electrical peak load on the service is 154 kVA, leaving 65% spare capacity. The proposed additional load on the service from adding the steam generation is 165 kW. Adding the electrical steam generation to the service would still leave a little more than 30% capacity to the building service for future loads to be added.

A building summary showing the added process steam loads at each building along with peak kW and associated steam generator kW is in Table 3.2 below.

Building	Existing Electrical Peak(kW)	Transformer Size (kW)	Transformer Capacity (kW)	% Spare Capacity	Added Peak KW for Process Steam (kW)	Electric Steam Generator Size (kW)	% Spare Capacity after added Electric Steam Generation
Bradfield/Emerson Hall	662	1500	611.56	50.96%	409.46	420	22.96%
Duffield Hall	1193	2500	939.56	46.98%	TBD	TBD	46.98%
Guterman	829	1000	63.11	7.89%	480	480	None
Federal Nematode Lab	27	300	216	90.00%	51.18	60	70.00%
Morrison North	204	750	418.67	69.78%	51.18	60	61.78%
Physical Sciences North	427	1500	820.44	68.37%	TBD	TBD	68.37%
Plant Science	423	2000	1224	76.50%	307.1	320	60.50%
Riley Robb	350	1000	488.89	61.11%	153.55	160	45.11%
Stocking Hall (Winery)					270.13	280	
Stocking West (Autoclaves)					105.21	120	
Stocking East (Pilot Plant)					422.54	440	
Stocking East Addition (Dairy)					1371.98	1404	
Stocking Total	731	2000	950.22	59.39%	2169.86	2244	None
Tower Road Yellow Greenhouse	22	500	380.44	95.11%	142.17	160	63.11%
Tower Road Green Greenhouse	65	300	182.22	75.93%	142.17	160	22.59%
Uris Hall	662	650	-68.44	-13.16%	443.3	480	None
Vet Research Tower	562	1500	700.44	58.37%	324.16	340	35.70%
Wing Hall	128	300	126.22	52.59%	307.1	315	None
Wing Hall Wing	154	500	263.11	65.78%	153.55	165	32.78%

Table 3.2 – Added Load and Existing Transformer Capacity Summary by Building

3.3. Process Steam from Natural Gas

The process loads that are fed from natural gas boilers installed locally at buildings are located in the buildings listed below. These boiler ratings were collected through fieldwork, emails from building coordinators and from the inventory system Maximo utilized by Cornell.

Building	NG Units/BTU	LB/HR	MBH	BHP	Peak BTU	Peak KW
ECRF	9,000,000	7,418	9,000	215	7,198,470	2,109 kW
	9,000,000	7,418	9,000	215	7,198,470	2,109 kW
	3,500,000	2,898	3,500	84	2,812,236	824 kW
					Total	5,043 kW
VMC	2,471,580	2,070	2,472	60	2,008,740	589 kW
	2,520,000	2,087	2,520	60	2,024,859	593 kW
					Total	1,182 kW
Shurman	TBD	TBD	TBD	TBD	TBD	TBD
Weill & Biotech	9,750,000	7,865	9,750	228	7,632,242	2,236 kW
	9,750,000	7,865	9,750	228	7,632,242	2,236 kW
					Total	4,473 kW
Total Peak KW						10,697 kW

Table 3.3 – Natural Gas Steam Boiler Information

East Campus Research Facility (ECRF)

There are a total of three boilers in ECRF. Two of the boilers have a rating of 9 million BTU, while the third is a 3.5 million BTU boiler. The total equivalent peak kW for the entire steam production using electric would be 5,043 kW. This comes to a total of 6,075 amps at 480 volts. The existing service at ECRF is only sized for 4,000 amps through two 1500 kVA transformers in a main-tie-main configuration to handle the existing load. The steam boilers would require their own service larger than any building service that currently exists on campus.

Vet Medical Center (VMC)

There are a two boilers in VMC. The two boilers have a rating of approximately 2.5 million BTU each. The entire steam production using the electric equivalent would be a peak of 1,182 kW. This comes to a total of 1,424 amps at 480 volts. The existing service at VMC is a made up of two 4,000 amp, 480 volt switchboards in a main-tie-main service with an east and a west section. The two sections are each fed from their own 2,500 kVA transformer with over 70% capacity on the East Section of electrical gear. After adding the electrically generated steam, the spare capacity would be reduced to about 24%.

Schurman Hall

The final natural gas steam loads have yet to be determined for Schurman Hall.

Weill Hall

Weill Hall is home to the largest natural gas boilers on campus. There are two identical clean steam boilers that are 9.75 million BTU each. The total equivalent peak kW for the entire steam production using electric would be 4,473 kW. The existing service at Weill Hall comes from two 1,500kVA transformers into two 2,400 amp switchboards in a main-tie-main arrangement. The added steam generation would require another 5,388 amps of capacity. The existing 100% capacity of the existing two service transformers is a total of 3,600 amps. This is another building that would require a new service just for steam generation that would be larger than any existing service we currently have on campus.

Biotech Hall

The steam loads in Biotech Hall originate in Weill Hall. All loads in this study referred to as Weill Hall loads include those that are in Biotech Hall.

3.4. MV System Impacts from Converting Campus Steam Process Loads to Electric

Each building listed above gets power from one of several substations on campus, including Kite Hill, Campus Road and Plantations Road Substations. The medium voltage circuit that serves the building is listed in the table below.

