Better Plants
U.S. DEPARTMENT OF ENERGY

Combined Heat and Power Technical Assistance Partnership (CHP TAPS) Virtual INPLT Training & Assessment

Session 1

November 29, 2022

10 am – 12:30 pm

U.S. DEPARTMENT OF ENERGY

Fundamentals of CHP and the TAP Program

November 29, 2022

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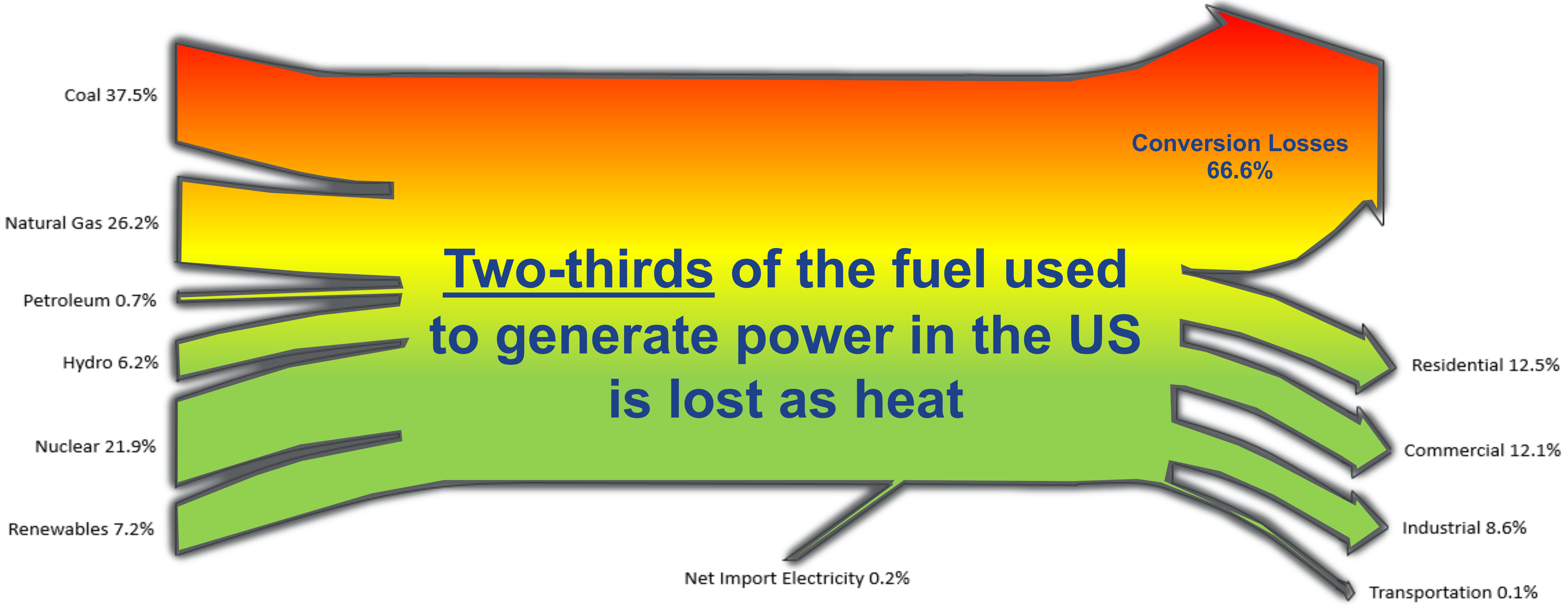
Safety and Housekeeping

- You are welcome to ask questions at any time during the webinar
- When you are not asking a question, please <u>MUTE</u> your mic and this will provide the best sound quality for all participants
- We will be recording all these webinars and by staying on-line and attending the meeting you are giving your consent to be recorded
    - A link to the recorded webinars will be provided, afterwards

Outline

- Intro to DOE CHP Technical Assistance Partnership (TAP) Program
- Fundamentals of CHP Systems
- National CHP e-Catalog
- Current & Future Trends
- Technical Assistance and DOE CHP TAP Resources
- Next steps and Q&A

Why CHP?


Coal 37.5%
Natural Gas 26.2%
Petroleum 0.7%
Hydro 6.2%
Nuclear 21.9%
Renewables 7.2%
Conversion Losses 66.6%
Two-thirds of the fuel used to generate power in the US is lost as heat
Residential 12.5%
Commercial 12.1%
Industrial 8.6%
Transportation 0.1%
Net Import Electricity 0.2%

Shaw Industries
Columbia, South Carolina

- Project Snapshot: Shaw®
  - CHP for Sustainability and Cost Savings

Application	Carpet Fiber Production
Capacity	14.1 MW
Prime Mover	Gas Turbine
Fuel Type	Natural Gas
Thermal Use	Process steam, hot water, cooling
Installation Year	2018

Project Highlights: The 14.1 MW CHP system has the capacity to meet 100% of the plant's load as well as 75% of its electric demand. Shaw Industries has been significantly investing in their operations to minimize its environmental footprint. Shaw has invested more than $30 million since 2011 to reduce its greenhouse gas impacts. Shaw currently has a target of 40% GHG emission reduction by 2030.

With the help of a CHP plant and other measures such as energy efficiency, Shaw Industries has reduced GHG emissions by over 25% since 2010.

Project Testimonial

"Climate change is a complex, global issue. While no one company or individual can tackle this challenge alone, as a globally oriented company we have a responsibility to positively contribute to the solution. The Combined Heat and Power Plant (at Plant 8S) exemplifies one of many ways we are doing our part to have a positive impact on the world we all share."
- Troy Virgo, Director of Sustainability

Southeast CHP TAP – https://chptap.lbl.gov/profile/201/ShawIndustries-Project_Profile.pdf

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

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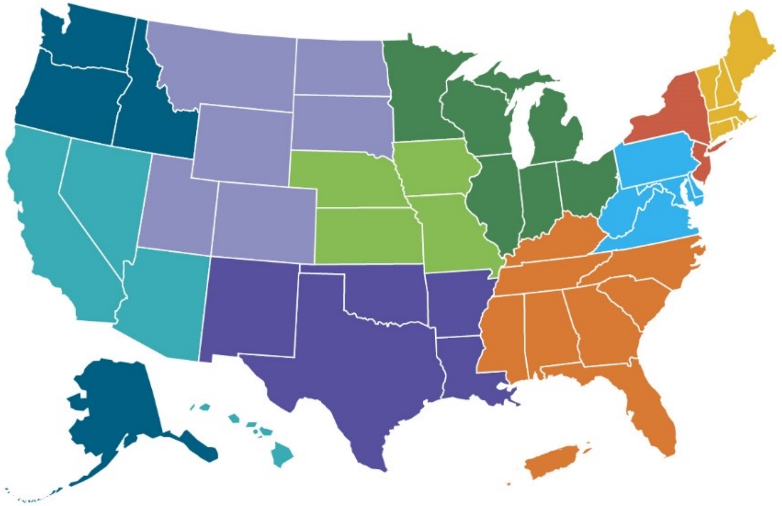

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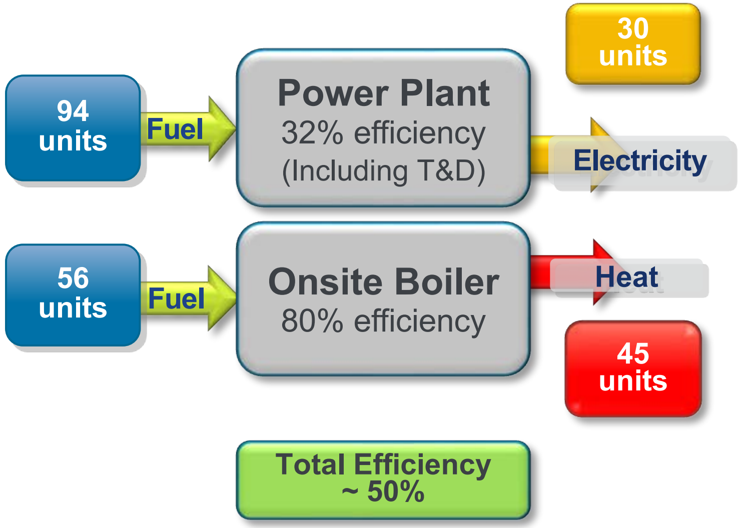
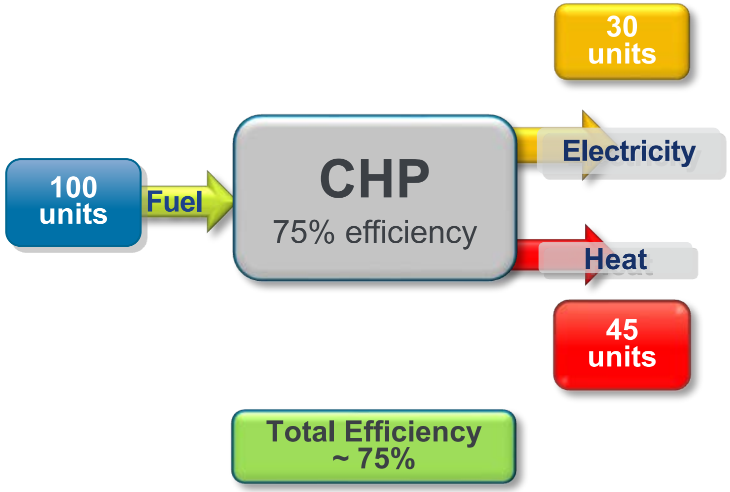
Fundamentals of CHP

CHP: A Key Part of Our Energy Future

CONVENTIONAL System



CHP System



30% to 55% less greenhouse gas emissions

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

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

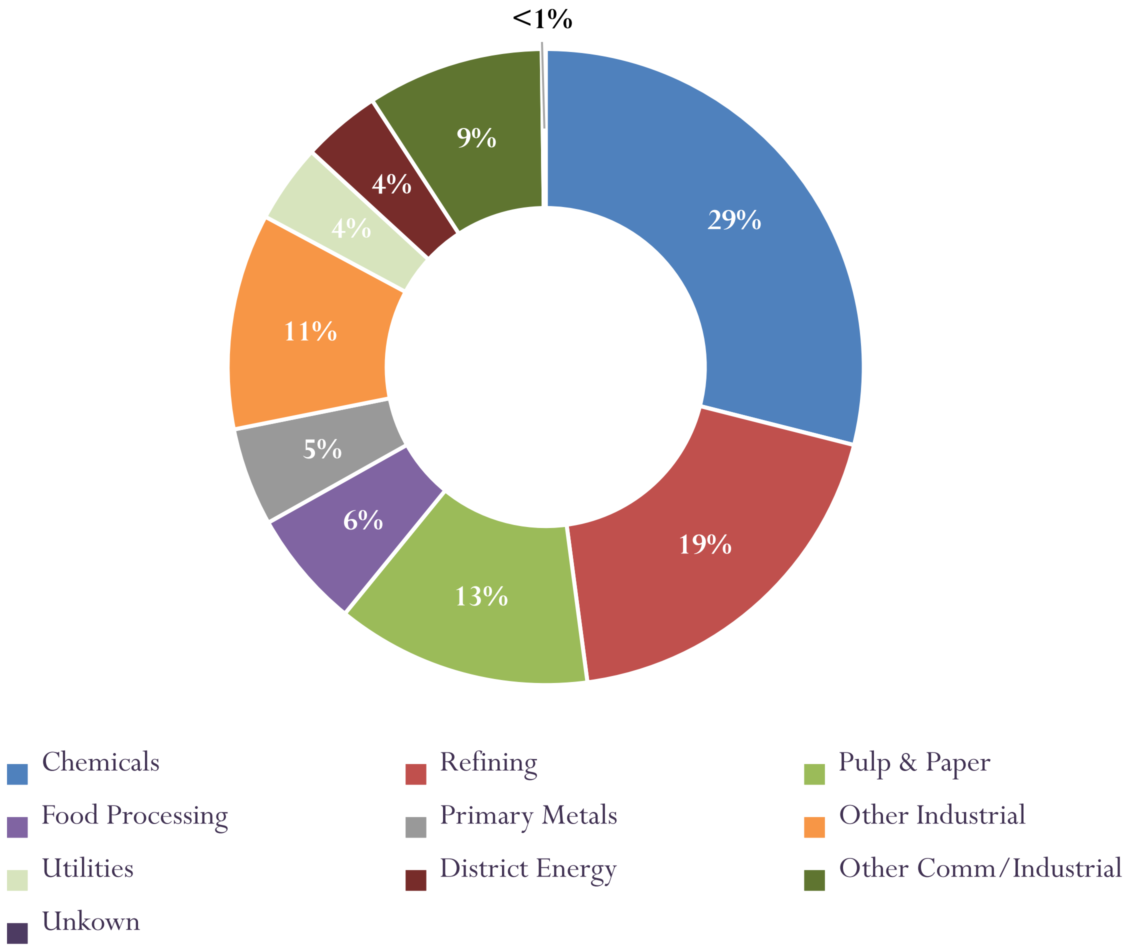
Source: www.energy.gov/chp

What are the Benefits of CHP?

