Combined Heat and Power (CHP) Basics for IAC Students

February 11, 2021

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CHP Technical Assistance Partnerships

Agenda

- What is the US DOE CHP TAP Program
- CHP Concepts, Available Resources, & Project Snapshots
- CHP TAP Screening Analysis
- CHP Project Assessment Case Studies

Introduction

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AMO Technical Partnership Sub-Programs Collaborate

Direct engagement with Industry

Driving the continuous improvement and wide-scale adoption of proven technologies (e.g., CHP) to reduce energy use in the manufacturing sector

Core Programs

1. Combined Heat and Power
2. Industrial Assessment Centers
3. Better Plants
4. ISO 50001/SEP

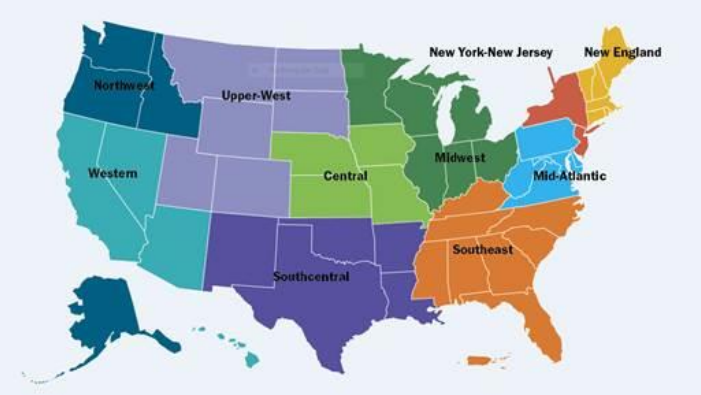
✓Validate the performance and energy impacts of established advanced manufacturing technologies and identify opportunities for further development or commercialization by the private sector.

✓Foster feedback from stakeholders on critical technology challenges that might be addressed by follow-on, early-stage applied R&D.

What is the US DOE CHP TAP Program?

U.S. DOE CHP Technical Assistance Partnerships (CHP TAPs)

- **End User Engagement**
  Partner with strategic End Users to advance technical solutions using CHP as a cost effective and resilient way to ensure American competitiveness, utilize local fuels and enhance energy security. CHP TAPs offer fact-based, non-biased engineering support to manufacturing, commercial, institutional and federal facilities and campuses.
- **Stakeholder Engagement**
  Engage with strategic Stakeholders, including regulators, utilities, and policy makers, to identify and reduce the barriers to using CHP to advance regional efficiency, promote energy independence and enhance the nation's resilient grid. CHP TAPs provide fact-based, non-biased education to advance sound CHP programs and policies.
- **Technical Services**
  As leading experts in CHP (as well as microgrids, heat to power, and district energy) the CHP TAPs work with sites to screen for CHP opportunities as well as provide advanced services to maximize the economic impact and reduce the risk of CHP from initial CHP screening to installation.



www.energy.gov/chp

National Manufacturing Day 2019 at the University of Illinois at Chicago

DOE CHP Technical Assistance Partnerships (CHP TAPs)

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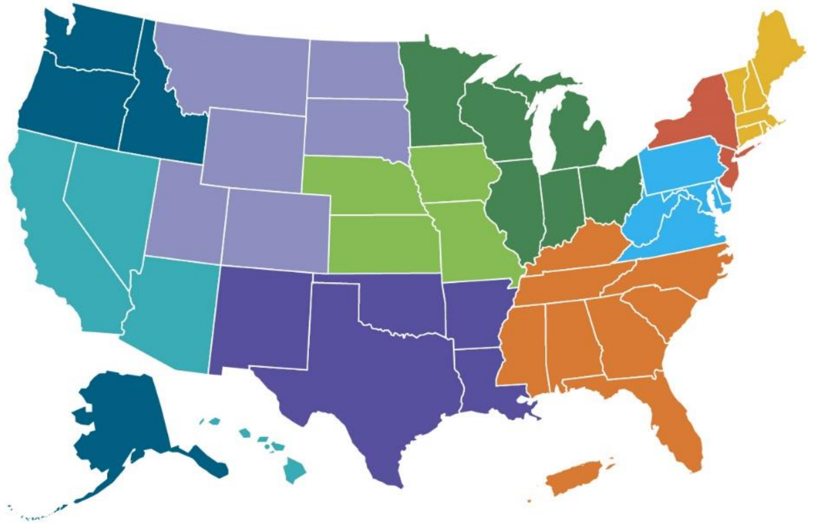

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DOE CHP Deployment Program Contacts
www.energy.gov/CHPTAP

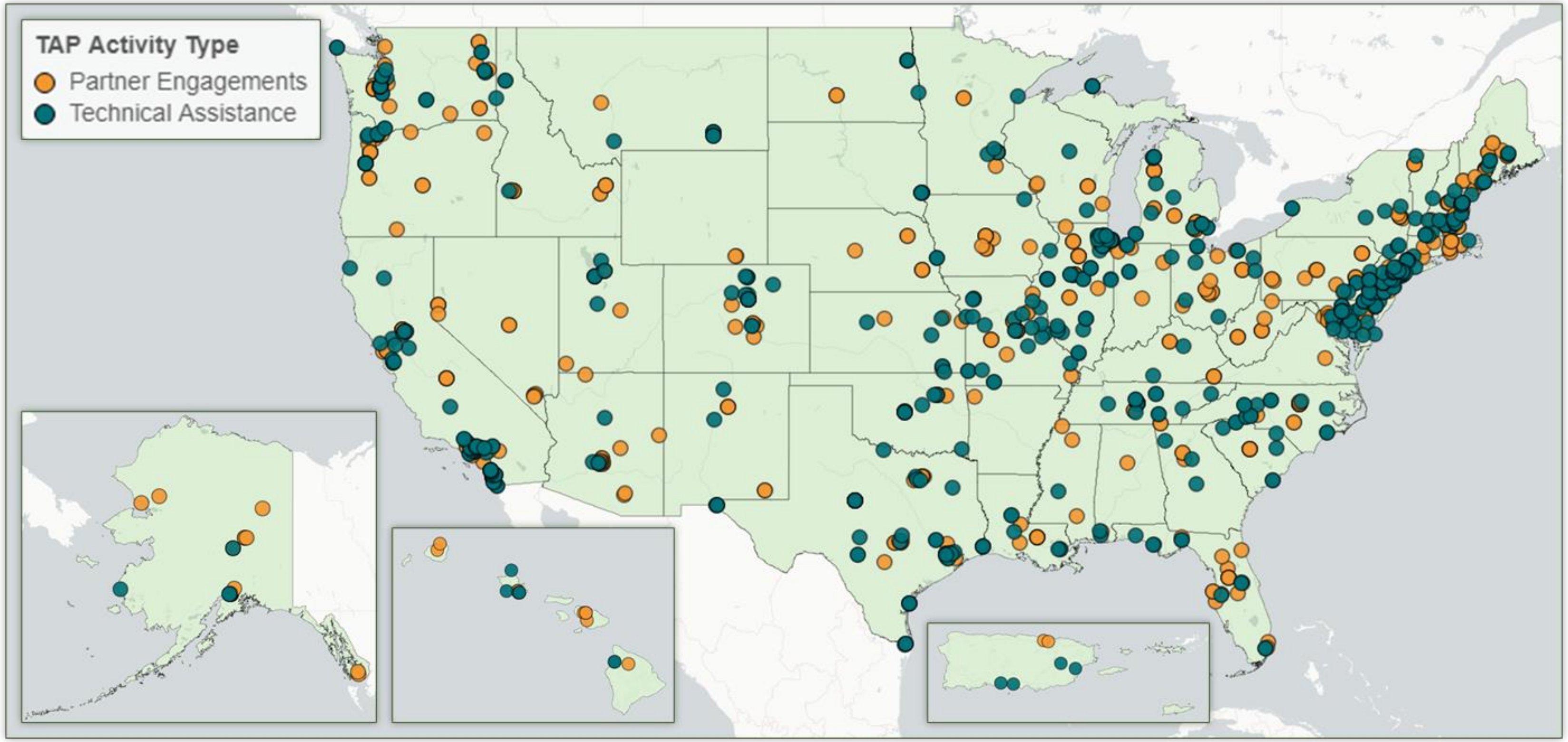
CHP Technical Assistance Partnerships

CHP TAP Activities FY19 and FY20 (through November 2020):

Completed 633 Technical Assistance Activities with an estimated capacity of 991 MW

Identified 204 end-user partners and completed 303 engagements

Identified 140 stakeholder partners and completed 208 engagements

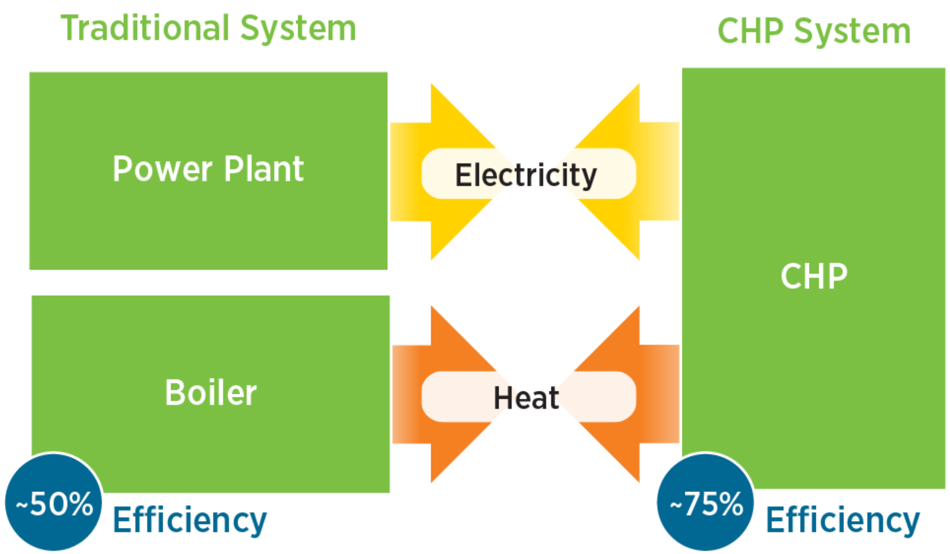


Some partner engagements physically occur in a single state and engage representatives from multiple states (e.g. at regional conferences, workshops, etc.). These engagements are reflected once in the map in the state where they occurred, even if they impacted other states. For example, multiple engagements occurred with representatives from Wyoming and South Dakota, although these are not reflected in the map because the engagements occurred outside their states.