Building	MV Circuit
Physical Sciences Building	2C13
Duffield Hall	3C17
Uris Hall	3C17
Bradfield/Emerson Hall	R12
Plant Science	R12
Guterman	R23
Riley Robb	R33
Morrison Hall	R34
Stocking Total	R34
Vet Research Tower	R34
Wing Hall	R34
Wing Hall Wing	R34
Federal Nematode Lab	S25
Tower Road Green Greenhouse	S27
Tower Road Yellow Greenhouse	S27

Table 3.4 – Building List by Circuit

As seen in the chart, the buildings included in this study mainly affect the load on the Campus Road Substation. Designated by the breaker that feeds the circuits, these are referred to as “R” circuits. The majority of the buildings in this study are on circuits R12, R23, R33 and

R34. The "S" circuits are part of the 2.4kV distribution system fed from the Plantations Road Substation. The circuits with a "C" originate from the Kite Hill Substation.

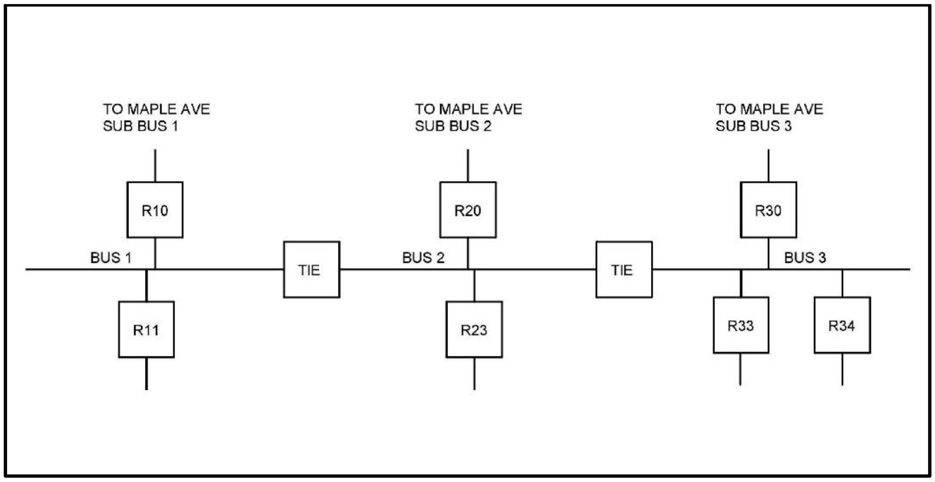

Figure 3.4A – Campus Road Substation Bus Configuration

Circuit R12

The buildings on Circuit R12 that currently have process steam served from the campus steam generation are Bradfield Hall, Emerson Hall and Plant Science Building. The total load for all three buildings is 740kW. The existing peak for the circuit is 3.4 MW, as shown by Figure 3.4B. Adding the electric steam generation will bring the peak load to 4.14 MW.

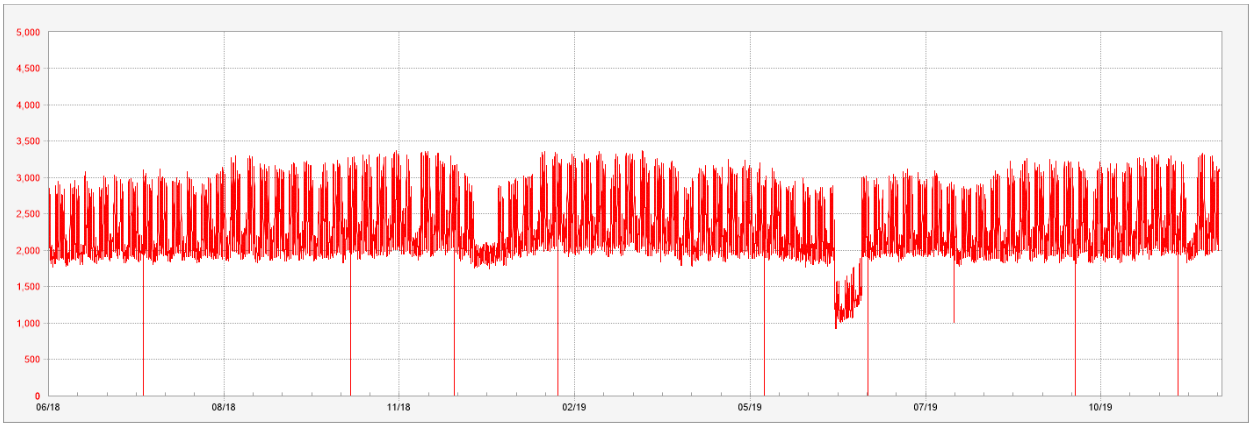

Figure 3.4B – 13.2 kV Circuit R12 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Circuit R23

The only building on Circuit R23 that has process steam is Guterman Lab. The total load proposed load is 480kW. The existing peak for Circuit R23 is 1.9 MW, shown below in Figure 3.4B. Adding the electric steam generation will bring the peak load to 2.38 MW.