- More efficient than separate generation of electricity and heating/cooling
  - Lower carbon and other pollutant emissions
  - Lower operating costs (but requires capital investment)
- Works with any fuel, including carbon neutral fuels
  - Efficiency becomes more important as fuels become scarce
- Increases energy reliability and resiliency
- Reduces grid congestion and avoid distribution costs
  - Complements intermittent renewable resources

CHP Today in the United States

Existing CHP Capacity: 81.7 GW



Avoids more than **1.3 quadrillion Btus** of fuel consumption annually.

Avoids **215 million metric tons of CO^2** compared to separate production.

81.7 GW of installed CHP at more than **4,700** industrial and commercial facilities.

7% of U.S. electric generating capacity

Prime Mover Technologies & Configurations

- Five Prime Movers
  - Reciprocating engines
  - Gas turbines
  - Microturbines
  - Steam turbines
  - Fuel cells
- Three Main Configurations (described on following slides)
  - Engine/Turbine with Heat Recovery
  - Boiler & Steam Turbine
  - Fuel Cell with Heat Recovery
- Information based on Overview of CHP Technologies, CHP Technology Fact Sheet Series
  - https://energy.gov/eere/amo/combined-heat-and-power-basics#factsheet

Reciprocating Engines

- Well-established and widely used technology
- Diesel and spark-ignition configurations
- Important for both transportation and stationary uses
- Sizes range from very small (<5 kW) to very large (>80MW, 5-story tall marine propulsion systems weighing over 5 million pounds)
- Engines are rugged, reliable, and economic choice as a prime mover for CHP applications
- Pros: High part-load operation efficiency, fast start-up, suitable for a variety of applications
- Cons: Lower temperature output for CHP applications, routine maintenance

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

Gas Turbines

- Aircraft applications drove innovations and technology development, with millions of hours of operation, making it a dependable and trusted technology
- Range in size from 500 kW to over 300 MW
- Pros: GT have high reliability, high efficiency, low emissions, benefit from economies of scale, and can offer a wide range of power-to-thermal ratios (e.g. from a high thermal duct-fired SCGT to a high power CCGT)
- Cons: GT at industrial size applications can be expensive

Gas turbine CHP installation at a university.
Photo courtesy of Solar Turbines

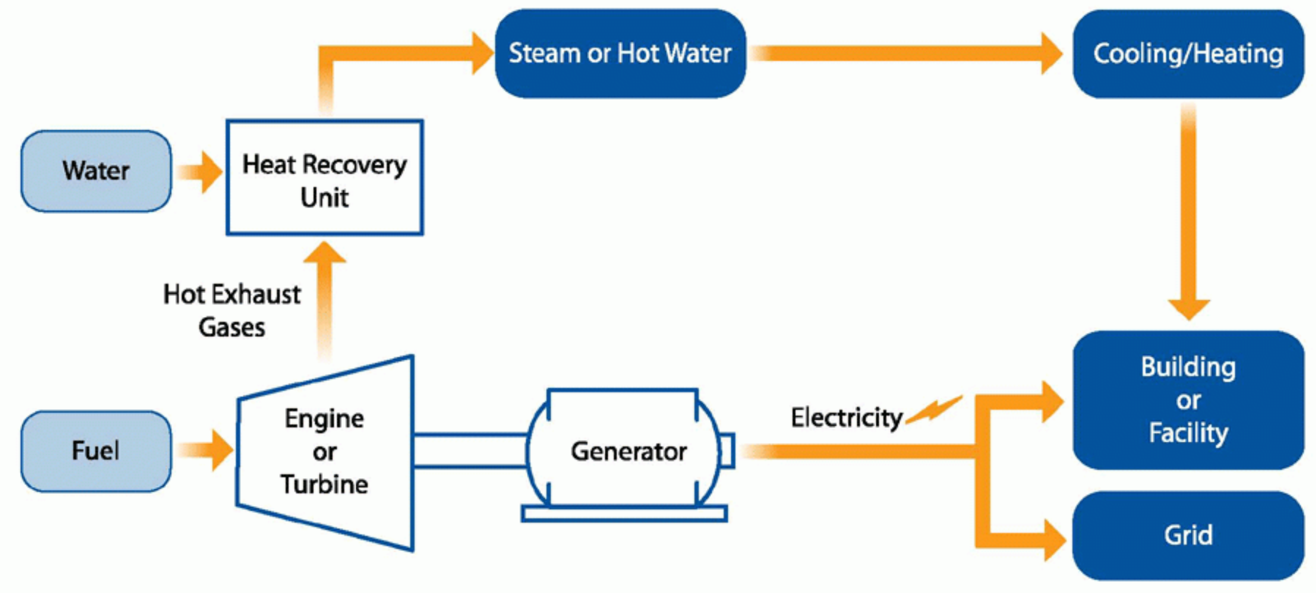
Microturbines

- Relatively newer prime mover that entered the market in 1990s
- Sizes range from 30 kW to 250 kW (with modular packages exceeding 1 MW)
- Fuel flexible including natural gas, sour gas, and liquid fuels such as gasoline, diesel, and heating oil
- Exhaust in the 500 to 600°F range, suitable for supplying a variety of thermal needs.
- Pros: Microturbines have small number of moving parts, compact size and light weight, low emissions, no cooling required
- Cons: Microturbines are higher in costs, relatively low part load efficiency

Microturbine CHP installation at a commercial facility.
Photo courtesy of Capstone Turbine Corporation

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



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

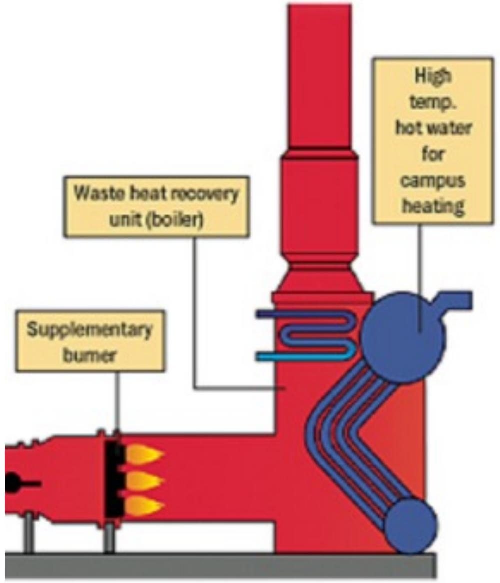


Image Source: University of Calgary

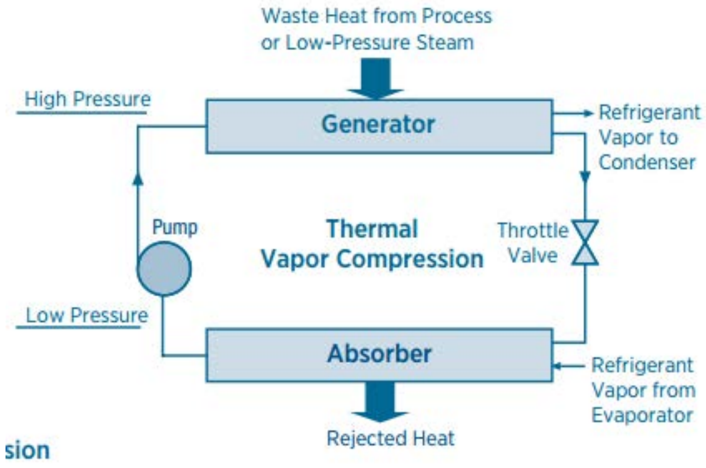


Image Source: DOE - EERE

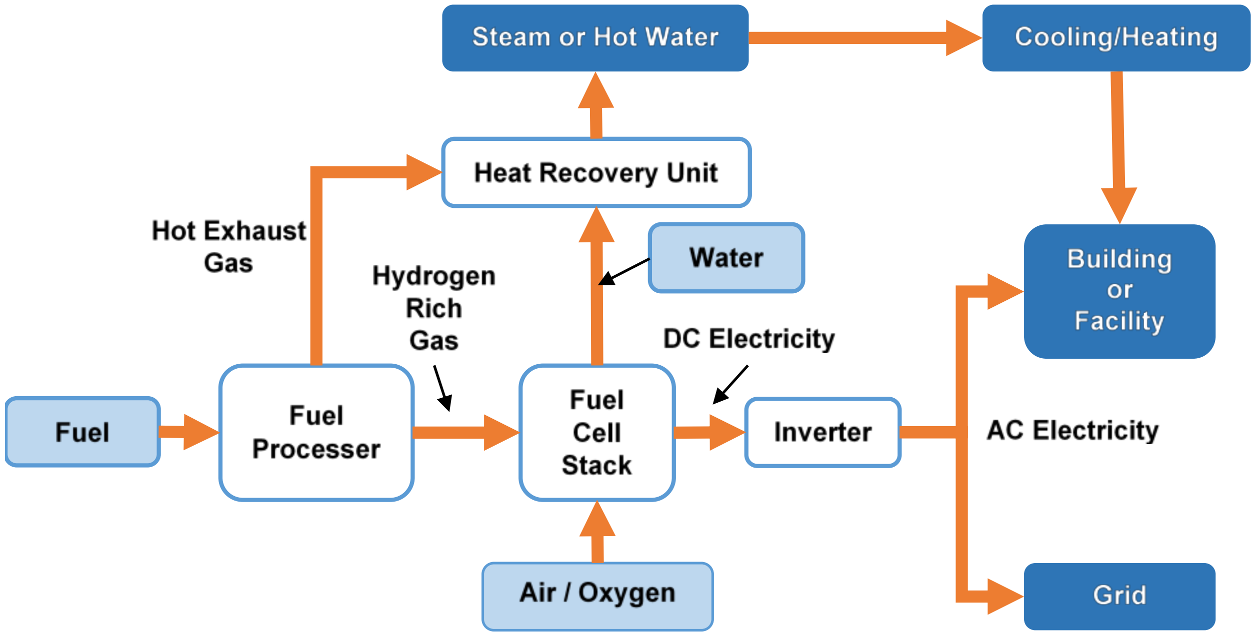
Fuel Cells

- A fuel, such as natural gas, is reformed in a fuel processor to create hydrogen
- Hydrogen and oxygen are converted to direct current (DC) electricity using an electrochemical process in a fuel cell stack
- An inverter is used to convert DC electricity to alternating current (AC) electricity
- Heat from the fuel processor and fuel cell stack are recovered to provide useful thermal energy for the site
- Pros: High Efficiency, Environmentally Friendly, Low Noise
- Cons: Very High Capital Cost, Long term reliability in commercial operations not yet proven, except for Phosphoric Acid fuel cells

CHP fuel cell installation at Verizon data center.[1]
Photo courtesy of Verizon Communications.

Fuel Cell with Heat Recovery

- A fuel, such as natural gas, is reformed in a fuel processor to create hydrogen
- Hydrogen and oxygen are converted to direct current (DC) electricity using an electrochemical process in a fuel cell stack
- An inverter is used to convert DC electricity to alternating current (AC) electricity
- Heat from the fuel processor and fuel cell stack are recovered to provide useful thermal energy for the site



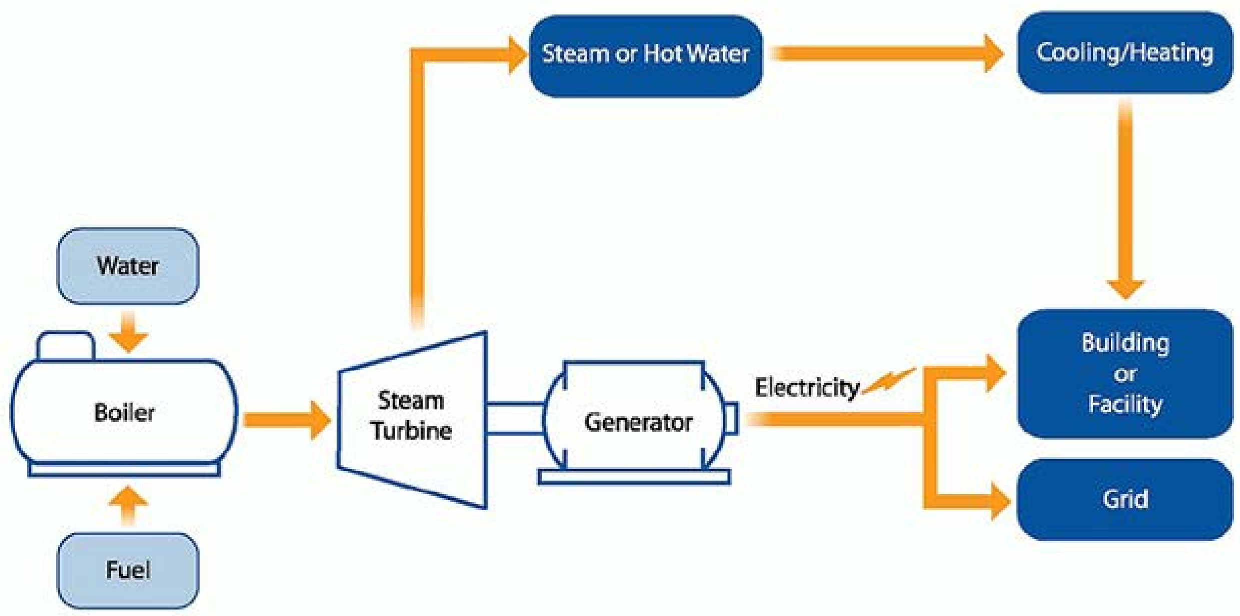
Steam Turbines

- Invented in 1884, quickly replaced reciprocating engines as main prime mover technology
- Wide power range from 50kW (0.05 MW) to 250 MW
- Boilers can operate on variety of fuels (e.g. natural gas, solid waste, coal, wood, wood waste, agricultural byproducts)
- Good efficiency combined with relative cleanliness of the feedstock lead to relatively low carbon dioxide, nitrogen oxides and other emissions
- Two typical designs:
  - Single-stage back-pressure or condensing turbines
  - Multi-stage turbines (higher power ranges)
- Pros: Variety of applications where steam is expanded from high pressure to low, emissions depend on feedstock,
- Cons: Relatively high capital costs

