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Design Considerations for Small Scale Heat Recovery Steam Generators

October 4, 2022

Agenda

CHP and HRSGs

AGENDA #	SECTION
1	Refresher on Cogeneration
2	CHP System Design Review
3	Combined Cycle Design Characteristics
4	Design Scenarios
5	Resources
6	Questions?

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Power of Total Integration

Enabling Customers to Achieve Sustainability Goals

Industry leading companies around the world are making progress toward their environmental commitments with high-efficiency, low-emissions solutions from Cleaver-Brooks.

The power of total integration.

Integrated Equipment
Cleaver-Brooks solutions are engineered with an end-to-end focus on sustainability: high-efficiency, low emissions and reduced waste.

Service Solutions
A global network of the industry's best trained and certified technicians keep your boilers running efficiently and reliably, maximizing lifetime and optimizing performance.

Trusted Expertise
From our Boiler Plant Optimization program to deep expertise on infrastructure and sustainability engineering, we have valuable insights to share. Let us partner with you to meet your sustainability goals.

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Key Sustainability Drivers

What is CHP?

What is Cogeneration?

- Cogeneration, also known as Combined Heat and Power(CHP), is a system of commercially available technologies that decrease total fuel consumption and related emissions by generating both electricity and useful heat from the same fuel input.
- Cogeneration is a form of local or distributed generation (DG) as heat and power production take place at or near the point of consumption.

CHP "A Key Part of Our Energy Future"

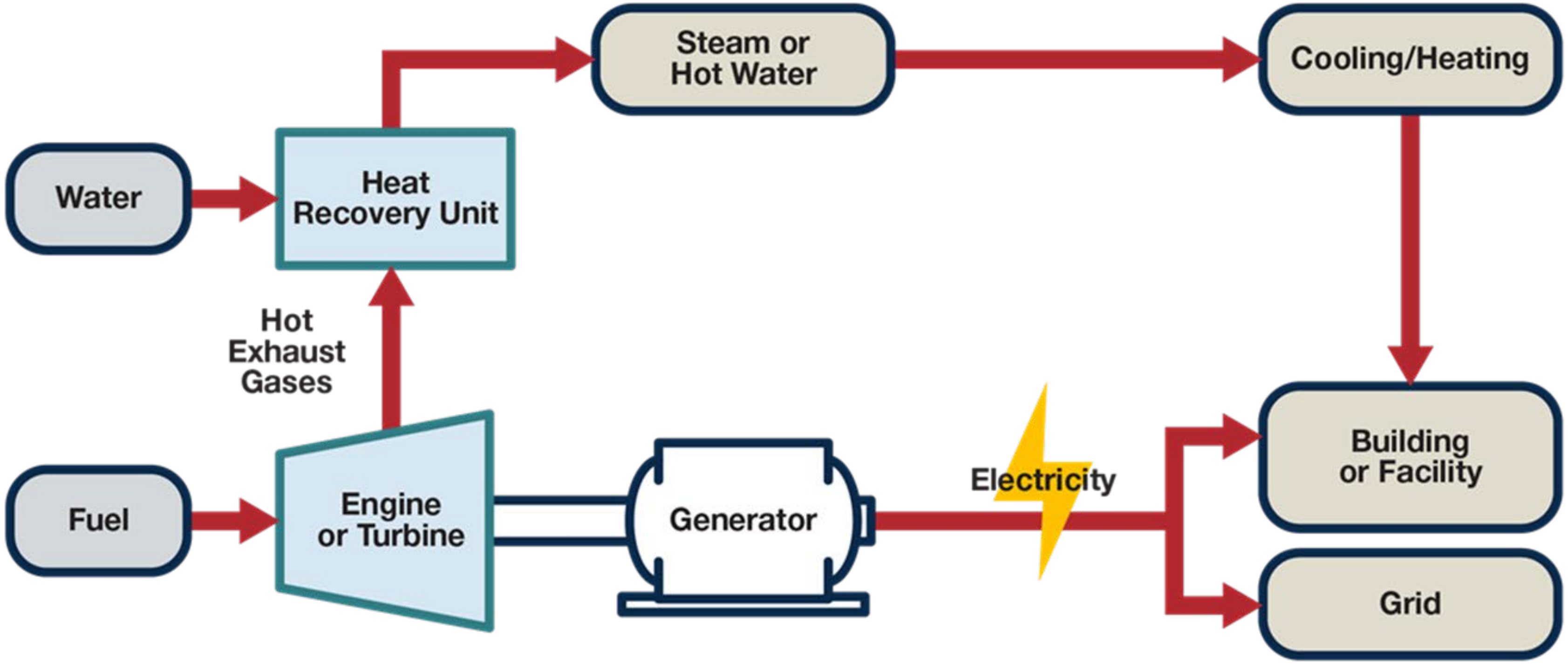
Cogeneration is not limited to any specific type of facility and is generally used in operations with sustained heating requirements.

What are some benefits of Cogeneration?

- **Efficient**-For the same output energy, cogeneration uses far less fuel than does traditional separate heat and power production.
- **Sustainable**-Reduces air pollutants including GHG(Greenhouse gas), SO2, NOX, Hg.
- **Reliable**-Provides power for critical services in emergencies and avoids economic losses during grid interruptions.
- **Responsible**-Society avoids or defers investments in new electricity transmission and distribution infrastructure and relieves constraints on existing infrastructure by using existing industrial and commercial sites for incremental power generation.