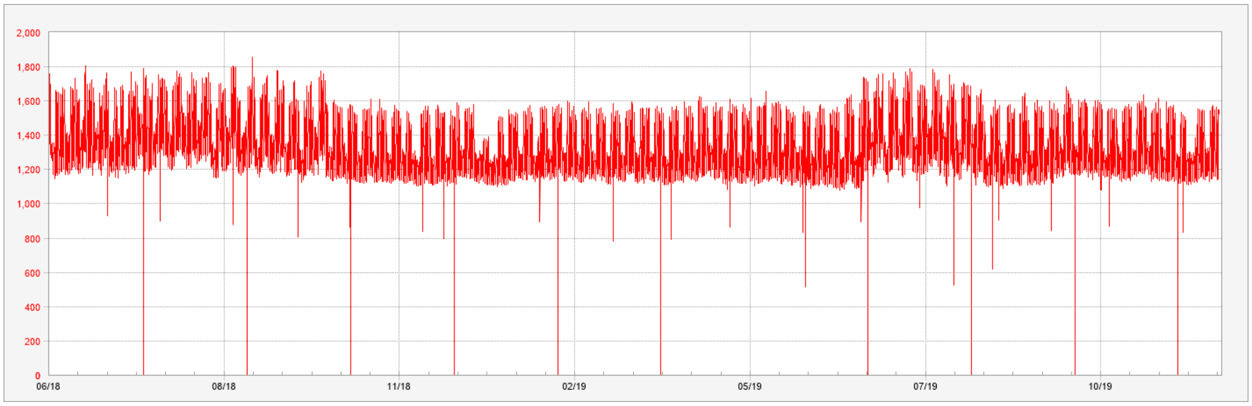

Figure 3.4C – 13.2 kV Circuit R23 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Circuit R33

Riley Robb Hall is the only building on Circuit R33 that has process steam served from the campus steam distribution. The total proposed load at Riley Robb is 160 kW. The existing peak for the circuit is 1.8 MW, shown below in Figure 3.4C. Adding the electric steam generation will increase the peak load to 1.96 MW.

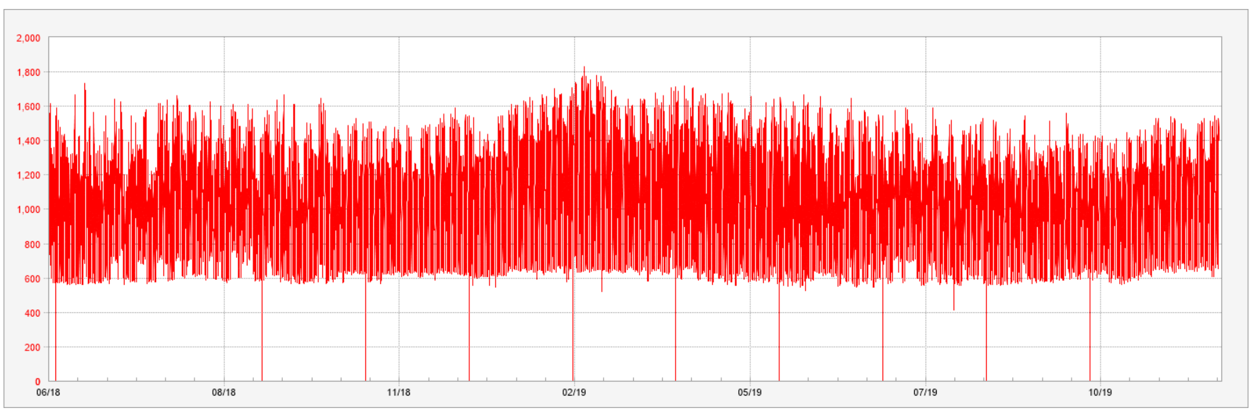

Figure 3.4D – 13.2 kV Circuit R33 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Circuit R34

Buildings that have process steam fed from the campus distribution Circuit R34 are Morrison Hall, Stocking Hall, Vet Research Tower, Wing Hall and Wing Hall Wing. The total added electrical load for steam generation in all three buildings is 3.12 MW. Most of this load is from Stocking Hall. The existing peak for the circuit is 1.5 MW, as shown by Figure 3.4D. Adding the electric steam generation will bring the peak load to 4.62 MW.

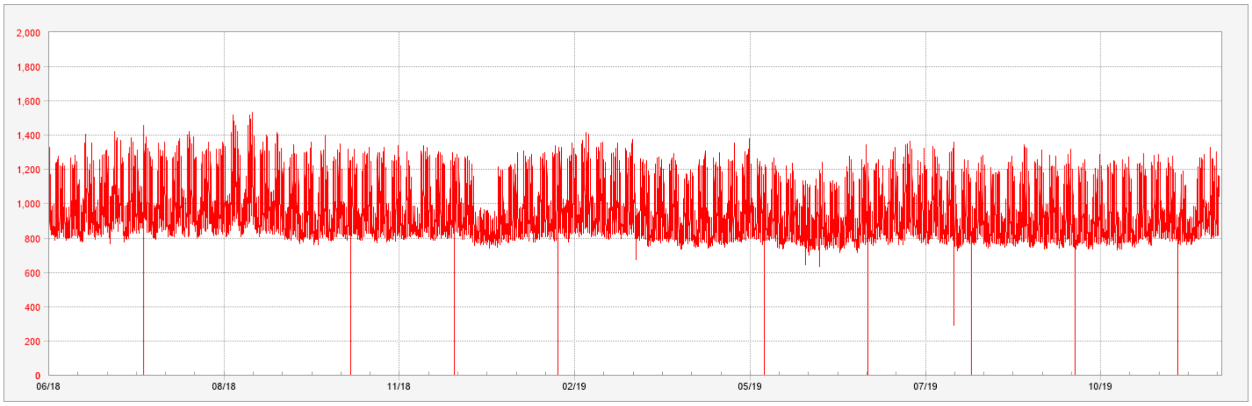

Figure 3.4E – 13.2 kV Circuit R34 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Two other circuits that are affected by the electric steam generated loads are 3C17 and S25.

Circuit 3C17

3C17 Circuit originates out of the third bus in Kite Hill Substation and provides power to Duffield Hall and Uris Hall. The additional load is 480kW, just below a half of a megawatt. The existing load on the circuit peaks at almost 3.5MW, so adding the electrically generated steam load increases the peak to approximately 4MW.

