Verification and Validation of Performance, Dissemination of Best Practices in District Energy Systems

Combined Heat and Power/District Energy System Portfolio Meeting
Southwest Research Center San Antonio Tx
June 7, 2022

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Henry Johnstone PE
Technical Analyst

INTERNATIONAL DISTRICT ENERGY ASSOCIATION

International District Energy Association

IDEA

Founded: 1909

3700+ Active Members in 27 Countries

Education, Best Practices, Peer Exchange, Advocacy

Conferences & Trade Shows, Magazine, Webinars

INTERNATIONAL DISTRICT ENERGY ASSOCIATION

https://www.districtenergy.org/resources/resources/system-maps

Project Particulars

Federal Agency/ Organization Element: DOE/EERE/ Advanced Manufacturing Office (AMO)

FOA Name and Number: Emerging Research Exploration (FOA-0001465)

Award Number: DE-EE0009142

Award Type: Cooperative Agreement

Project Title: Verification and Validation of Performance with Dissemination of Best Practices in District Energy and CHP for Enhanced Resiliency, Energy Efficiency and Cybersecurity

Recipient Organization: International District Energy Association

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Stated Goals and Objectives

Project Goals/Objectives:
This project aims to analyze, validate and verify actual performance data of existing district energy systems and identify industry best practices for: Incorporating efficient CHP systems and community-based microgrids (MG); Integration of renewable, intermittent energy sources and thermal energy storage (TES); and enhanced cybersecurity of highly networked DE systems.

The project aims:

- increase stakeholder awareness of the role of district energy, CHP and microgrid assets in supporting and participating in the grid of the future.

- verify, validate and analyze performance metrics of district energy, CHP and microgrid systems and identify industry best practices.

The project potential:

- help unleash billions of dollars in private investment in critical energy infrastructure and accelerate deployment of district energy, CHP and microgrids in communities across the US as the electricity grid continues to evolve.

Tasks

Task 1: Collect performance data from operational central plants, distribution systems and connected customer buildings in diverse regions and a range of technologies. **Complete**
Task 2: Identify cybersecurity strategies of district energy, distributed generation, and microgrids. **Complete**
Task 3: Analyze, verify and validate performance metrics including system energy efficiency, operational reliability, system availability and resiliency. **In progress**
Task 4: Showcase the impact of best practices in design, asset optimization and operations. **In progress**
Task 5: Produce *Handbook of Thermal Energy Storage (TES) Strategies for Peak Shifting and Carbon Reduction.* **In progress**

Identify Cybersecurity Strategies of District Energy, Distributed Generation and Microgrids

Data has been collected and clarified. System data and cybersecurity best practice data have been prepared for inclusion in the final best practices report

TES Handbook status

- Collect and prepare TES Strategies for Peak Shifting and Carbon Reduction
- Draft table of contents created and revised
- Draft outline created and revised
- Chapter content being finalized
- System examples are being identified

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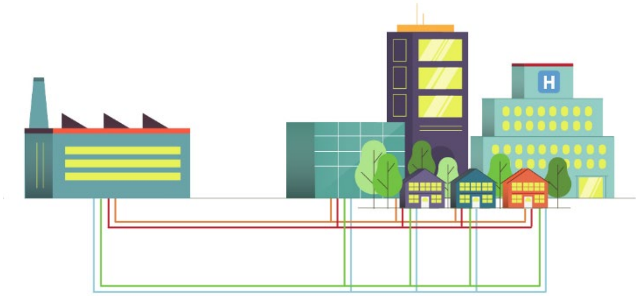
Range of Topics

Cybersecurity

- Third-party security audits
- Fully isolated OT networks
- Air-gapped networks

- Utility controls network security policy
- Physical hardware security
- Regular system compliance checks



Renewables & TES

- TES for peak shifting, optimizing renewable generation
- Geothermal and Geoexchange
- Carbon leading buy/make/sell decisions
- Research collaboration on campus
- CHP as a key enabling technology for decarbonization

CHP & Microgrids

- Steam to hot water conversion
- Reclaimed water usage
- Phased electrification
- Highly integrated data and controls systems
- Plant and building-based optimization projects
- Innovative approaches to grid integration
- System hardening and analysis for resiliency

Management

- Comprehensive master planning
- Energy Savings teams
- Campus academic collaboration

- Extensive & holistic training
- Wholesale market participation
- Leadership championing

Site Selection

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Site Profiles

site #	State	Sector	DH-Steam Capacity (pph)	DH-HW Capacity (MMBtu/hr)	DC Capacity (tons)	CHP Capacity (MW)	Solar PV Capacity (MW)	TES - CHW Usable Tank Volume (Mgal)	TES-CHW Discharge Capacity (tons)	TES-Delta T (DEG F)	TES-CHW Discharge Capacity (ton-hours)
1	DC	Government									
2	PA	College/University									
3	OH	College/University									
4	NJ	College/University									
5	MO	College/University									
6	NE	College/University									
7	TX	College/University									
8	OH	College/University									
9	TX	Healthcare									
10	NC	College/University									
11	GA	College/University									
12	WI	Healthcare									
13	VT	College/University									
14	FL	College/University									
15	CA	College/University									

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Site Performance

Best Practice Sites for Strategies and Opportunities for Verification & Validation of CHP & District Energy

System Performance Indicators

- Improve System Energy Efficiency
- Provide Peak Load Shaving, Demand Response from TES
- Improved Chilled Water Delta T and Rightsizing Capacity to Accommodate Growth
- Increase Availabilty and Reliability with CHP
- extra: Increase Heat Recovery/CHP

State	Site #	Best Practice Sites	Optimizing Chilled Water Systems	Conversion from Steam to Hot water	Use of CHP	Boiler and Heating System Modernization	Distribution System Improvements (Tunnels, Leak Detection, Insulation, etc.)	Chilled Water System Design and Optimization	Integration of Thermal Energy Storage (TES)	Advanced Metering, Monitoring, and System Optimization	Redundancy and Resiliency Measures for Avalability and Reliability
DC	1	Government									
PA	2	College/University							CHW TES		
OH	3	College/University							CHW TES		
NJ	4	College/University							CHW TES		
MO	5	College/University									
NE	6	College/University							CHW TES		
TX	7	College/University							CHW TES		
OH	8	College/University									
TX	9	College/University							CHW TES		
NC	10	College/University							CHW TES		

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Surveys

INTERNATIONAL DISTRICT ENERGY ASSOCIATION

2019 IDEA District Energy, CHP, Microgrids

CAMPUS & DOWNTOWN Systems and Operations Questionnaire

Date:

Applicant Name | Applicant Organization

Overview

Your completing this questionnaire will help IDEA in our efforts to educate important stakeholders and advance the district energy industry in North America. Please fill out the sections that are relevant to your system.