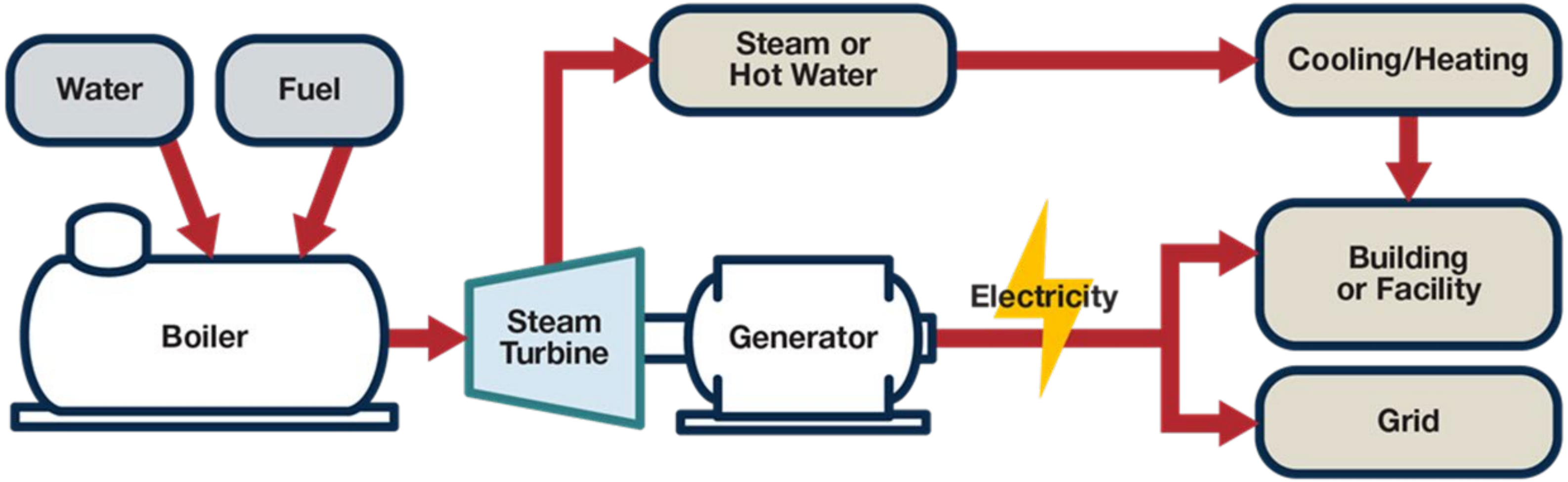
What is Cogeneration And How Is It Designed?

Topping Cycle-Most Common in Utilities

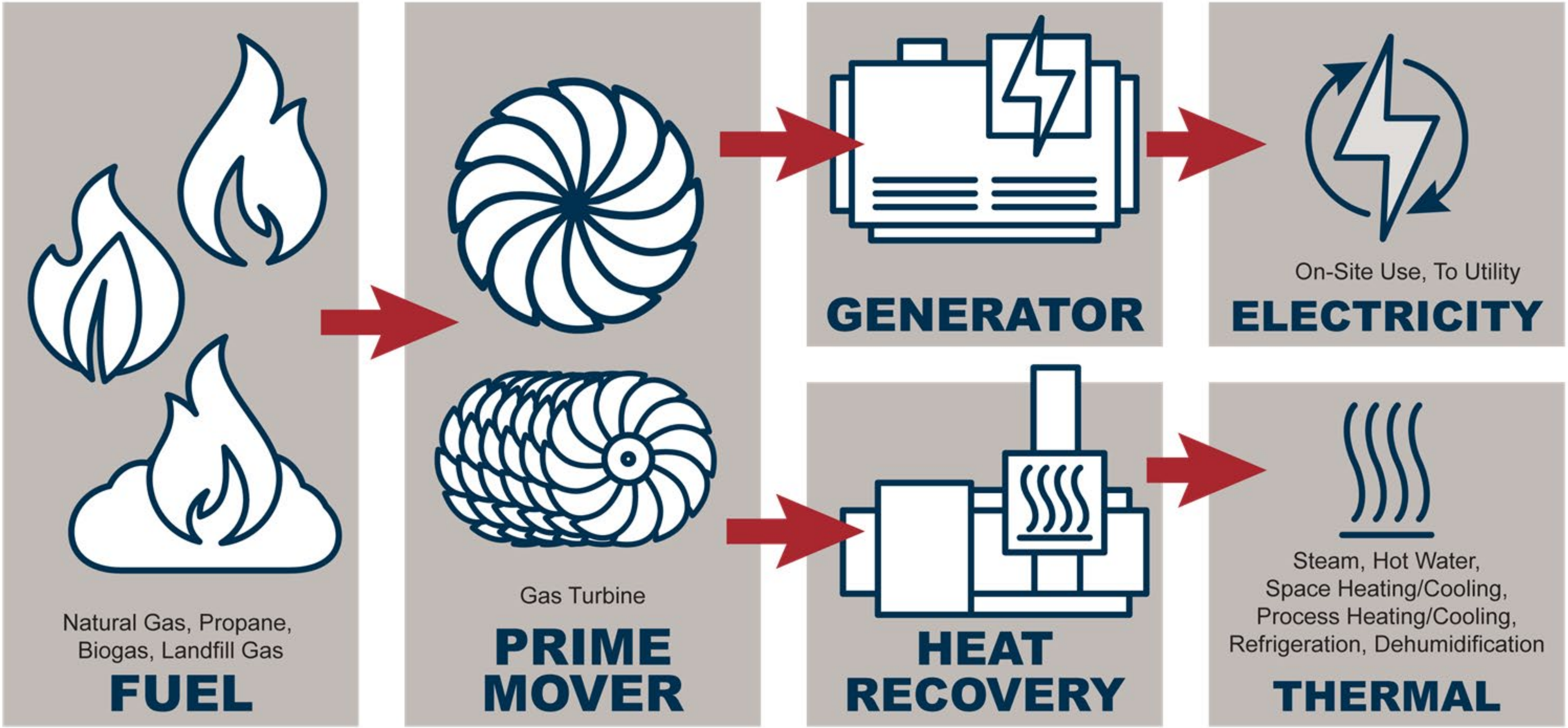


What is Cogeneration And How Is It Designed?

