Interconnection and Sizing of Combined Heat & Power (CHP) in Renewable Energy Microgrids

Presented by

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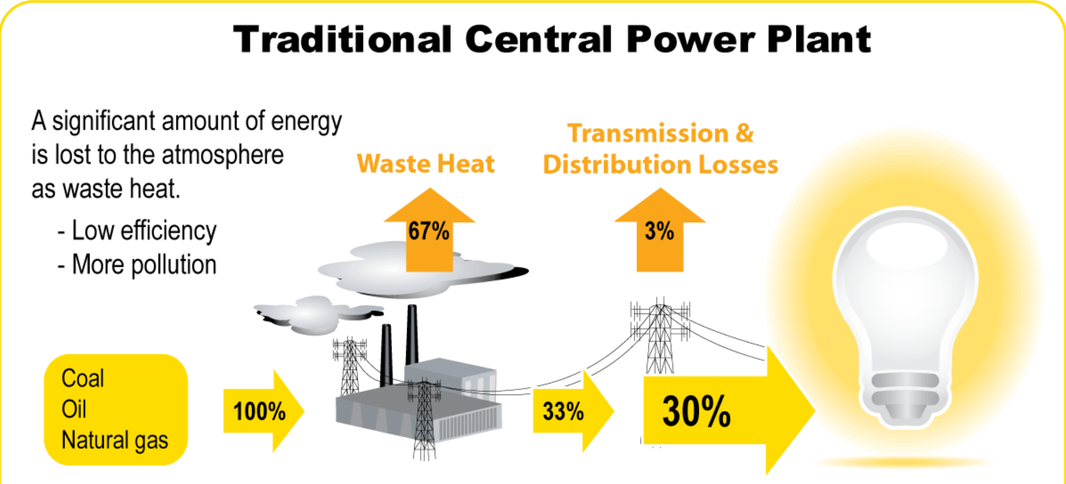
What is Combined Heat & Power (CHP)?



Source: Adapted from U.S. Combined Heat and Power Association.

Table 1-1. U.S. Installed CHP Sites and Capacity by Prime Mover

Prime Mover	Sites	Share of Sites	Capacity (MW)	Share of Capacity
Reciprocating Engine	2,194	51.9%	2,288	2.7%
Gas Turbine*	667	15.8%	53,320	64.0%
Boiler/Steam Turbine	734	17.4%	26,741	32.1%
Microturbine	355	8.4%	78	0.1%
Fuel Cell	155	3.7%	84	0.1%
Other	121	2.9%	806	1.0%
Total	**4,226**	**100.0%**	**83,317**	**100.0%**

* includes gas turbine/steam turbine combined cycle
Source: ICF CHP Installation Database, April 2014

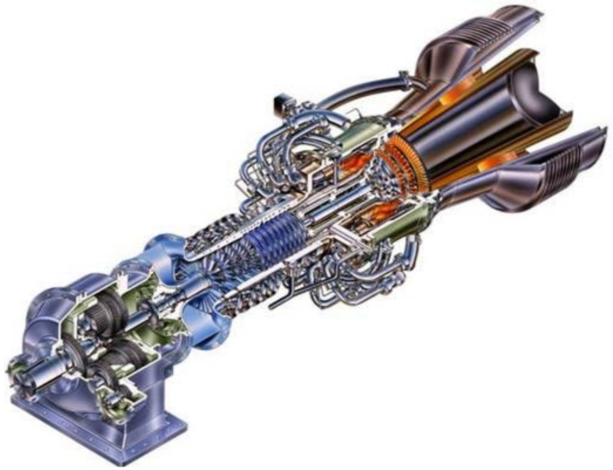
Simple cycle power plant: 30-35% electrical efficiency

Combined cycle power plant: 60-65% electrical efficiency

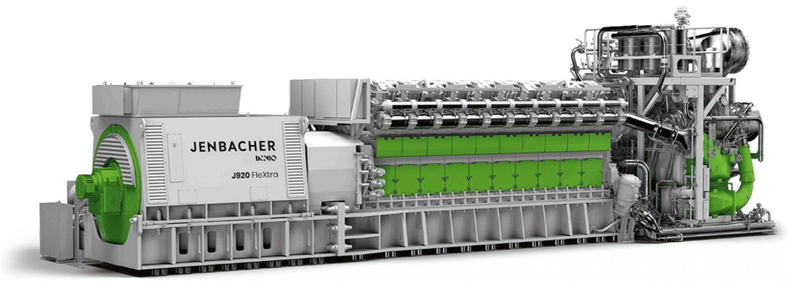
Combined heat and power: 60%-80% CHP efficiency

- 1 fuel source, 2 useful outputs of energy (electricity and heat)

Gas Turbines (1-20 MW+)



Reciprocating Engines (5 kW - 10 MW)



What is Combined Heat & Power (CHP)?