Data Confidentiality

The capacity data provided to IDEA by respondents will be made publicly available in detail or aggregate form. Operational and performance data will be treated as confidential, and system identity will be anonymized. Any analysis of such data will only be provided in the aggregate.

Thank you for your contribution.

Response Deadline: February 19, 2021

Instructions

a) Please download the Questionnaire from the IDEA website at <Jason to insert URL of location>

b) Please complete the sections of the questionnaire that apply to your system.

c) Please save the completed Questionnaire Excel file with your Organizations name **e.g. MIT_2019_data.xlsx** and send by email to **data.idea@districtenergy.org**

d) Please send in any questions you may have to **data.idea@districtenergy.org**

e) The Questionnaire has the following sections:

1. Contact Information
2. System Name and Location
3. Ownership Type and Ownership Model
4. System Overview
5. Generation Capacity
6. Central Plant Generation Equipment
7. Central Plant Distribution
8. Annual Production and Fuel

e) Please click on any of the section boxes below to navigate directly to that specific section.

1. Contact Information | 2. System Name and Location | 3. Ownership Type and Operational Model

4. System Overview | 5. Generation Capacity | 6. Central Plant Generation Equipment

7. Central Plant Distribution | 8. Annual Production and Fuel

6.Central Plant System Generation Equipment

Please fill in cells, color coded in white.

STEAM Generation Equipment

Primary Generation Equipment Type	Energy Input Type (Biomass, Electricity, Natural Gas, No. 6 Fuel Oil, Waste to Energy, Geothermal, Other)	Nameplate Capacity	Unit (lbs/hr – pph or MMBTU/hr) Please indicate below
Boiler 1	NG & No.2 Fuel Oil (ULSD)	179.7 MMBtu/hr	125kpph
Boiler 2	NG & No.2 Fuel Oil (ULSD)	162.1 MMBtu/hr	125kpph
Boiler 3	NG & No.2 Fuel Oil (ULSD)	162.1 MMBtu/hr	125kpph
Boiler 4	NG & No.2 Fuel Oil (ULSD)	39.8 MMBtu/hr	35kpph
Boiler 5	0		
Boiler 6	0		
Boiler 7	0		
Boiler 8	0		
Boiler 9	0		
Heat Recovery Steam Generator (HRSG)	NG & No.2 ULSD	128 MMBtu/hr	100kpph

HOT WATER Generation Equipment

Primary Generation Equipment	Energy Input Type (Biomass, Electric, Natural Gas, No. 6 Fuel Oil, Waste to Energy, Geothermal, Other)	Nameplate Capacity	Unit (lbs/hr – pph or MBTU/hr) Please indicate below
Hot Water Generator 1	N/A	N/A	N/A
Hot Water Generator 2	N/A	N/A	N/A
Hot Water Generator 3	N/A	N/A	N/A
Hot Water Generator 4	N/A	N/A	N/A
Hot Water Generator 5	N/A	N/A	N/A