Bottoming Cycle– Most common in process industries



CHP: Common Design-Simple Cycle with Heat Recovery



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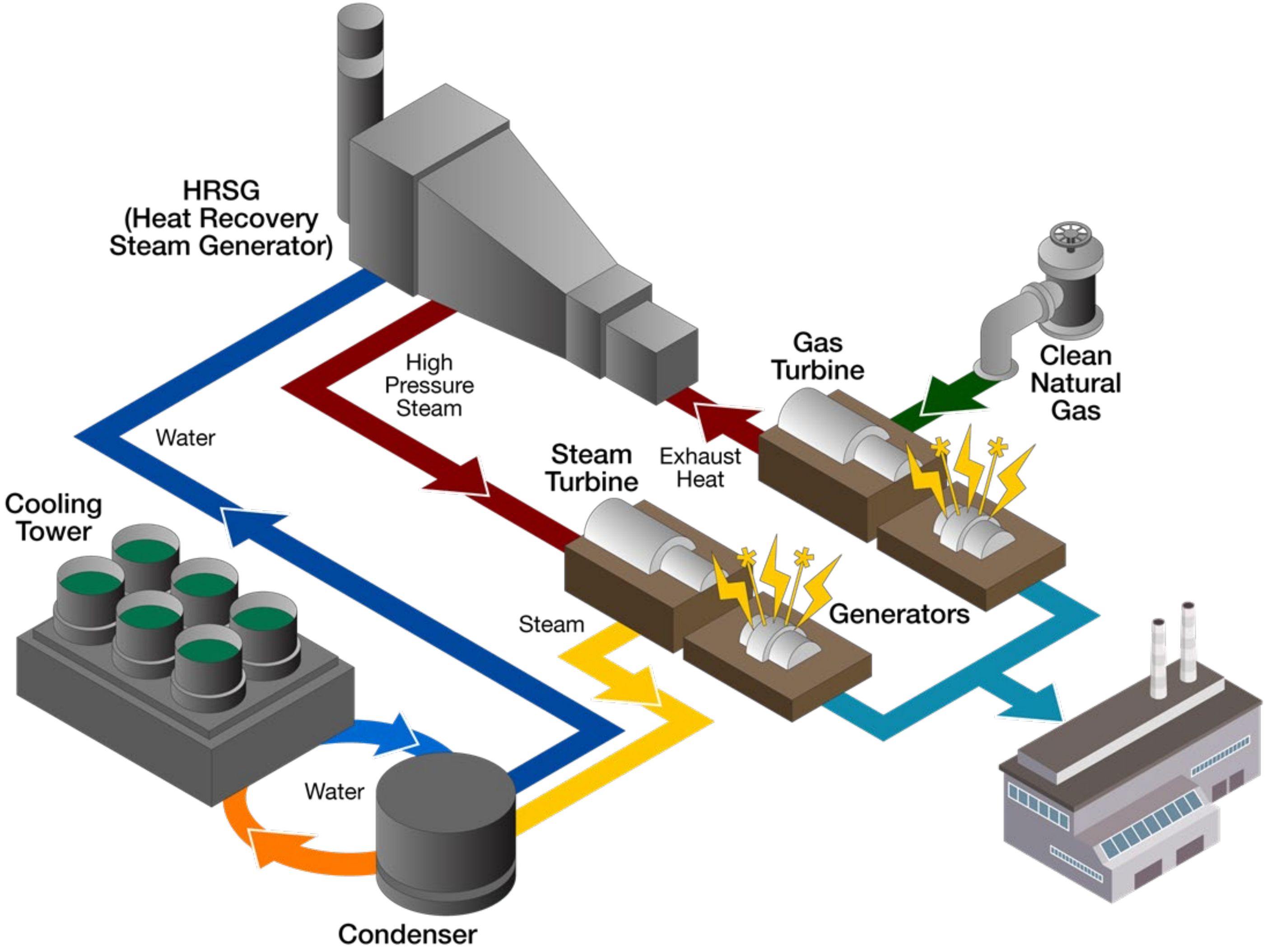
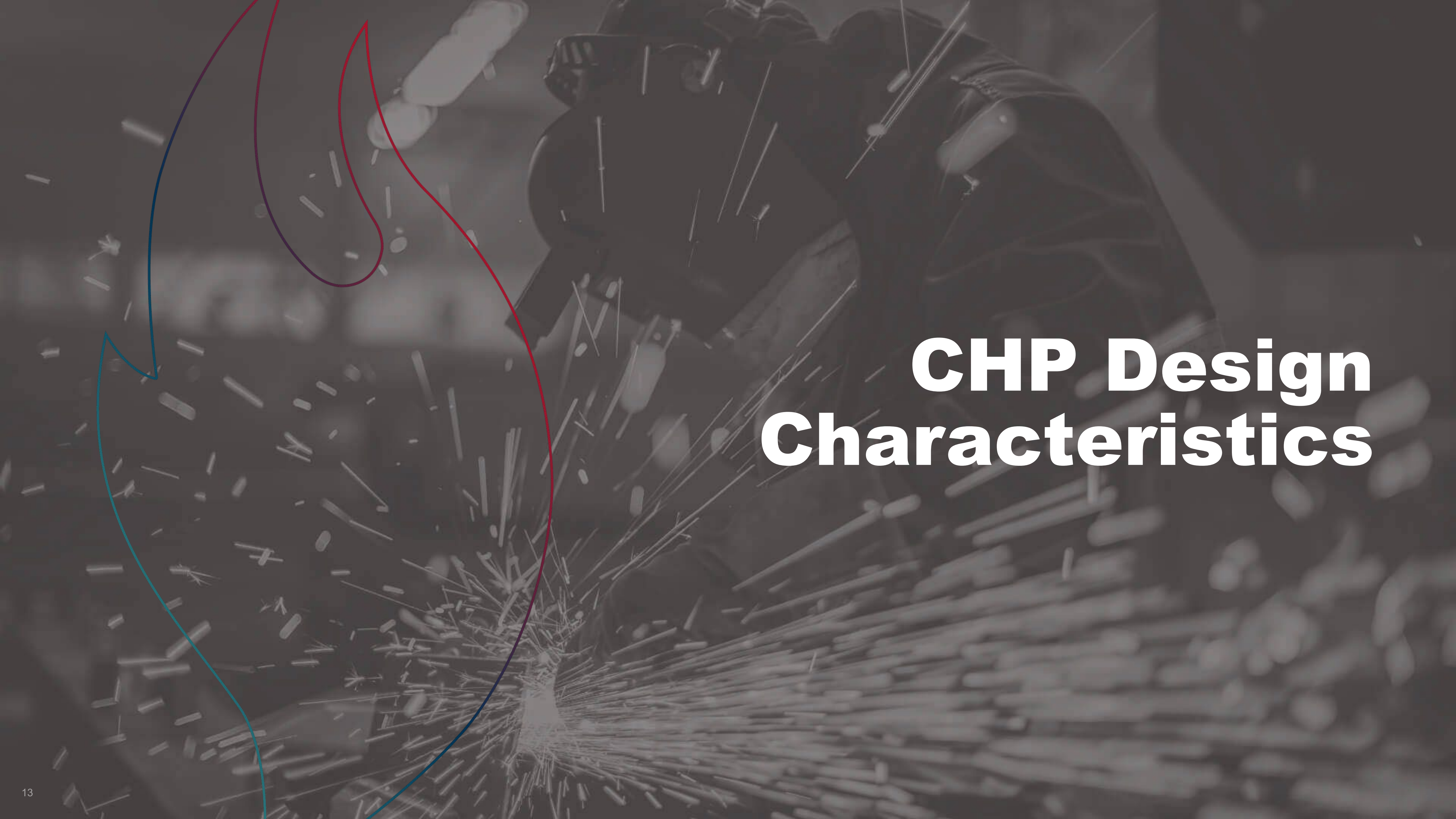
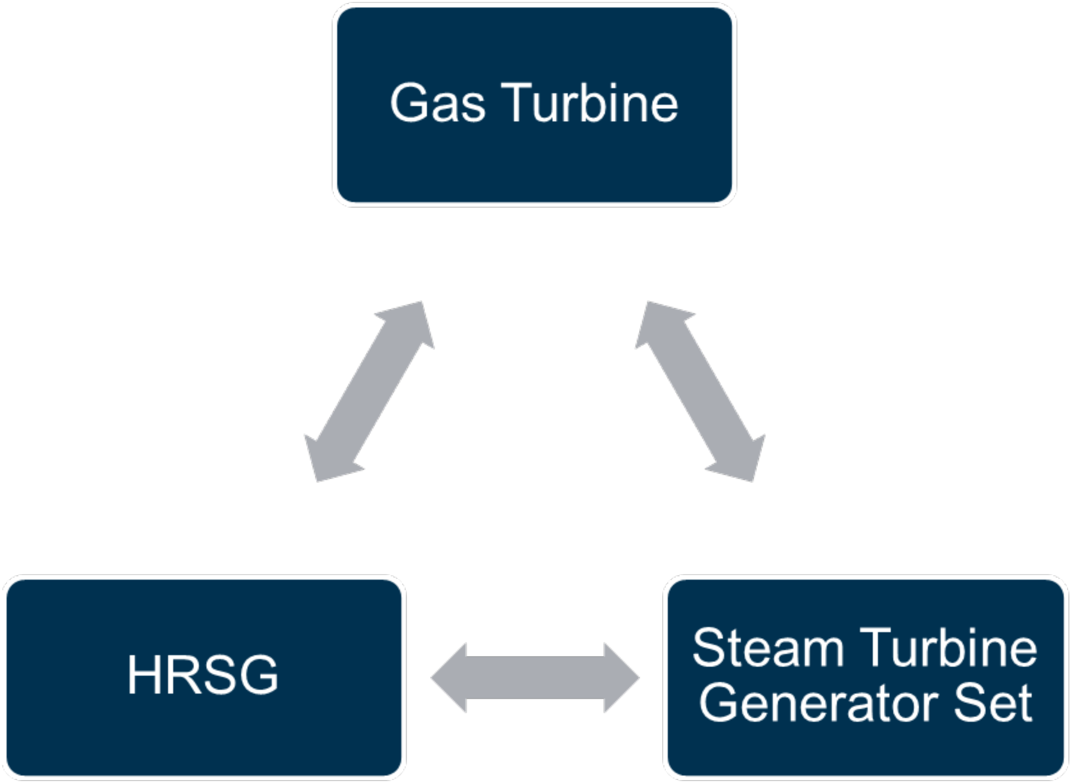
CHP: Common Design-Combined Cycle