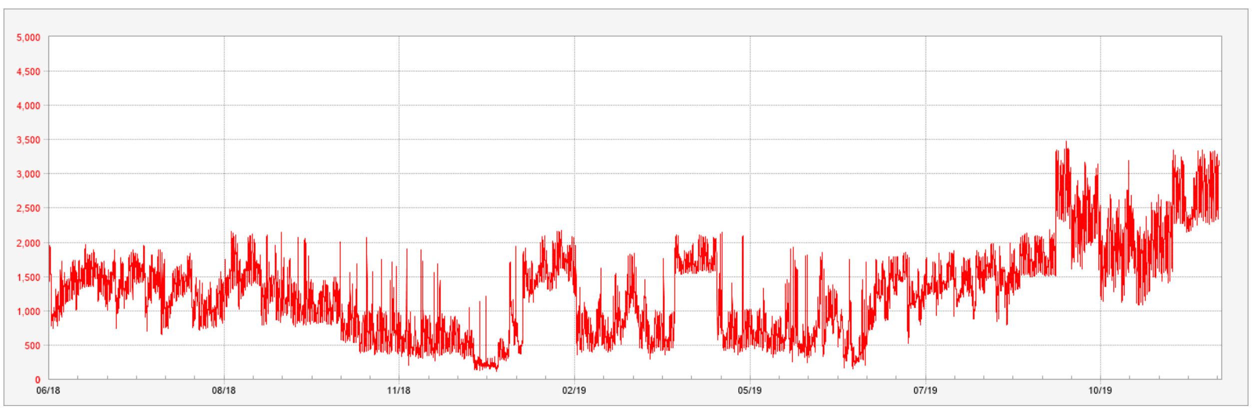

Figure 3.4F – 13.2 kV Circuit 3C17 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Circuit S25

S25 is part of the older 2.4kV electrical distribution system. The existing peak on the circuit is only about 155kW and additional the load of 60kW is minimal. The gaps in the data below are due to switching events between the ends of the loops for circuit upgrades or changes. When the existing circuit load is switched to the other side of the loop, no power is present to be metered.

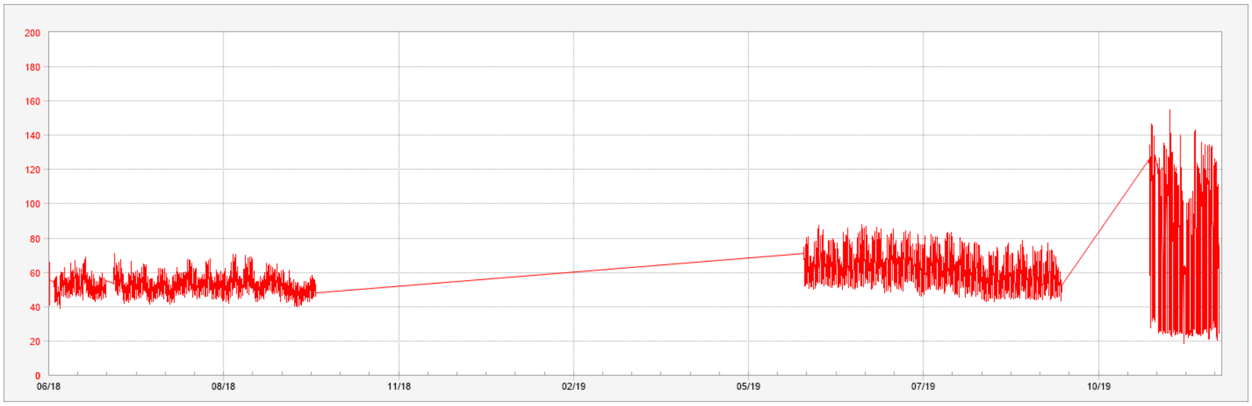

Figure 3.4G– 2.4kV Circuit S25 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Circuit S27

S27 is also part of the 2.4kV electrical distribution system. The existing peak on the circuit is 360kW and additional the load is estimated at 320kW. Similar to S25, there are gaps in the meter data, indicated the circuit load was shifted to the other side of the loop temporarily.

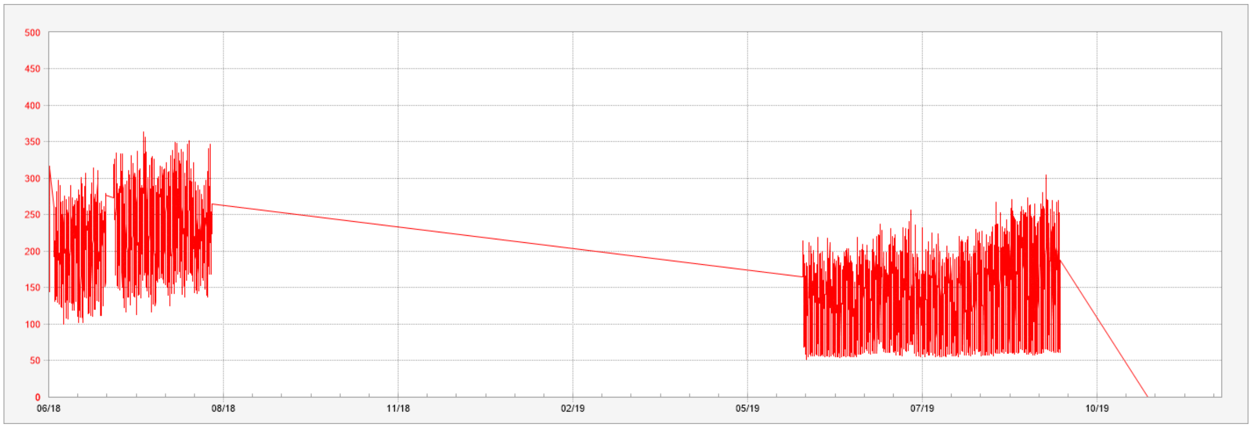

Figure 3.4H– 2.4kV Circuit S27 Peak Data – Source (Factory Talk Energy Metrix, 2019)