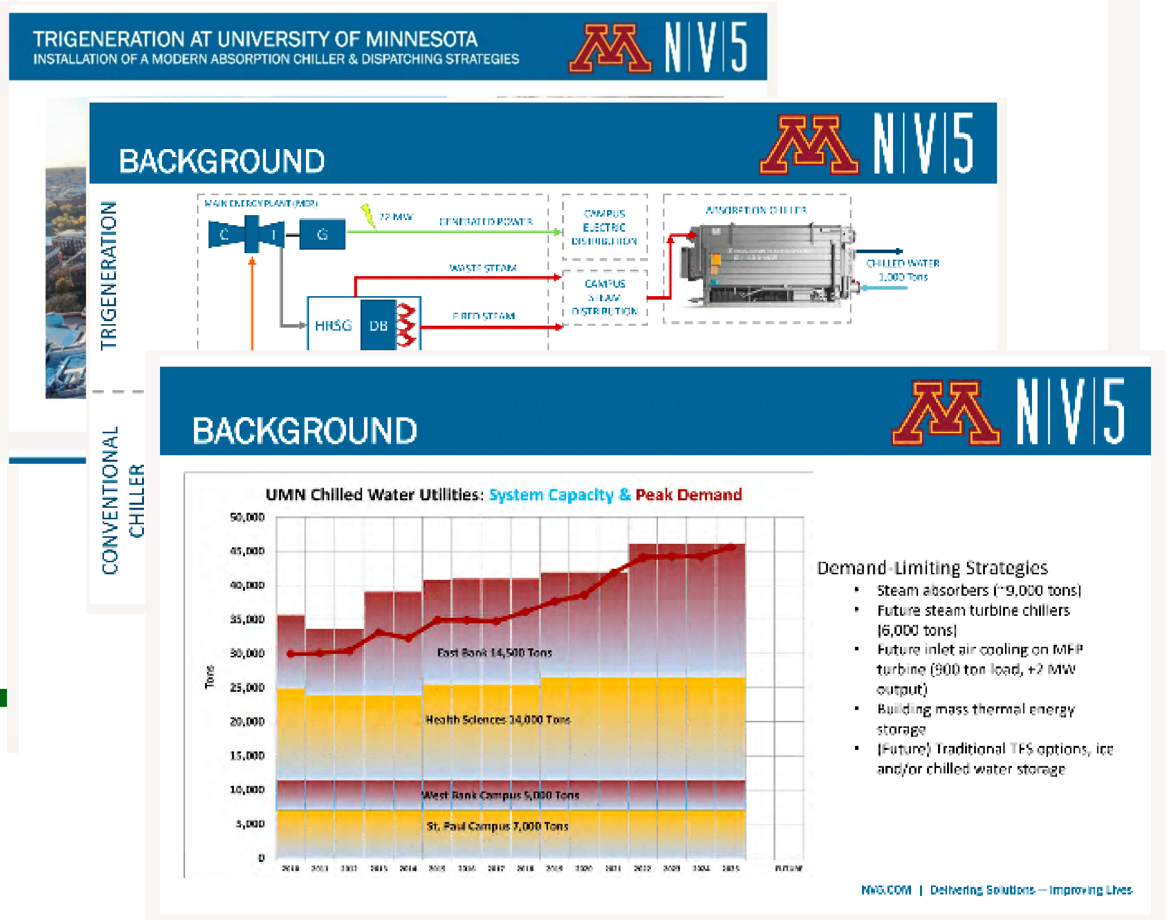
CHILLED WATER Generation Equipment

Primary Generation Equipment	Chiller Type (Electric Centrifugal, Steam Centrifugal, Frictionless Centrifugal, Screw Driven, Absorption, Gas Engine)	Nameplate Capacity (tons)
Chiller 1	Electrical chillers	15891
Chiller 2	Absorbtion chillers	5358
Chiller 3		
Chiller 4		
Chiller 5		

ELECTRICITY Generation Equipment

Equipment Type	Name Plate Capacity (MW)
Gas Turbine	11MW
Steam Turbine	6MW
Solar PV	5MW
Wind Turbine	N/A
Diesel (non - emergency)	N/A
Recip Engine	N/A

IDEA Database



Rich Background Information

IDEA Conference Proceedings
District Energy Magazine Articles
Conference Plant Tour Materials
DOE TAP Profiles
IDEA System of the Year Submissions

Interviews

IDEA Team
Scott Szycher
Sarah Theurkauf
Henry Johnstone

Participant Team –
Utilities Directors, Plant Operators, Energy Engineers

A free flowing discussion:
Verify/clarify/fill in survey data
Current System configuration and recent improvements

Organization and Management Structure

Building loads and energy conservation strategies

Utility interface issues

Sustainability and pressures to decarbonize

Water consumption

Funding sources and pressures

Technical and Management Best Practices

Interviews and Written Summaries

System Performance Best Practices

Pennsylvania State University, Hershey Medical Center – Hershey, PA

Climate Zone	5
Cooling Degree Days	1448
Heating Degree Days	4428
ISO	PJM
Local Utility	PPL electric
2018 State Energy Intensity	5.6

System Profile

Penn State Hershey Medical Center is a 550 acre, 548 bed medical school and hospital campus located in Hershey Pennsylvania. The campus includes two hospitals, five institutes, and the Penn State College of Medicine, includes a Level-One Trauma Center, and serves over 1.2 million patients annually. Since 2009, the utilities team has undertaken a comprehensive energy system upgrade to improve reliability and resiliency (critical for a major hospital and research facility) and decrease the overall cost and carbon emissions of the campus. These upgrades have included a major chilled water optimization project and implementation of CHP. Annual energy consumption is about 112,000,000 kWh of electricity and 573,000 mmbtu of natural gas.

The 8 MW natural-gas fired CHP system is based on one combustion gas turbine generator and one heat recovery steam generator with duct firing capability to supply 90,000 lb/hr of steam, most of which is used for climate control, cooking, hot water generation, and sterilization of medical equipment. The CUP provides an additional 180,000 pph of district heating using three boilers. Three chiller plants serve 2.6 million square feet of building space. The central plant uses 8 chillers and two satellite plants use 2 chillers each, for a combined total of 13,300 tons of cooling.

1. **System Efficiency**
   - District Cooling (kW/ton): improved from .83 to .68
   - CHP efficiency improved from 45% to 80%
2. **System Reliability and Availability**
   - No data
3. **TES Reducing Peak Demand**
   - 1,624,040 kWh peak reduction from 1.4 million gallon TES tankk
4. **Improved CHW system deltaT**
   - Before improvements: 10 degrees F, after improvements: 15 degrees F

Technical Best Practices

CHP

4.16 GWh/yr in energy savings, $300,000/yr savings in electrical costs, an electrical demand reduction of 874 kW, and a CO_2 reduction of 3,200 tons/year.

Importantly, the medical center elected to partner with Optimum Energy because OE was committed to working within the constraints set out by the utilities team. As a hospital system with a Level One trauma center, the medical center has extremely specific energy needs that other optimizing products were ill-suited to accommodate. Optimum was willing to work with MHC based on the utilities team's feedback, which led to a much more effective partnership and end product.

Altogether, the medical center's energy efficiency measures saved million pounds of CO_2 emissions through March 2017 and 1.4 million gallons of water annually, earning the US Green Building Council's Central PA Forever Green Award.

Management and Financial Best Practices

TES for Demand Response

Though Penn State Hershey Medical Center initially installed its TES tank to take advantage of off-peak energy rates (the rate structure has since changed), it is now used primarily to participate in PJM's demand response program and prevent disruption in instances where chillers either break down or are taken offline.

Budget Process

Until the early 2000's the medical center's utilities team participated in the same budget request process as the rest of the campus: individual upgrades (new chillers, etc) would be requested from the central budgeting committee, where they would compete for funds against all other requests, which disadvantaged them. As a result, the campus utilities became very reactive, leaving the campus prone to faults. The CFO at the time elected to revise the request process so that utilities would request renewal funding based on baseline performance data, which established a pool of money the utilities team could use to make necessary upgrades.