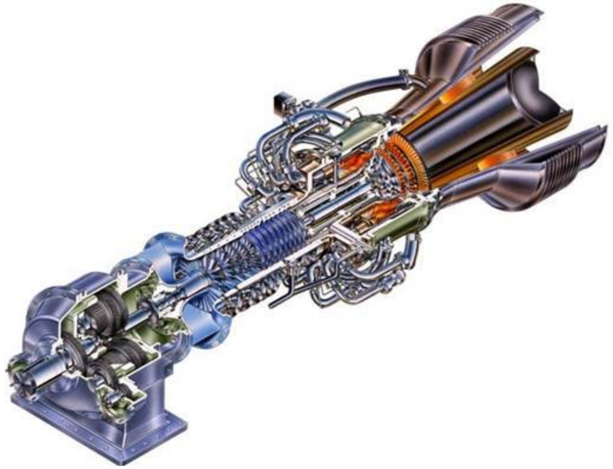
Gas Turbines & Reciprocating Engines can operate continuously between 50-100% of rated load and remain in emissions compliance.

- Gas Turbine performance will also vary based on the ambient conditions (temperature, elevation, humidity).

Gas Turbine Performance

Solar Turbines
A Caterpillar Company

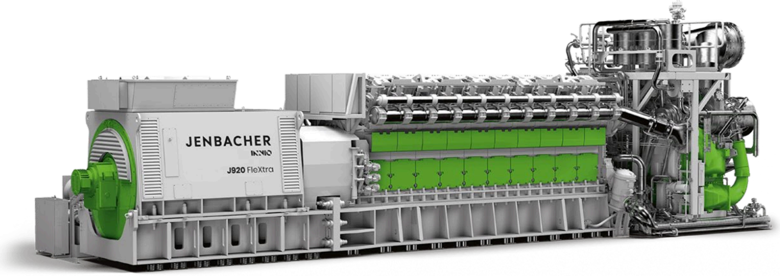
Engine Inlet Temperature	deg F	0	20.0	40.0	59.0	80.0
Relative Humidity	%	60.0	60.0	60.0	60.0	60.0
Specified Load*	kW	FULL	FULL	FULL	FULL	FULL
Net Output Power*	kW	9091	8678	8228	7726	7023
Fuel Flow	mmBtu/hr	90.42	86.64	82.63	78.52	73.30
Heat Rate*	Btu/kW-hr	9946	9983	10044	10163	10437
Therm Eff*	%	34.307	34.179	33.973	33.574	32.691



Reciprocating Engine Performance

JENBACHER

		100%	75%	50%
Power input	MBTU/hr	25,158	19,296	13,434
Gas volume	scfhr	27,435	21,042	14,650
Mechanical output	bhp	4,601	3,450	2,300
Electrical output	kW el.	3,358	2,512	1,660
Electrical efficiency		45.5%	44.4%	42.2%
Thermal efficiency		43.0%	44.7%	46.5%
Total efficiency		88.6%	89.1%	88.7%



What is Net-Metering?