Summary

To summarize the load information above, the proposed additional load by adding electric steam generation per circuit is as in the following list and subsequent graph:

- R12 - Increase from 3.4 MW to 4.14 MW
- R23 - Increase from 1.9 MW to 2.38 MW
- R33 - Increase from 1.8 MW to 1.96 MW
- R34 - Increase from 1.5 MW to 4.62 MW
- 3C17 - Increase from 3.5 MW to 3.98 MW
- S25 - Increase from 155 kW to 215 MW
- S27 - Increase from 360 kW to 680 MW

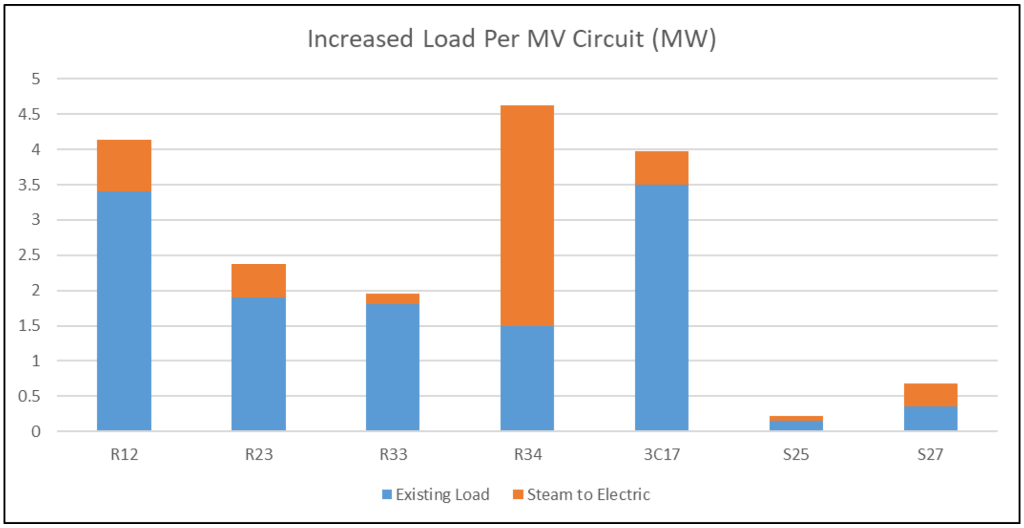

Figure 3.4I – Proposed Additional Load on MV Circuits

3.4.1. Circuits and Switching

The medium voltage circuits used on campus are in a loop configuration. The loop configuration refers to the circuit having two sources from two separate buses, sometimes in a different substation. This setup is used to provide added reliability to the distribution. Because it is possible to close the circuits from both ends of our loop, limiting the electrical load on each circuit is important. Typically, common practice is to keep the circuits limited to around 50%, which equates to 200A or about 4.5MW as the circuit breakers are set to open the circuit at 400A or approximately 9MW. This allows for a circuit to be closed in from one source and provide power to the entire loop. Simply put, it makes it possible to combine two circuits from one source in the event of an outage on one of the sources.

For example, taking another look at Circuit R12 shows that adding the electrically generated steam load increases the load to 4.14MW. Circuit R12 is connected to Circuit 2C19 to loop the circuit into Kite Hill Substation. The existing electrical load on Circuit 2C19 is 1.5MW. After closing the circuit together, the load would increase to 5.64MW. This is well below the 9MW threshold for a loop. If we add an electrical load of 4.72MW by converting Weill Hall's process steam from a natural gas source to electric, the total load becomes 10.34MW. This would trip the circuit breaker on an overcurrent load and power would be lost to the circuit. In order to avoid this in event of an issue, buildings would be shed from the circuit in order to handle the load if necessary. Another option is all buildings would be online with no steam use for autoclaves on the circuit until normal operating conditions were resumed.