Grants

The medical center's CHP system was partially funded by a $940,000 grant from the Pennsylvania Department of Community and Economic Development, and qualified for an additional $500,000 incentive through PPL's ACT 129 program.

Leadership

When it came time for Penn State Hershey Medical Center to replace its aging electrical infrastructure, the campus took the opportunity to reinforce the overall system's reliability and resiliency by installing a natural gas fired CHP system. Additionally, adding CHP allowed the campus to extend the life of existing boilers, rather than forcing replacement. As the medical center went through the process of integrating CHP, they also found it useful to replace electric gear in the plant to accept the power being generated from the new system.

CHP generates 54% of the campus power and 96% of the steam load, which reduces the annual utility costs, improves resiliency, and lowers overall campus carbon emissions by 83,120 metric tons. CHP provides the campus with $4 million in annual energy savings. The campus also employs a 1.4 million gallon TES tank.

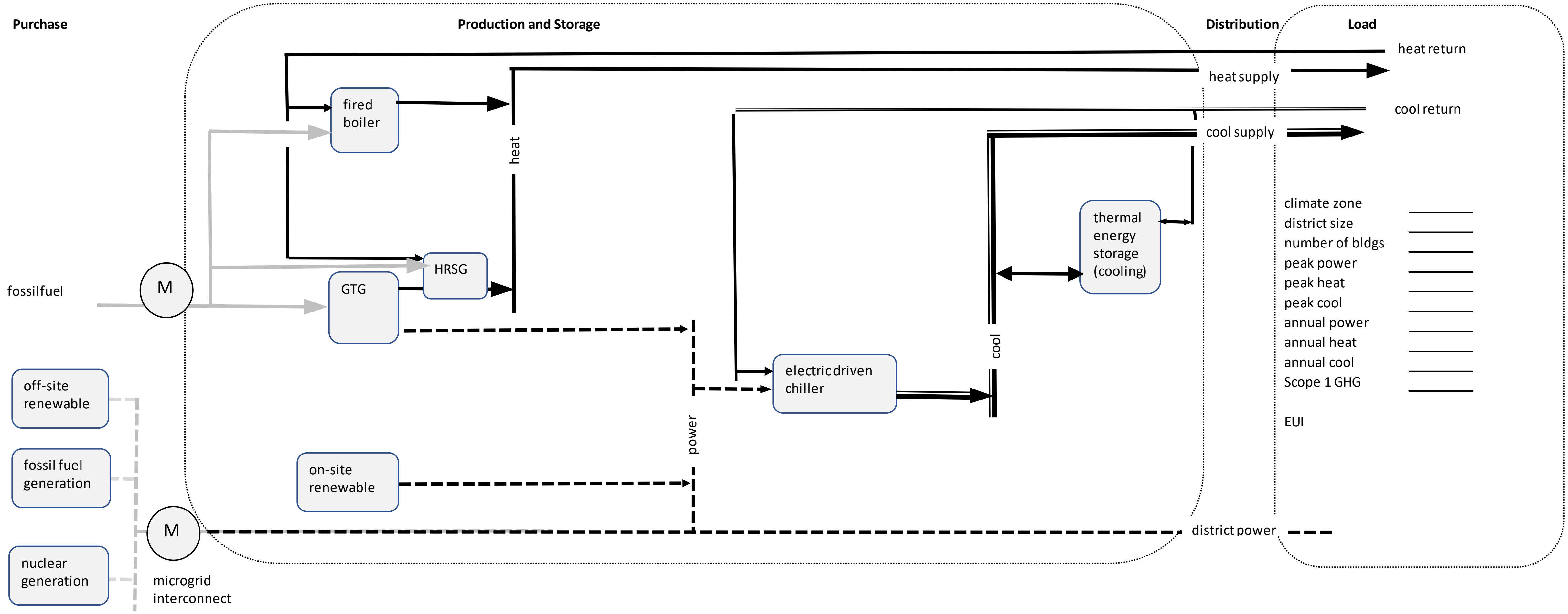
Chilled Water Optimization (Interview plus word doc)

Starting in 2009, the campus utilities team embarked on a comprehensive energy efficiency plan that culminated in the implementation of a high-end cold water optimization program. The plant had not been substantially updated since the late 70s, when energy efficiency was less of a concern, so the chilled water system had a particularly low deltaT (8 degree), limiting the capacity of the installed chillers. In the winter of 2010 the group instituted an aggressive chilled water distribution preventative maintenance plan, which included strainer cleaning and replacement, valve replacement, and adding analog thermometers at air handler coils. They also replaced chilled water coils in older units with newer coils with higher deltaT splits, and sized them appropriately to the load. The also replaced two aging centrifugal chillers with magnetic-bearing centrifugal chillers, each rated to deliver 1,000 tons of cooling. Collectively, pre-optimization efficiency measure reduced the campus's energy intensity by 20%.[1]

Once the mechanical control systems issues were addressed, the medical center moved on to optimization. First, Johnson Controls installed variable-speed drivers on pumps and fans, fully automating the manual plant. The medical center then partnered with Optimum Energy to deploy their OptiCx platform and OptimumLOOP relational control software, which analyzes HVAC data and identifies opportunities to improve efficiency, and then makes equipment adjustments automatically. The system reviews the fully system (all chillers plus the TES tank) as a single unit, and deploys the best combination of technology based on equipment efficiency and cooling demand. Optimization resulted in electrical energy savings of 3,406,337 kWh/yr, and an electrical demand reduction of 183.7 kW. HMC also realized

1 https://www.dropbox.com/home/0DELIVERABLES_AND_AWARD_Henry/40SITES/42PENN%20STATE%20HERSHEY%20MEDICAL%20CENTER_ONEPAGER/PROCEEDINGS_YES?preview=Environmental+Leader+magazine+article+2017+-+PSU+Medical+Center.docx