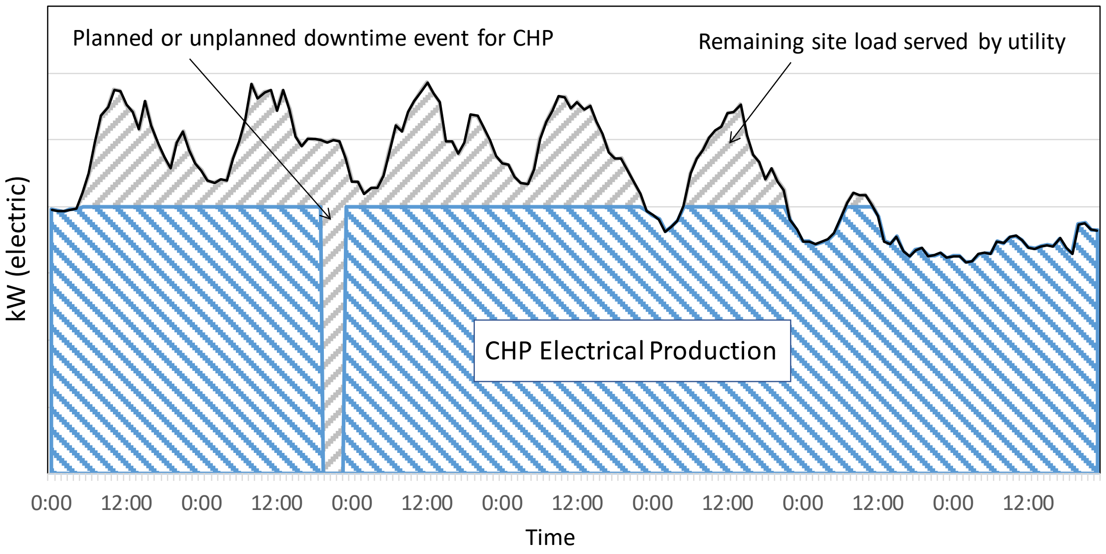
"Net-metering" refers to the ability to export electricity from renewable energy production to the grid during periods of overproduction.

- This exported power is credited on the customer's utility bill against periods where utility power is imported.
- Many utilities will do an annual "true-up", so export and import of power from the utility should be roughly balanced over a 12-month period.

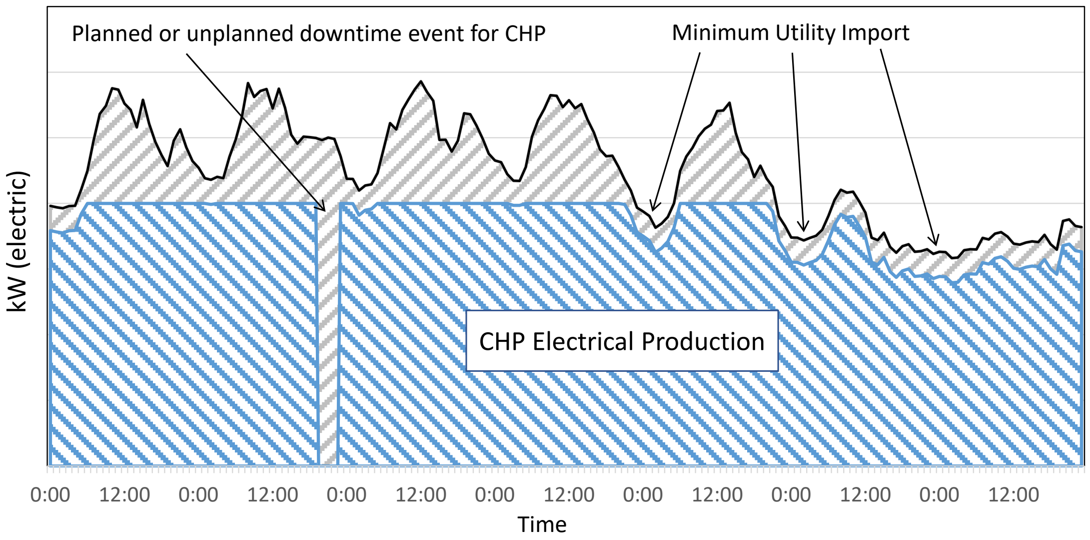
CHP

- Typically, the interconnecting utilities will not allow export of power for CHP systems. "Load following" operation.
- Not only will utilities limit export of power, but many utilities will also require a **minimum utility import** at all times.
- Some CHP can export power to the grid, but export power is only credited at the real-time or day-ahead electricity rate during that period.
  - Net-metered renewable energy sources offset electricity charged at the higher commercial/industrial tariff rates.