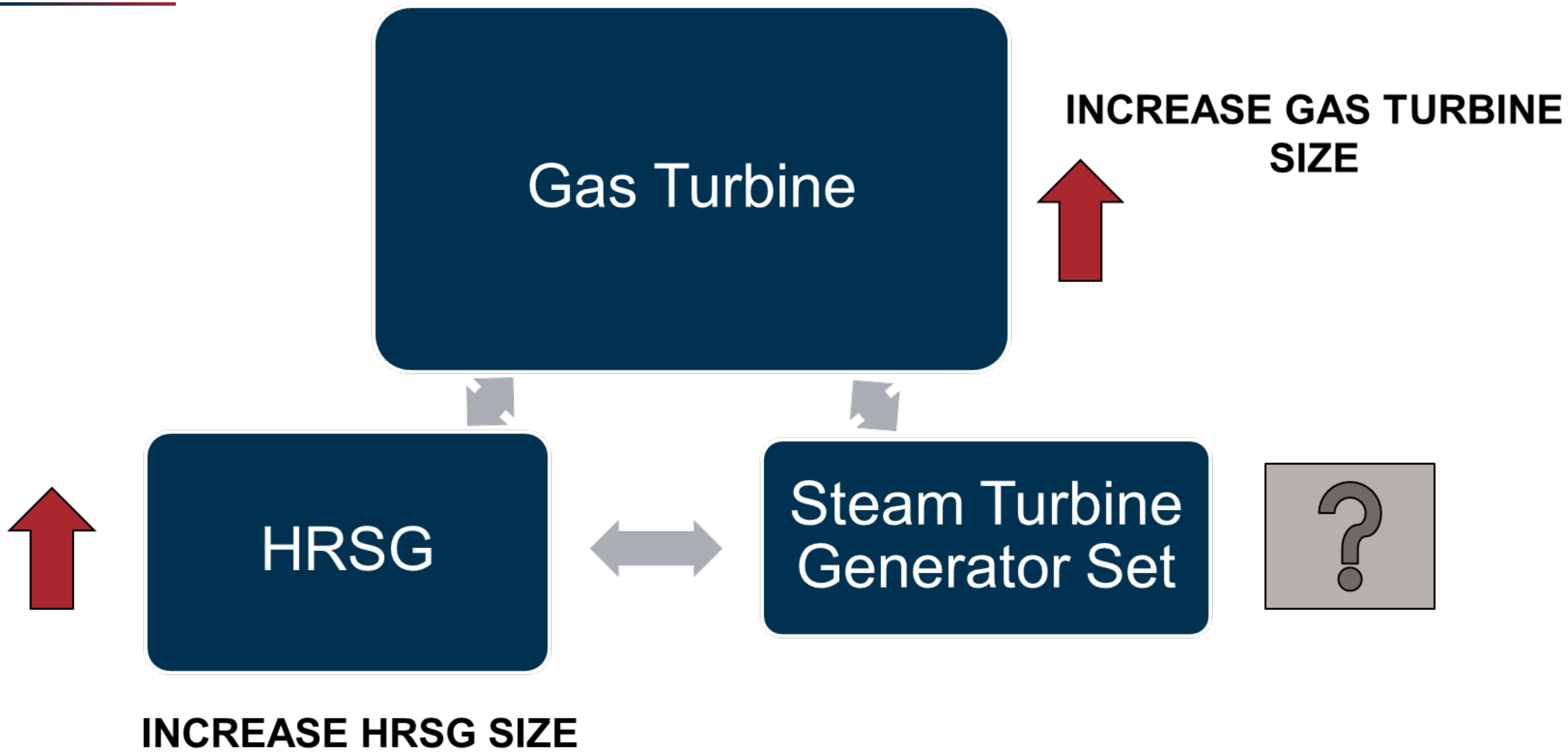
CHP Design Characteristics

How are CHP Systems Designed?