System Line Diagrams



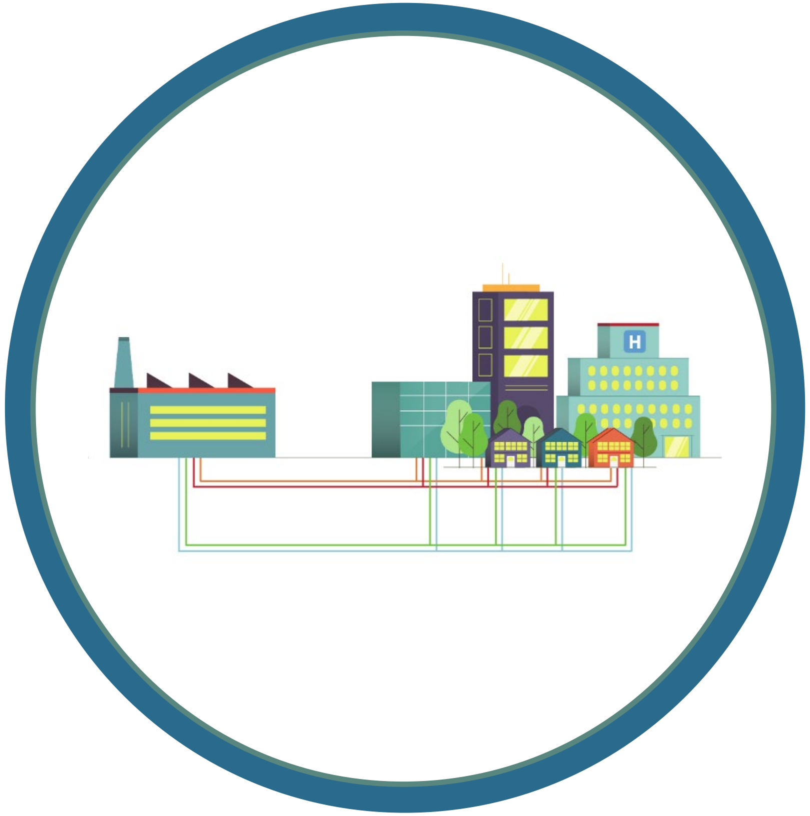
Analysis

- Quantify range, median, best in class performance parameters
- Characterize systems by institution type, load size, climate zone, grid connection…
- Collate common best practice themes within topics of
  - TES
  - CHP and Microgrid
  - Management, Organization and Leadership
  - Cybersecurity
- Identify common constraints and challenges to efficient operation
- Identify opportunities to improve efficiencies and interaction of microgrid
- Review master planning for decarbonization, load growth, deferred maintenance

Emerging Themes (mid point of interview process)

- Evolving use of chilled water thermal energy storage (TES) with renewables for load balance and decarbonization
- Utilizing CHP as key element in system transition to zero carbon emission
- Importance of operations management, organization, and leadership in overall system efficiency
- Integration of building efficiency into DE system optimization


Cybersecurity
Renewables & TES
CHP & Microgrids
Management



Renewables & TES

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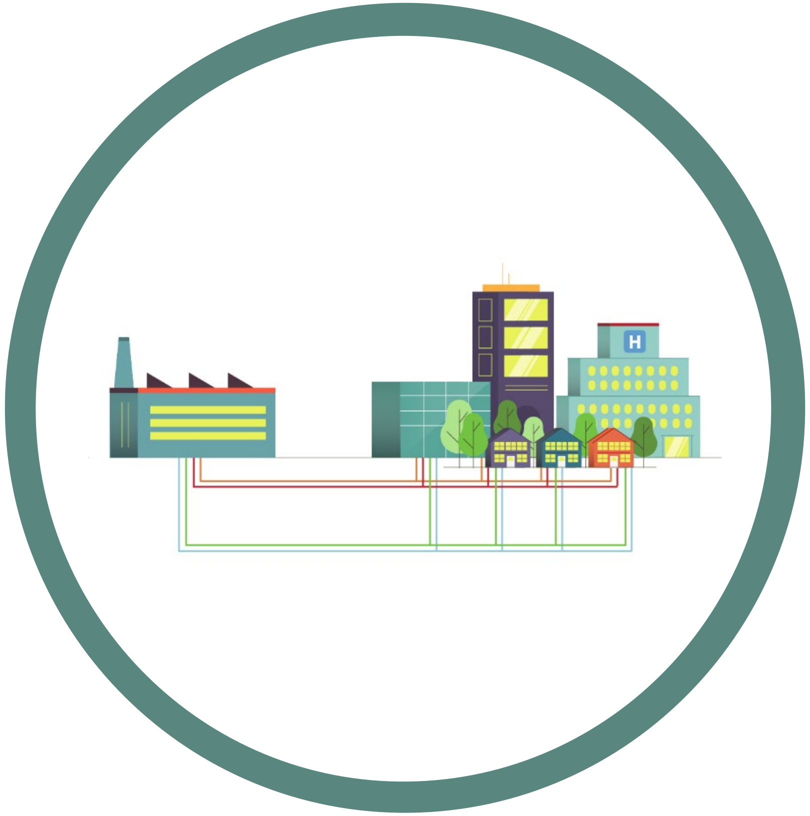