CHP Concepts, Available Resources, Project Snapshots

CHP: A Key Part of Our Energy Future

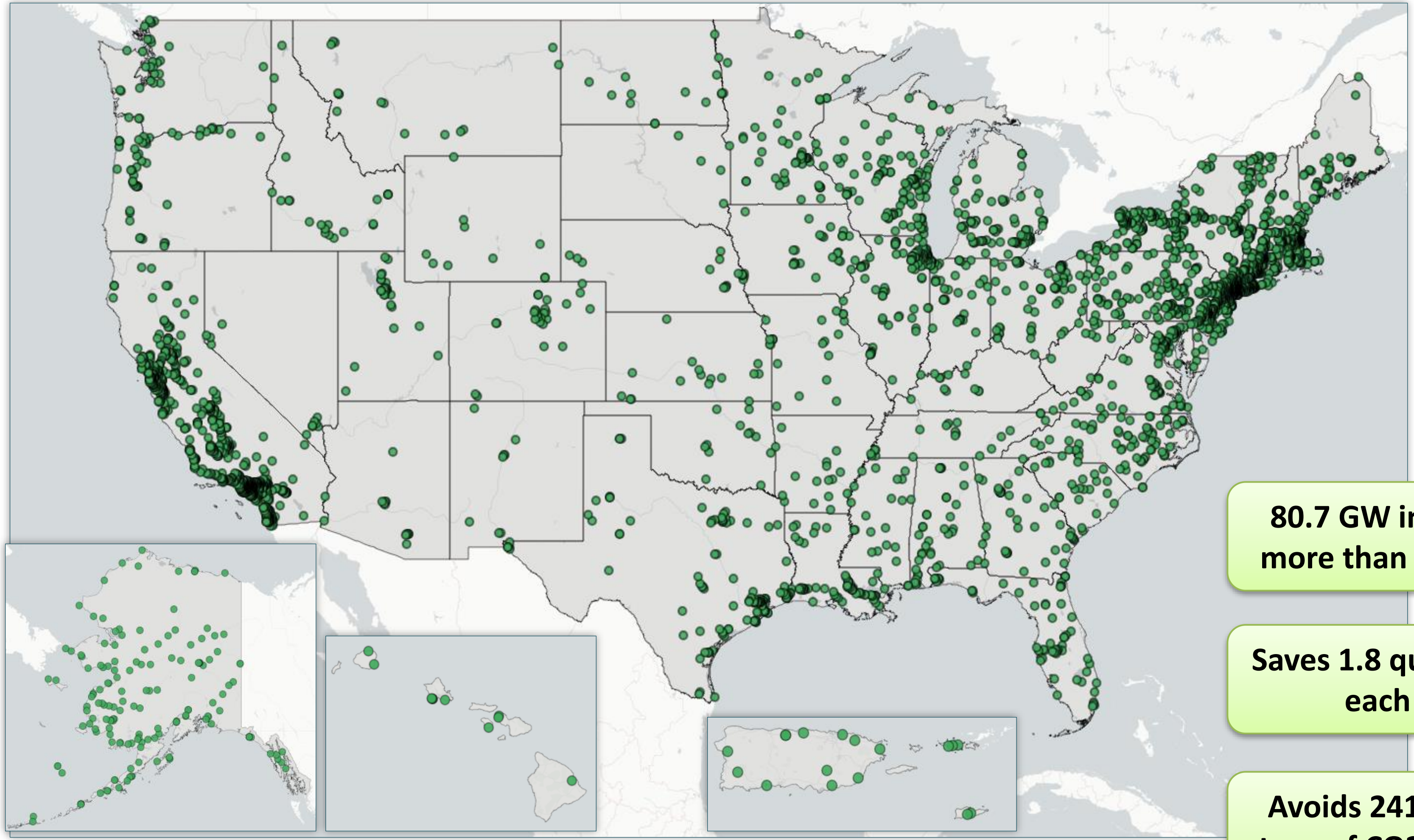
- Form of Distributed Generation (DG)
- An integrated system
- Located at or near a building / facility
- Provides at least a portion of the electrical load and
- Uses thermal energy for:
  - Space Heating / Cooling
  - Process Heating / Cooling
  - Dehumidification



CHP provides efficient, clean, reliable, affordable energy – today and for the future.

Source: www.energy.gov/chp

CHP is used Nationwide



80.7 GW installed at more than 4,600 sites

Saves 1.8 quads of fuel each year

Avoids 241 M metric tons of CO_2 each year

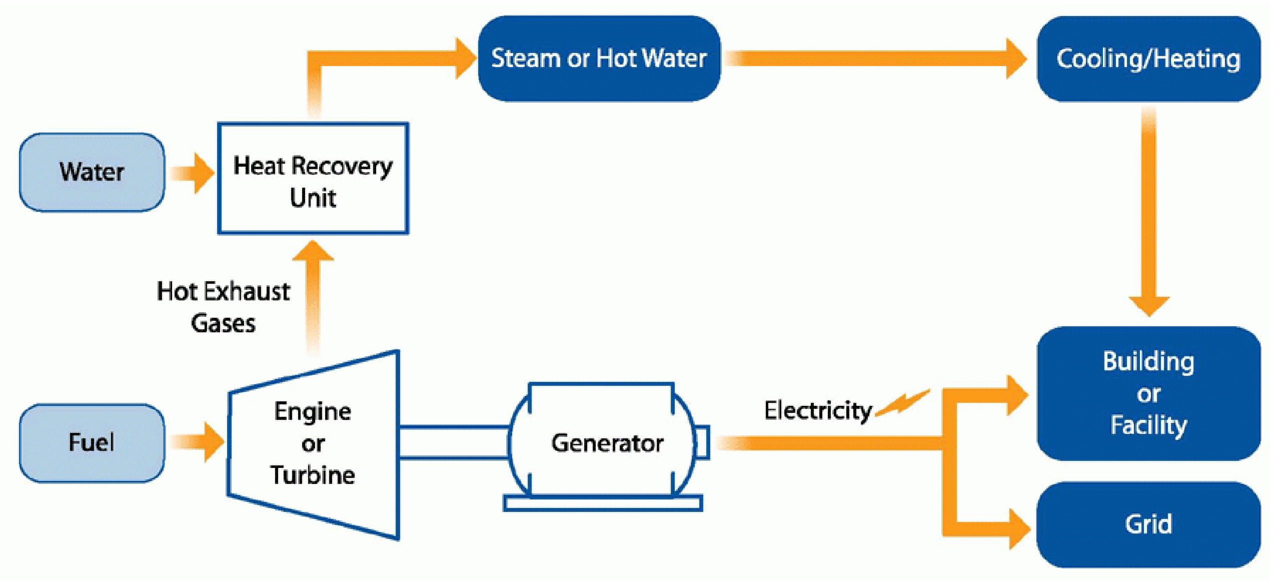
Source: DOE CHP Installation Database (U.S. installations as of Dec. 31, 2019)

What Are the Benefits of CHP?

- CHP is **more efficient** than separate generation of electricity and heating/cooling
- Higher efficiency translates to **lower operating costs** (but requires capital investment)
- Higher efficiency **reduces emissions** of pollutants
- CHP can also increase **energy reliability** and enhance power quality
- On-site electric generation can **reduce grid congestion** and avoid distribution costs.

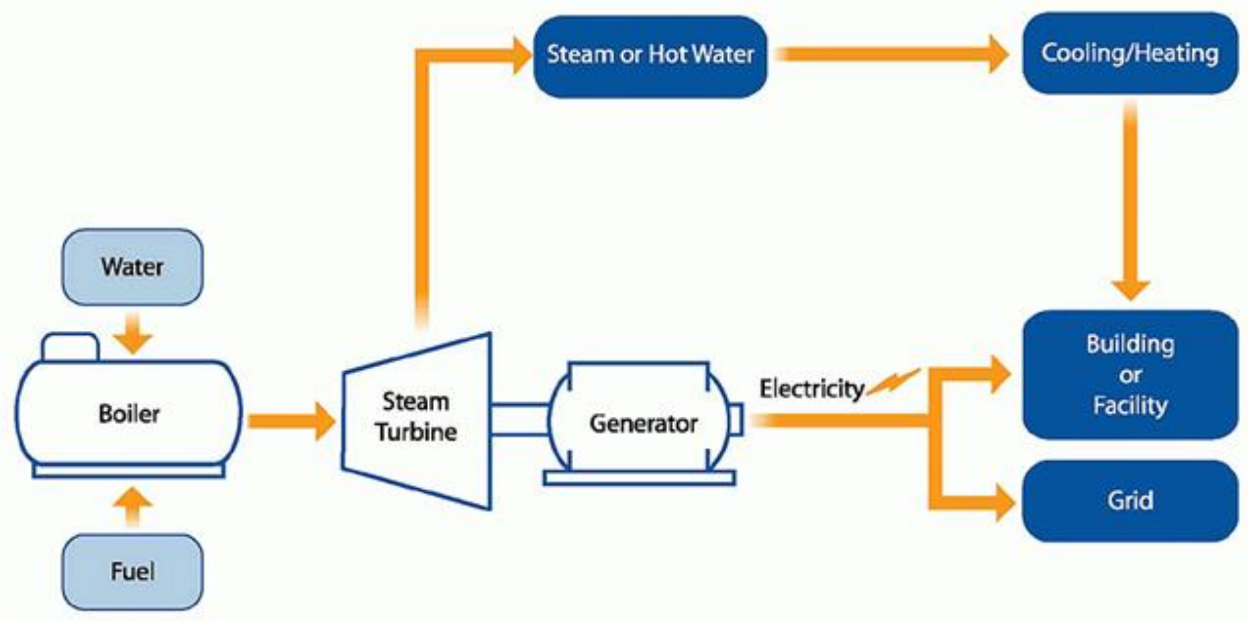
Reciprocating Engine or Turbine with Heat Recovery

- Gas or liquid fuel is combusted in a prime mover, such as a reciprocating engine, microturbine, or gas turbine
- The prime mover is connected to a generator that produces electricity
- Energy normally lost in the prime mover's hot exhaust and cooling system is recovered to provide useful thermal energy for the site



Boiler / Steam Turbine

- Fuel is burned in a boiler to produce high pressure steam that is sent to a backpressure or extraction steam turbine
- The steam turbine is connected to an electric generator that produces electricity
- Low pressure steam exits the turbine and provides useful thermal energy for the site



Heat Recovery

Heat Exchangers

- Recover exhaust gas from prime mover
- Transfers exhaust gas into useful heat (steam, hot water) for downstream applications
- Heat Recovery Steam Generators (HRSG) the most common

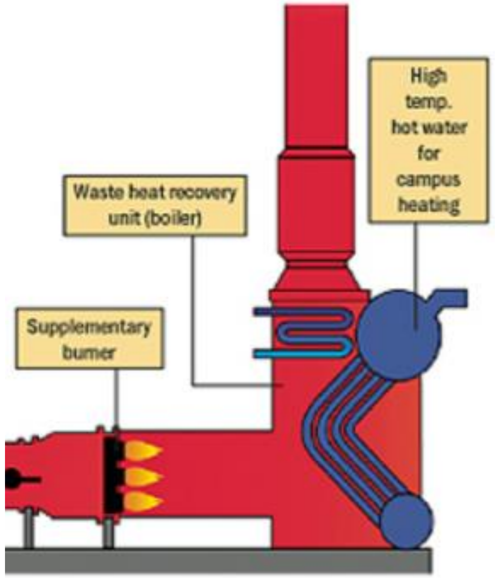


Image Source: University of Calgary

Heat-Driven Chillers

- Absorption Chiller
    - Use heat to chill water
    - Chemical process (not mechanical)
- Steam Turbine Centrifugal Chiller