CHP operation – No minimum utility import



CHP operation – w/ minimum utility import

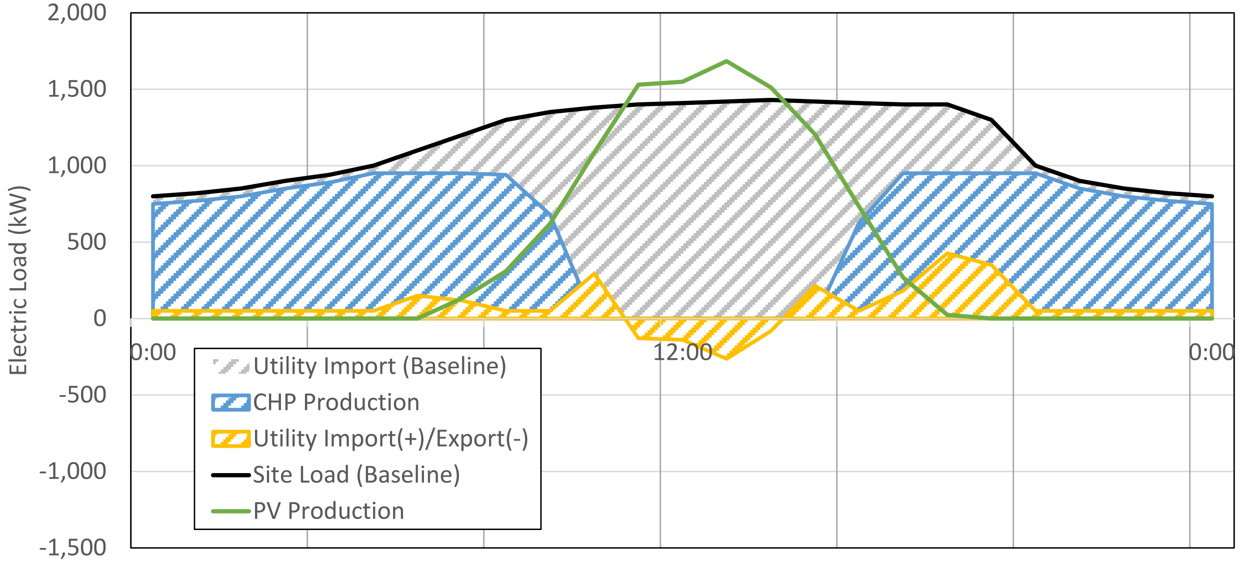


CHP + PV Microgrids – Dispatch methods

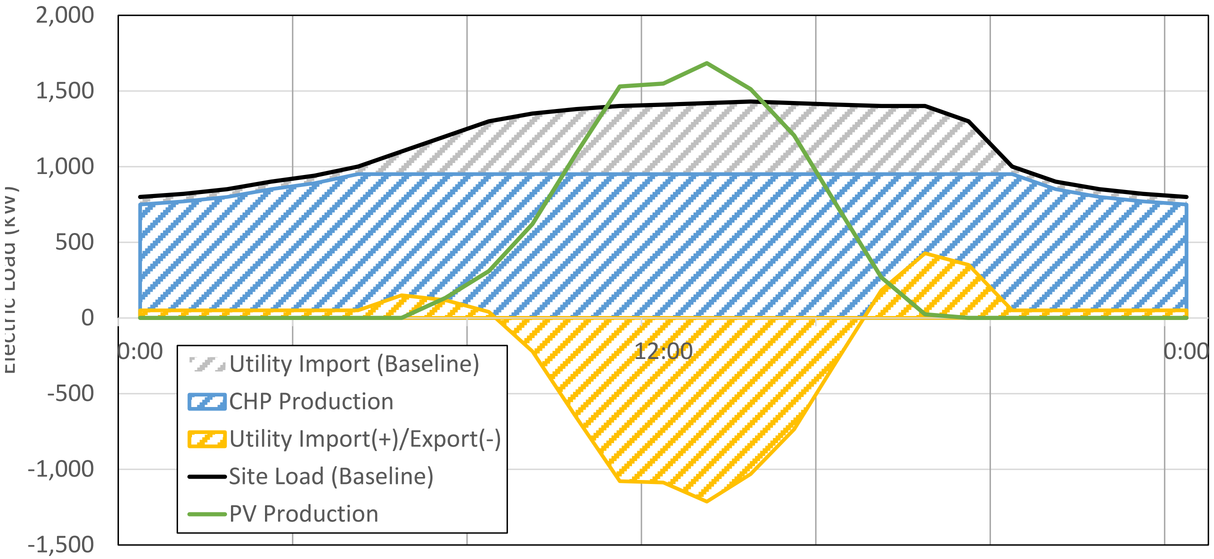
What is the best approach for power export and interconnection when you have both PV and CHP as part of a microgrid?