CHP & Microgrids

- Steam to hot water conversion
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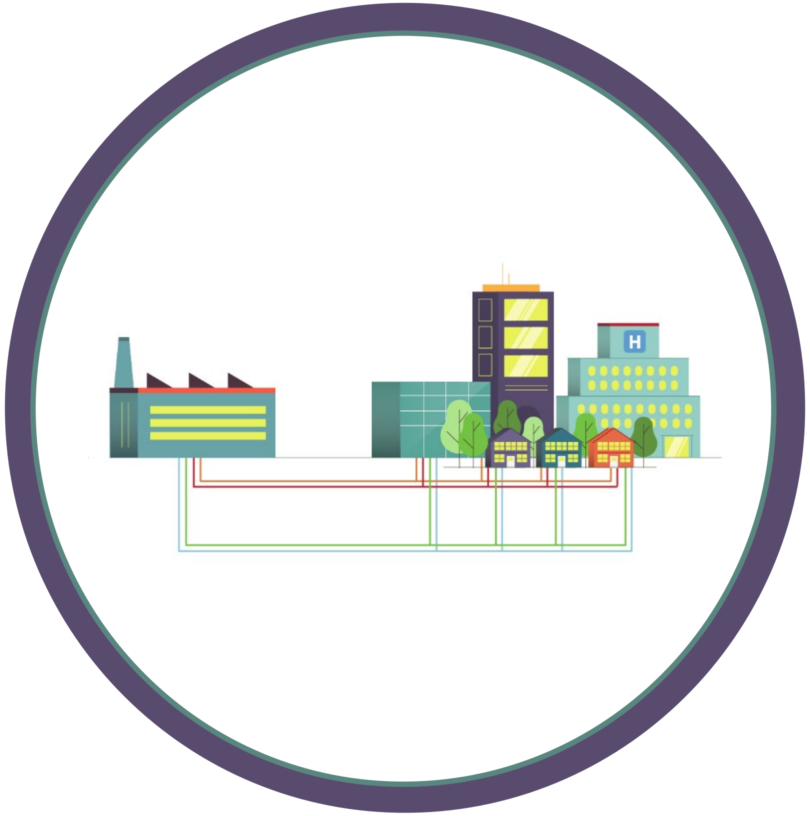


Cybersecurity

- Third-party security audits
- Fully isolated OT networks
- Air-gapped networks
- Utility controls network security policy
- Physical hardware security
- Regular system compliance checks

Best Practice Example:
Impact of Grid Carbon Intensity

ISO New England Operating Parameters:

- Evaluates demand on grid every 5 minutes
- Matches grid demand by choosing lowest cost resources available to operate
- Resources are placed into supply stacks that are called upon to operate when needed
- Stack that is "next in line" to be called upon is referred to as the ***marginal resource***
- Marginal resource sets price of electricity for every 5-minute interval

Average Grid Emission Rate

$$\frac{Annual\ Grid\ Emissions}{Total\ MWH\ Consumed\ (Grid)}$$

*Adoption of renewables does not directly displace fossil fuel burning resources, particularly in periods of higher demand.

→

Time-Weighted Average Marginal Grid Emission Rate

Annual average emission rates from marginal units over a certain time period when load is assumed to be split evenly amongst all operating units (i.e., % of hour marginal).

→

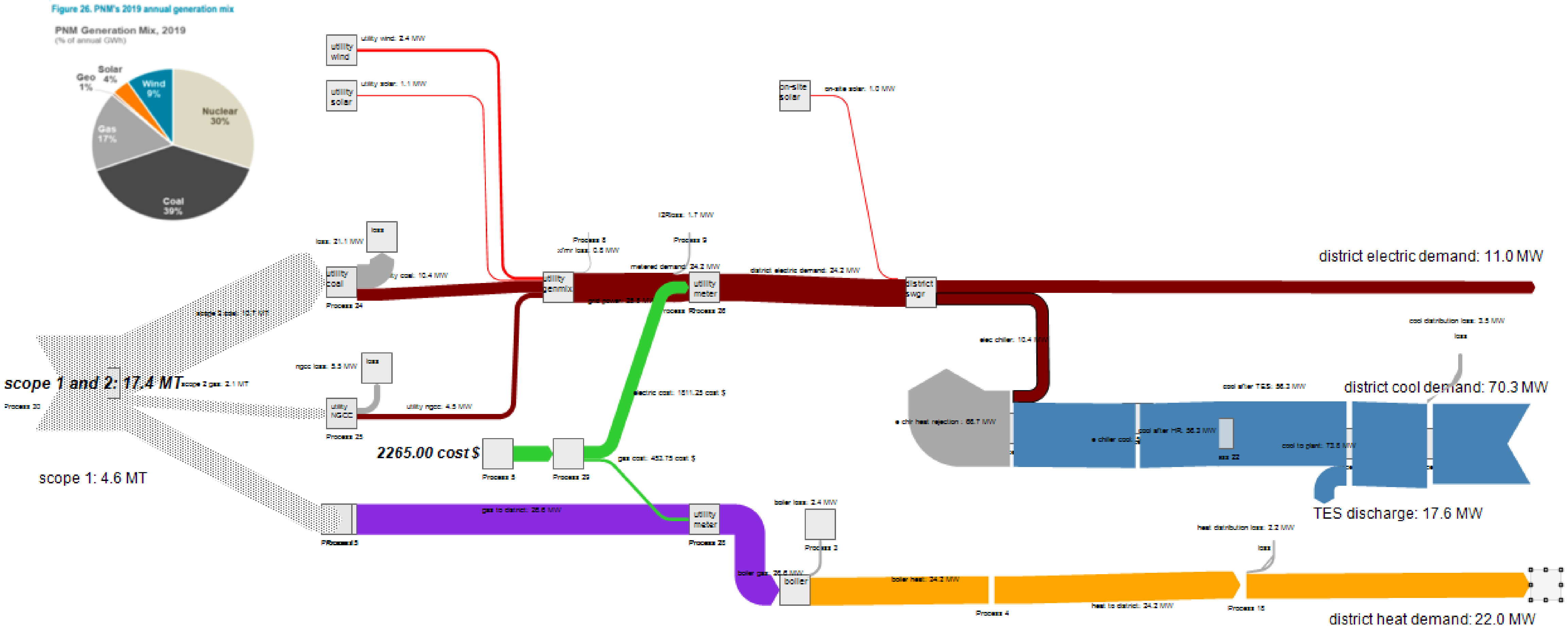
Load-Weighted Average Marginal Grid Emission Rate

Annual average emissions rates from marginal units on calendar year basis. Method weighs marginal emission rate by ***share of load*** served by that marginal resource.