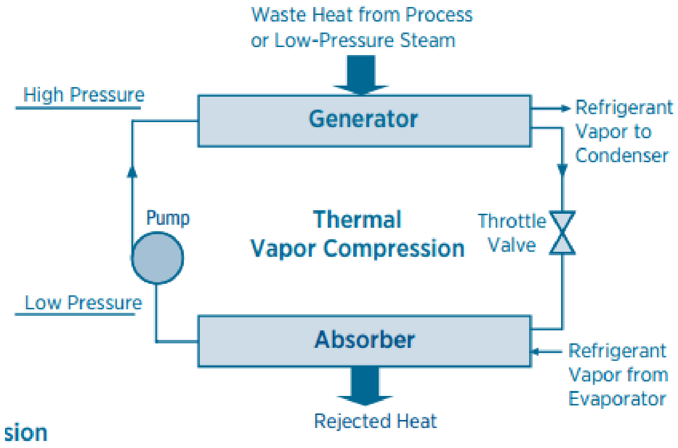
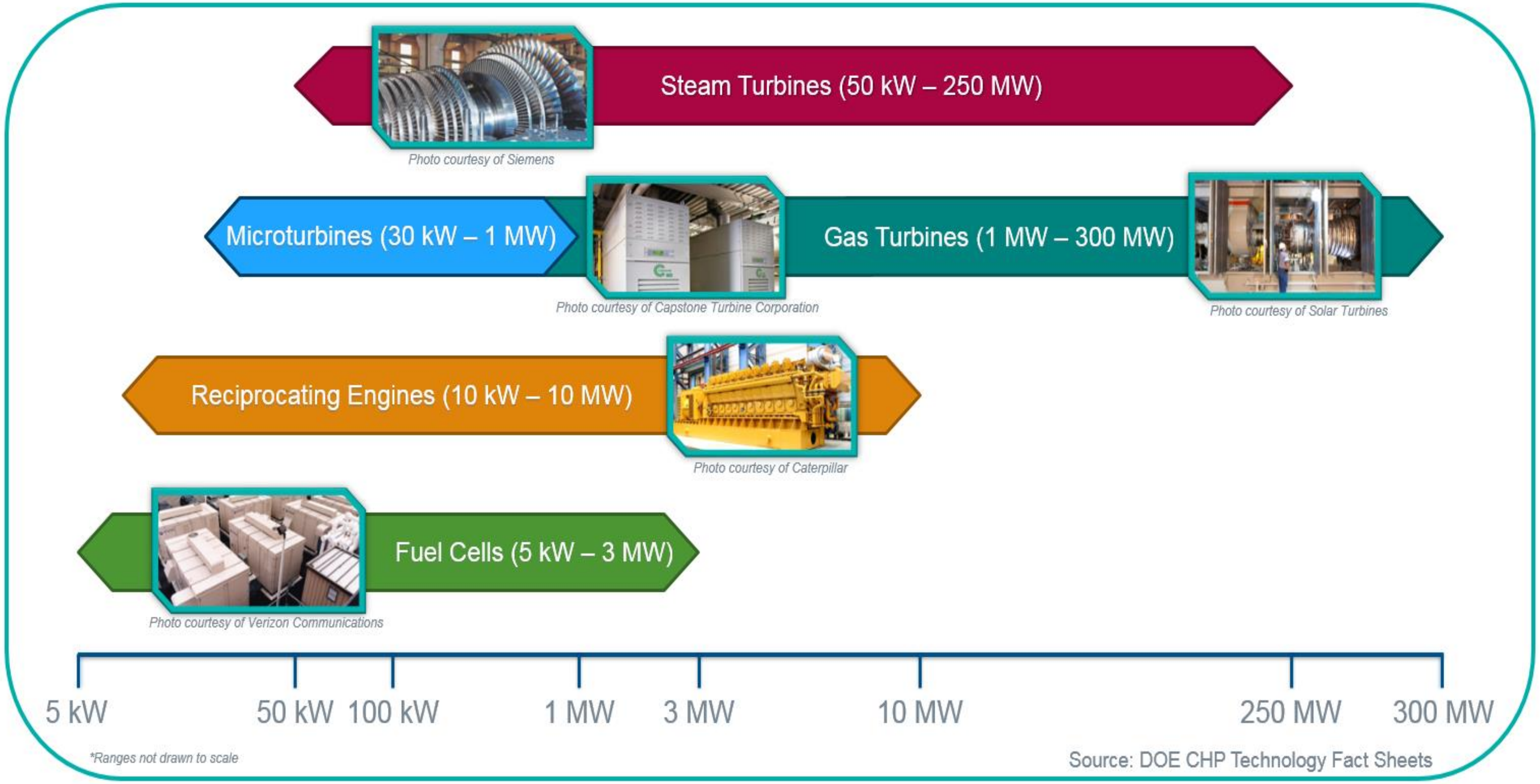


Image Source: DOE - EERE

Common CHP Technologies and Capacity Ranges

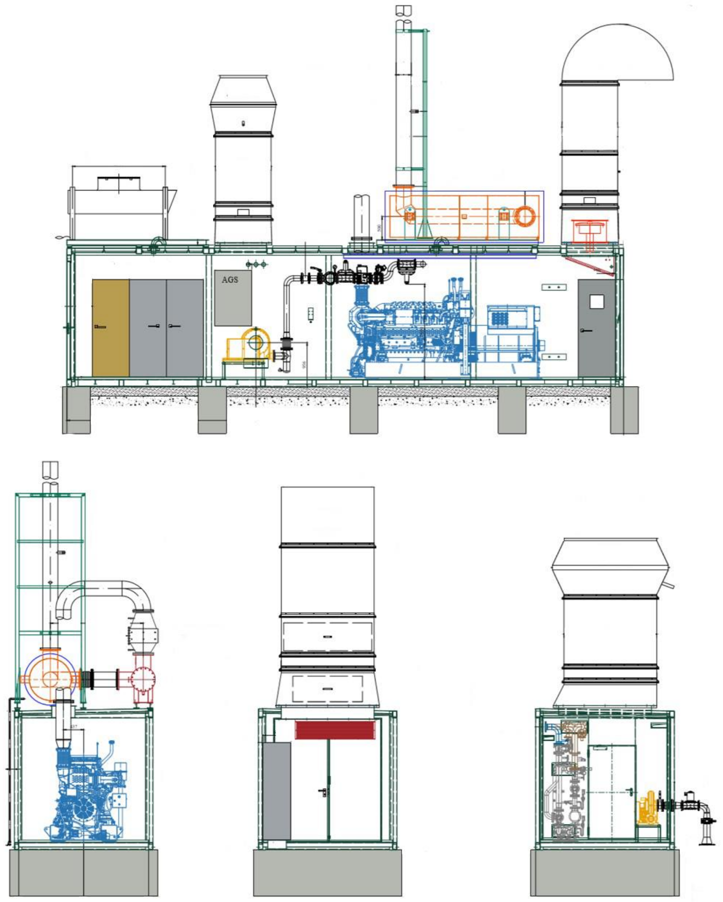
Five Common Prime Movers

- Reciprocating engines
- Gas turbines
- Microturbines
- Fuel cells
- Steam turbines



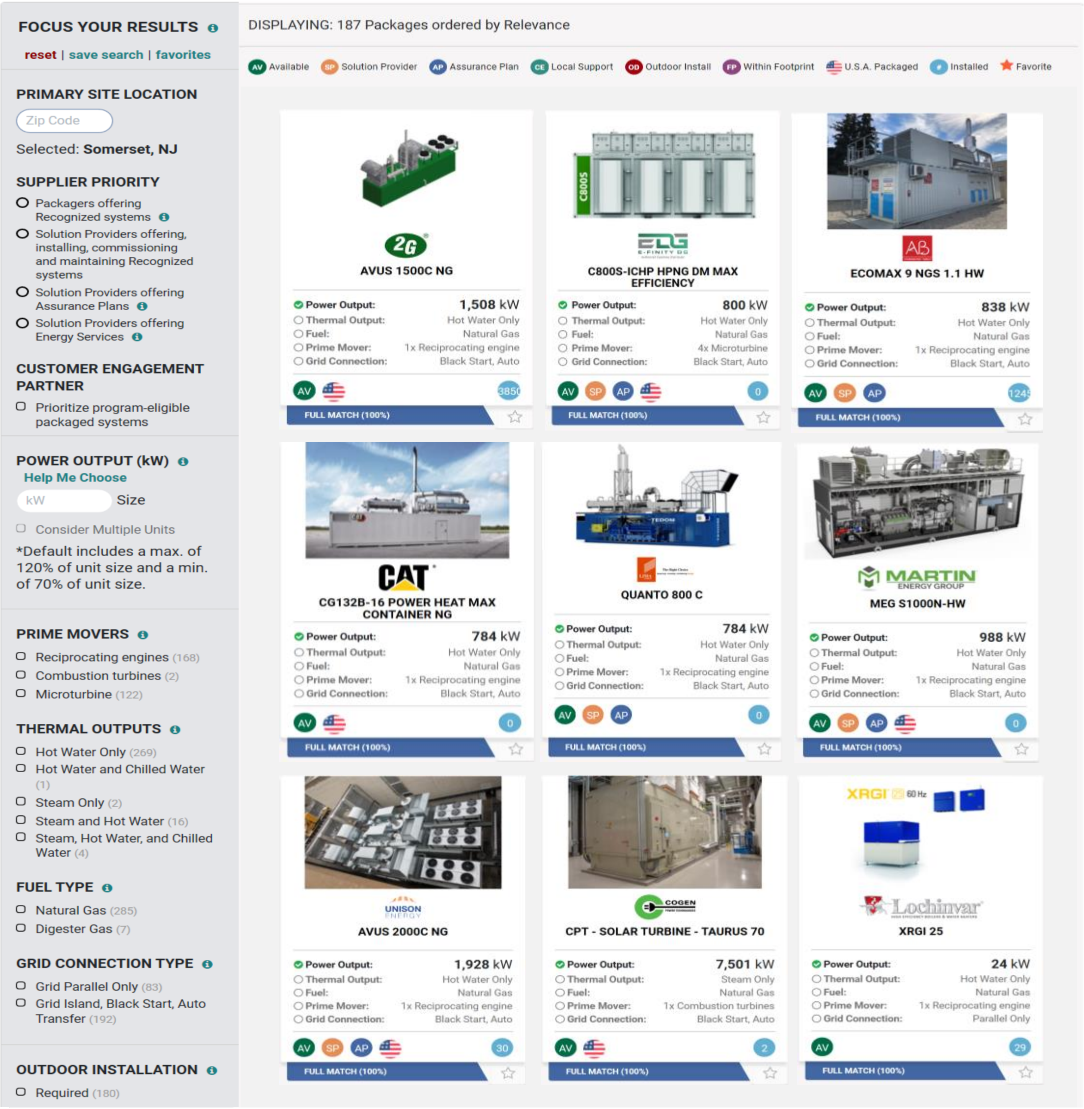
Packaged CHP System Have Standard Repeatable Designs

- 100% pre-wired
- 100% pre-piped with customer ready connection
- Properly ventilated
- Sound insulated
- Fire rated
- With a gas detection and smoke alarm
- Fluid containment system
- Auxiliaries sized appropriately and shipped complete with connecting piping and wiring
- Packagers have bulk purchasing power that local contractors do not have



US DOE Packaged CHP Systems eCatalog

- **A national web-based searchable catalog** (eCatalog) of **DOE-recognized packaged CHP systems and suppliers** with the goal to reduce risks for end-users and vendors through partnerships
- **Pre-engineered and tested packaged CHP systems** that meet DOE performance requirements
- **Launched Nov 8, 2019**
- **32 recognized Packagers**
- **21 recognized Solution Providers**
- **247 Package Offerings:** 164 reciprocating engine, 82 microturbine, 1 gas turbine, 226 natural gas, 20 digester gas, 1 propane, 57 grid parallel only, 178 grid islandable/auto transfer, 24 kW to 7.5 MW, Multiple suppliers and packages in every zip code
- **9 Customer Engagement Partners**



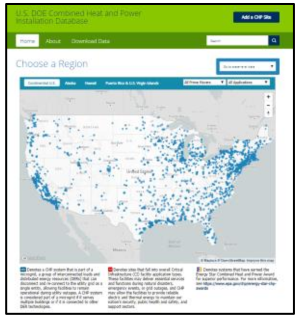
CHP Technical Assistance Partnerships

https://chp.ecatalog.lbl.gov/

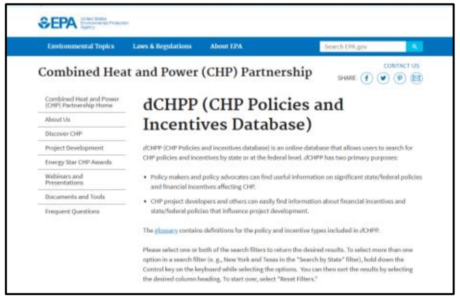
US DOE and US EPA CHP Resources

Visit DOE's CHP Resources: https://www.energy.gov/eere/amo/combined-heat-and-power-basics

DOE CHP Installation Database

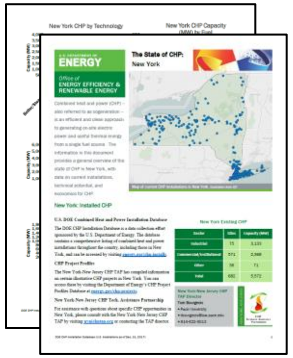


EPA dCHPP (CHP Policies and Incentives Database)



DOE CHP Technologies Fact Sheet Series

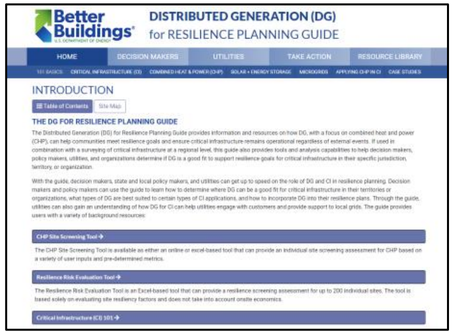
State of CHP Pages



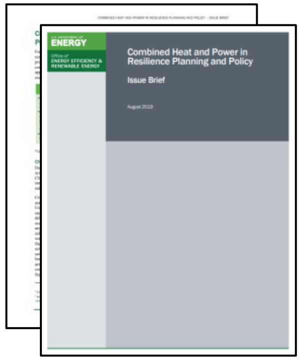
DOE Project Profile Database

DOE Policy/ Program Profiles

DG for Resilience Planning Guide



CHP Issue Brief Series



CHP Technical Assistance Partnerships

US DOE "CHP Technology Fact Sheets"

1. Overview of CHP Technologies
2. Fuel Cells
3. Gas Turbines
4. Microturbines
5. Reciprocating Engines
6. Steam Turbines
7. Absorption Chillers
8. Microgrids
9. District Energy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Combined Heat and Power Technology Fact Sheet Series

Reciprocating Engines

Reciprocating internal combustion engines are a mature technology used for power generation, transportation, and many other purposes. Worldwide production of reciprocating internal combustion engines exceeds 200 million units per year.[1] For CHP installations, reciprocating engines have capacities that range from 10 kW to 10 MW. Multiple engines can be integrated to deliver capacities exceeding 10 MW in a single plant. Several manufacturers offer reciprocating engines for distributed power generation, and these engines, which are most often fueled with natural gas, are well suited for CHP service (see **Table 1** for summary of attributes).