Steam turbine CHP installation at an industrial facility in New York.
Photo courtesy of Recycled Energy Development

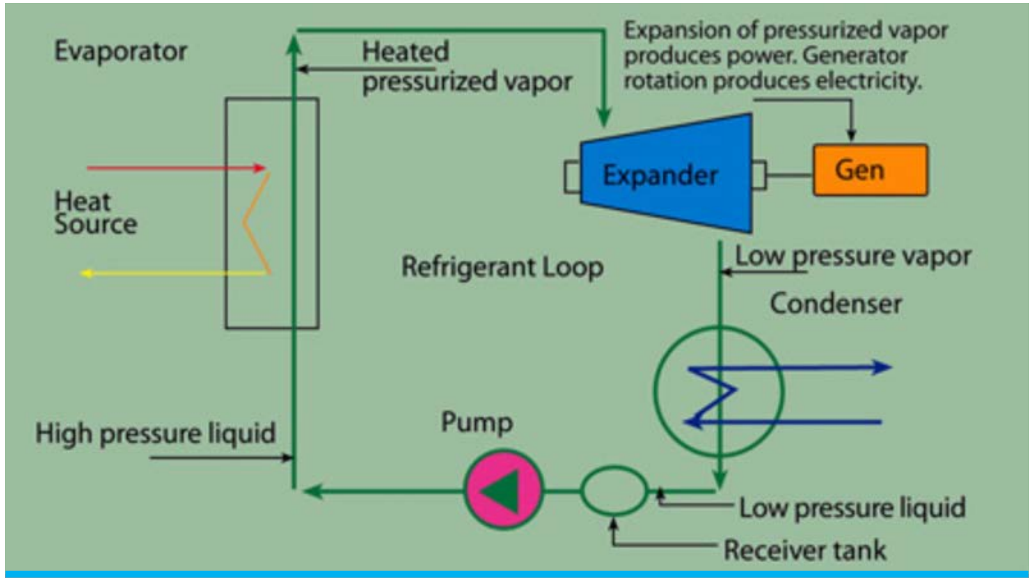
Boiler / Steam Turbine

- 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



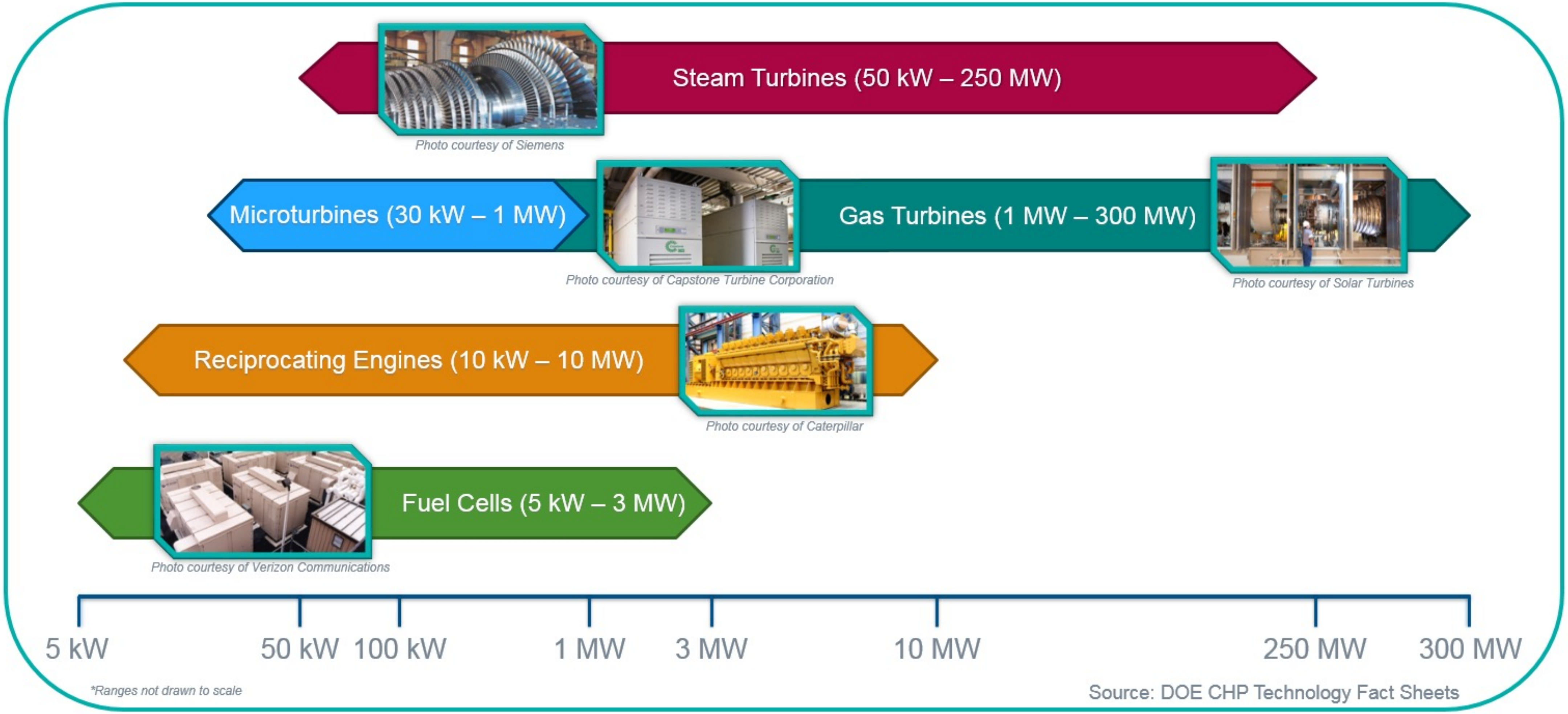
Organic Rankine Cycle

- For low-temperature waste heat recovery applications typically between 170-600°F
- Commercially available size ranges from 100 kW to 8 MW
- Uses working fluid other than water/steam such as a hydrocarbon or ammonia, allowing for lower working temperatures, potentially eliminating need for 24/7 boiler operators
- Pros: Variety of temperature and size range applications across numerous market sectors, no emissions
- Cons: High installation costs (~1.5 X Steam Turbine costs), complex engineering



Organic Rankine Cycle Thermodynamic Cycle
Photo courtesy of gulfcoastgreenenergy.com

Common CHP Technologies and Capacity Ranges



Source: DOE CHP Technology Fact Sheets

Comparison of CHP Characteristics [1, 2]

Characteristic	Technology				
	Reciprocating Engine	Gas Turbine	Microturbine	Fuel Cell	Steam Turbine
Size Range	10 kW – 10 MW	1 – 300 MW	30 kW – 330 kW (larger modular units available)	5 kW – 1.4 MW (larger modular units available)	100 kW – 250 MW
Electric Efficiency (HHV)	30% – 42%	24% – 36%	25% – 29%	38% – 42%	5% – 7%
Overall CHP Efficiency (HHV)	77% – 83%	65% – 71%	64% – 72%	62% – 75%	80%
Total Installed Cost ($/kW) [3]	$1,400 – $2,900	$1,300 – $3,300	$2,500 – $3,200	$4,600 –$10,000	$670 – $1,100 [4]
O&M Cost (¢/kWh)	0.9-2.4	0.9-1.3	0.8-1.6	3.6-4.5	0.6-1.0
Power to Heat Ratio	0.6 – 1.2	0.6 – 1.0	0.5 – 0.8	1.3 – 1.6	0.07 – 0.10
Thermal Output (Btu/kWh)	2,900 --6,100	3,400 --6,000	4,400 --6,400	2,200 --2,600	30,000 --50,000

Notes:
1) Unless noted otherwise, information based on U.S. Department of Energy, CHP Technology Fact Sheet Series, 2016, 2017.
2) All performance and cost characteristics are typical values and are not intended to represent a specific product.
3) Costs will vary depending on site specific conditions and regional variations.
4) Costs shown are for a steam turbine only, and do not include costs for a boiler, fuel handling equipment, steam loop, and controls.

Comparison of CHP Characteristics continued...

Characteristic	Technology				
	Reciprocating Engine	Gas Turbine	Microturbine	Fuel Cell	Steam Turbine
Fuel Pressure (psig) [1]	1-75	100-500 (may require fuel compressor)	50-140 (may require fuel compressor)	0.5-45	n/a
Part Load Efficiency	Good at both part-load and full-load	Better at full-load	Better at full-load	Better at full-load	Good at both part-load and full-load
Type of Thermal Output	LP steam, hot water, space heating, chilled water	LP-HP steam, hot water, process heating, chilled water	LP steam, hot water, chilled water	LP steam, hot water, chilled water	LP-HP steam, hot water, chilled water
Fuel	Can be operated with a wide range of gas and liquid fuels. For CHP, the most common fuel is natural gas.			Hydrogen, natural gas, propane, methanol	Steam turbines for CHP are used primarily where a solid fuel (e.g., coal or biomass) is used in a boiler. [2]

Notes:
1) Adapted from Catalog of CHP Technologies, U.S. Environmental Protection Agency Combined Heat and Power Partnership, 2015.
2) Backpressure steam turbines can be used to produce power by replacing pressure reducing valves (PRVs) in existing steam systems.

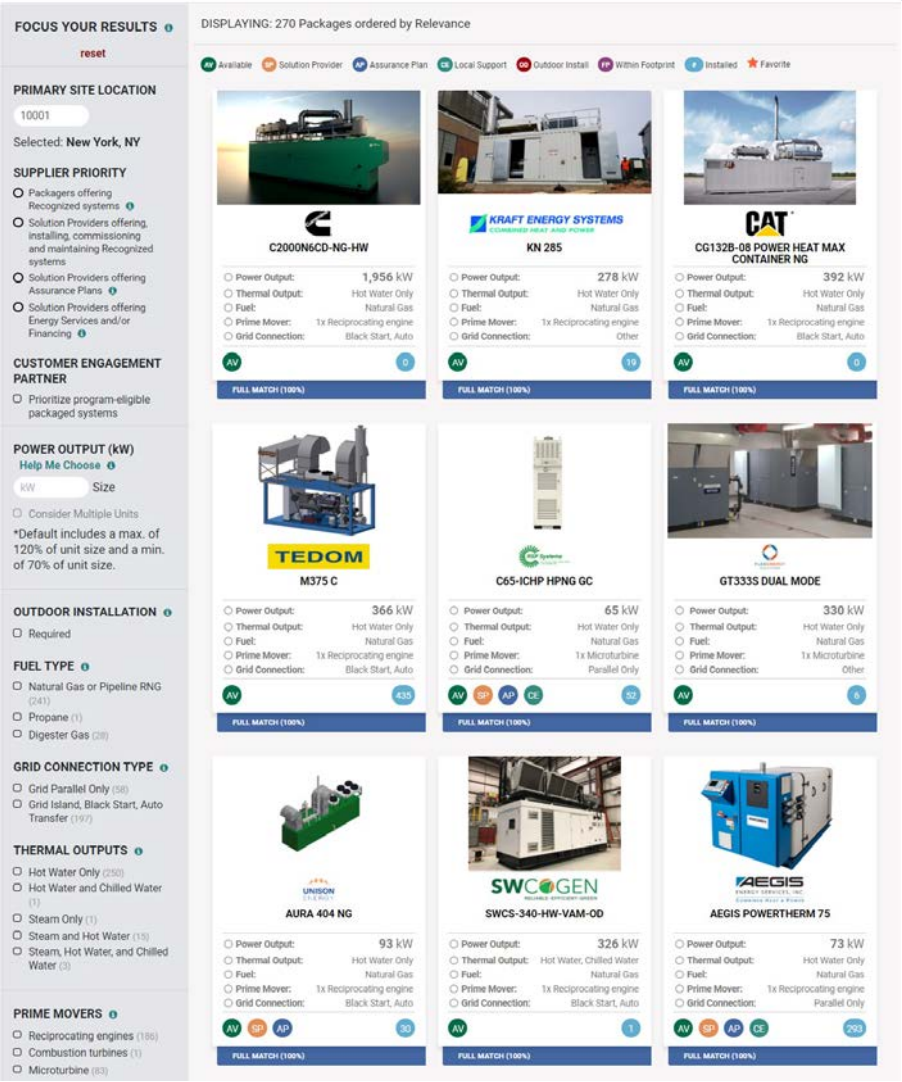
DOE Packaged CHP eCatalog

DOE Packaged CHP eCatalog

- A national web-based searchable catalog of DOE-recognized packaged CHP systems and suppliers with the goal to reduce risks for end-users and vendors through partnerships with:
  - *CHP Packagers that assemble and support recognized packaged CHP Systems*
  - *Solution Providers that install, commission and service packaged CHP systems*
  - *CHP Engagement partners that provide CHP market deployment programs at the state, local and utility level*
- Pre-engineered and tested packaged CHP systems that meet DOE performance requirements.
- eCatalog audience: end-users with engineering staff, consulting engineers, utilities, state energy offices, regulators, federal agencies, and project developers.
- Users search for applicable CHP system characteristics, and get connected to packagers, installers and CHP engagement programs
- Allows users to compare technology options on a common basis.

