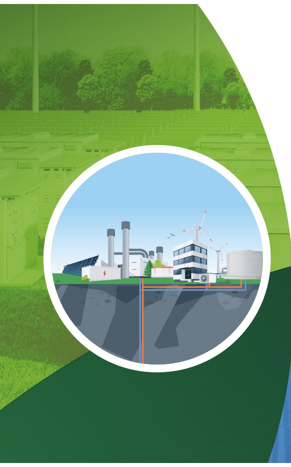


Onsite Energy Technical Assistance Partnerships
U.S. DEPARTMENT OF ENERGY
Midwest

Understanding and Quantifying the Decarbonization Benefits of CHP in Campus District Energy Systems: University of Missouri Case Study

Graeme Miller, University of Illinois Chicago
Jim Wilbur, University of Missouri

February 2024

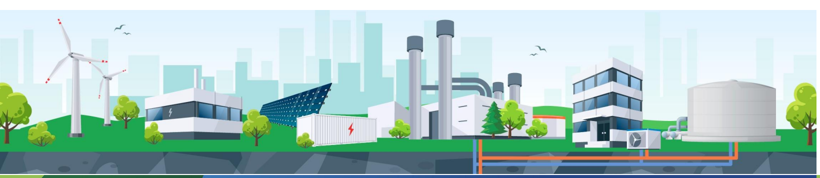
Agenda

- New Onsite Energy TAP Introduction
- Overview of the University of Missouri's Physical Plant
- University of Missouri Carbon Analysis
- Questions

Onsite Energy Program

The U.S. Department of Energy's (DOE) Onsite Energy Program provides technical assistance, market analysis, and best practices to help industrial facilities and other large energy users increase the adoption of onsite clean energy technologies.

battery storage | combined heat and power | district energy | geothermal | industrial heat pumps | renewable fuels | solar PV | solar thermal | thermal storage | wind



Onsite Energy Technical Assistance Partnerships (TAPs)

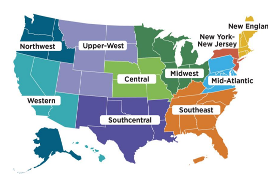
DOE's 10 regional Onsite Energy TAPs provide technical assistance to end users and other stakeholders about technology options for achieving clean energy objectives. Key services include:

Technical Assistance: Screen sites for opportunities to implement onsite energy technologies and provide advanced services to maximize economic impact and reduce risk from initial screening to installation to operation and maintenance.

End-User Engagement: Partner with organizations representing industrial and other large energy users to advance onsite energy as a cost-effective way to transition to a clean energy economy.

Stakeholder Engagement: Engage with strategic stakeholders, including utilities and policymakers, to identify and reduce barriers to onsite energy through fact-based, unbiased education.

Onsite Energy Technical Assistance Partnerships
U.S. DEPARTMENT OF ENERGY



https://betterbuildingssolutioncenter.energy.gov/onsite-energy/taps

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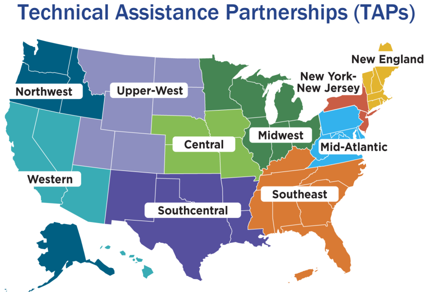

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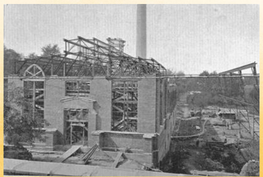
University of Missouri Onsite Energy System

MU'S DISTRICT ENERGY HISTORY

To support the growing campus, a new power plant started construction in 1921, and began operation in 1923 at its current location.

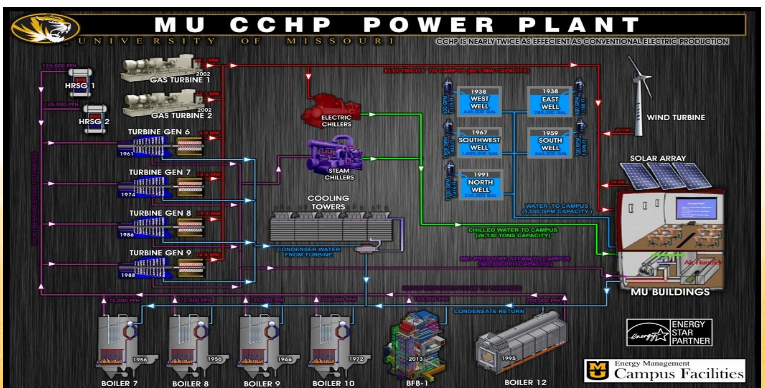


January 3, 1923 the Power Plant begins operation.