Reciprocating engine CHP installation at an industrial facility. *Photo courtesy of Caterpillar.*

Applications

Reciprocating engines are well suited to a variety of distributed generation applications and are used throughout industrial, commercial, and institutional facilities for power generation and CHP. There are nearly 2,400 reciprocating engine CHP installations in the U.S., representing 54% of the entire population of installed CHP systems.[2] These reciprocating engines have a combined capacity of nearly 2.4 gigawatts (GW), with spark ignited engines fueled by natural gas and other gas fuels accounting for 83% of this capacity. Thermal loads most amenable to engine-driven CHP systems in commercial/institutional buildings are space heating and hot water requirements. The primary applications for CHP in the commercial/institutional and residential sectors are those with relatively high and coincident electric and hot water demand. Common applications for reciprocating engine CHP systems include universities, hospitals, water treatment facilities, industrial facilities, commercial buildings, and multi-family dwellings.

Table 1. Summary of Reciprocating Engine Attributes

Size range	Reciprocating engines for CHP are available in sizes from 10 kW to 10 MW. Multiple engines can be combined to deliver higher capacities. The majority of CHP installations with reciprocating engine are below 5 MW.[2]
Thermal output	Thermal energy can be recovered from the engine exhaust, cooling water, and lubricating oil, and then used to produce hot water, low pressure steam, or chilled water (with an absorption chiller).
Part-load operation	Reciprocating engines perform well at part-load and are well suited for both baseload and load following applications.
Fuel	Reciprocating engines can be operated with a wide range of gas and liquid fuels. For CHP, natural gas is the most common fuel.
Reliability	Reciprocating engines are a mature technology with high reliability.
Other	Reciprocating engines have relatively low installed costs and are widely used in CHP applications. Reciprocating engines start quickly and operate on typical natural gas delivery pressures with no additional gas compression required.

1 Power Systems Research, EnginLink™, 2013.
2 U.S. DOE *Combined Heat and Power Installation Database*, data compiled through December 31, 2015

ADVANCED MANUFACTURING OFFICE

Location of Fact Sheets: https://www.energy.gov/eere/amo/combined-heat-and-power-basics

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Project Snapshot:

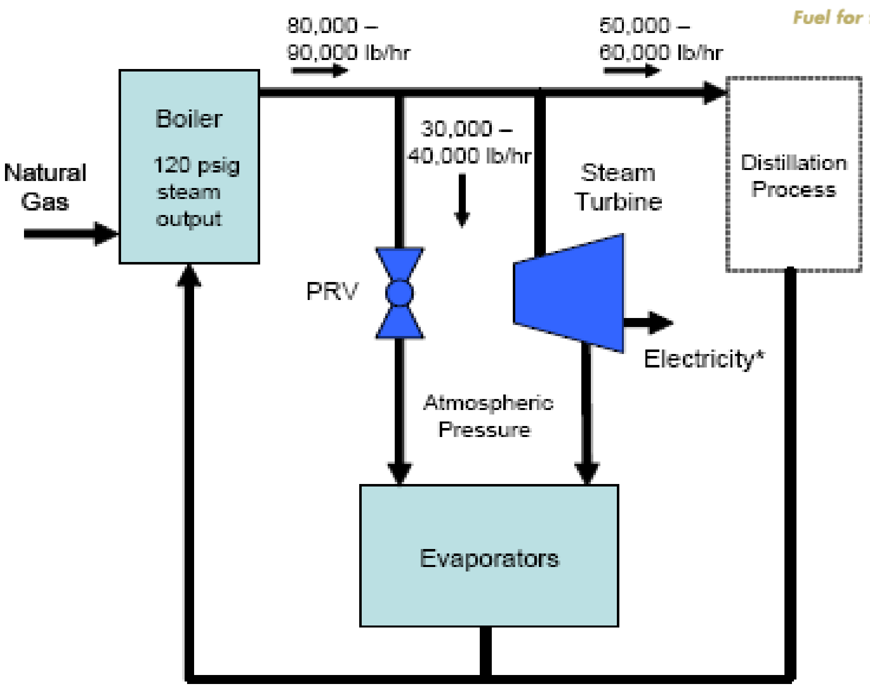
Replacing Pressure-Reducing Valve with Steam Turbine

East Kansas Agri-Energy (EKAE)
Garnet, KS

Application/Industry: Ethanol plant
Capacity: 1.6 MW
Prime Mover: Steam turbine
Fuel Type: Natural gas
Thermal Use: Process heat
Installation Year: 2005
Energy Savings: $180,000/year

Testimonial: *"I have to make the steam for the production process. This is a classic cogeneration application that's been around forever. It's nearly a perfect conversion of heat to work when you have an application where you use low-pressure exhaust steam."*
- Ken Ulrich, Design Engineer

Steam Turbine Generator
(installed in parallel with PRV)



Source: https://chptap.lbl.gov/profile/63/EastKansasAgriEnergy-Project_Profile.pdf

Project Snapshot:

Waste Heat-to-Power Turbine Addition

Adkins Energy LLC
Lena, IL

Application/Industry: Ethanol plant
Capacity: 1.8 MW
Steam Flow: 37,000 lbs/hr
Prime Mover: Steam turbine
Fuel Type: Waste heat
Thermal Use: Electricity
Installation Year: 2019
Est. Annual Savings: $674,000 based on $0.07/kWh

Testimonial:
"The CHP installations provide us economic stability and reliability for our electricity supply regardless of unforeseen electricity grid outages."
- Jason Townsend, Plant Manager, Adkins Energy LLC

Source: https://chptap.lbl.gov/profile/2/AdkinsEnergyWHP-Project_Profile.pdf

Project Snapshot:

Reduced Energy Costs & Lower Carbon Footprint

Bell's Brewery
Galesburg, MI

Application/Industry: Brewery
Capacity: 150 kW
Prime Mover: Reciprocating engine
Fuel Type: Biogas
Thermal Use: Anaerobic digester and water heating
Installation Year: 2014

Highlights:
Due to its efficient and green use of the wastewater byproducts, the CHP plant at Bell's Brewery won an Engineering Honorable Conceptor Award from the American Council of Engineering Companies of Michigan in 2016.

Testimonial:
"We have taken something that was being treated as a waste and converted it to savings and renewable energy. We've reduced the Brewer's water treatment costs while generating electricity and heat, two inputs to our process that we were already purchasing prior to the project"- Walker Modic, Sustainability Manager

BELL'S® Inspired Brewing®

Source: https://chptap.lbl.gov/profile/299/BellsBrewery-Project_Profile.pdf

Project Snapshot:

3rd Party Build, Own, and Operate

Solvay Specialty Polymers / DTE Marietta
Marietta, Ohio

Application/Industry: Chemicals
Capacity: 8 MW
Prime Mover: Combustion turbine
Fuel Type: Natural gas
Thermal Use: Process heating
Installation Year: 2015

Testimonial: *"Solvay Specialty Polymers and DTE Energy Services worked together closely to develop a customized energy supply facility to meet our plant's specific needs. The DTE Marietta cogeneration project has provided a reliable, efficient, economic energy supply solution to the Solvay complex to ensure that our plant can meet its production goals."*
  - Al Wanosky, Solvay Site Utilities Manager

DTE Energy

SOLVAY

Source: https://chptap.lbl.gov/profile/210/Solvay_Specialty_Plastics-Project_Profile.pdf

Project Snapshot:

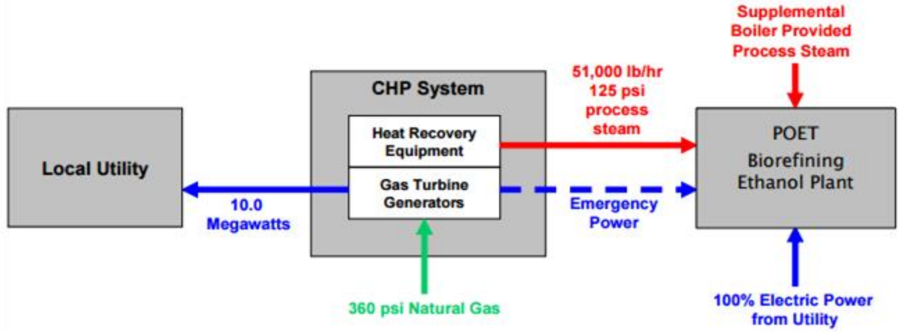
Municipal Utility / Ethanol Plant Partnership

POET Biorefining & City of Macon, Missouri
Macon, MO

Application/Industry: Ethanol Plant, Utility
Capacity: 10 MW
Prime Mover: Gas turbine
Fuel Type: Natural gas
Thermal Use: Thermal requirements of the ethanol production process
Installation Year: 2003
Energy Savings: 15-25% reduction in natural gas steam production costs

Highlights: The CHP system at POET provides nearly 60% of the facility's steam requirements, electric power for the plant, and grid electricity sales for Macon Municipal Utilities. The plant has experienced numerous grid outages since CHP operations began in 2003 and has successfully maintained operation of the plant during these outages by switching the load totally to the CHP system.

POET biorefining



Source:
https://chptap.lbl.gov/profile/184/POETandCityofMacol-Project_Profile.pdf

Project Snapshot:

Targeting Net-Zero

Downers Grove Sanitary District
Downers Grove, IL

Application/Industry: Wastewater Treatment
Capacity: 655 kW
Prime Mover: Reciprocating engines (2)
Fuel Type: Biomass
Thermal Use: Heat for the digestion process
Installation Year: 2014, 2017

Highlights: Waste grease from nearby restaurants helps power the CHP system, which offsets about 50% of the wastewater treatment plant's energy consumption. The expanded CHP system, the DGSD is reaching net-zero.

Downers Grove Sanitary District

Source: https://chptap.lbl.gov/profile/58/DownersGrove-Project_Profile.pdf

CHP TAP Screening Analysis and Case Studies

Steps to Developing a CHP Project and the Technical Assistance Available through the CHP TAPs

Screening and Preliminary Analysis

Quick screening questions with spreadsheet payback calculator; Advanced technical assistance to explore equipment or operational scenarios.

Feasibility Analysis

Perform 3rd Party reviews of site feasibility assessments: Estimates on savings, installation costs, simple paybacks, equipment sizing, and type.

Investment Grade Analysis

Perform 3rd Party reviews of Engineering Analysis. Review equipment sizing and choices.

Procurement, Operations, Maintenance, Commissioning

Review specifications and bids.