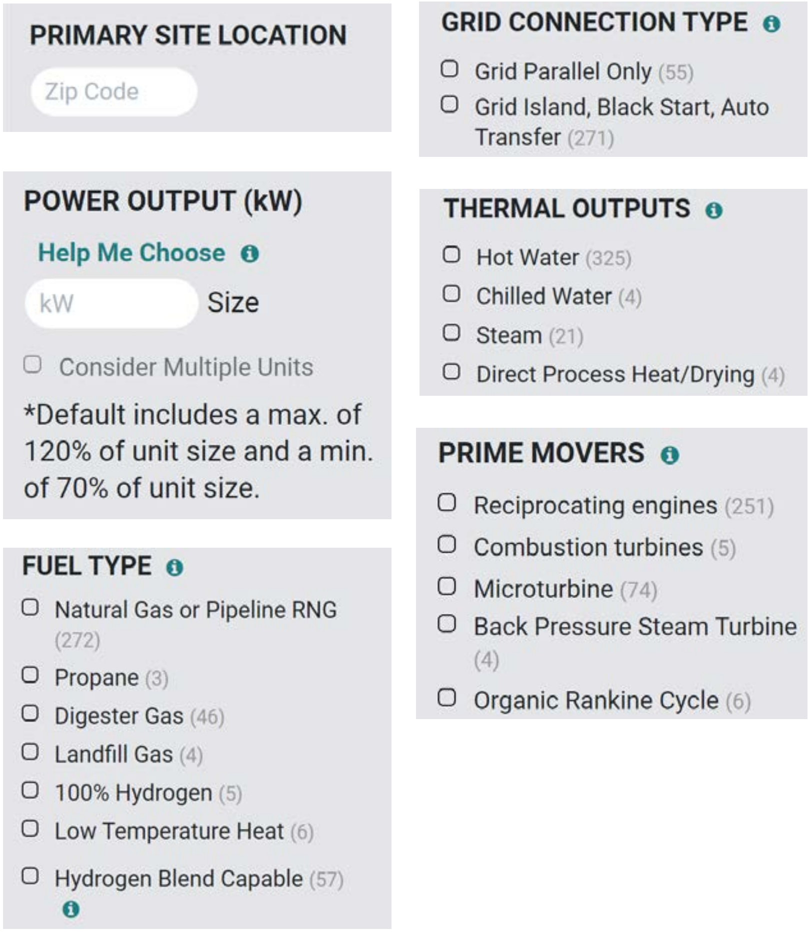
DOE Packaged CHP eCatalog*

- Launched Nov 8, 2019
- 41 recognized Packagers
- 25 recognized Solution Providers
- 18 Customer Engagement Partners
- 24 kW to 7.9 MW
- Multiple suppliers and packages in every zip code
- 340 Package Offerings
  - *251 reciprocating engine*
  - *74 microturbine*
  - *5 gas turbine*
  - *4 backpressure steam turbine*
  - *6 organic rankine cycle*
- Package offerings by Fuel Type
  - *272 natural gas and pipeline RNG*
  - *57 hydrogen blend capable*
  - *5 100% hydrogen*
  - *46 digester gas*
  - *3 propane*



Navigating the eCatalog

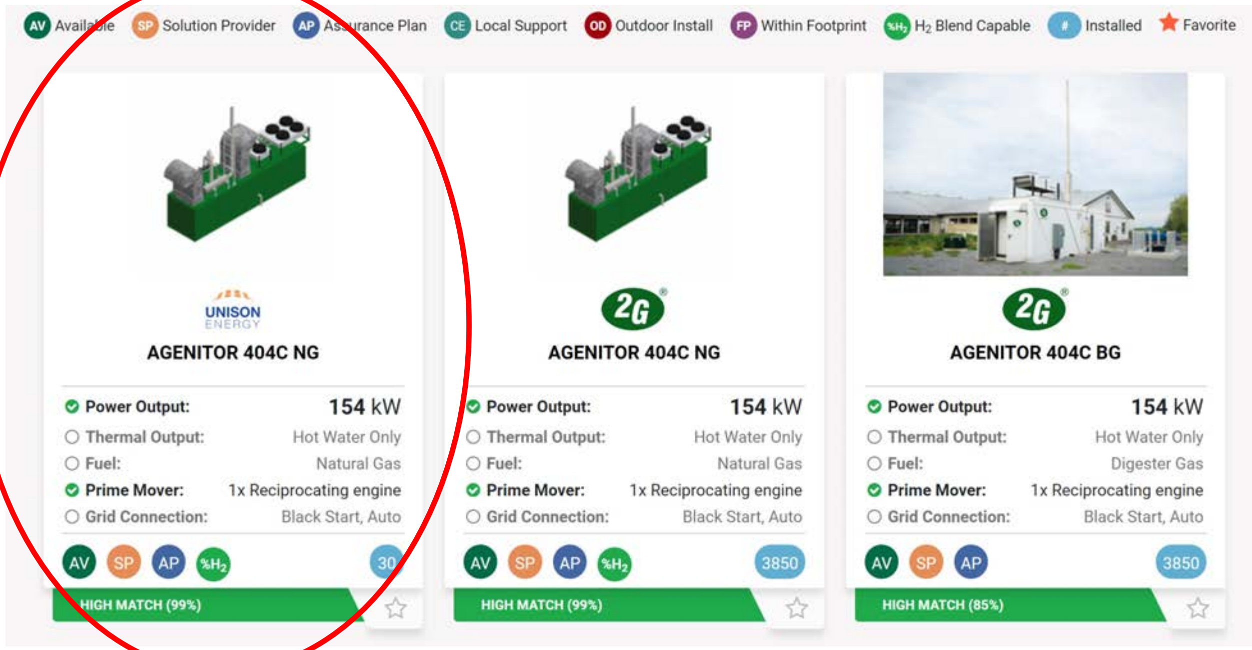
- Create a user account (optional)
- Enter a valid zip code
- Enter Electrical Power Output (from CHP TAP screening)
- Other optional inputs include: fuel type, grid connection type (parallel or black-start/islanding capabilities), thermal output (hot/chilled water, steam), prime movers (discussed earlier)
- Outputs include packages that best match your search criteria, each with performance data, packager/solution provider descriptions with installation experience, emission rates, schematics, and more.



Navigating the eCatalog continued…

- Example – Enter the following inputs: 02108 (Boston MA), 150kW, hydrogen blend capable, reciprocating engine

Let's choose the highest match



Navigating the eCatalog continued…

PACKAGED CHP SYSTEM HIGHLIGHTS

Solution Provider	2G Energy Inc.
Model	agenitor 404c NG
Thermal Outputs	Hot Water
Assurance Plan	Depends on location
Grid Connection Type	Grid Parallel and Stand-alone Transition: Automatic
Outdoor Placement	Standard Option

KEY PERFORMANCE DATA

Prime Mover	Reciprocating engines 2G agenitor 404c NG
Number of Prime Movers	1
Net Power Output (kW)2	154
Fuel	Natural Gas or Pipeline RNG and up to 40% Hydrogen

Note: The ratings below are based on the fuel designated above without any hydrogen. Contact the Packager for Package rating with hydrogen blending.

1. *(Net Power Output + Thermal Output) / Energy Input at 59°F and 100% gross power*
2. *Net Power Output is Gross Prime Mover Power less CHP system parasitics, less fuel gas booster if required and less chiller parasitics during chiller operation*
3. *Hot water capacity is usable energy assuming 180F supply and minimum allowable return temperature to the Packaged CHP System*

INSTALLATION EXPERIENCE

3,850	3	-	-
Total Company Installs	**Total Company Installs In MA**	**Installs Of This Package**	**Company Installs Of This Package**
Total systems installed by 2G Energy Inc.	Total systems installed by 2G Energy Inc. in MA	Total packages with this prime mover and fuel	Installs of this package (prime mover and fuel) by 2G Energy Inc.

PERFORMANCE DATA

		100% GROSS POWER			75% GROSS POWER			50% GROSS POWER		
	Ambient Temperature	95°F	59°F	0°F	95°F	59°F	0°F	95°F	59°F	0°F
	CHP Fuel Input (MMBtu per hour HHV)	1.49	1.51	1.51	1.20	1.20	1.20	0.86	0.86	0.86
POWER	Gross Electricity Output (kW)	157	160	160	120	120	120	80	80	80
POWER	Net Electricity Output (kW)	150	154	154	114	114	115	74	74	75
POWER	Net Electric Efficiency % (HHV)	34.4	34.7	34.8	32.3	32.5	32.6	29.4	29.4	29.6
HOT WATER	Supply Temp to Site (°F)		180 °F			180 °F			180 °F	
HOT WATER	HW flow (GPM)	45	45	45	45	45	45	45	45	45
HOT WATER	Return Temp from Site (°F)	153	153	153	158	158	158	164	164	164
HOT WATER	Hot Water Capacity (MMBtu/hr)	0.60	0.61	0.61	0.49	0.49	0.49	0.37	0.37	0.37
HOT WATER	Thermal Efficiency % (HHV)	40.3	40.4	40.4	40.8	40.8	40.8	43.0	43.0	43.0

EMISSIONS		
EMISSIONS	**Emissions Aftertreatment**	Lean-burn engine with no aftertreatment
EMISSIONS	**NOx Emissions (lb/MWhe)**	3.50
EMISSIONS	**CO Emissions (lb/MWhe)**	6.20

CHP Calculations (Using eCatalog Ex.)

- CHP Overall Efficiency = Output / Input (must be same units)
  - Inputs: Fuel
  - Outputs: Electricity and Heat
- Assuming 100% gross power at standard operating temperature of 59°F:
  - Fuel input = 1.51 MMBtu/hr = 1,510,000 BTU/hr (HHV)
  - Outputs = 154 kWe & 0.61 MMBtu/hr of hot water (HHV)
    - 154 kWe * 3412 BTU/kWh = 525,448 BTU/hr
    - 0.61 MMBtu/hr = 610,000 BTU/hr
- CHP Efficiency = Output/input

= (610,000 BTU/hr + 525,448 BTU/hr) / 1,510,000 BTU/hr

≈ 75.1% (HHV)

PERFORMANCE DATA

		100% GROSS POWER			75% GROSS POWER			50% GROSS POWER		
	Ambient Temperature	95°F	59°F	0°F	95°F	59°F	0°F	95°F	59°F	0°F
	CHP Fuel Input (MMBtu per hour HHV)	1.49	1.51	1.51	1.20	1.20	1.20	0.86	0.86	0.86
POWER	Gross Electricity Output (kW)	157	160	160	120	120	120	80	80	80
POWER	Net Electricity Output (kW)	150	154	154	114	114	115	74	74	75
POWER	Net Electric Efficiency % (HHV)	34.4	34.7	34.8	32.3	32.5	32.6	29.4	29.4	29.6
HOT WATER	Supply Temp to Site (°F)		180 °F			180 °F			180 °F	
HOT WATER	HW flow (GPM)	45	45	45	45	45	45	45	45	45
HOT WATER	Return Temp from Site (°F)	153	153	153	158	158	158	164	164	164
HOT WATER	Hot Water Capacity (MMBtu/hr)	0.60	0.61	0.61	0.49	0.49	0.49	0.37	0.37	0.37
HOT WATER	Thermal Efficiency % (HHV)	40.3	40.4	40.4	40.8	40.8	40.8	43.0	43.0	43.0

CHP Overall Efficiency from eCatalog:

34.7% + 40.4% = 75.1%

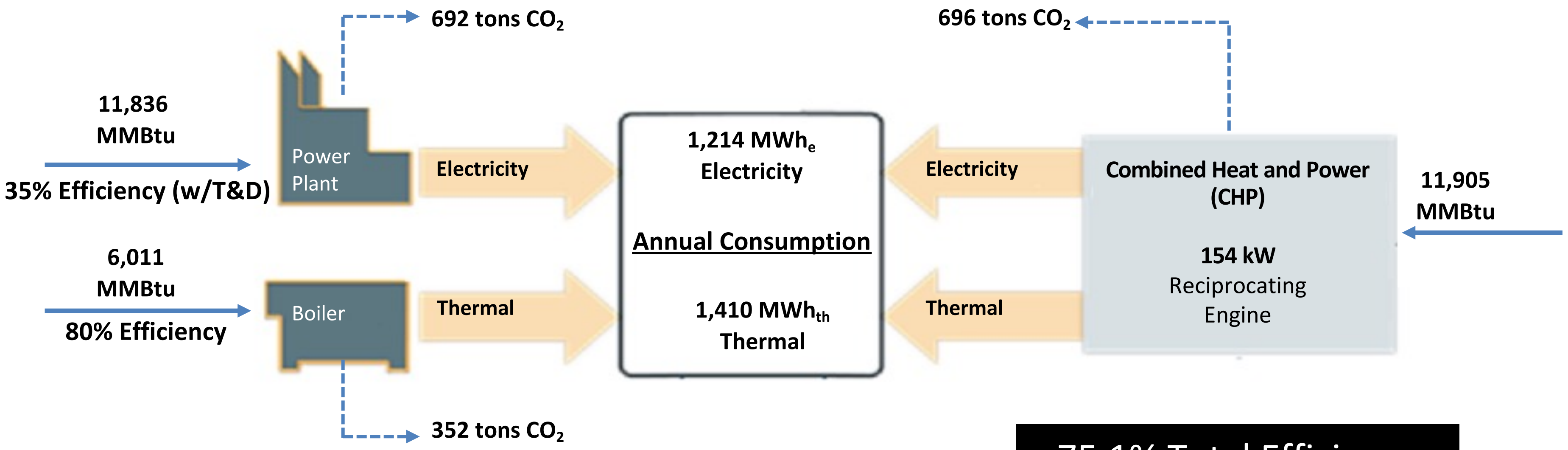
CHP Calculations (Using eCatalog Ex.) continued…