- Method #1: Total PV + CHP production can never exceed site load. CHP production must be ramped down as PV production increases.
  - CHP power will equal zero whenever power from the PV is being exported because PV production is larger than the site load.
  - Most conservative approach in terms of CHP electrical production.
- Method #2: CHP electrical production can never exceed site load (ignoring any PV production).
  - CHP power can be greater than zero when power is being exported because any net power that is being exported is net-metered PV.
  - This results in increased run-time for the CHP and higher CHP electrical production.

PV + CHP Dispatch – Method #1



PV + CHP Dispatch – Method #2



It is critical to understand the requirements of the local utility to ensure the project is modelled and sized correctly.

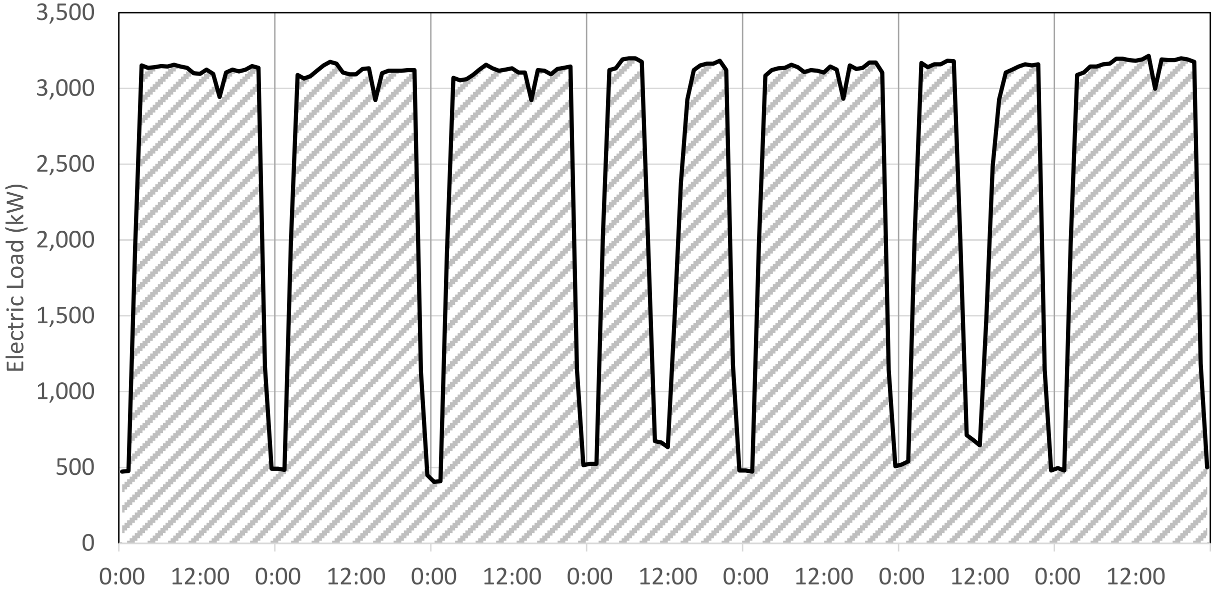
CHP + BESS Microgrids – Indoor Agriculture Example

Indoor Agriculture Example: During a typical week, electric load at the facility drops significantly for 3 hours, 1-2 times per day.

- This is done deliberately as part of their grow process. The grow lights are turned off and the facility is quickly cooled down.
- Indoor agriculture is an ideal application for CHP. These facilities are energy intensive and use a lot of electricity for the grow lights.
- They also must be temperature-controlled, resulting in high seasonal heating and/or cooling loads.
- The exhaust from the CHP produces additional CO_2 that can be captured and used, offsetting expensive supplemental CO_2 tanks.

Aerial view of greenhouse

Indoor Agriculture Facility – Hourly Load Profile



How do you size a CHP system for facilities with variable load profiles?