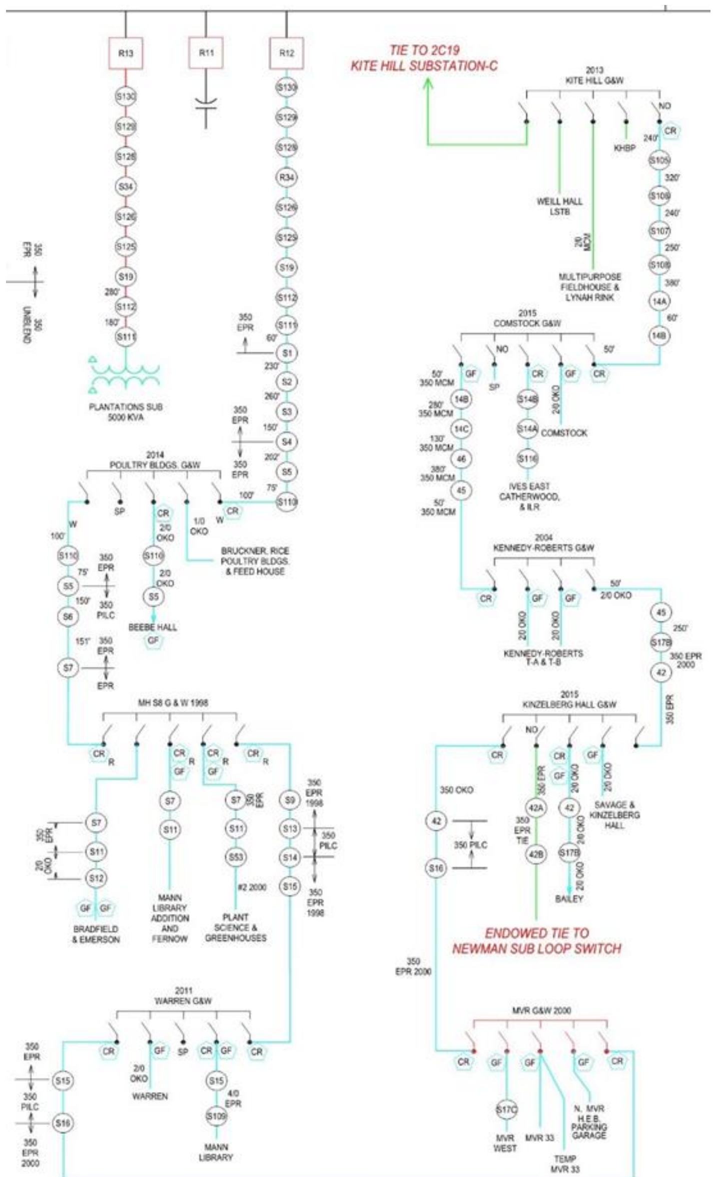

Figure 3.4.1 – R12-2C19 Loop

Analyzing the distribution shows that Circuits R23 and R33 are ends of a loop and so are Circuits R14 and R34. When adding the new estimated peak loads for both R23 and R33, the total comes to 4.34MW, which is well under the 9MW limit for a loop. Circuit R14 has an existing peak of 1.9MW, while Circuit R34 has an estimated peak of 4.62 with the added electrical steam generation. Although, this exceeds the typical circuit loading of 4.5MW, since the other end of the loop is loaded much less there won't be an issue unless other loads are added. This will require careful planning in the future after bringing the electrical steam boilers on the circuits.

3.4.2. Additional Loading of MV System from NG Sourced Process Steam Load Conversions to Electric

Replacing the natural gas generated process steam on campus is another item we decided to look at in this study. If we consider adding the natural gas boilers from ECRF, VMC and Weill Hall to the list of process steam we want transition to electric, the load becomes much greater. As shown in Figure 3.3, the total electrical load added to campus would be almost 11 MW. The individual loads for ECRF, VMC and Weill Hall are 5 MW, 1.2 MW, and 4.5 MW, respectively. Taking a closer look at which medium voltage circuits serve these buildings show that ECRF and VMC are on Circuit R23 and Weill Hall is on Circuit R12.

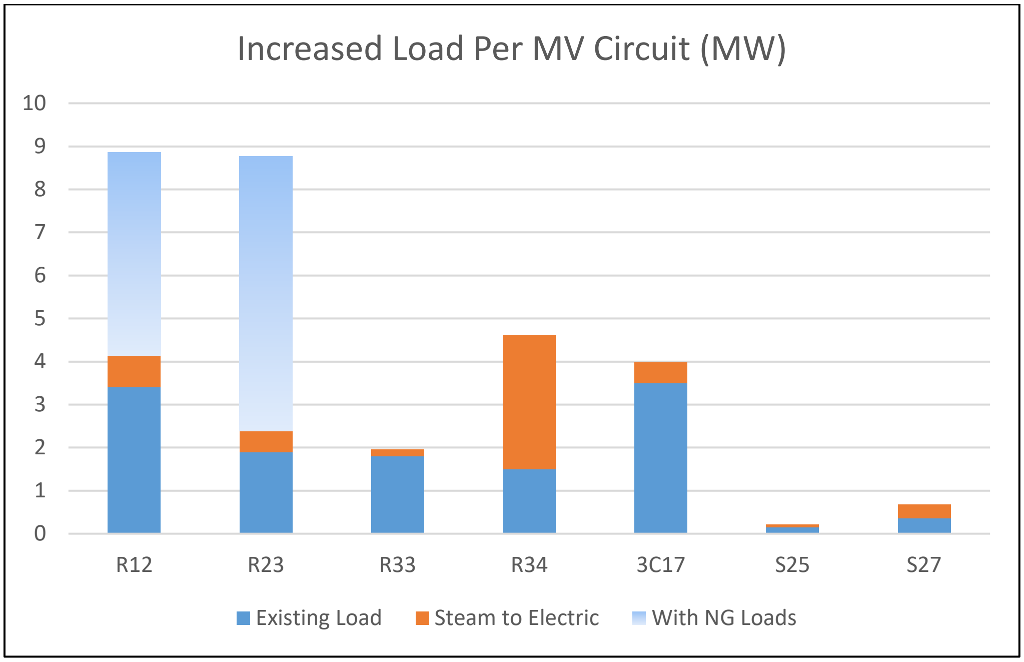

Figure 3.4.2 – MV Circuit Load Increases with NG Loads Included

3.5. Cost Analysis

3.5.1. Installation Costs

The installation costs per building were estimated based on quotes received for the installation of new electric steam boilers within the building based on the kW ratings calculated. The values shown in the table were calculated on a pro-rated basis per kW after initial calculations for Bradfield and Emerson Hall were completed. In order to refine these numbers to make them more accurate, additional information on a building by building basis will be needed in the future.

The numbers in Table 3.5.1 below include costs of the boiler equipment, an associated controller, water treatment installation, piping and electrical circuit installation. The figure below do not include additional electrical infrastructure upgrade costs. In the cases for Stocking Hall, Wing Hall and Uris Hall, electrical upgrades will need to be installed to accommodate the additional loads. These upgrades would include a new medium voltage switch, transformer and secondary distribution equipment. The switches and transformers could cost as much as $100,000 to $150,000 depending on options and sizes. Secondary equipment will range from $50,000 to $150,000.