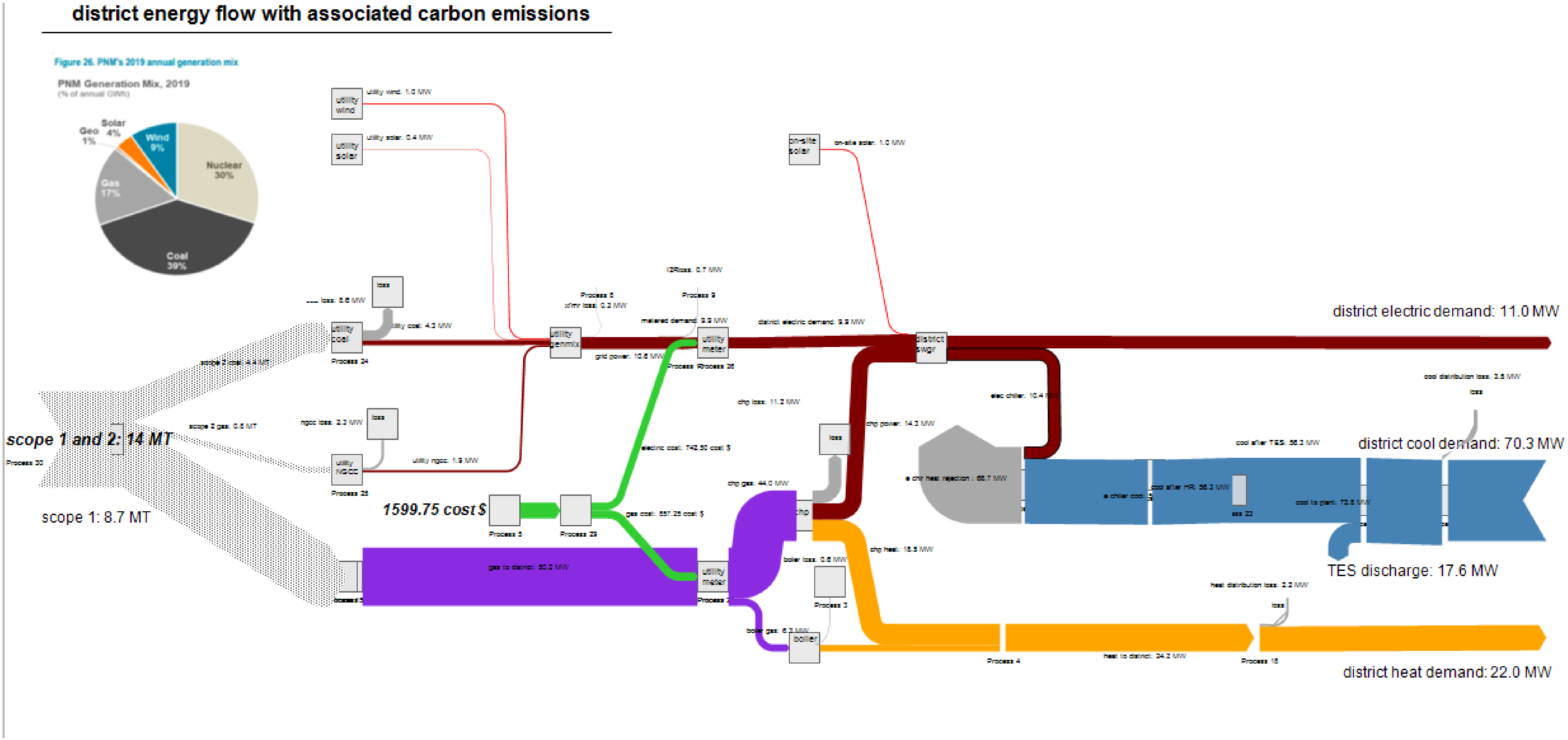
As the grid approaches decarbonization, the methodology for evaluating the grid's carbon intensity will evolve to consider the grid's carbon health during marginal periods of operation (historically more carbon-intensive).