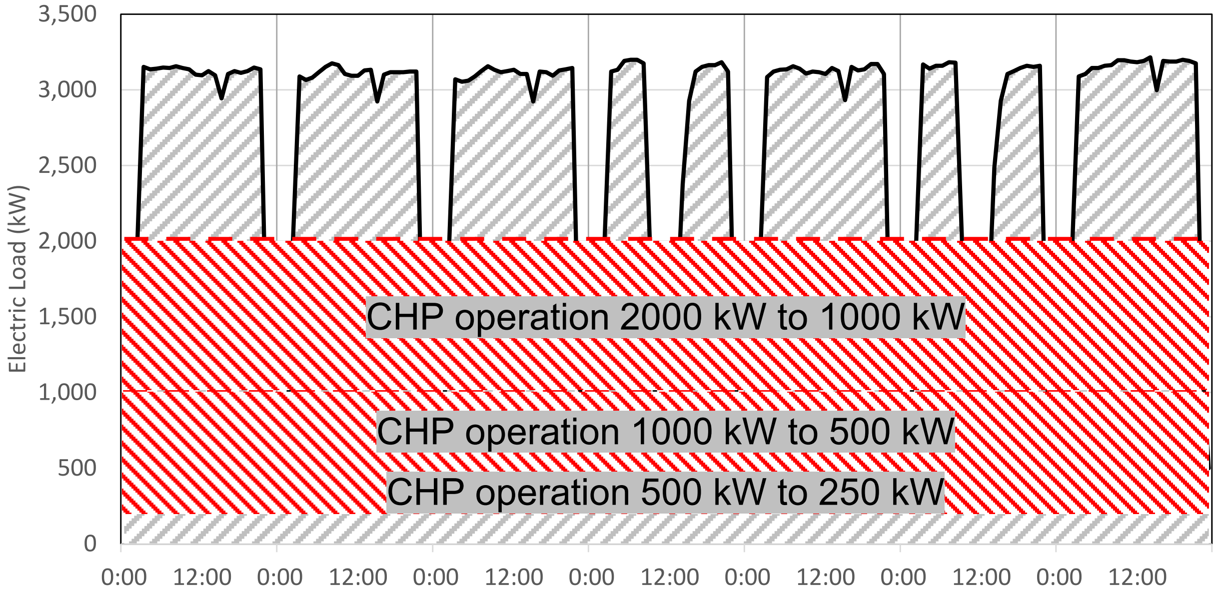
CHP + BESS Microgrids – Indoor Agriculture Example

CHP Sizing Options

Does adding a battery energy storage system (BESS) help with this variable load profile problem?

- <u>2000 kW</u>: Sizing closer to “peak load”, providing more power but will have to shut down during the periods of low electric load (<1000 kW).
  - Lowest per kW installed cost and the lowest installed cost per kWh of electrical production, assuming 20 years of CHP operation.
  - Confirmed with a full financial model incorporating 15-minute load profiles, O&M cost estimates, utility rates, and available incentives.
  - The larger CHP size also provides more dispatchable generation for resiliency needs.

<u>Indoor Agriculture Facility – Hourly Load Profile</u>



	Option #1 500 kW	Option #2 1000 kW	Option #3 2000 kW
Peak period kWh (~7000 hours/year)	3,500,000 kWh	7,000,000 kWh	14,000,000 kWh
Shutdown period kWh (~1000 hours/year)	500,000 kWh	500,000 kWh	0 kWh
Total kWh (Year 1 Production)	4,000,000 kWh	7,500,000 kWh	14,000,000 kWh
Total Operating Hours (Year 1)	8000 hours	8000 hours	7000 hours
Estimated Installed Cost (Equipment + Installation)	$2,000,000	$3,000,000	$5,400,000
Estimated Installed Cost ($/kW)	$4000/kW	$3,500/kW	$2,700/kW
Installed cost per kWh (Years 1-20 of kWh production)	$0.025/kWh	$0.020/kWh	$0.019/kWh