Assumptions:

- Natural Gas fueled power plant, boiler, and CHP system
- 90% uptime (7884 hours/yr)
- Emissions: 117 lb CO2/MMBtu[1]
- Est. Cost of Natural Gas = $10.00/MMBtu

Separate Heat and Power

Combined Heat and Power



50.2% Total Efficiency

75.1% Total Efficiency (found in previous slide)

Energy savings: 5942 MMBtu/yr

Est. Fuel Cost Savings: $59,420/yr

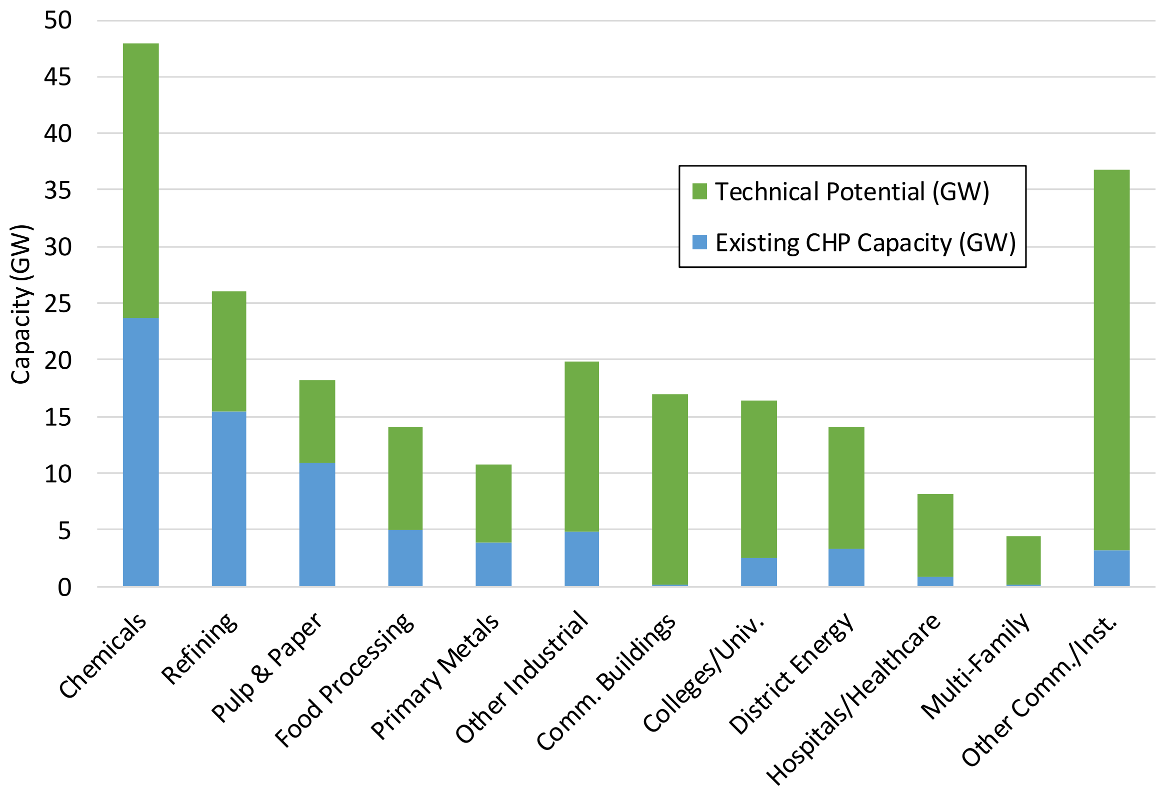
CO_2 Savings *for natural gas*: 348 tons/yr equivalent to taking 76 cars off the road annually[2]

1. EIA
2. EPA

Emerging Trends

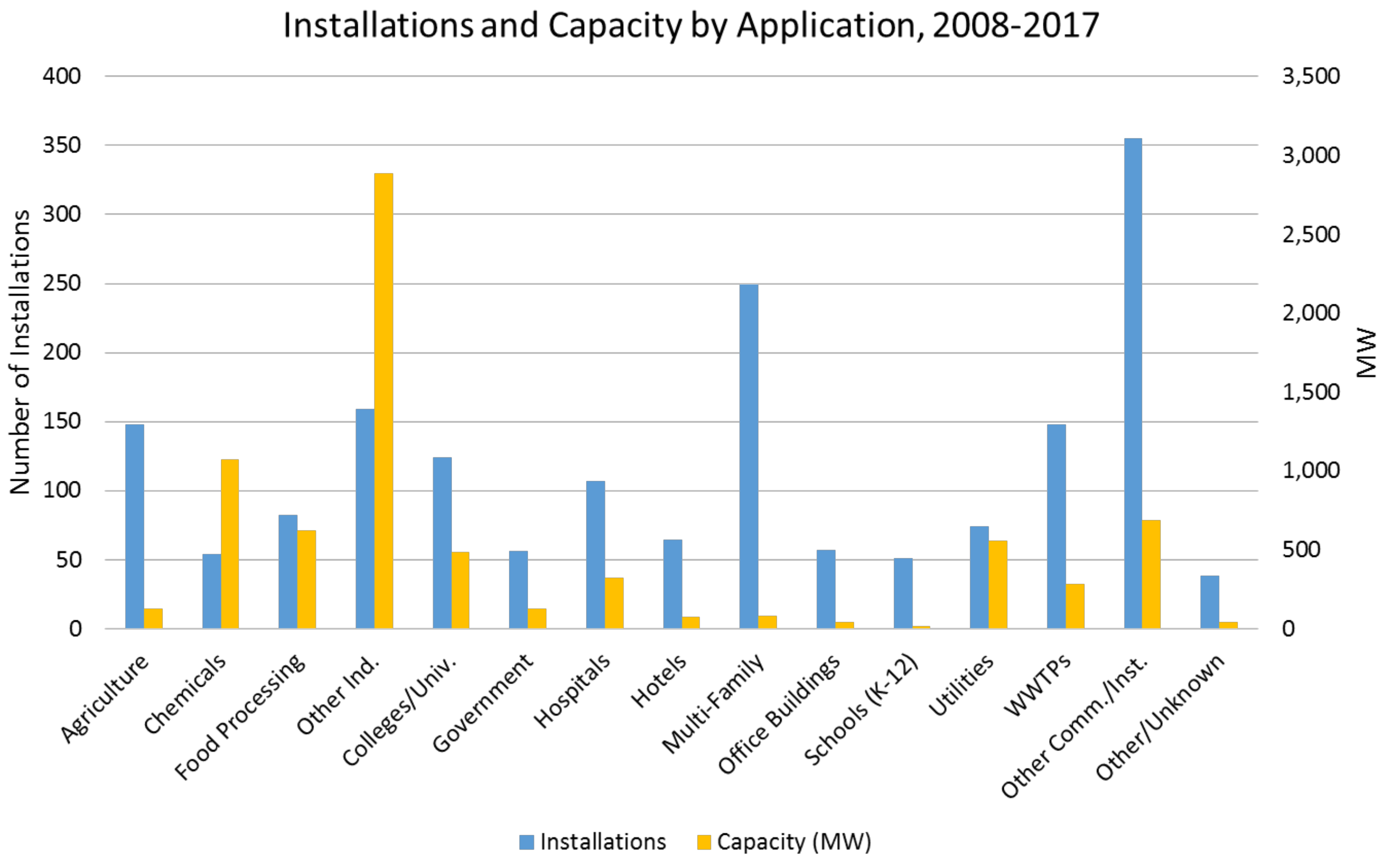
Packaged CHP Markets are an Untapped Resource

- Large CHP potential in small/midsized industrials, commercial, institutional, government and military applications
- Markets utilize smaller, packaged CHP systems (< 10MW)
- Markets have limited CHP experience
- Users have limited technical resources
- History of issues with system performance
  and with CHP sales and service support
- Many perceived risks by both users and suppliers



CHP is Growing in these Markets

- *Packaged CHP markets represented 35% of the capacity and 70% of the projects installed since 2008*

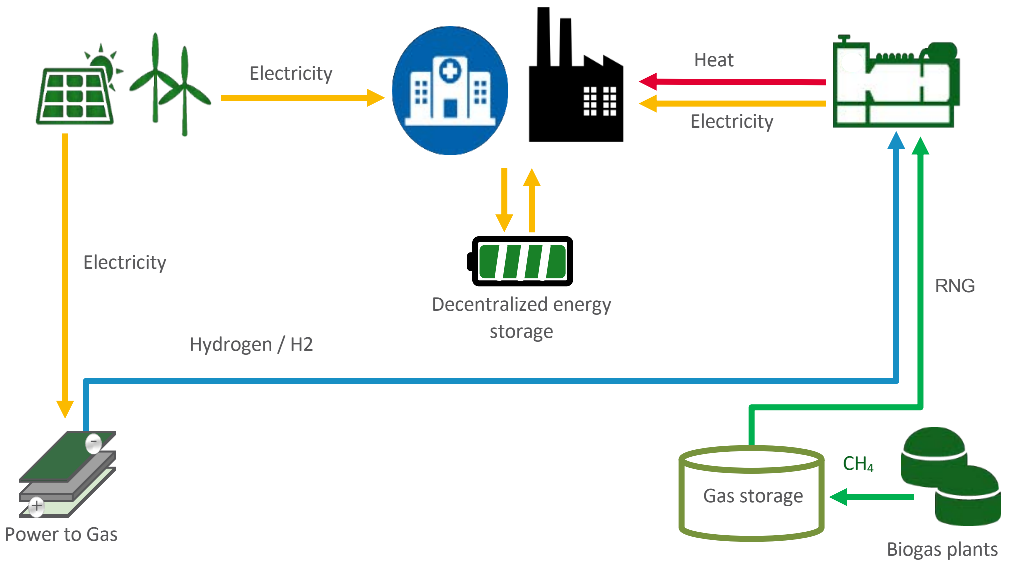


Source: DOE CHP Installation Database (U.S. installations as of Dec. 31, 2017)

CHP and Decarbonization

- CHP is fuel flexible
- CHP is the most efficient way to generate power and thermal energy, and reduces GHG emissions today
- CHP can decarbonize industrial and commercial facilities that are difficult to electrify
- CHP can decarbonize critical facilities that need dispatchable on-site power for long duration resilience
- CHP's high efficiency can extend the supply of renewable, low carbon and hydrogen fuels
- CHP can support the long-run resource adequacy of a highly renewable grid