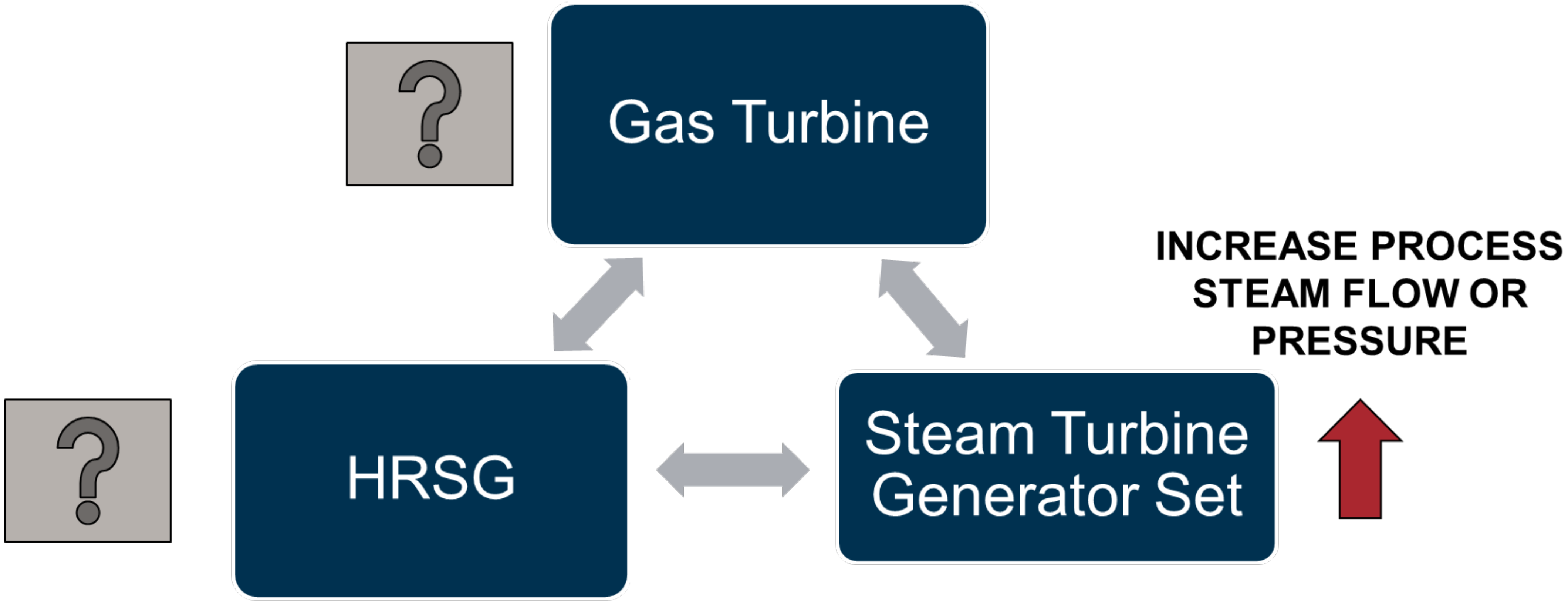


The design of a Combined Cycle System is an iterative process. The design of one component affects the design of the others. *You might have to work backwards.*

How are CHP Systems Designed?



How are CHP Systems Designed?



Gas Turbine Characteristics

Gas Turbine Output	Exhaust Flow	Temperature
(MW)	(lbs/hr)	(Deg F)
4.6	148,420	947
5.6	169,360	949
7.9	209,140	944
10.4	270,000	946
11.35	330,865	901
14.3	350,000	1030
16.45	387,385	935
21	548,964	851

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Steam Turbine Characteristics <20MW

- **Single Stage Steam Turbines**
  - Typically used for backpressure applications
  - ~3MW Output
  - Backpressure (~300 psig) and Flow Limitations
  - Does not require superheat

- **Multistage Steam Turbines**
  - Condensing or Backpressure Applications
  - Extraction Applications
  - Various Options
  - Requires Superheat

- **Backpressure Steam Turbines**
  - Providing steam to process or heating
  - Replacing a PRV

- **Extraction Steam Turbines**
  - Multistage Turbines
  - Allow for multiple pressures
    - Extraction/Condensing
    - Extraction/Backpressure
  - Require Superheat