COMPREHENSIVE UTILITY OPERATION

- 66 MW Electric Generation Micro Grid
- 40 MW 69KV Transmission Connection
- 1,100,000 lb./hr. Steam Capacity
- 4 Million gal/day Drinking Water Capacity
- Fully metered and automated

Serving all Mizzou's utility needs!

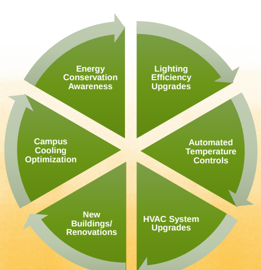


MU'S DISTRICT COOLING

- 34,000 Tons Chilled Water Capacity
- Two Independent CW Loops- Main Campus and Research Commons
- 34 Chillers with mixture of steam and electric driven chillers
- Underground distribution and looping
- N+1 Operational availability practice
- Proactive maintenance practices
- 100% utility availability

Fully automated and optimized ensuring highly reliable, resilient, and cost efficient service!

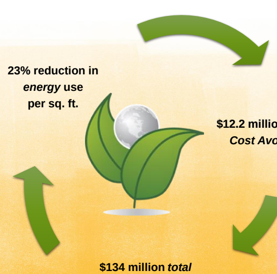
ENERGY CONSERVATION PROGRAM



MU's self managed energy conservation efforts began in 1990

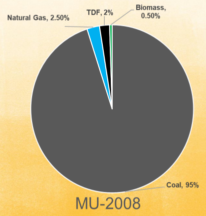
ENERGY CONSERVATION SUCCESS SINCE 1990!

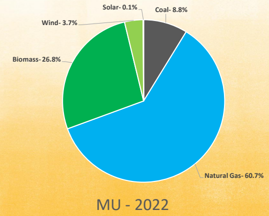
Energy conservation has reduced energy costs in existing space by an average of 1.5% annually



A portion of the savings is re-invested into new projects with returns averaging about five years or better.

FUEL PORTFOLIO SHIFT





RENEWABLE ENERGY

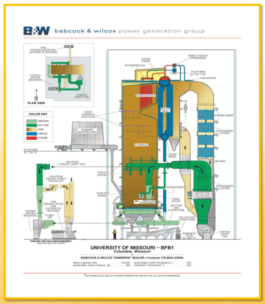
Wind Energy
PPA Wind and On-Campus

On-Campus Solar PV and Solar Thermal

Biomass Combined Heat & Power

Our on-site renewable technologies are education resources for students!

BIOMASS COMBINED HEAT AND POWER



- ***Fuel Flexibility***
- ***Energy Price Stability***
- ***Reduced Emissions***
- ***Advances Campus Sustainability***
- ***Teaching and Research Opportunities***
- ***Missouri Economic Development***

MU ENERGY SUSTAINABILITY SUCCESS!

2023

- Mizzou is generating or purchasing more than 30% of the campus electricity from renewable sources. (EPA Green Power partnership requirement is 3%)
- MU is No. 2 in on-site green energy generation among colleges and universities.
- MU is No. 9 in green energy on-site generation behind Apple, Wal-Mart, US DOE, State of California, and University of California System
- MU is No. 22 in amount of green power used among higher education institutions.

EPA GREEN POWER PARTNER

EPA GREEN POWER Leadership Award Winner 2017

WHAT'S NEXT FOR DISTRICT ENERGY?

Hydronic Thermal Storage

Parking Solar

Wind

Recyclable Fuels

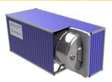
Battery Storage

Rooftop Solar

Clean Burning Hydrogen

Linear Generators

Thermal Storage for Steam



Micro Nuclear

Waste Water Heat Recovery

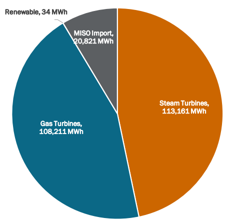
Fuel Cells

Quantifying the Carbon Emissions of the University's Onsite Energy System

Analysis Framework

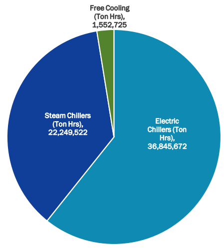
1. Does this University's system save carbon?
2. How can we provide accurate information to enable carbon emission tracking by departments/colleges?

Electricity, Steam, and Chilling Production (FY 22&23 Avg)



Total Onsite Generation	221,406 MWh
Total Campus Consumption	239,505 MWh

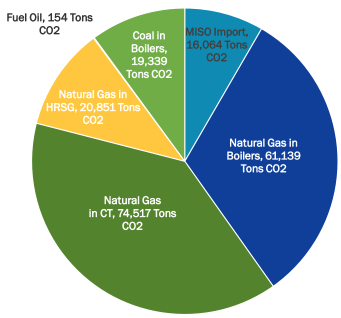
* Missouri Exported 2,722 MWh to MISO

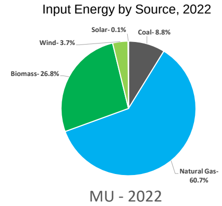


Electricity Consumed	24,376 MWh
Steam Consumed	204,099 Klbs
Total Chilling Tons	60,647,919