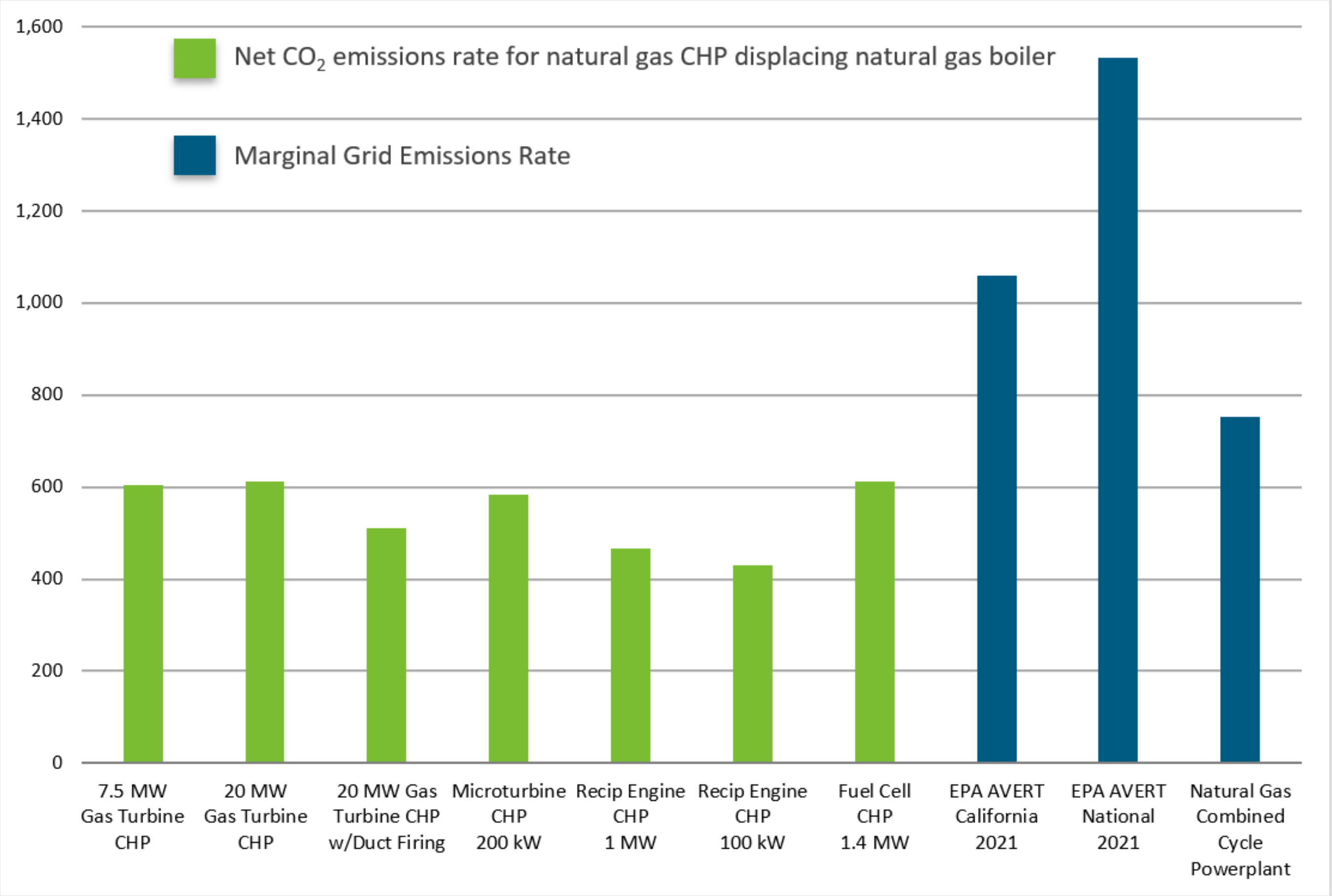
CHP in a Decarbonized Economy



Natural Gas CHP Emissions vs Marginal Grid Emissions

- Natural Gas CHP systems have lower net GHG emissions in terms of lbs CO2/MWh than current marginal grid generation
- Natural gas CHP displacing natural gas boilers provides emissions savings as long as the marginal grid emissions rate is greater than 430 to 615 lbs CO2/MWh
- Current marginal grid emissions factors range from 1,081 lbs CO2/MWh in California to 1,925 lbs CO2/MWh in the Rocky Mountain region based on 2021 EPA AVERT data (1,534 national average)
- Emissions factor for state-of-the-art natural gas combined cycle power generation is 750 lbs CO2/MWh (including T&D losses)

Net Electric CO_2 Emissions Rate, lbs /MWh



Based on 100% CHP Thermal Utilization

Prepared by: Entropy Research, LLC, 7/28/22

CHP's High Efficiency Saves CO2 Emissions Today

- CHP and renewables displace marginal grid generation (including T&D losses)
- Marginal generation is currently a mix of coal and natural gas in most regions of the US
- CHP's high efficiency and high annual capacity factor currently results in significant annual energy and emissions savings
- CHP's efficiency advantages will continue as the gas infrastructure decarbonizes
- "Because emissions are cumulative and because we have a limited amount of time to reduce them, carbon reductions now have more value than carbon reductions in the future"

Source: "Time Value of Carbon", Larry Strain, Carbon Leadership Forum, April 2020

Category	Natural Gas CHP	Utility Solar PV	Utility Wind	Biogas CHP
Capacity, MW	1.1	1.1	1.1	1.1
Annual Capacity Factor	80%	24.3%	34.3%	80%
Annual Electricity, MWh	7,709	2,342	3,305	7,709
Annual Thermal Provided, MWh_{th}	8,831	None	None	8,831
Annual Energy Savings, MMBtu	**40,834**	**21,065**	**29,733**	**40,834**
Annual CO_2 Savings, Tons	**4,019**	**1,796**	**2,677**	**8,114**

Savings based on EPA AVERT Uniform EE Emissions Factors as a first level estimate of displaced marginal generation (https://www.epa.gov/avert)

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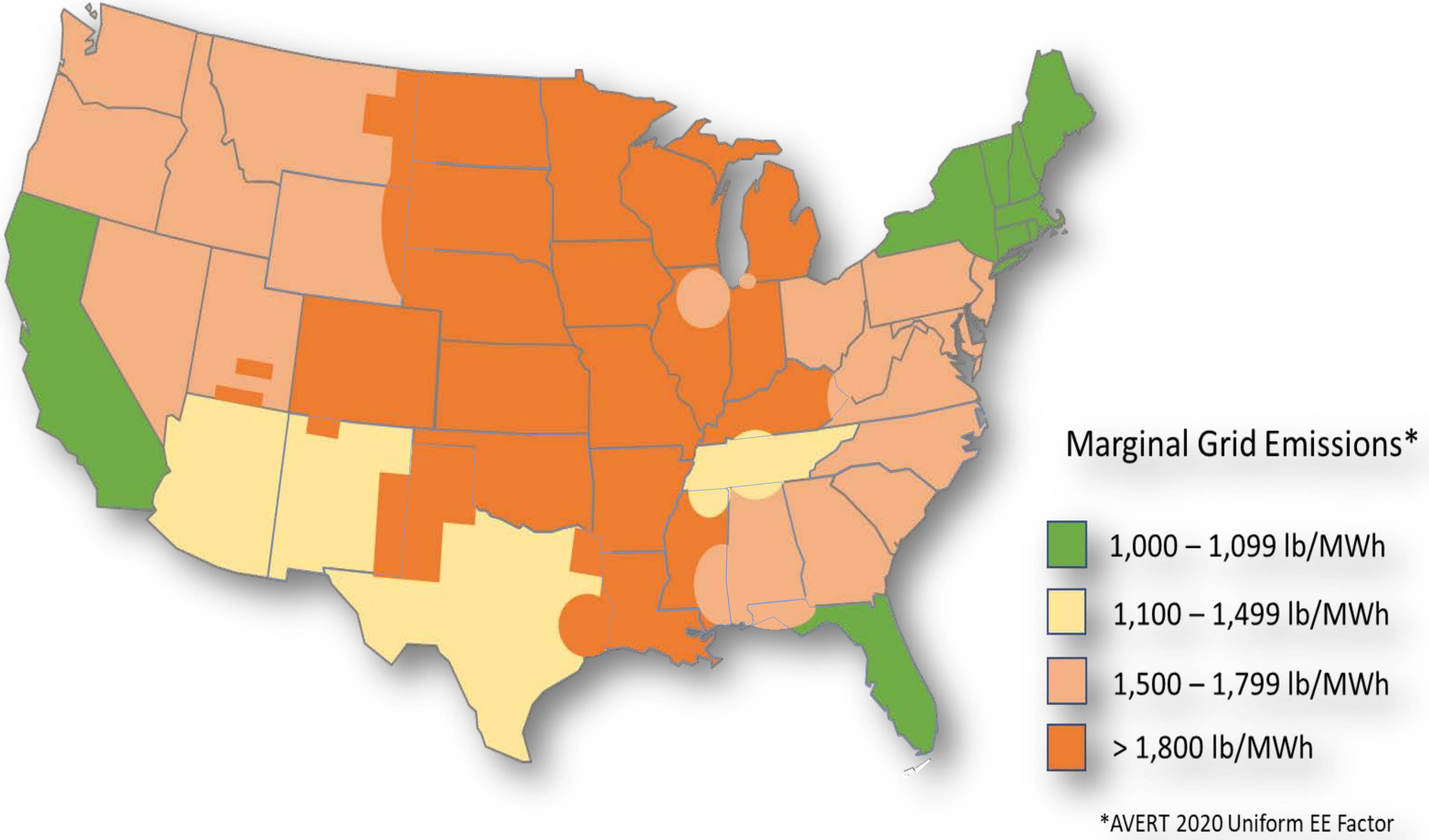
Source: "Time Value of Carbon", Larry Strain, Carbon Leadership Forum, April 2020

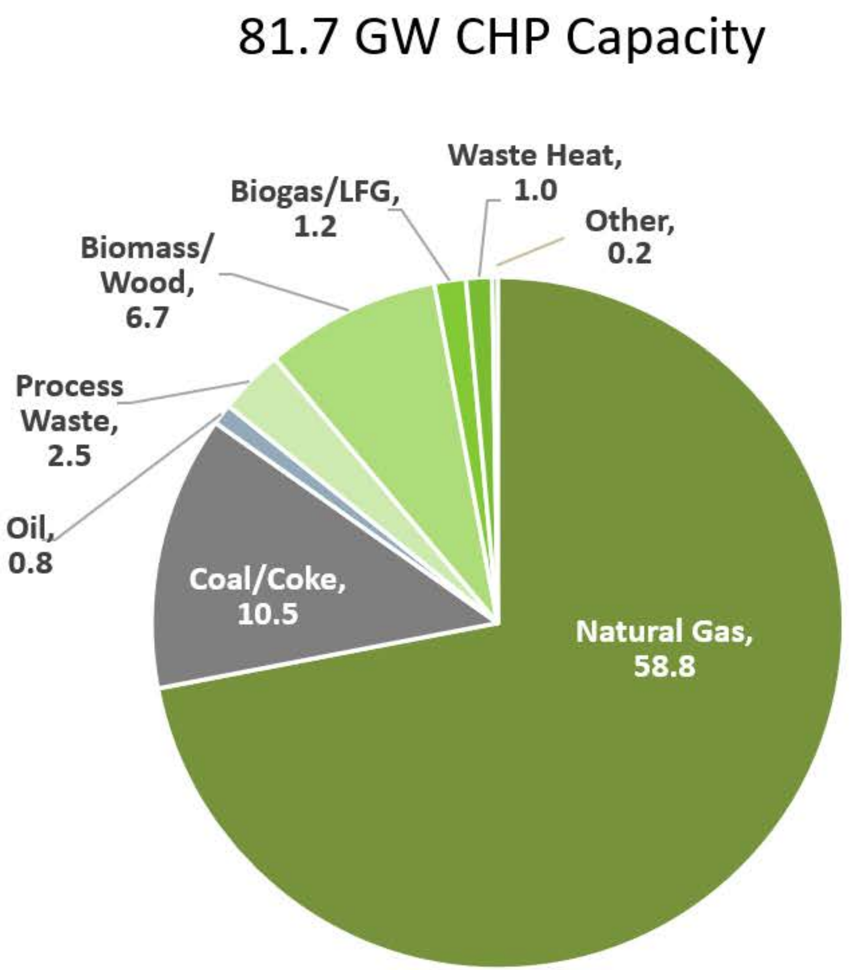
Category	Natural Gas CHP	Utility Solar PV	Utility Wind	Biogas CHP
Capacity, MW	20.0	20.0	20.0	20.0
Annual Capacity Factor	90%	24.3%	34.3%	90%
Annual Electricity, MWh	157,680	42,574	60,094	157,680
Annual Thermal Provided, MWh_{th}	169,466	None	None	169,466
Annual Energy Savings, MMBtu	**628,000**	**382,992**	**540,002**	**628,300**
Annual CO_2 Savings, Tons	**70,114**	**32,654**	**46,092**	**163,187**
Annual NOx Savings, Tons	53.5	16.4	23.1	53.5

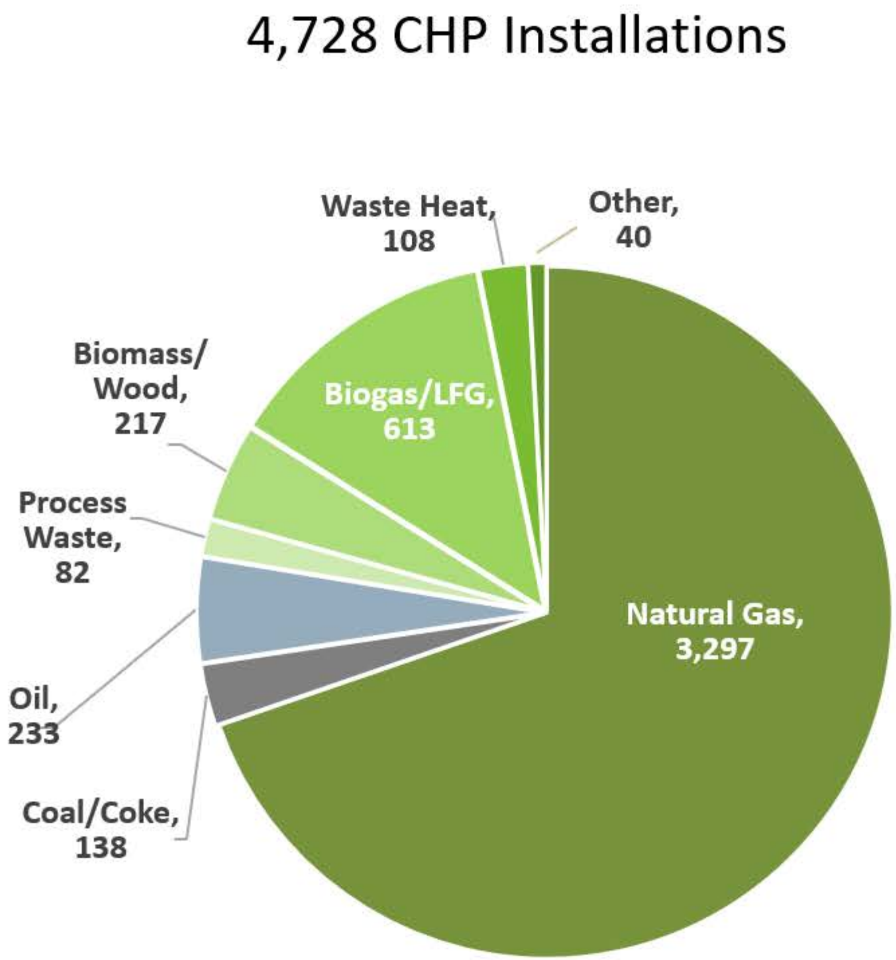
Savings based on EPA AVERT Uniform EE Emissions Factors as a first level estimate of displaced marginal generation (https://www.epa.gov/avert)