Building	Installation Costs
Bradfield/Emerson Hall	$ 180,000
Duffield Hall	TBD
Guterman	$ 206,000
Federal Nematode Lab	$ 26,000
Morrison North	$ 26,000
Physical Sciences North	TBD
Plant Science	$ 137,000
Riley Robb	$ 69,000
Stocking Total	$ 962,000
Tower Road Yellow Greenhouse	$ 69,000
Tower Road Green Greenhouse	$ 69,000
Uris Hall	$ 206,000
Vet Research Tower	$ 146,000
Wing Hall	$ 135,000
Wing Hall Wing	$ 71,000
Total	$ 2,302,000

Table 3.5.1 – Estimated Electric Steam Boiler Installation Costs
(Campus Steam sourced process steam loads only)

3.5.2. Operational Costs

Operational costs for all of the buildings listed in Figure 3.5.1.1 range from $400,000 to $600,000 per year based varying usages from 4-6 hours a day at $0.075/kWh. These costs are based on the existing utility rate that power is purchased from NYSEG, which is what the cost would be to Cornell University. Cornell Utilities sells power to campus customers at a slightly higher rate to cover Capital Projects, operation and maintenance.

3.5.3. NG Boiler Replacements

3.5.3.1. Installation Costs

Installation costs for the replacement of the gas boilers were not calculated for the purpose of this study. The cost to install a new electric service and associated infrastructure at Weill Hall alone is estimated at $800K - $1M. The installation of this equipment is unfeasible at this time.

3.5.3.2. Operational Costs

Operational costs per year for the natural gas boiler replacements at ECRF, VMC and Weill Hall are estimated at $855K. This is based on 11MW, running for 4 hours a day at $0.075 per kWh. The equivalent cost for using natural gas at the current rate of $0.29 per therm would be $113K, $160K at the NYSEG rate of $0.41 per therm.

3.5.4. Electric Generation vs Natural Gas Costs

3.5.4.1. Utility Costs

Cornell University currently spends about $8M on natural gas every year to produce electricity. Campus consumption per year is an average of 215 million kWh, this includes both the power produced at the CCHPP and the power imported from NYSEG. If the plant were to switch from using natural gas to produce that power and pay for the entire load to be delivered by NYSEG at the current rate of $0.075 per kWh, the power would cost a little over $16M. This is an increase of over $8M for campus power. With the upcoming 6% rate increase scheduled for May 2020 the cost would be $17M, over $9M more than what it costs to produce at the CCHPP.

It is possible that the campus could be re-classified by NYSEG as a customer if we no longer produced our own power on site. This re-classification has still not been determined at the date of this study but costs for power could increase as much as 20% in the future if we were to only import electric from NYSEG and stop using natural gas to generate any power (Mark Howe, Jeff Lapar, personal communication, December 2019). A 20% increase in rates would translate to a $19.4M electric bill per year.

The NYSEG electric bill for Maple Ave Substation, which is for all the power Cornell's campus imports monthly, is currently offset by Cornell's Musgrave Farm East Photovoltaic Installation (Pam Anderson, Cornell University Finance, personal communication November 2019). Using the past two years of historical data for the kWh produced by the 2MW installation and the credits (in dollars) given to Cornell from NYSEG, two different rates were calculated. Based on this information, the first rate was the cost per kWh Cornell pays the developer for power produced by the solar farm, which is about $0.10 per kWh. The second number was calculated to find the amount of dollars per kWh that NYSEG credited back to the University, which is just under $0.14 per kWh. This means that under the current rates, Cornell is getting more money back from the installation that it pays for it. This will change as the purchase agreement with the developer climbs above $0.14 per kWh over time. Every five years the rate of cost increases about 7-8%.

If importing the entire power from campus from NYSEG would cost $16M and Cornell wanted to offset the cost increase of $8M with a solar farm similar to the Musgrave East PV installation, it would have to be sized at 38MW to cover the difference. That size increases to 42MW with the upcoming rate increase. To cover the entire bill as Cornell currently does, these numbers jump to 74MW and 79MW, respectively.

Considering the calculated load increase on campus for the electric steam generation of 5.4MW added to these hypothetical costs, the price to purchase power would be $16.5M at today's rate and $17.6M with the upcoming rate increase. Solar farm offsets for these costs would be 76MW and 80MW, respectively.

Operational costs per year for the natural gas boiler replacements at ECRF, VMC and Weill Hall are estimated at $855K if they were put in at today's rates. This is based on 11MW, running for 4 hours a day at $0.075 per kWh. This cost increases to $910K when factoring in the NYSEG rate increase. The equivalent cost for using natural gas at the current Cornell purchase rate of $0.29 per therm would be $113K vs $160K at the NYSEG rate of $0.41 per therm.

3.5.4.2. Usage and Demand

As stated previously, the existing campus demand peaks around 30MW. If we added the proposed electrical steam generation to replace the campus steam loop generated process steam, the added 5.4MW would make the peak about 35MW. There is a project in progress on Cornell University North Campus which is adding an estimated 5MW peak. The ideal loading at the Maple Avenue Substation is under 40MW, which is referred to as the firm capacity because cooling isn't required and we still have on 20MW transformer in reserve. This allows for maintenance on one transformer while the other two can handle the campus electrical load. After the North Campus project finishes and we consider adding the electrical steam generation the load is peaking at the 40MW mark we want to limit the campus to.