Ideal Conditions for a CHP System

1) Necessary conditions
   - ✓High Electric Usage
   - ✓Coincidental thermal load
   - ✓High hours of operation
2) Equipment replacement
   - ✓Older Back-up Generator
   - ✓ Replacing Chillers
   - ✓ Replacing Boilers
3) Customer motivation
   - ✓ Utility cost
   - ✓ Power reliability
   - ✓ Waste heat or biofuel untapped resource
   - ✓Sustainability & environmental
   - ✓Plans to expand facility
4) Other factors
   - ✓ EE measures already implemented
   - ✓ Centralized HVAC

CHP Screening Analysis Considerations

What should be included in a CHP screening analysis?

Inputs

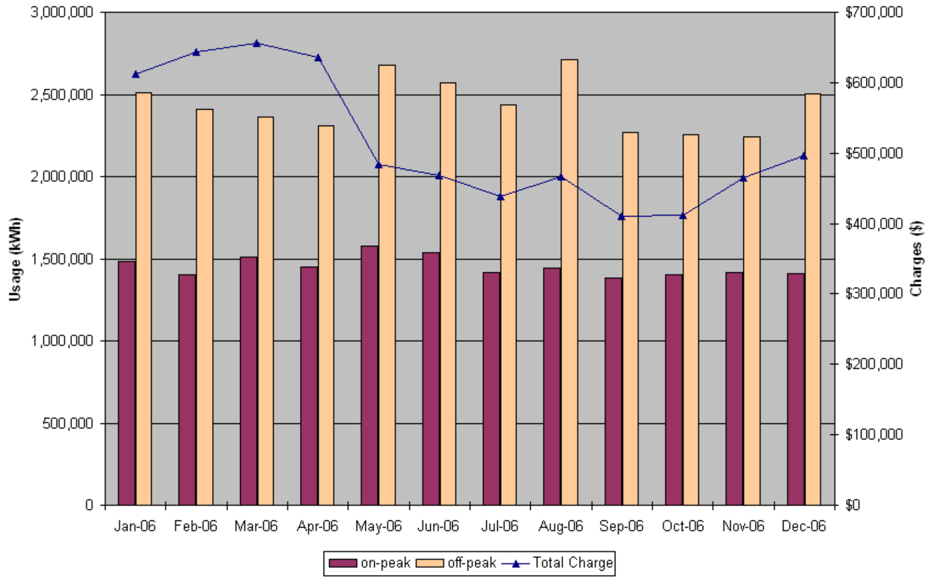
- Installed Costs ($/kW installed)
- O&M Costs ($/kWh)
- Elec Generating Capacity (kW)
- Therm Generating Capacity (Btu/hr)
- Fuel Consumption (Btu/hr)

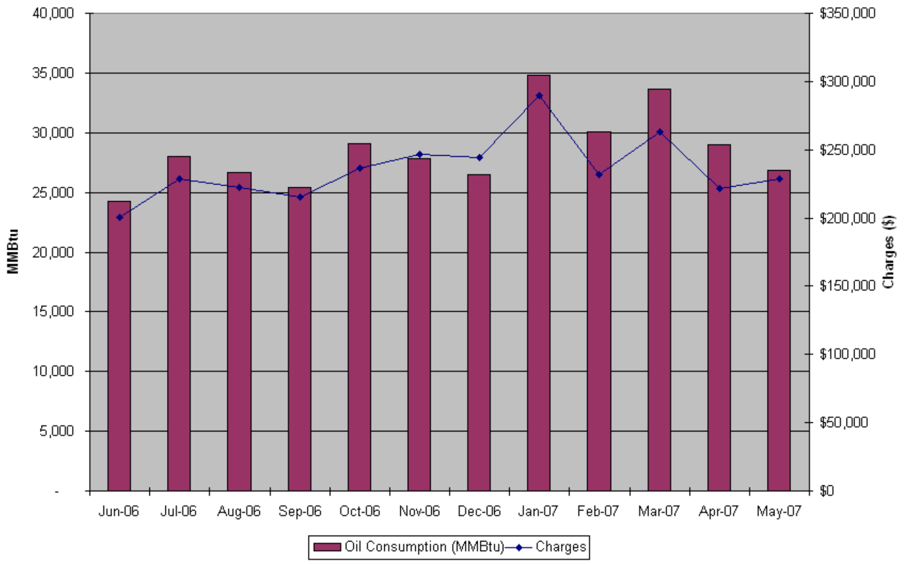
Outputs

- Electric Savings (kWh and $/yr)*
- Thermal Savings (Btu/yr and $/yr)
- Fuel Costs (Btu/yr and $/yr)
- Total Annual Savings ($/yr)
- Simple Payback (years)**
- Overall CHP Efficiency (%)

* Account for standby charges
** Account for incentives, grants, tax credits, etc.

Ideal Conditions for a CHP System





1) Necessary conditions
   - ✓High Electric Usage
   - ✓Coincidental thermal load
   - ✓High hours of operation

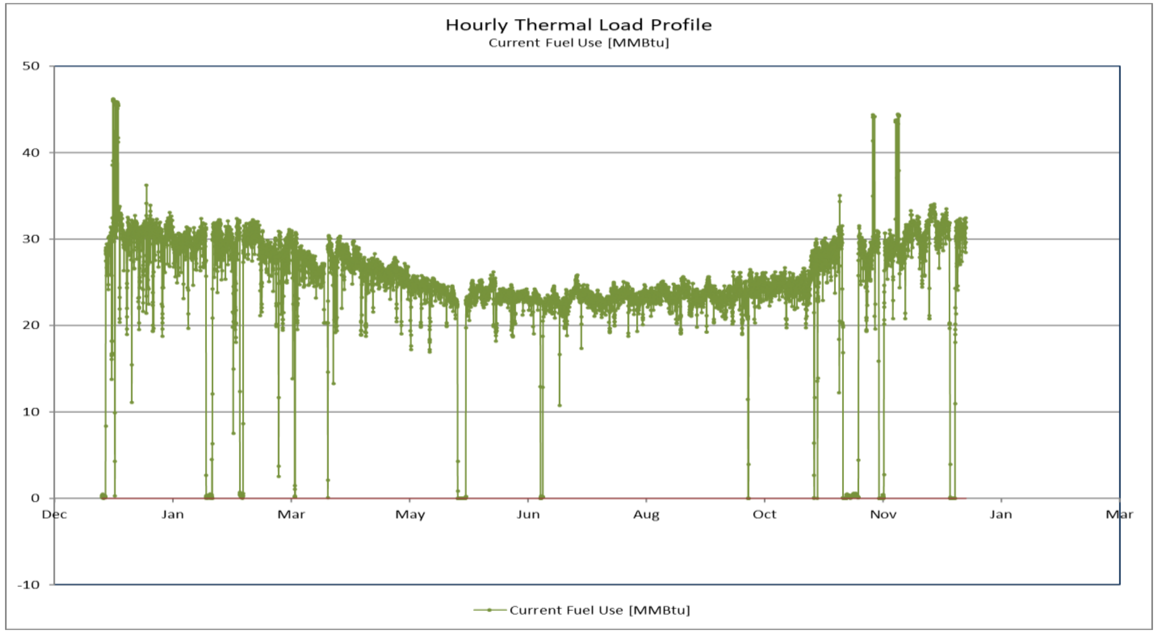
2) Equipment replacement
   - ✓Replacing Boilers

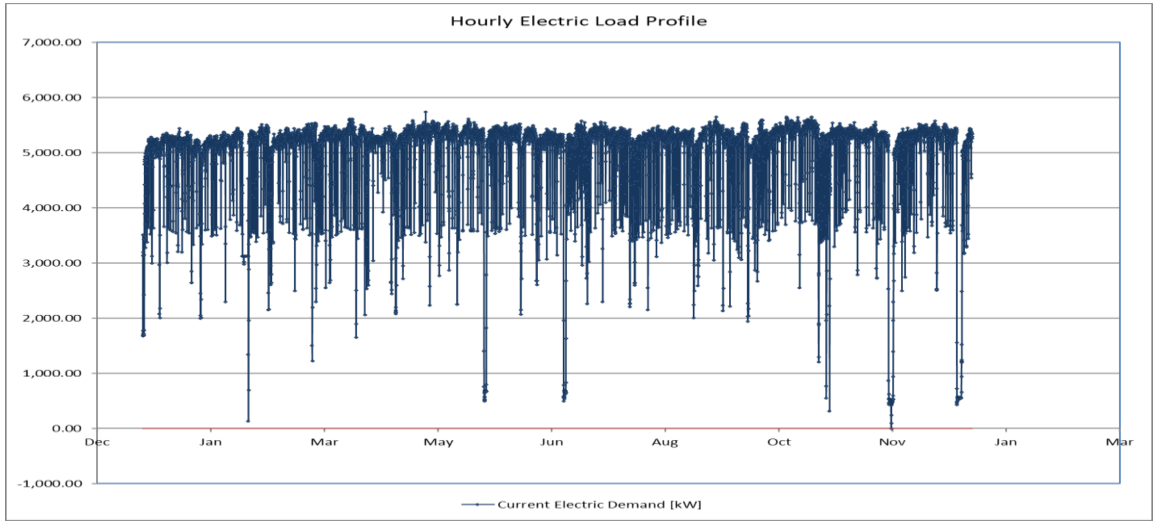
3) Customer motivation
   - ✓ Utility cost
   - ✓ Power reliability
   - ✓Plans to expand facility

4) Other factors
   - ✓ EE measures already implemented

CHP Technical Assistance Partnerships

Ideal Conditions for a CHP System





Necessary conditions

RESOURCE	UNITS CONSUMED	MILLION BTU'S CONSUMED	COST
Electricity	46,682,650 kWh	159,328	$6,189,578
Electricity Demand	76,053 kW		$346,041
Other fees & discounts			$848
#2 Fuel Oil	526,968 gallons	73,065	$1,156,108
#6 Fuel Oil	2,251,224 gallons	342,186	$2,981,695
TOTAL	–	574,579	$10,674,270

Customer motivation

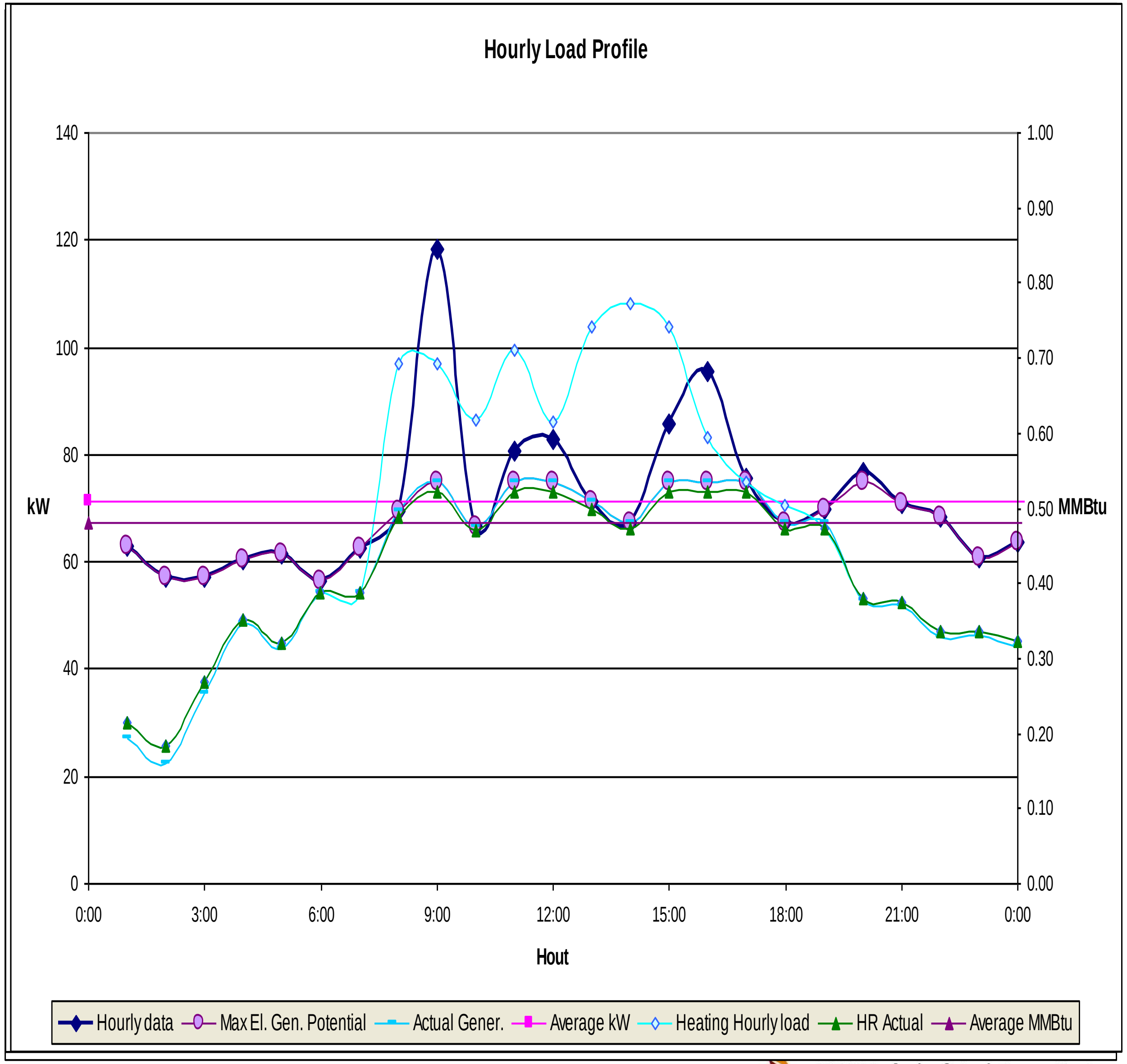
Electricity Usage	$0.1328/kWh
Electric demand	$4.55/ kW
#6 Heating oil	$8.71/MMBtu
#2 Heating oil	$15.82/MMBtu