Regional Marginal Grid Emissions Factors based on EPA AVERT 2021



CHP Is Fuel Flexible



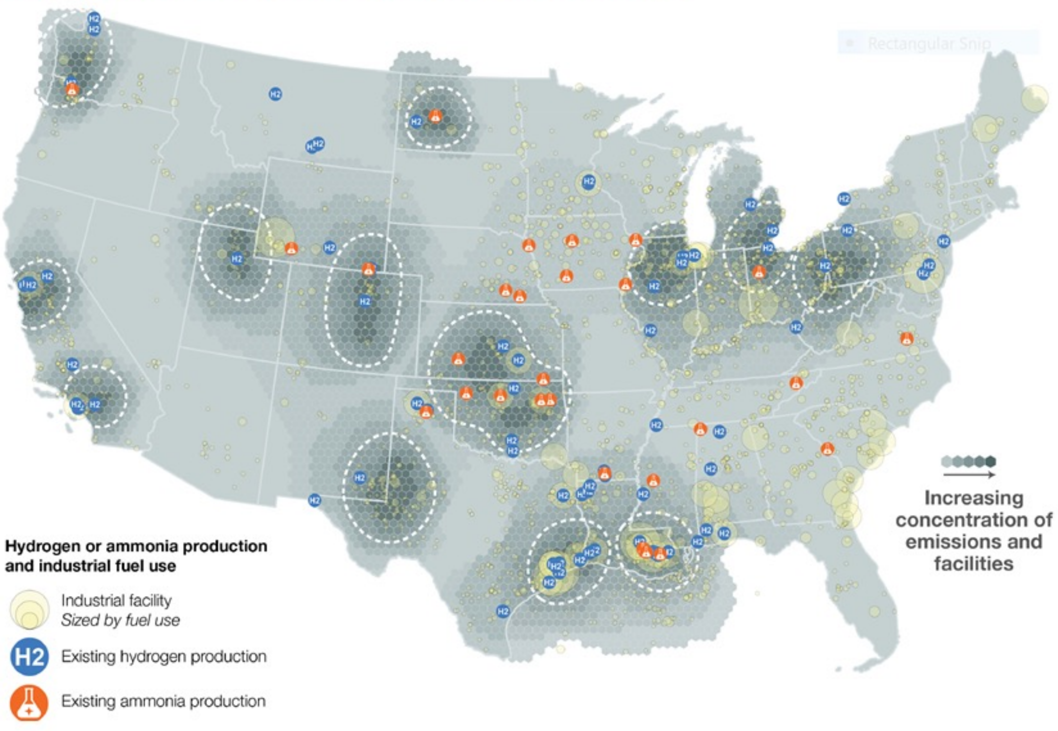


Source: DOE CHP Installation Database (U.S. installations as of December 31, 2021)

Renewable and Net-Zero Fueled CHP

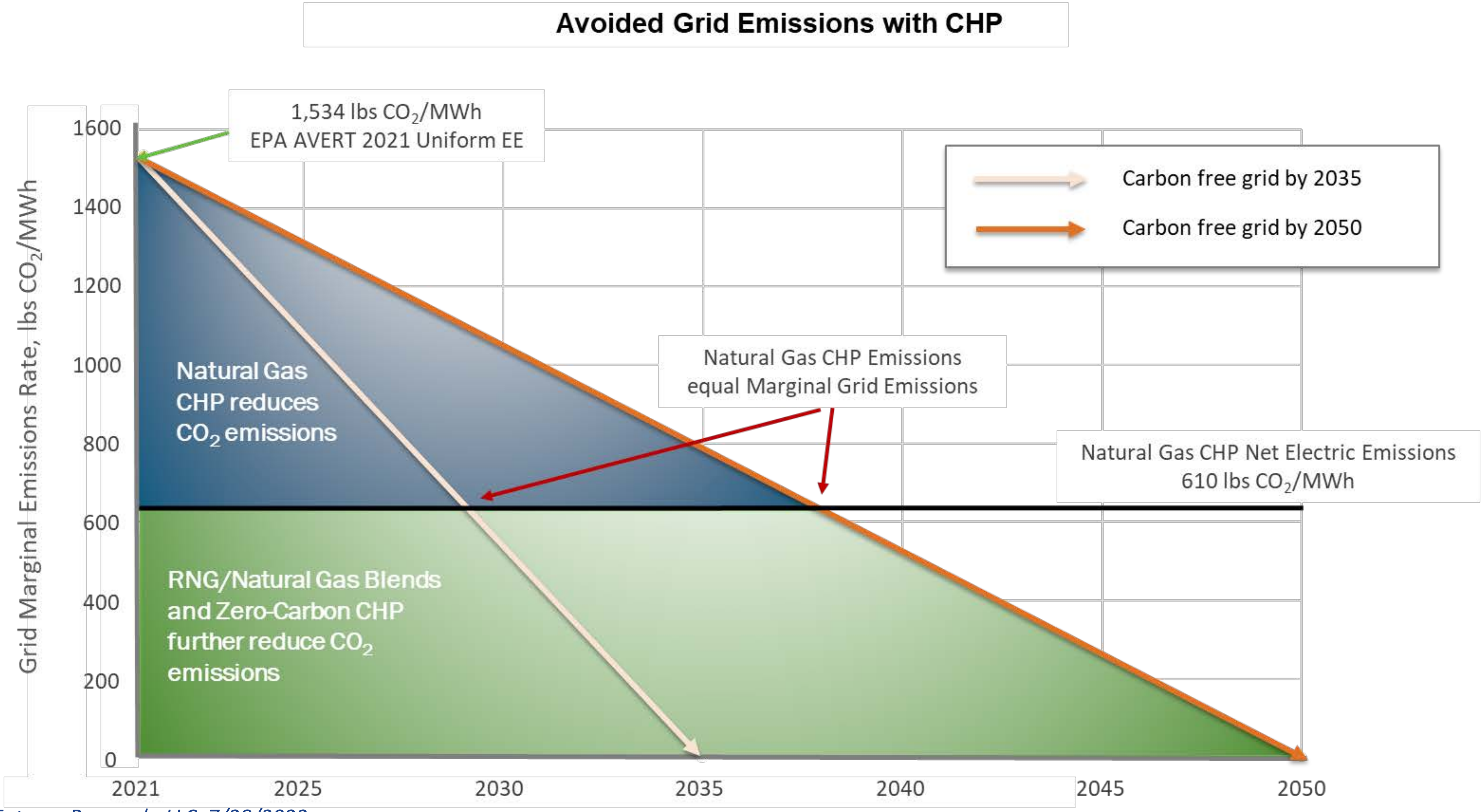
- Existing CHP systems can utilize biogas and biofuels.
- All natural gas-fueled CHP is compatible with renewable gas.
- Most existing turbines and engines can operate on hydrogen mixtures up to 10-40%.
- All major engine and gas turbine manufacturers are working on the capability to operate at high levels of hydrogen, targeting 2030 for 100% hydrogen prime movers.
- CHP systems can be changed out or modified in the field to 100% hydrogen-fuel blends

The ultimate scale of renewable and hydrogen-fueled CHP deployment will depend on resource availability.



Source: Atlas of Carbon and Hydrogen Hubs, Great Plains Institute, February 2022

Renewable and Net-Zero Carbon Fuels Maintain CHP's Advantage



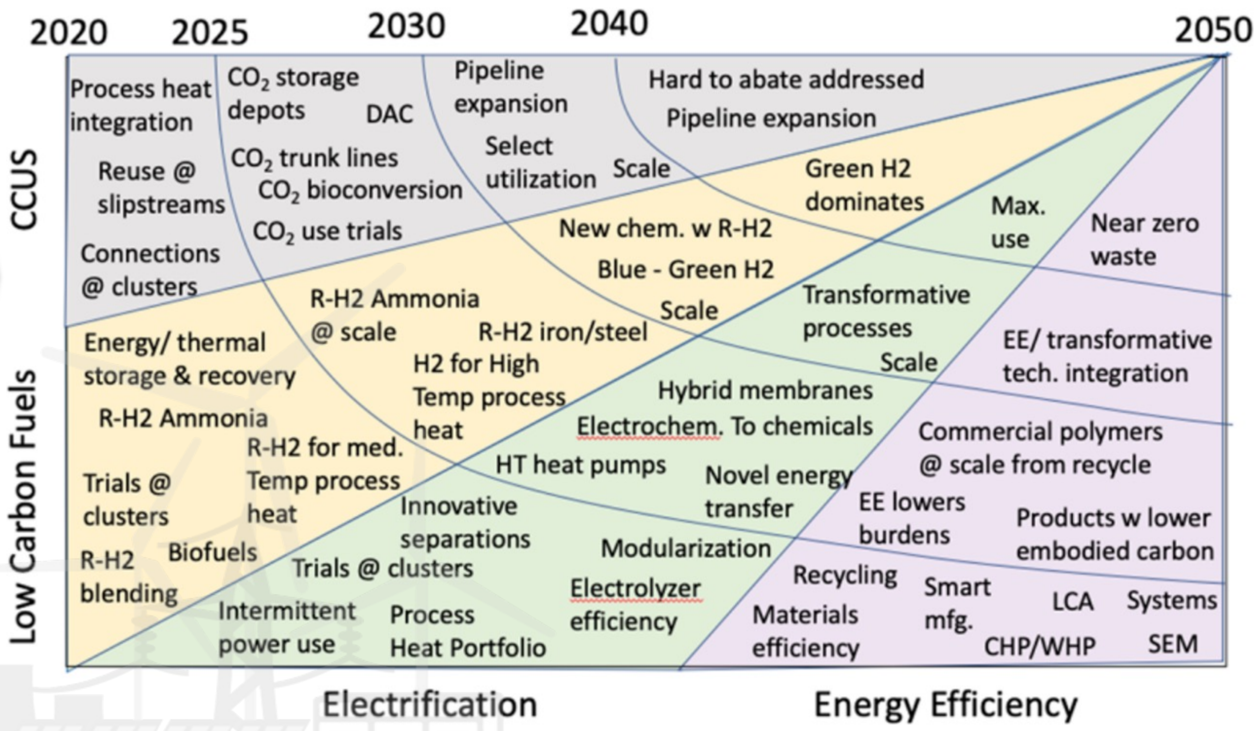
 Prepared by Entropy Research, LLC, 7/28/2022

CHP for Difficult to Decarbonize Industries

- CHP is well suited to address steam and process heating needs, 95% of which is currently fossil fueled.
- CHP enables three of the four pathways for industrial decarbonization (energy efficiency; low-carbon fuels; electrification) while mitigating the need for CCUS.
- Renewable and net-zero fueled CHP can decarbonize industrial thermal processes that are difficult or prohibitively expensive to electrify.

CHP supports decarbonization of the industrial sector while additional technologies reach maturity.