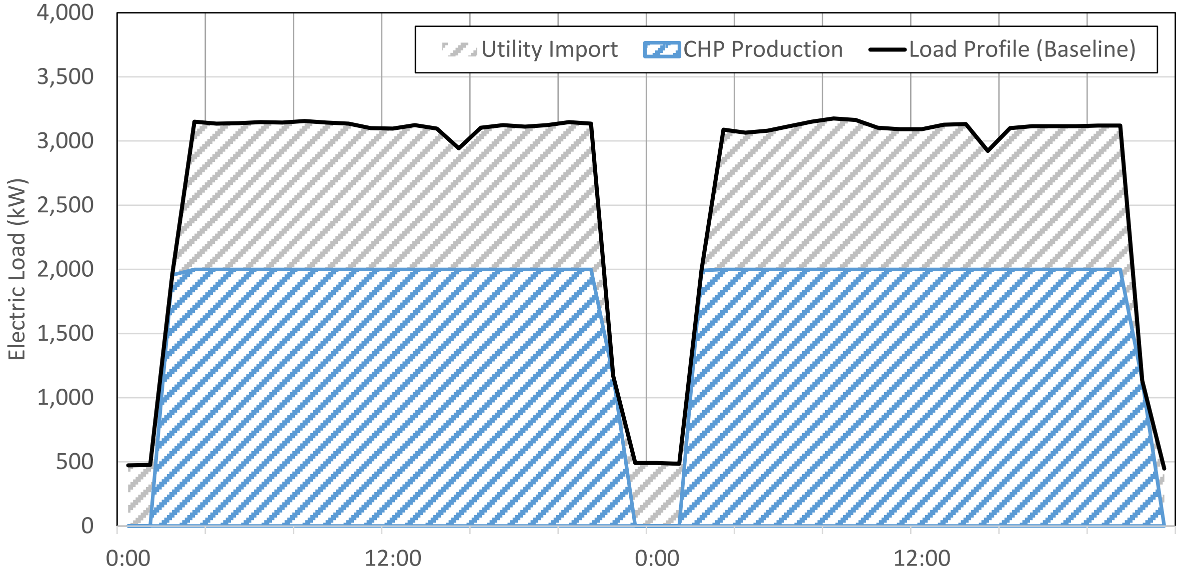
CHP + BESS Microgrids – Indoor Agriculture Example

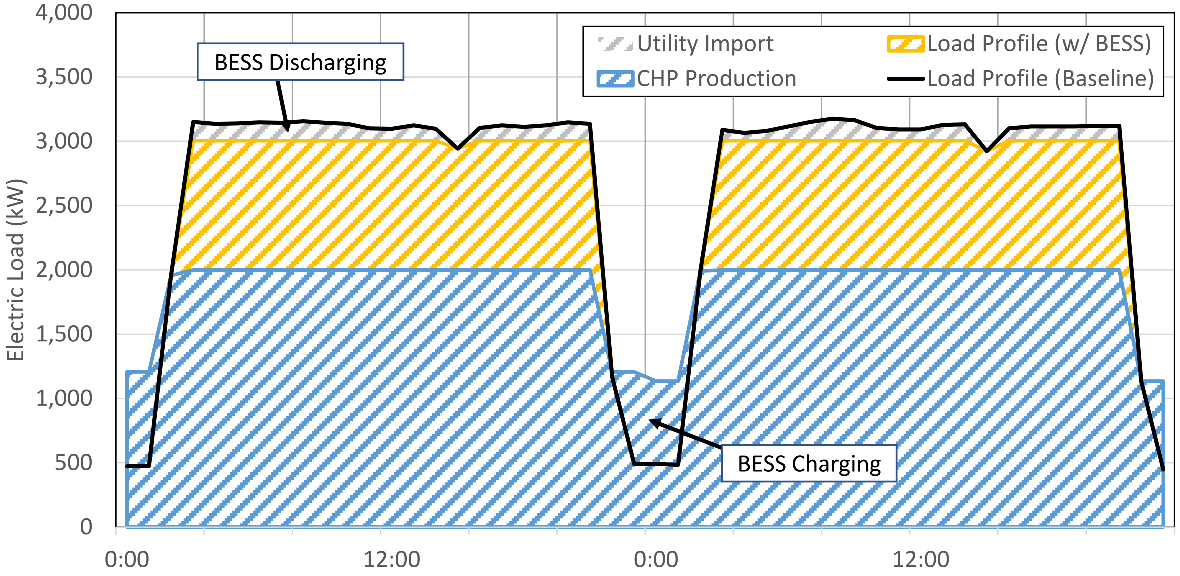
BESS is a flexible distributed energy resource and renewables smoothing, energy arbitrage, and peak shaving are common use cases.

- The BESS would be fully discharged in advance of any shutdown occurring at the facility and the CHP would continue operating during the shutdown to charge the battery.
- During the day when facility electricity usage is high, the BESS can be dispatched for energy arbitrage or peak shaving.
- Since the facility chooses when these low electrical load events occur, the discharging and charging can be done with complete foresight.

1000 kW/3000 kWh (3 hour) BESS was evaluated to increase CHP operating hours to 8000+ hours per year.