Other factors

8,700 operating hours

CHP Technical Assistance Partnerships

Load Considerations - Winter

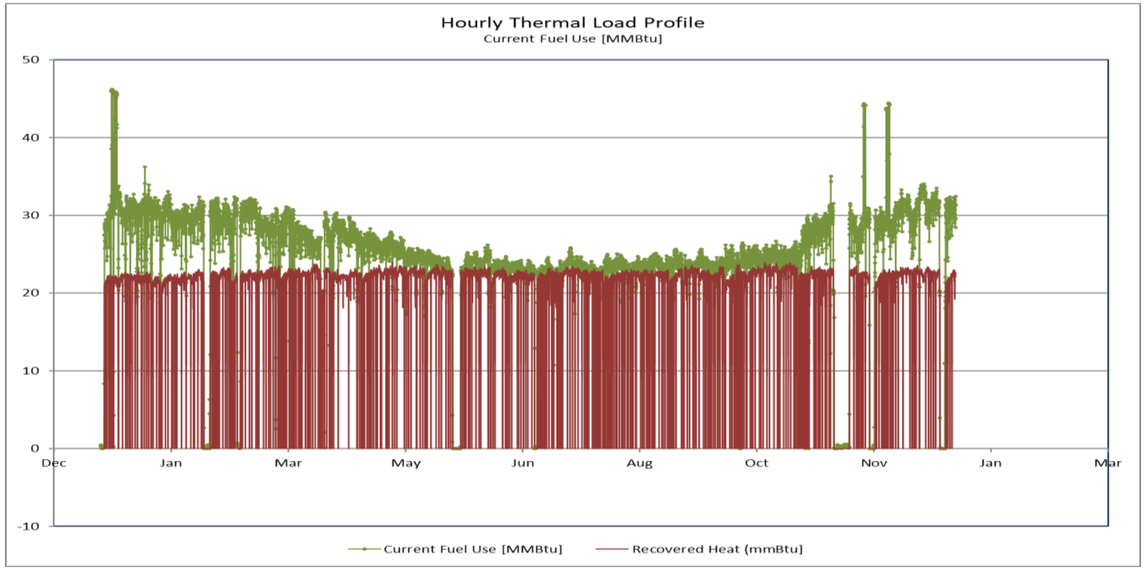


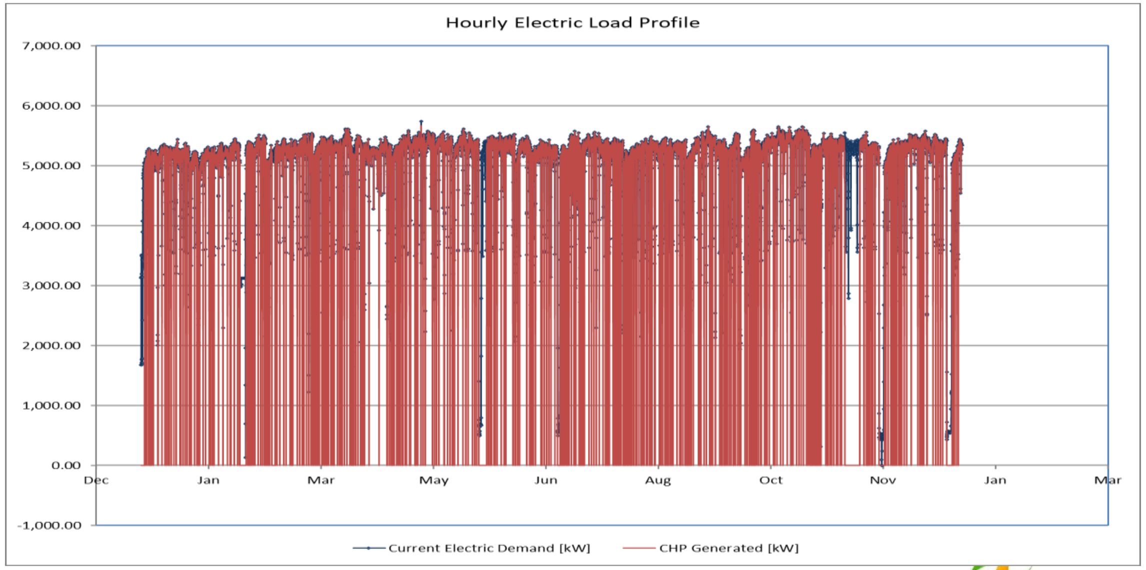
Average Load: 71.18 kW
Average Thermal: 0.41 MMBtu

Actual numbers:
-24 hr operation (same)
-85% heat recovered
-84% electricity generated
-323 kWh not delivered

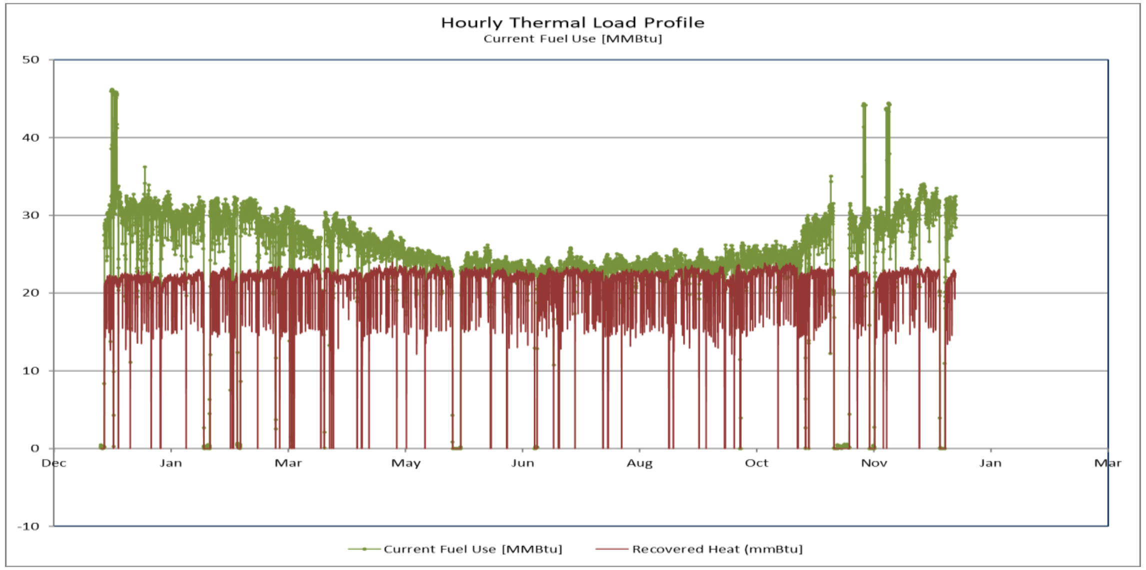
Load Considerations

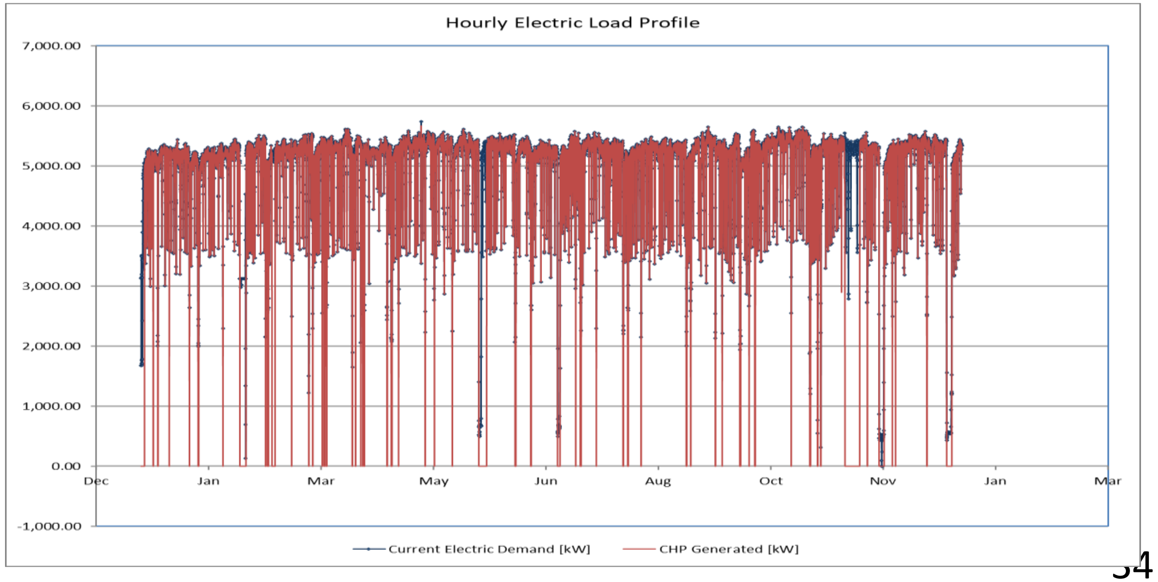
Minimum allowed load: 75%; 7,450 operating hours





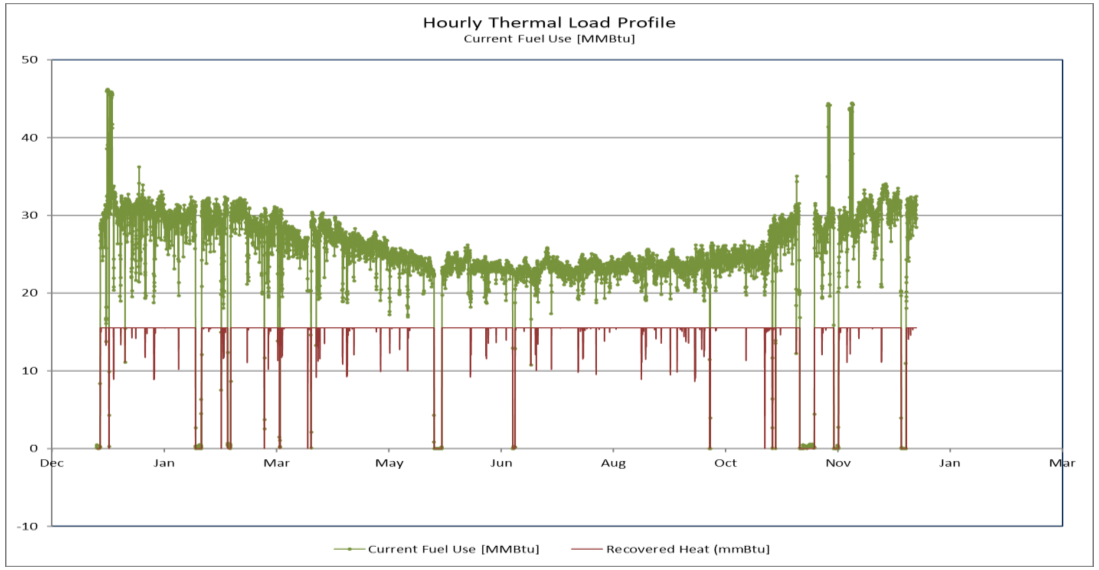
Minimum allowed load: 50%; 8,120 operating hours