Steam to Campus	1,143,282 Klbs
Total Steam Generation	2,001,123 Klbs

Mizzou Carbon Emissions, by source (FY 22&23 Avg)





University of Missouri Onsite CO2 Responsibility (tons)	176,000 Tons CO2
University of Missouri Total CO2 Responsibility (Tons)	192,064 Tons CO2

Analysis – Test Case – 85% efficient NG Boilers

Total Test Case Emissions

Gas Boiler Emissions (Tons)	91,479
Electric Grid Emissions (Tons)	170,818
Total Emissions (Tons)	**262,298**

Chilled Water Carbon Allocation

Electric Chiller (Ton Hrs)	36,845,672
Electricity Consumed (MWh)	20,348
Electric Chiller Carbon Allocation (Tons)	15,699
Steam Chiller (Ton Hrs)	22,249,522
Steam Consumed (Klbs)	204,099
Electricity Consumed (MWh)	4,028
Steam Chiller Carbon Allocation (Tons)	19,439
Free Chilling (Ton Hrs)	1,552,725
Free Chilling Carbon Allocation (Tons)	0
Total Chiller Output (Ton Hrs)	**60,647,919**
Total Carbon Allocation (Tons)	**35,138**
Carbon Allocation (lbs CO2/Ton Chlling)	**1.16**

Test Case Eletric Carbon Allocation

Onsite Electric Energy (MWh)	221,406
Avg. Grid Carbon Emissions (lbs/MWh)	1,543
Electric Carbon Emissions (Tons)	170,818

Test Case Steam Carbon Allocation

Mass of Steam (klbs)	1,143,282
Output Enthalpy (btu/lb)	1,232
Blended Condensate Enthalpy (Btu/lb)	68
Steam Energy (MMBtu)	1,330,323
Boiler Efficiency	85%
Natural Gas Required (MMBtu)	1,565,085
Steam Carbon Emissions (Tons)	91,479
lbs CO2 per KPPH of Steam	160.03

Analysis Methodology - World Resources Institute / GHG Protocol

Efficiency Method: GHG emissions are allocated based on the energy inputs used to produce the separate steam and electricity products.

$$E_H = \frac{H/e_H}{H/e_H + P/e_P} * E_T \quad \text{and} \quad E_P = E_T - E_H$$

where:

- E_H = emissions allocated to steam production
- H = steam output (energy)
- e_H = assumed efficiency of steam production
- P = delivered electricity generation (energy)
- e_P = assumed efficiency of electricity generation
- E_T = total direct emissions of the CHP system
- E_P = emissions allocated to electricity production

Energy Content Method: GHG emissions are allocated based on the energy content of the output steam and electricity products.

$$Energy = F_i \times (h_i - h_{ref})$$

Where:

- F_i = the mass of steam in tonnes (1,000 kg)
- h_i = the specific enthalpy of steam flow i, in kJ/kg
- h_{ref} = the specific enthalpy at reference conditions (corresponding to returned condensates, assume at 100°C and 1 atm pressure)

Work Potential Method: GHG emissions are allocated based on the useful energy represented by electric power and heat, and defines useful energy on the ability of heat to perform work

$$W_i = F_i \times \left[(h_i - T_{ref} \times S_i) - (h_{ref} - T_{ref} \times S_{ref}) \right]$$

where:

- W_i = work potential of stream *i* (kJ)
- F_i = mass of steam (kg)
- T_{ref} = reference temperature (°K)
- h_i = specific enthalpy of steam flow *i* (kJ/kg)
- h_{ref} = specific enthalpy at reference conditions (kJ/kg)
- S_i = specific entropy of steam flow *i* (kJ/kg-°K)
- s_{ref} = specific entropy at reference conditions (kJ/kg-°K)

Analysis – Results Comparison

Carbon Intensity Summary

Analysis Methodology	Steam lbs CO2 per KPPH	Electricity lbs per MWh	Chiller Tons lbs CO2 per Ton	Total Carbon Responsibility
Energy Content	196.37	660	0.926	192,064 lbs CO2
Efficiency	129.41	976	0.828	
Work Content	94.28	1,147	0.778	
Test Case	160.03	1,543	1.159	262,298 lbs CO2

Current Results

Carbon Intensity Summary

Analysis Methodology	Steam lbs CO2 per KPPH	Electricity lbs per MWh	Chiller Tons lbs CO2 per Ton	Total Carbon Responsibility
Energy Content	174.80	660	0.853	172,725 lbs CO2
Efficiency	115.19	976	0.780	
Work Content	83.92	1,035	0.698	
Test Case	160.03	1,543	1.159	262,298 lbs CO2

With No Coal

Summary

- Onsite Energy centered around Combined Heat and Power provides robust and immediate carbon savings for the University of Missouri
- Fuel diversity helps ensure system reliability
- Moving away from coal will extend the University's carbon savings

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