If we consider the natural gas boilers to be replaced, the campus peak load would climb another 11MW. The ideal loading at the Maple Avenue Substation is under 40MW, which is referred to as the firm capacity because cooling isn't required and we still have on 20MW transformer in reserve. This allows for maintenance on one transformer while the other two can handle the campus electrical load. By adding the 11MW of load, the total load would exceed the 40 MW of firm capacity that is preferred at the Maple Avenue Substation. If that was to happen, additional changes would need to be considered at the substation and utility service level.

4. Conclusions and Recommendations

All of the buildings that utilize the campus steam distribution for process steam in the following list have services large enough to add electric steam generation:

- Bradfield Hall
- Duffield Hall
- Emerson Hall
- Federal Nematode Lab
- Morrison Hall
- Physical Sciences Building
- Plant Science Building
- Riley Robb
- Tower Road Greenhouses
- Vet Research Tower
- Wing Hall Wing

Further investigation will be required to address additional factors of circuit breaker availability to provide power to the units, available floor space in the buildings for electrical equipment installations and additional water treatment equipment.

Guterman Lab

As stated previously, the ongoing design in progress will address this load.

Stocking Hall

The existing electrical service can be used to provide power to the loads for the Winery and Stocking West. The other two loads for the Pilot Plant and The Dairy will require a new transformer and switchboard. In order provide another transformer, an additional medium voltage switch will be required in the building as well. There is some space in the basement and in the dairy to accommodate the steam generators. Additional space will be needed for electrical equipment.

Uris Hall

There are two options to accommodate the load at Uris Hall. The first option is that the existing 150 kVA, 480 Volt transformer can be upgraded to a 750kVA transformer to serve the existing building loads and the additional electrical steam generation. The other option is to add a 750kVA transformer via the spare switch-way on the newly installed medium voltage switch.

Wing Hall

With the proposed additional electrical steam generation exceeded the existing service size by over 50%, the service will require an additional transformer and switchboard. Aside from consolidating and scheduling autoclave use to reduce the peak load, the building may need to consider sharing autoclaves with Wing Hall Wing, which is attached. Meetings with the end users will be needed to determine any future options.

Natural Gas Boilers at ECRF, Weill Hall and VMC

After reviewing not only the electrical service and infrastructure costs but the magnitude of changes required to change these boilers to electric it is recommended that the natural gas boilers remain in place. An option to make these carbon neutral would be to install solar or wind to offset the gas usage. Using the same figures as the East Musgrave Solar Installation discussed in Section 3.5.2.2, a solar farm of approximately 8MW would offset the usage of natural gas load at an estimate runtime of 8 hours a day. Another option would be to purchase the carbon credits to offset the usage, which would be roughly $25,000 per year, until other sustainable fuels are available. This calculation is based on the boilers producing 4,140 tons of carbon (if run 8 hours a day) and using $6 per ton cost from Regional Greenhouse Gas Initiative (RGGI). Cornell does not belong to RGGI but the cost is used for this purpose (David Frostclapp, Cornell University Engineer, personal communication, December 2019). If we consider the social cost of carbon to keep the boilers running, which is around $50 per ton, the cost is closer to $210,000 per year.

The long term goal for these loads will be to source a renewable natural gas or biogas. Neither of these are currently available but may be in the future. Cornell University is looking into options for the future.

5. Future Considerations to Study

Over the course of the study many topics came up as possible items to further investigate in the future. The following items should be considered:

- Emergency power distribution impacts by switching process loads to electric. Loads that are critical may need to be added to the generators or new generators may need to be installed to accommodate the load.
- Domestic hot water was not included in the study and it was mentioned by multiple building coordinators during discussions. It was assumed that the new Earth Source Heat would generate the domestic hot water at buildings but this will need further investigation. If the ESH isn't able to provide the domestic hot water, additional electric may be needed.
- Added HVAC cooling loads due to adding transformers and equipment into buildings will need to be considered. With added heat rejection of equipment, the AC load will increase which also increases the electrical load.
- Consolidation of autoclave use should be investigated in the future. Most users prefer having their own autoclave for convenience. If some of the uses could be combined and reduce the overall electrical peak, the demand would be reduced. Additional meetings should be held to stress the importance of this in the future.
- Additional options for reducing the amount of electricity required to provide process steam, e.g, for autoclaves, could be considered. For example, the low temperature hot water loop might be used to preheat the intake water for the autoclave so that the electrical boost needed might be reduced. Similarly, heat pumps might be used to reduce the amount of electricity required.
- Changes to the way electrical energy is used and controlled might be introduced in response for the growing demand for electricity as the campus becomes increasingly electrified. For example, new protocols might come into place to constrain peak usage of electricity for non-life-critical applications such as autoclaves. Also, Cornell Utilities could institute demand charges to encourage campus customers to flatten out peak energy usage.

6. Exclusions and Assumptions

Exclusions and assumptions for this project included the following:

- Natural gas usage not related to steam generation was not included in this study.
- Development of specific hardware designs is in general outside the scope of the project. This project is a systems-level feasibility study focused on systems integration, so it is not the intent to develop all-new technologies. Instead, the systems design is built out of existing, off-the-shelf component designs. An exception may be made if suitable steam generation technology cannot be found and the best option is for Cornell to work with a supplier to develop a new device from the ground up.

- All stakeholders studied by the team are assumed to acting in good faith and to be truthfully stating cost or performance characteristics of any system in which they have an interest.
- For projects where political or social barriers may bring into question the overall feasibility of a proposed technology or system, it is not the responsibility of the team to overcome such limitations, as the primary focus of the study is technical and economic. The team should state that such barriers exist where they are identified. Thereafter they can leave off further discussion, or optionally probe these political/social barriers for possible solutions.

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