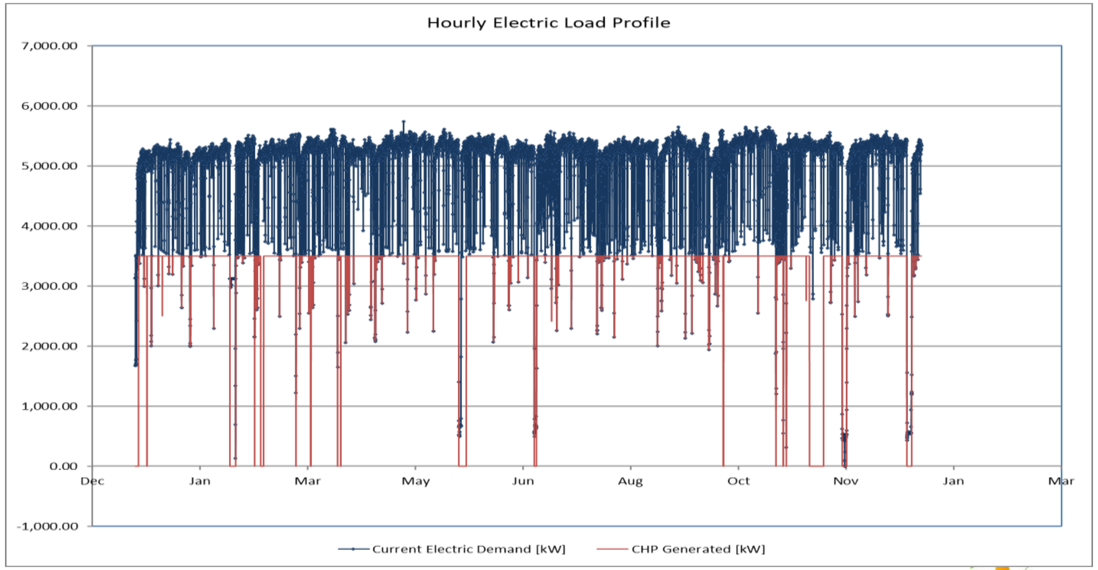




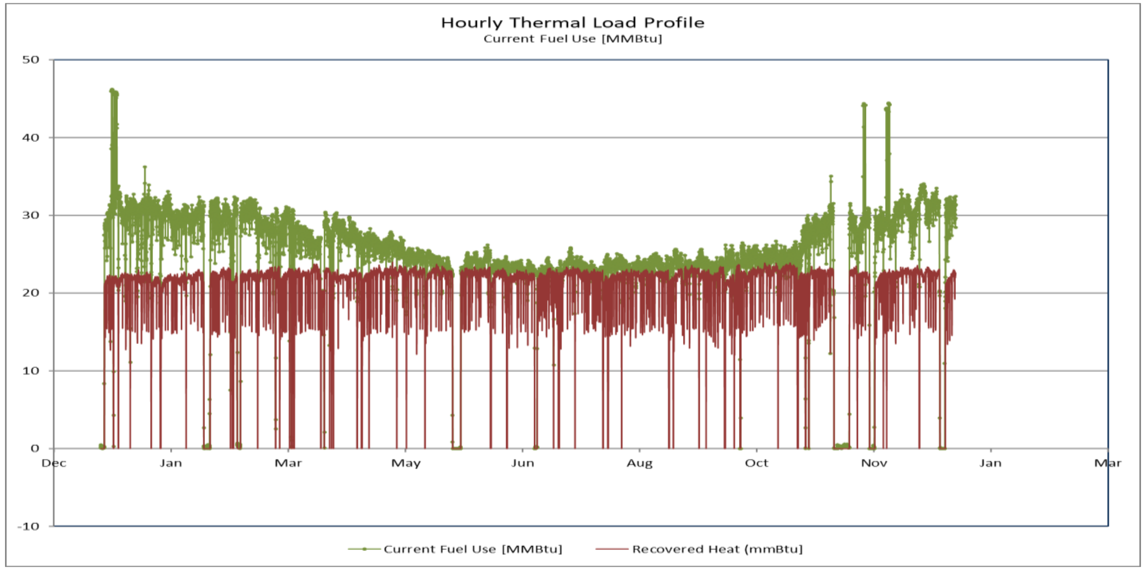
System Size Considerations

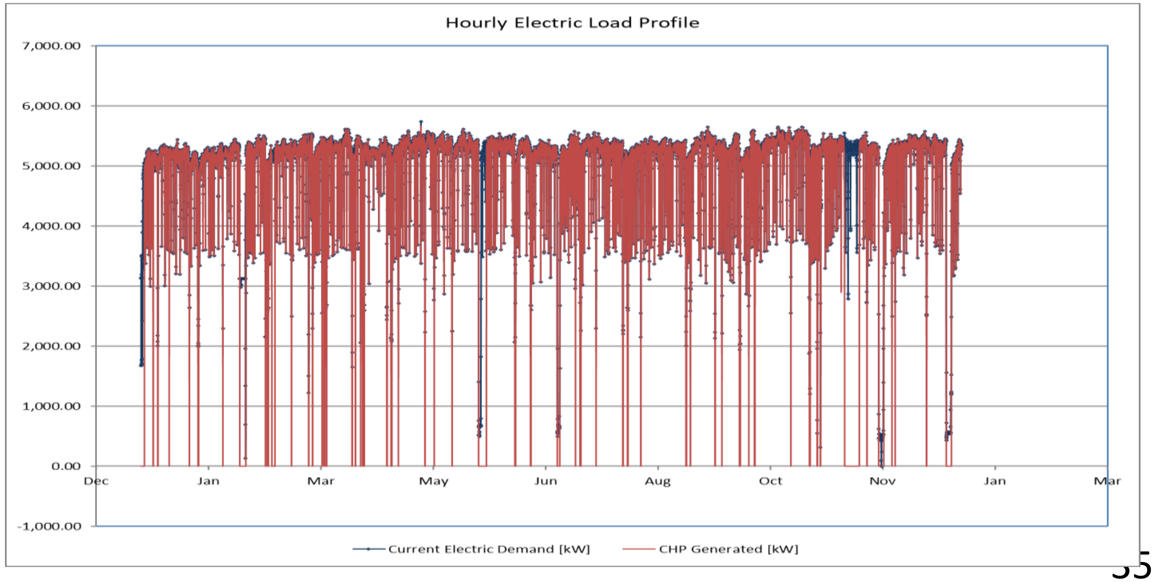
3.5 MW; min load: 50%; 8,240 hrs; 7.9 years





5.7 MW; min load: 50%; 8,120 hrs; payback 9.5 years





Project Profile:

Steam Turbine Application

SEAMAN PAPER COMPANY OF MASSACHUSETTS

Seaman Paper
Otter River, Massachusetts

Application/Industry: Specialty Paper
Capacity: 283 kW
Steam Flow: 40,000 lbs/hr
Prime Mover: Steam turbine
Fuel Type: Biomass
Thermal Use: Electricity
Installation Year: 2009

- Biomass takes up a great deal of space. Make sure there is adequate space for fuel delivery and storage.
- Biomass is not energy dense. It can require multiple trailer truck deliveries per day. The facility needs to be able to handle this. The effect of the increased truck traffic on the neighbors should also be considered.
- The plant's electrical output depends on the amount steam the plant is calling for. The system has averaged about a 70% capacity factor over the most recent year of operation.




Source: https://chptap.lbl.gov/profile/198/Seamanpaper1.pdf

Project Profile:

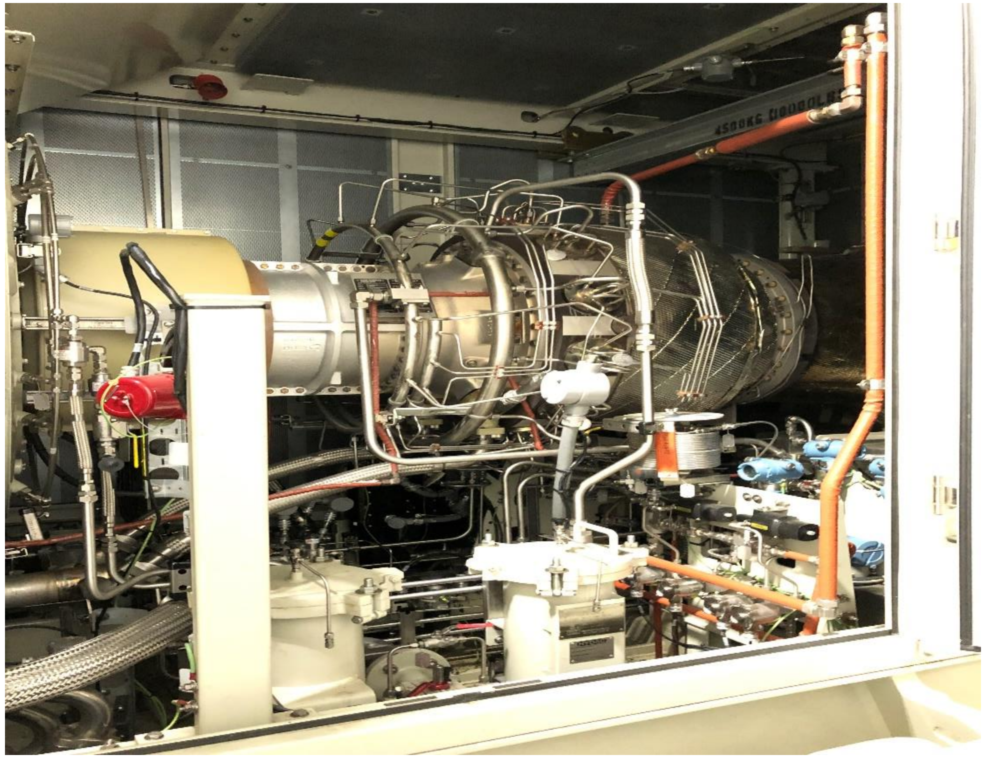
6.2-MW CHP System

ERVING INDUSTRIES
WE'RE ON A ROLL

Erving Paper
Erving, Massachusetts

Application/Industry: Pulp and Paper
Capacity: 6.2 MW (5.67 MW GT & 0.525 MW ST)
Steam Flow: 32,500 lbs/hr
Prime Mover: Gas & Steam turbine
Fuel Type: CNG
Thermal Use: Steam
Installation Year: 2015

Testimonial:
“We wouldn’t be operating today if not for the CHP system.”
Michael Peterson, Maintenance/Electrical Manager, Erving Industries



Source: https://chptap.lbl.gov/profile/71/ErvingIndustries-Project_Profile.pdf

Summary

- CHP can provide lower operating costs, reduce emissions, increase energy reliability, enhance power quality, and reduce grid congestion and avoid distribution costs
- CHP is a substantial energy efficiency option for IAC clients with coincident high electric and thermal load throughout the year, high hours of operation, and need for uninterruptible energy
- CHP resources are available at www.energy.gov/chp

Thank You!
Any Questions?