Example

district energy flow with associated carbon emissions



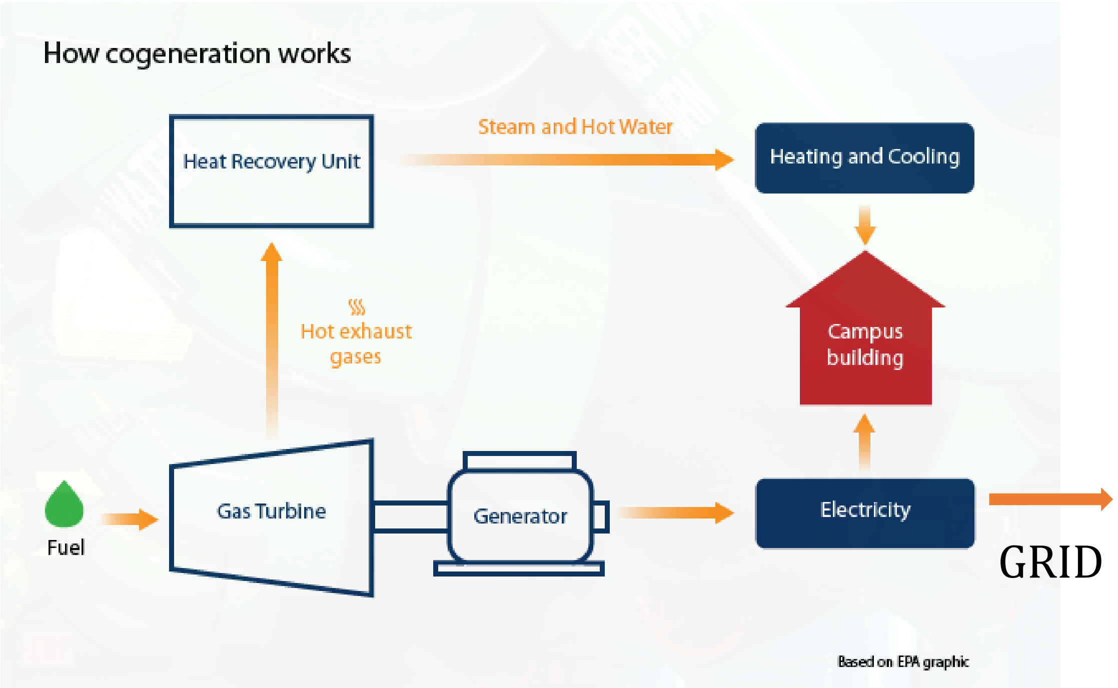
Example



district energy flow with associated carbon emissions
Figure 26. PNM's 2019 annual generation mix
PNM Generation Mix, 2019
Solar 4%
Geo 1%
Wind 9%
Nuclear 30%
Gas 17%
Coal 39%
district electric demand: 11.0 MW
district cool demand: 70.3 MW
TES discharge: 17.6 MW
district heat demand: 22.0 MW
scope 1 and 2: 14 MT
scope 1: 8.7 MT
1599.75 cost $

Best Practice Example
MIT's District Energy System

- Central Utilities Plant (CUP) serves campus electrical, heating, and cooling needs
  - Peak electrical ~38MW
  - Peak steam load ~365 kpph
  - Peak chilled water load ~26,000 tons
- Ability to export to grid when excess power produced (rarely)



Source: EPA

Best Practice Example

High-Level Conclusions

- Based on current understanding and assuming a 3% reduction per year, we anticipate that the CUP will outperform the grid's average emissions for the next 7-8 years. However, there are a lot of factors, and we will have to monitor the situation yearly.
- During peak demand times, the CUP can help offset the marginal unit, which is typically more GHG-intensive.
- Currently, the market costs and GHG values are aligned.
- If done appropriately, we can optimize costs and GHG without compromising resiliency for the campus.

Questions?

rob.idea@districtenergy.org

- IDEA Video

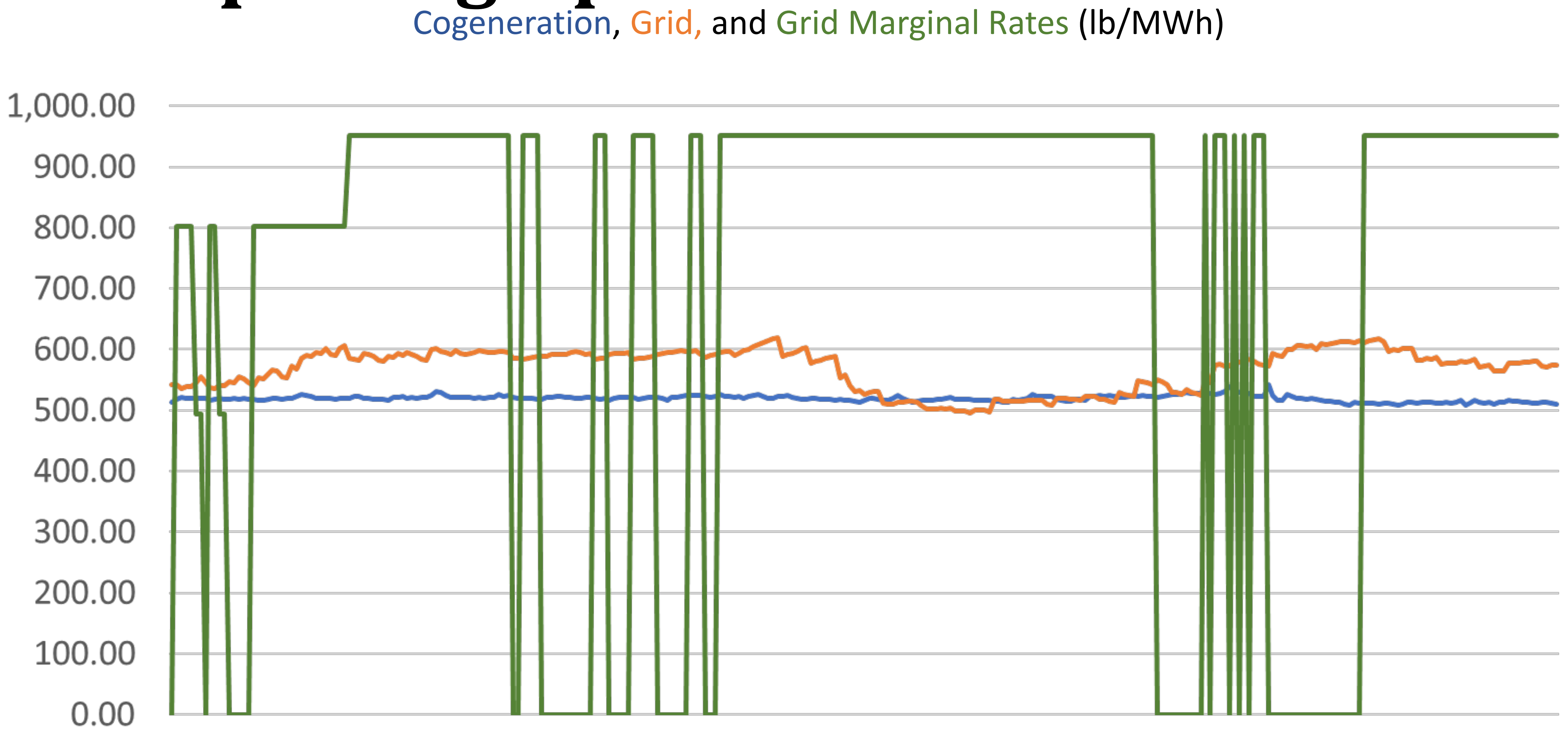
Example
Serving Campus / Exporting to Grid

Carbon accounting for serving campus load accounted for

Carbon implications for exporting MWh to grid during high grid carbon under discussion

*Common scenario for microgrids designed for resiliency, sized for peak power loads – ability to inject in shoulder/winter months

Example
Exporting Operation - GHG Evaluation



12/14/21 – 12/15/21 Real Time Trends