- The project was evaluated in the feasibility stage and the BESS improved the financials, if we qualified for state incentives.
- Since the load profile is flat over a 20-hour period, the amount of peak shaving will be a maximum of 150 kW for a 3000 kWh BESS.
- The reduction in number of startups and shutdowns of the CHP prime mover will reduce maintenance and improve reliability

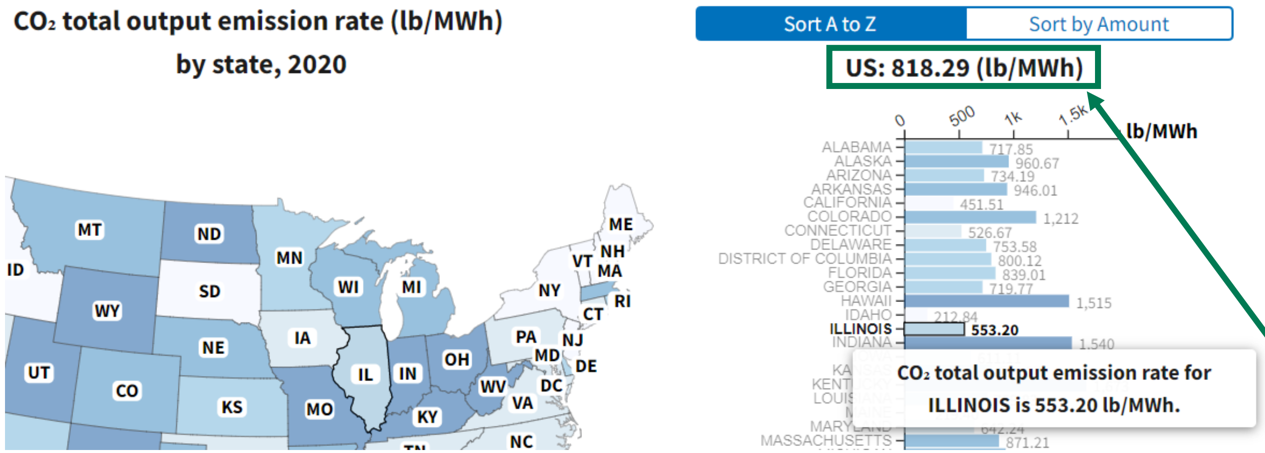




CHP Environmental Considerations

CHP provides sustainability benefits when operating on hydrogen or renewable natural gas (RNG), or when cleaner than comparable utility grid electricity.

https://www.epa.gov/egrid/data-explorer



	2020
Illinois	
All fuels	173,395
Coal	31,238
Petroleum liquids	30
Petroleum coke	0
Natural gas	24,516
Other gases	285
Nuclear	100,246
Conventional hydroelectric	135
Other renewables	
Wind	16,226
All utility-scale solar	79
Geothermal	--
Biomass (total)	391
Wood and wood-derived fuels	0
Other biomass	391
Hydro-electric pumped storage	--
Other	249
All solar	506
Small-scale solar photovoltaic	427
All utility-scale solar	79

https://www.eia.gov/electricity/state/

Illinois Electricity Profile 2020

Table 1. 2020 Summary statistics (Illinois)

Item	Value	Rank
Primary energy source		Nuclear
Net generation (megawatthours)	173,394,525	5
Emissions		
Carbon dioxide (lbs/MWh)	603	39

Illinois electricity cleaner on-average in 2020 due to high percentage of nuclear power production.

Conclusions

Net-metering of CHP & Solar PV in microgrids

- **Solar PV and CHP can complement each other in renewable energy microgrids because CHP provides baseload generation and solar PV (with or without BESS) can be used to serve peak loads.**
- **For renewable energy microgrids with both PV and CHP, it is critical to understand the requirements of the local utility to ensure the project can be modelled and sized correctly.**

CHP + BESS Use-case in Microgrids

- CHP prime movers can only operate within a defined load range (50-100% load), creating challenges in sizing for facilities with variable load profiles.
- **Adding BESS with CHP can improve project financials and reliability, in addition to all the other benefits and use-cases for batteries in microgrids.**

- CHP provides sustainability benefits when operating on hydrogen or renewable natural gas (RNG), or when cleaner/more efficient than comparable utility grid electricity.

Question & Answer Session

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