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For more information visit www.energy.gov/chp

Appendix
(additional information)

CHP in the U.S. Represents a Variety of Fuels, Technologies, Sizes, and Applications

Industrial

Residential

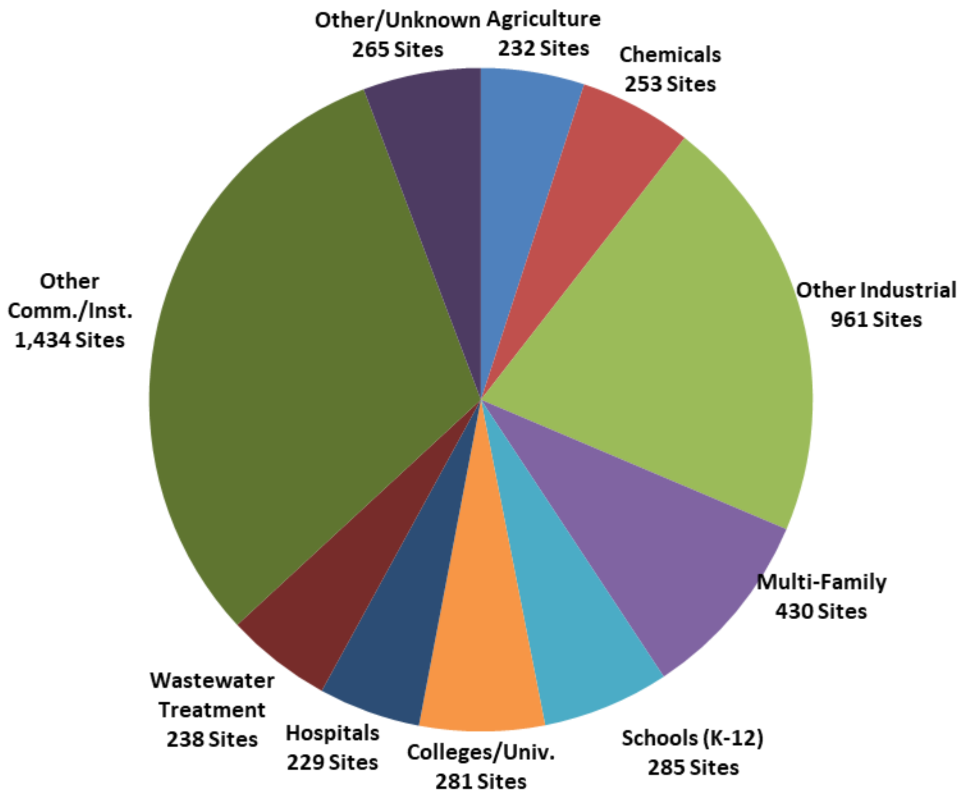
Utility Scale

Commercial

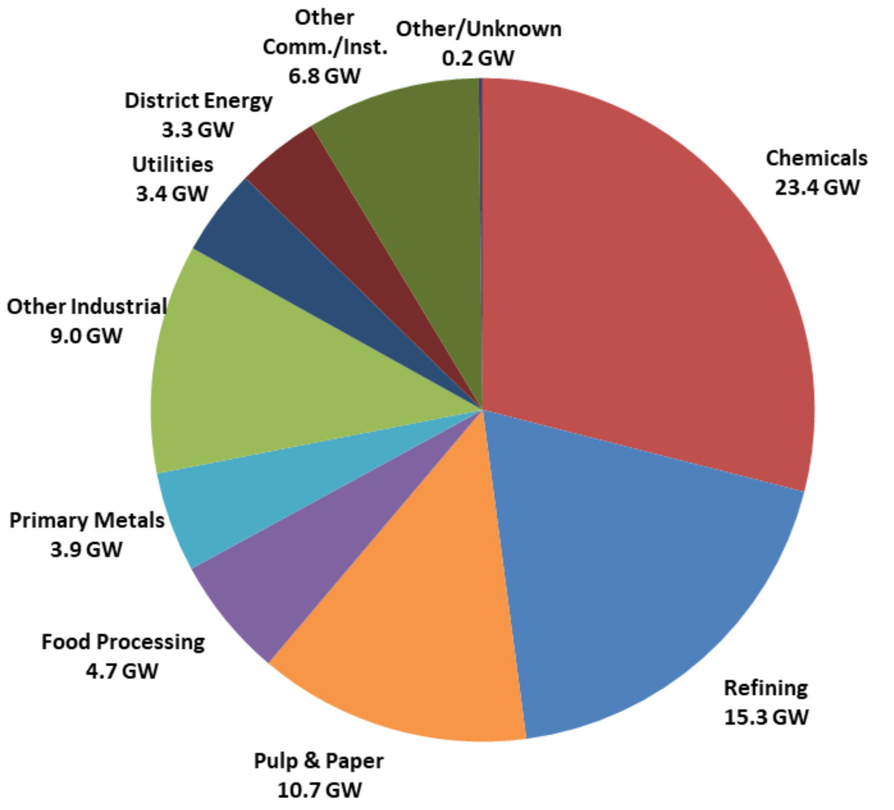
Institutional

Total CHP Installations by Application

By Site – 4,608 Sites



By Capacity – 80.7 GW



Source: DOE CHP Installation Database (U.S. installations as of December 31, 2019)

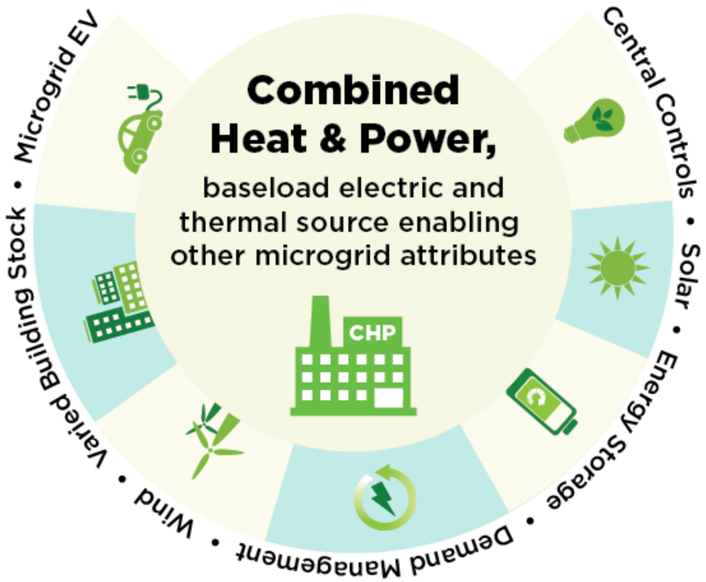
CHP and Microgrids

A microgrid is a **group of interconnected loads and distributed energy resources** within clearly defined electrical boundaries that acts as a **single controllable entity** with respect to the grid.

A microgrid can **connect and disconnect** from the larger utility grid to enable it to operate in both **grid-connected** or **island-mode**.

Source: U.S. Department of Energy Microgrid Exchange Group

- With a CHP system providing reliable baseload electric and thermal energy, microgrids can add renewables and storage
- Increased focus on resilience for critical infrastructure
  - Universities, Hospitals, Military bases, Communities



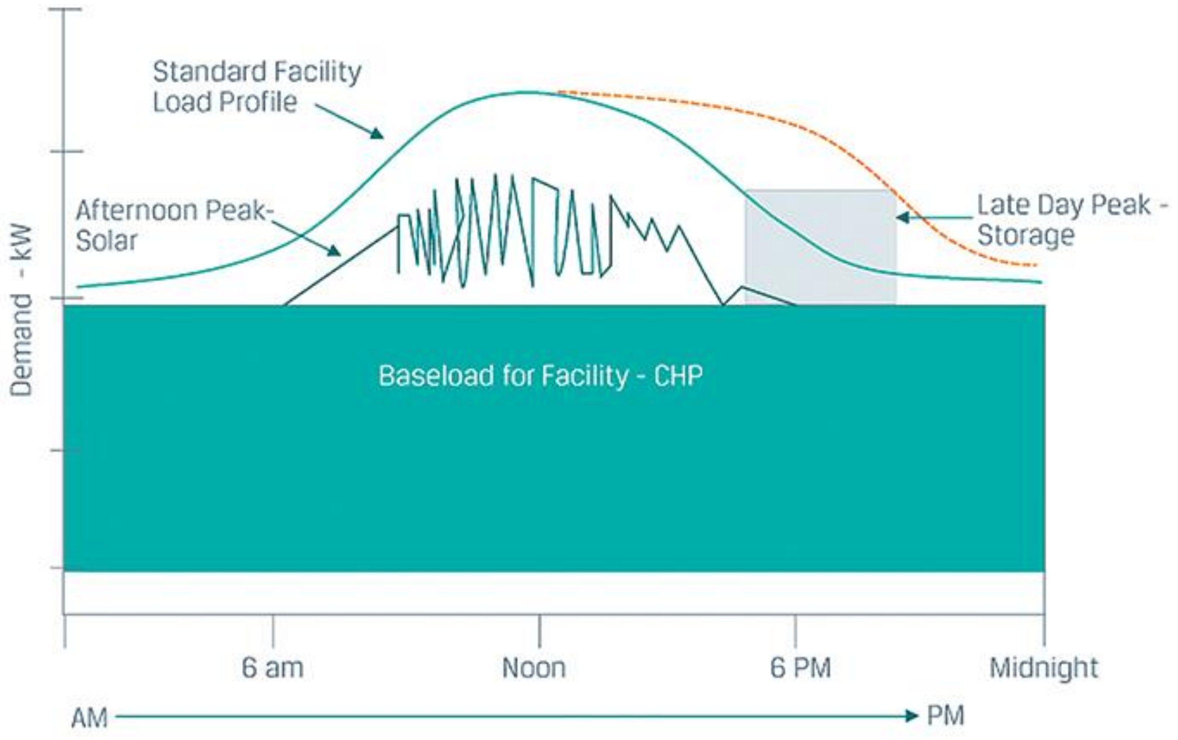
CHP Increases Resilience

For Industrial Applications:

- Provides continuous supply of electricity and thermal energy for critical loads
- Can be configured to automatically switch to “island mode” during a utility outage, and to “black start” without grid power
- Ability to withstand long, multiday outages

Growth of Hybrid DER Systems

- Hybrid DER approaches offer the opportunity for technologies to complement one another
- Hybrid systems combine characteristics of individual technologies
  - CHP – provides baseload energy
  - Solar – variable renewable generation can now be "firmed"
  - Storage – adding flexibility
- Allows CHP to be a key part of the move toward a distributed/renewable grid



DOE TAP CHP Screening Analysis

- High level assessment to determine if site shows potential for a CHP project
  - Quantitative Analysis
    - Energy Consumption & Costs
    - Estimated Energy Savings & Payback
    - CHP System Sizing
  - Qualitative Analysis
    - Understanding project drivers
    - Understanding site peculiarities

	Base Case	CHP Case
Annual Energy Consumption		
Purchased Electricty, kWh	88,250,160	5,534,150
Generated Electricity, kWh	0	82,716,010
On-site Thermal, MMBtu	426,000	18,872
CHP Thermal, MMBtu	0	407,128
Boiler Fuel, MMBtu	532,500	23,590
CHP Fuel, MMBtu	0	969,845
Total Fuel, MMBtu	532,500	993,435
Annual Operating Costs		
Purchased Electricity, $	$7,060,013	$1,104,460
Standby Power, $	$0	$0
On-site Thermal Fuel, $	$3,195,000	$141,539
CHP Fuel, $	$0	$5,819,071
Incremental O&M, $	$0	$744,444
Total Operating Costs, $	$10,255,013	$7,809,514
Simple Payback		
Annual Operating Savings, $		$2,445,499
Total Installed Costs, $/kW		$1,400
Total Installed Costs, $/k		$12,990,000
Simple Payback, Years		**5.3**
Operating Costs to Generate		
Fuel Costs, $/kWh		$0.070
Thermal Credit, $/kWh		($0.037)
Incremental O&M, $/kWh		$0.009
Total Operating Costs to Generate, $/kWh		**$0.042**

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