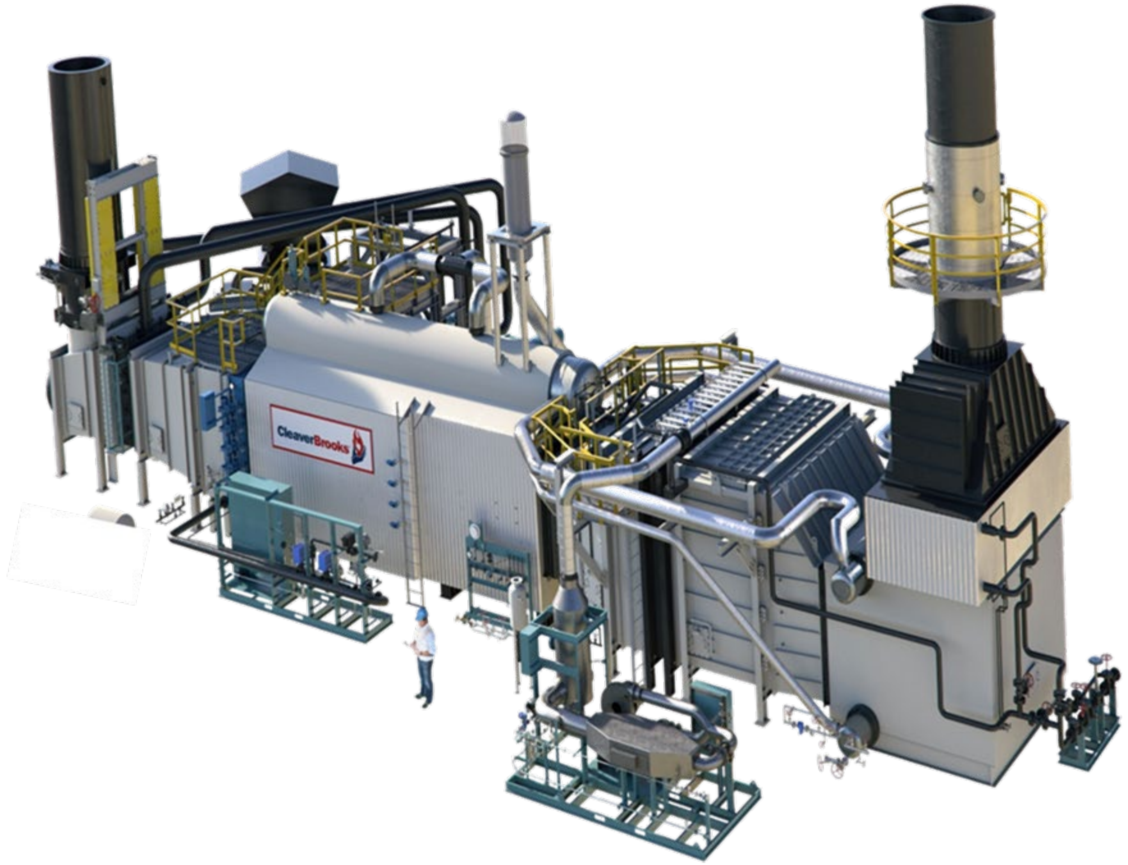
- **Condensing Steam Turbines**
  - Multistage
  - Condense into a vacuum
  - Requires condenser/cooling tower
  - Require Superheat

HRSG Characteristics

Main goal of the HRSG is to capture the exhaust of the gas turbine. Not only are there multiple HRSG designs but there can also be many auxiliary components:

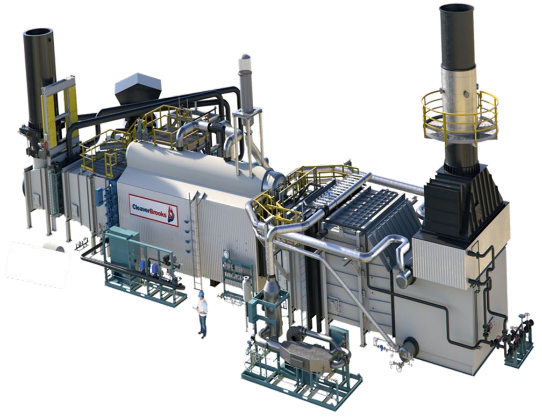
- Duct Burners
- Bypass Stacks with Diverters
- Fresh Air Fans
- Augmenting Air Fans
- Selective Catalytic Reactors
- Ammonia Injection Grids
- Economizers
- Stacks

Example: Multiple Design Options



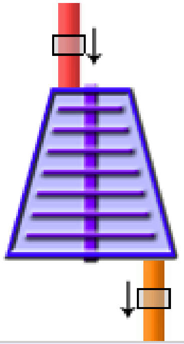
- Capturing Exhaust from an 8.2 MW Gas Turbine
- Output steam at 150 psig with 50°F superheat
- Producing 165,000 lbs/hr for process

Adding a Steam Turbine Generator Set....



Solve for:	
Outlet Properties	
Inlet Steam	
Pressure*	650 psig
Temperature *	700 °F
Turbine Properties	
Selected Turbine Property	Mass Flow
Mass Flow *	165 klb/hr
Isentropic Efficiency *	70 %
Generator Efficiency *	96 %
Outlet Steam	
Pressure*	150 psig
* Required	Enter [reset]

Inlet Steam		Mass Flow	165.0 klb/hr
Pressure	650.0 psig	Sp. Enthalpy	1,347.0 btu/lbm
Temperature	700.0 °F	Sp. Entropy	1.574 btu/lbm/R
Phase	Gas	Energy Flow	222.3 MMBtu/hr



Isentropic Efficiency	70.0 %
Energy Out	16.3 MMBtu/hr
Generator Efficiency	96.0 %
Power Out	4,597.0 kW

Outlet Steam		Mass Flow	165.0 klb/hr
Pressure	150.0 psig	Sp. Enthalpy	1,248.0 btu/lbm
Temperature	454.1 °F	Sp. Entropy	1.622 btu/lbm/R
Phase	Gas	Energy Flow	205.9 MMBtu/hr

***US DOE Steam System Modeler Tool (SSMT)*

- Addition of 4.6 MWe to project
- Potential for ~$6,000,000 of additional annual savings
- Additional GHG Reduction