Technology Pathways: Industrial Decarbonization



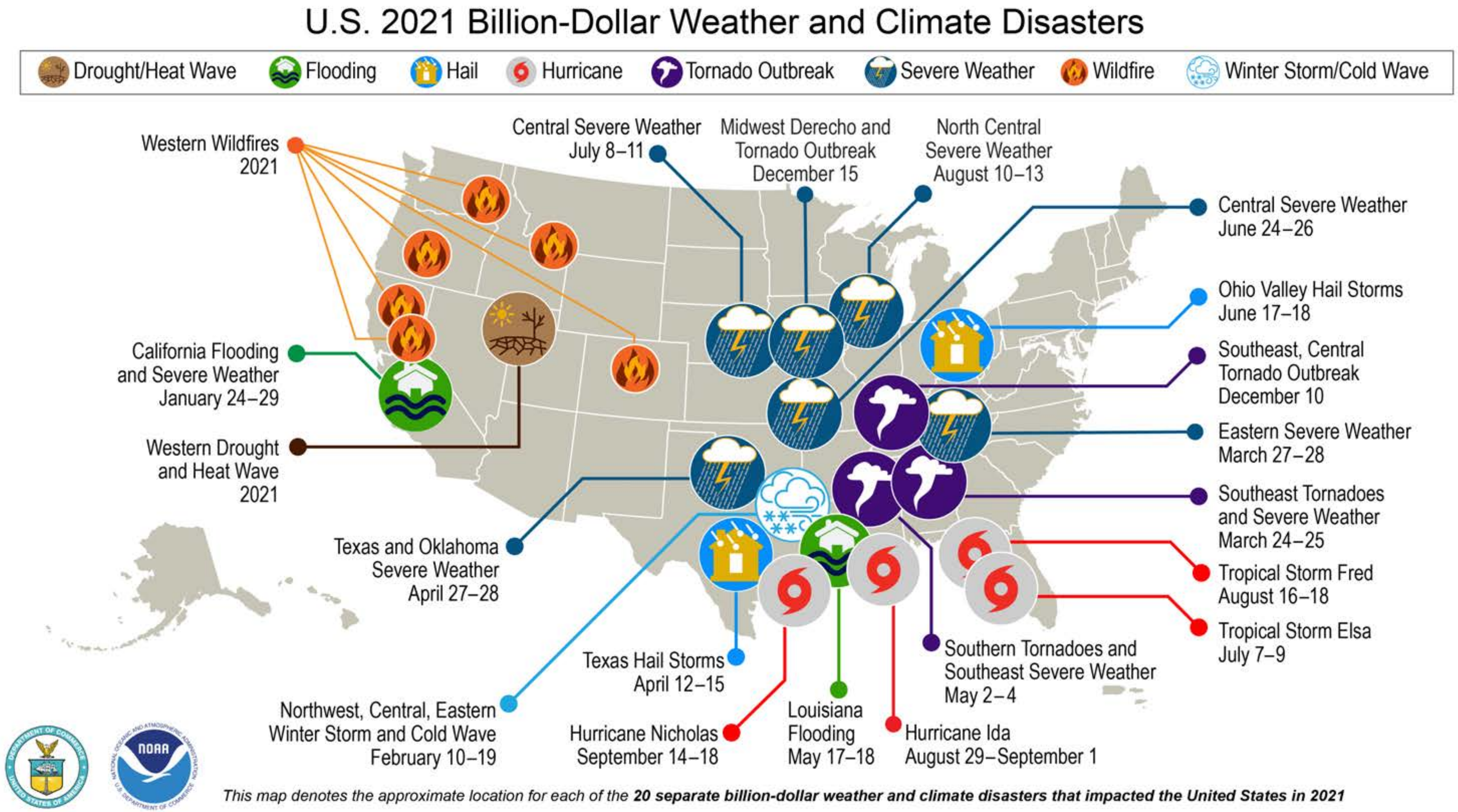
Source: Industrial Decarbonization Roadmap, DOE, May 2022 Draft

CHP Resiliency

- Resilience: the ability of an entity—e.g., asset, organization, community, region—to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance
  - Reducing the magnitude and duration of energy service disruptions
- Reliability: the ability of the electric power system to deliver the required quantity and quality of electricity demanded by end-users

Source: State Energy Resilience Framework, Argonne National Laboratory (2017)

Power Outages are Costly



NOAA map by NCEI www.climate.gov

CHP verses Status Quo

Metric	CHP	Backup Generation
System Performance	• Designed and maintained to run continuously • Improved performance and reliability	• Only used during emergencies
Fuel Supply	• Natural gas infrastructure typically not impacted by severe weather	• Limited by on-site storage – finite fuel supply
Transition from Grid Power	• May be configured for "flicker-free" transfer from grid connection to "island mode"	• Lag time may impact critical system performance
Energy Supply	• Electricity • Thermal (heating, cooling, hot/chilled water)	• Electricity
Emissions	• Typically natural gas fueled • Achieve greater system efficiencies (80%) • Lower emissions	• Commonly burn diesel fuel

CHP is a Resilient Anchor for Clean Microgrids

- CHP provides efficient, resilient, baseload power and localized thermal energy
- CHP supports increased integration of renewable energy sources
- Storage adds additional flexibility and can help optimize CHP sizing and operation
- CHP supports the move toward a resilient, distributed, more renewable grid

Natural Disaster or Storm Events	*Flooding*	*High Winds*	*Earthquakes*	*Wildfires*	*Snow/Ice*	*Extreme Temperature*
Battery Storage	◒	○	◒	●	○	◒
Biomass/Biogas CHP	◒	◒	◒	●	○	○
Distributed Solar	○	◒	◒	●	◒	◒
Distributed Wind	○	◒	◒	◒	◒	◒
Natural Gas CHP	○	○	◒	◒	○	○
Standby Generators	◒	○	◒	●	◒	○

Ranking Criteria

Four basic criteria were used to estimate the vulnerability of a resource during each type of disaster event. They include the likelihood of experiencing:

1. *a fuel supply interruption,*
2. *damage to equipment,*
3. *performance limitations, or*
4. *a planned or forced shutdown*

○ *indicates the resource is unlikely to experience any impacts*

◒ *indicates the resource is likely to experience one, two, or three impacts*

● *indicates the resource is likely to experience all four impacts*

Pairing CHP with Renewables and Storage: Case Study

- CHP can be a resilient base load anchor for multi-technology microgrids, particiularly those incorporating renewable generation sources like solar PV or wind.
- CHP paired with renewable DERs optimizes overall emissions reductions and resilience.
- Net-zero fueled CHP can decarbonize critical facilities that need dispatchable on-site power for long duration resilience and operational reliability

critical infrastructure, cities, and communities

United States Marine Corps Recruit Depot (MCRD) Parris Island, SC, installed a hybrid microgrid including a 3.5 MW natural gas-fired CHP system plus 5.5 MW solar photovoltaic arrays to provide secure and resilient energy. The site also incorporated an 8 MWh battery-based energy storage system, all of which are controlled by a microgrid control system capable of fast load shedding.

Investment Tax Credit Changes in IRA 2022

- Prior to 2022 Inflation Reduction Act
  - 10% granted for newly installed CHP as well as improvements to eligible existing systems for taxable entities. Combined efficiency ≥ 60% unless the system is fueled by biomass.
- After 2022 Inflation Reduction Act
  - CHP is still a recognized sustainable energy solution and was extended again in the Inflation Reduction Act of 2022. Construction must be started before January 1, 2025.
  - Base Credit - 6-30% for newly installed CHP systems regardless of fuel type
    - Projects under 1 MW, or larger projects commenced less than 60 days after labor guidelines are developed, receive the full 30% credit
    - Projects over 1 MW must meet prevailing wage and apprenticeship requirements[1]
  - Bonus Credits - Domestic Content and Energy Community (additional 2-10% for each)
  - Utility Interconnection Costs Now Eligible for Projects less than 5 MW
  - Now eligible for non-taxable entities, including non-profits, state/local governments, etc.
  - After 1/1/25, the Clean Electricity ITC takes into effect, replacing the traditional ITC.
    - All generation facilities and energy storage systems that anticipate zero greenhouse gas emissions are eligible. Technology agnostic.

https://programs.dsireusa.org/system/program/detail/658/business-energy-investment-tax-credit-itc

Attractive CHP Markets

Industrial
- Chemicals
- Refining
- Food processing
- Petrochemicals
- Natural gas pipelines
- Pharmaceuticals
- Rubber and plastics
- Pulp and paper
- Lumber/wood products

Commercial
- Data centers
- Hotels and casinos
- Multi-family housing
- Office buildings
- Refrigerated warehouses
- Restaurants
- Supermarkets
- Retail
- Green buildings

Institutional
- Hospitals
- Schools (K–12)
- Universities & colleges
- Wastewater treatment
- Landfills
- Correctional facilities
- Government buildings
- Airports

Agricultural
- Dairies
- Concentrated animal feeding operations
- Greenhouses
- Wood waste (biomass)

CHP TAP Technical Assistance Services

CHP TAP Role: Technical Assistance

Screening and Preliminary Analysis → **Feasibility Analysis** → **Investment Grade Analysis** → **Procurement, Operations, Maintenance, Commissioning**

- **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

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

Annual Energy Consumption		
	Base Case	CHP Case
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**

CHP Screening Analysis Considerations

What are Next Steps & Go / No-Go Decisions?

<u>Go / No-Go</u>

- Determined from Site Requirements, most common include:
  - Payback Threshold
  - CapEx Threshold
  - Annual Savings
  - Resiliency Improvements
  - GHG Reductions
  - Other, site specific categories

<u>Next Steps</u>

- Advanced Technical Assistance if site requirements are met i.e. CHP is designated as “qualified”

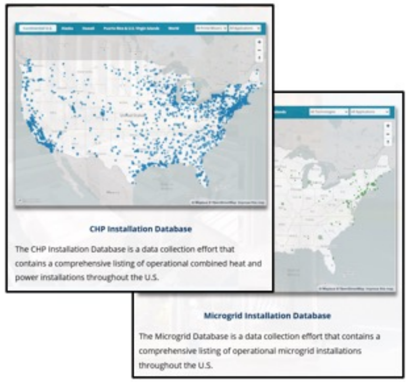
Advanced Technical Assistance Examples

- 15-Min Performance Model
- Financial Pro-Forma (NPV, ROI, etc.)
- GHG Analysis
- Utility Rate Analysis (Standby Rates)
- Thermal use determination (what to do with the heat)
- Installation cost estimation (Equipment Budgetary Pricing)
- Biogas Analysis (Cleanup Equipment Required)
- RFP/RFQ Assistance
- 3rd Party Review
- Other, as-needed analysis

DOE CHP Resources
(betterbuildingssolutioncenter.energy.gov/chp)

- The CHP TAPs are available to guide clients through the following DOE and other resources.

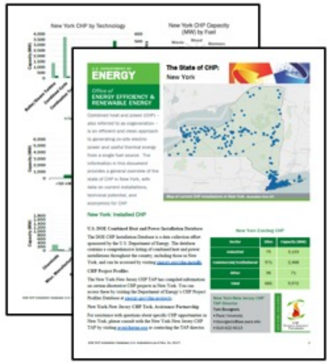
DOE CHP/Microgrid Installation Database



Packaged CHP eCatalog

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

Homework Questions

1. Briefly describe why CHP is the most efficient way to use fuel.
2. When converting fuel to electrical energy, approximately how much energy is lost as heat?
3. What CHP Prime Movers are best suited to provide hot water? Which can best provide high pressure steam?
4. List a few site conditions that would be ideal for a CHP system.
5. What is the difference between resilience and reliability?

CHP Systems Virtual In-Plant Training Agenda

Session 1: Fundamentals of CHP Systems. (10:00 – 12:30 PM E.T.; November 29; Tuesday)

- Introduction to the DOE CHP Technical Assistance Partnerships (TAPs) Program: outreach, engagements, and education.
- Fundamentals of CHP: overview, concepts and benefits of CHP, major components and technologies of CHP, and calculating the efficiency of CHP systems.
- DOE Packaged CHP Systems e-Catalog: use and navigation of e-Catalog, comparison of CHP systems.
- Current and Future Trends: emerging markets, decarbonization, resiliency, renewable and low/no carbon fuels, and federal funding.

Session 2: CHP Project Screening. (10:00 – 12:30 PM E.T.; December 1; Thursday)

- Favorable conditions for CHP application
- The process and required data points for CHP project screening
- What is next after project screening?

Session 3: CHP project implementation. (10:00 – 12:30 PM E.T.; December 6; Tuesday)

- Project development options
- Project Implementation
- Microgrid/utility Integration

CHP Systems Virtual In-Plant Training Agenda (cont.)

Session 4: Success stories and Case studies (10:00 – 12:30 PM E.T.; December 13; Tuesday)

- What makes for a CHP success story?
- CHP Case Studies
    - Perdue Farms, Cromwell, Kentucky - Food Processing, Renewable Energy
    - Shaw Industries, Columbia, South Carolina - Chemicals
    - Penn Medicine Princeton Health, Plainsboro, New Jersey - Resilient Microgrid
    - Durham Advanced Wastewater Treatment Facility and Gresham Wastewater Treatment Plant, Oregon - Resilient and Renewable
- Measuring outcomes from CHP
- Available Resources and Support (including CHP Project Profile Database)

Session 5: Virtual Reality Demonstration for CHP and Participants Presentation; (10:00 – 12:30 PM E.T.; December 20; Tuesday)

- Use Oculus to demonstrate real CHP systems
- Discussions on the use of virtual reality as a learning and teaching tool for CHP systems
- Participants share their findings from the CHP screening, optimization, and what they have learned

Summary

- CHP gets the most out of a fuel source, enabling
  - High overall utilization efficiencies
  - Reduced environmental footprint through low-carbon fuels
  - Reduced operating costs
- The National CHP eCatalog offers lower perceived risk of CHP in non-traditional markets, also reduced cost and lead time.
- An increasing number of CHP systems can run on low-carbon fuels including RNG and Hydrogen
- Incentives are a crucial part to CHP implementation
- CHP can be utilized in various market sectors and for different strategies including resiliency and reliability.
- The CHP TAPs can assist potential CHP projects at no-cost offering unbiased technical assistance and resources from initial screening through installation.

Next Steps

Contact your Regional CHP TAP for assistance if:

- You are interested in having a “no-cost” Qualification Screening performed to determine if there is an opportunity for CHP on-site.
- If you have an existing CHP plant and are interested in expanding the plant.
- If you need an unbiased 3rd Party Review of a CHP proposal.

Thank You

Questions?

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gmille7@uic.edu

For more information about the CHP TAPs:
https://betterbuildingssolutioncenter.energy.gov/chp/chp-taps