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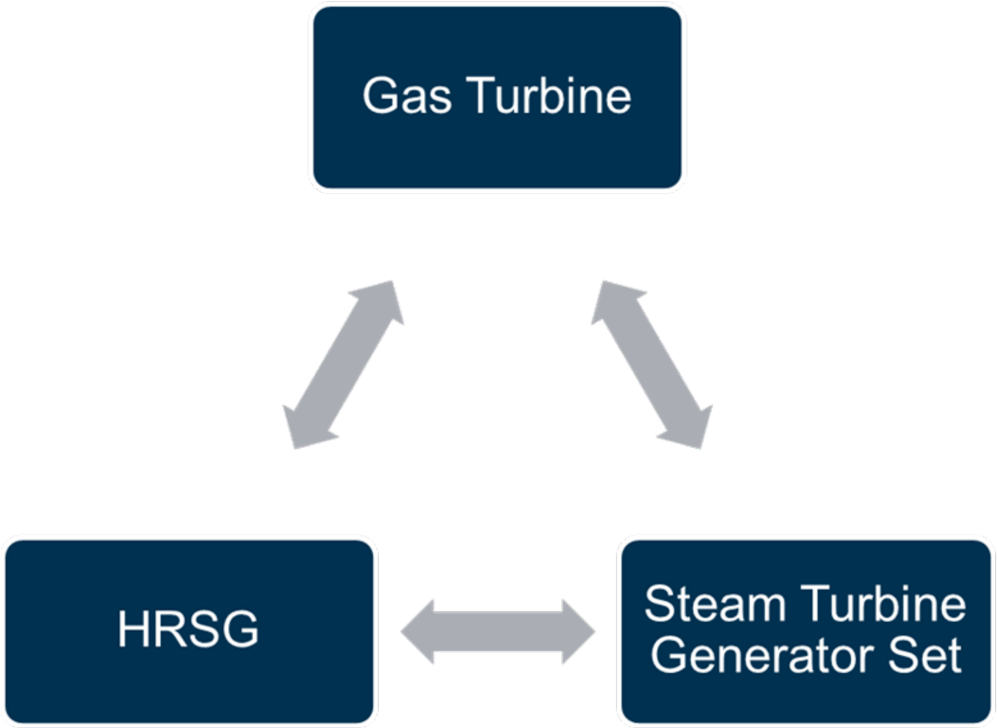
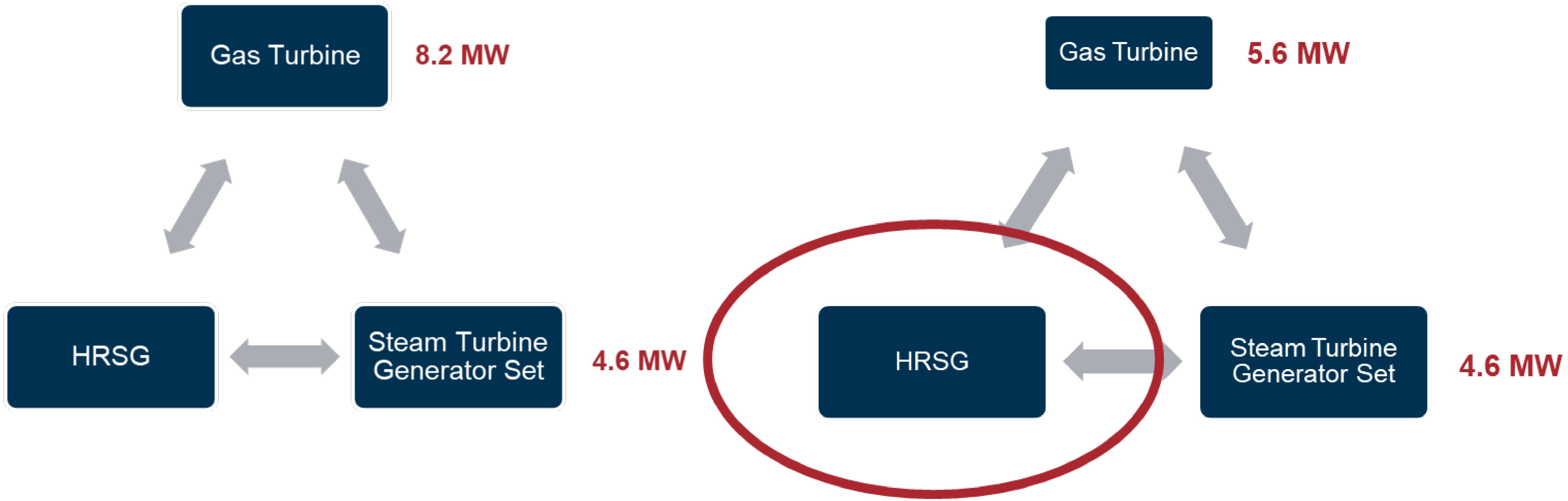
What is the Effect on the HRSG Design?



- Original Project Design 8.2 MWe
- Addition of 4.6 MWe with steam turbine genset
- Total of 12.8 MWe onsite generation available

Change in Design?

10 MW LIMITATION



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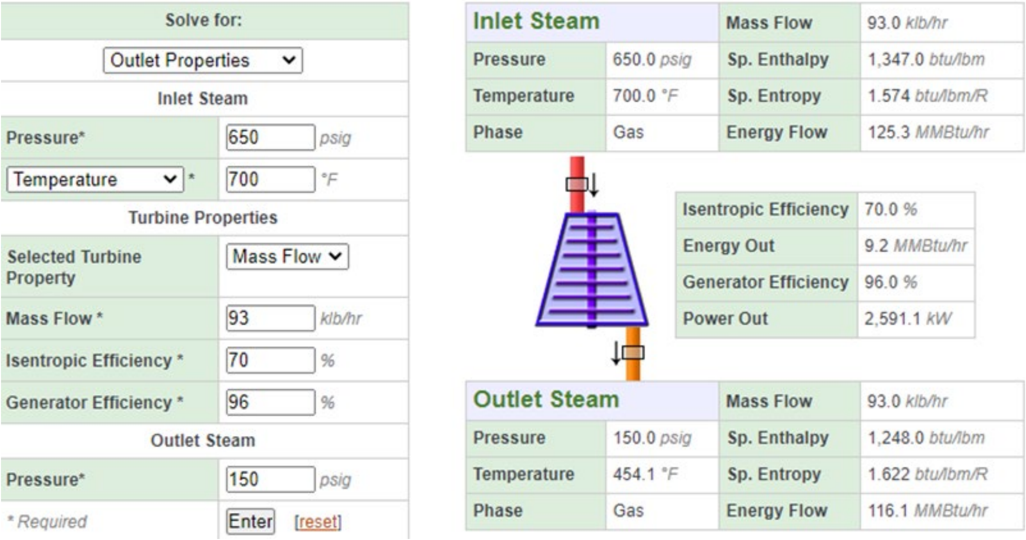
Now What?

HRSG

- Gas turbine exhaust
  - 215,000 lbs/hr -> 169,300 lbs/hr

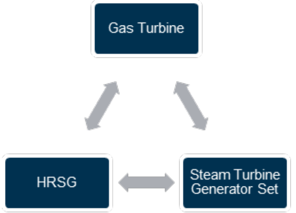
- Still have process need of 165,000 lbs/hr of 150 psig, superheated steam

1. Less heat from gas turbine means less heat into the HRSG. Maximum duct burning will only produce 93,000 lbs/hr. Do you buy an auxiliary boiler to make up the difference?
2. Reduce the size of the steam turbine generator set. 93,000 lbs/hr of steam will generate 2.5 MW. Will still need an auxiliary boiler to make up the process difference.



The most successful CHP projects are the ones that have a steady electrical and heat demand and are relatively matched.

Example: High Electric Demand



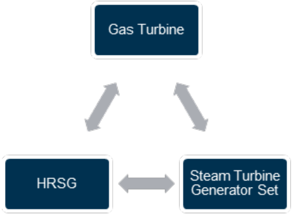
Customer needs 16 MW from gas turbines but has very low process steam load at 150 psig, D&S. – 20kpph.

Pay $.15/kWh for electricity.
Wants to do cogeneration but the thermal and electrical is not a match.

Energy recovery from a 16 MW gas turbine will produce ~64,000 pph of steam at 150 psig with no duct firing.

Let's push it to 600 psig and add a steam turbine generator.

Example: High Electric Demand



Results don't prove that increasing only the pressure adds any significant value.

Options:

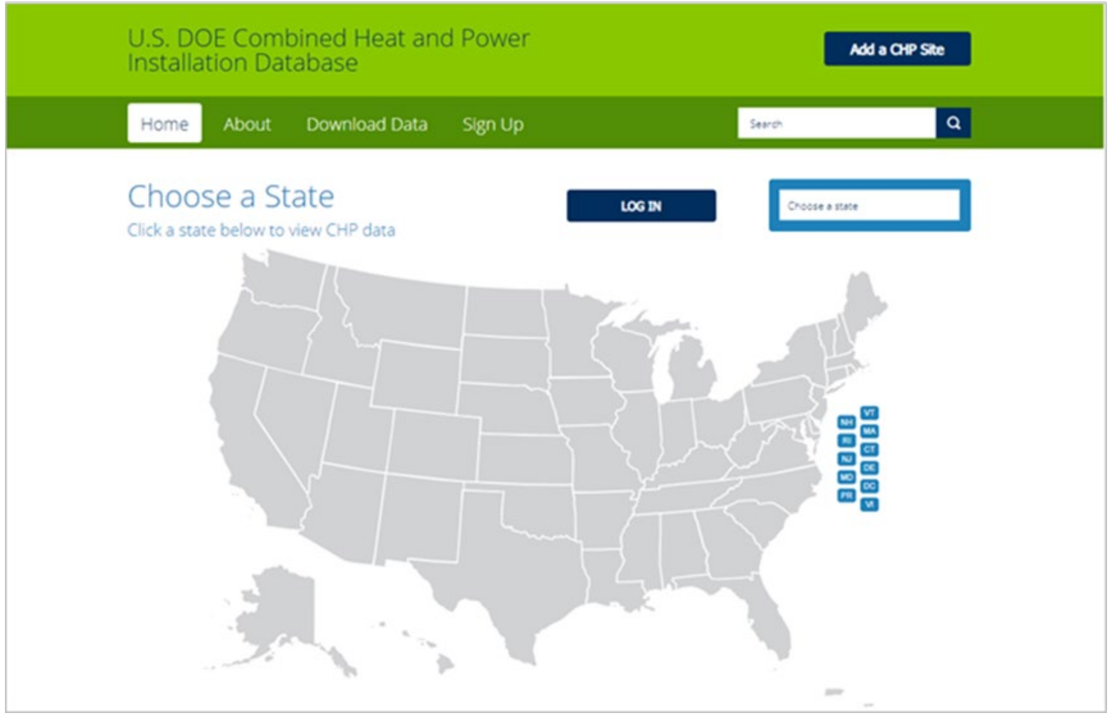
1. Add duct firing to get an increase in steam production. Add an extraction/condensing steam turbine generator set.
2. Buy an auxiliary boiler for the process heat and send recovered steam to steam turbine generator set.

Resources

Project Resources

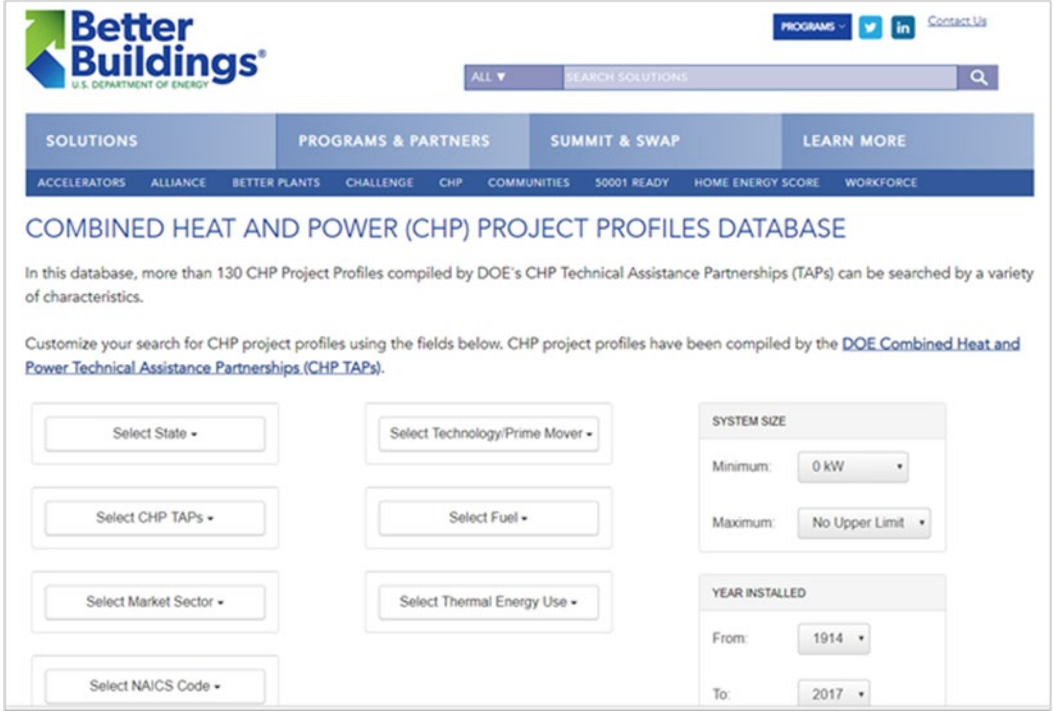
DOE CHP Installation Database

https://doe.icfwebservices.com/chpdb/



DOE Project Profile Database

https://betterbuildingssolutioncenter.energy.gov/chp/chp-project-profiles-database



Integrated Equipment
Seamless operation, unparalleled efficiency, single-source accountability

Service Solutions
Preventive maintenance, genuine parts, global network of authorized service reps

Trusted Expertise
True strategic partnership, customer education, optimization program, certified expertise

The power of total integration.

Any Questions?

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