Advantages of Reciprocating Engines (RICE) and Boilers for Variable Steam Demand

Presented by:

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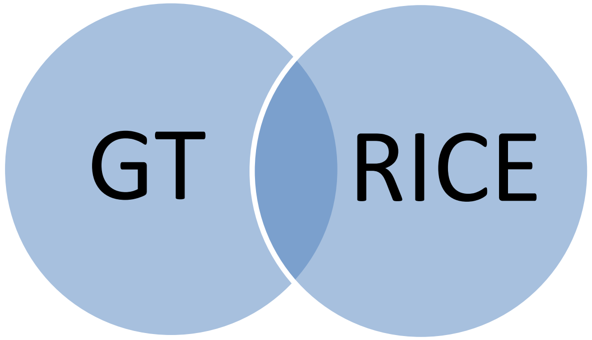
Comparing CHP Technology

- Gas turbines (GTs) attractive/popular option for base-load and central plant power needs
- Compared to GTs, reciprocating engines have less steam capacity per kWe.



- Over the years, RICE CHPs have increased efficiency through technology improvements.
- This presentation focuses on variable steam loads and when RICE/Boiler combination outperforms gas turbines.

Application Selection

	Recip Engine	Steam Boiler	Gas Turbine
Capacities	10kWe to 18MWe	-	500kWe to ~500MWe
Thermal Outputs	LP Steam, Hot Water	LP or HP Steam	LP or HP Steam
Functionality	Fast response to step load	-	Fast response to step load
Start up time	Fast	Slow	Slow
Gas Pressure	1-75 PSIG	1-75 PSIG	100-500 PSIG
Black Start	Battery or Comp. Air	-	Aux Generator
CHP Installed costs ($/kWe)	$1,500-$2,900	-	$1,200-$3,300

Equipment Selection Considerations:

- Electrical capacity required
- Steam rates and pressures (LP or HP)
- Recip engine hot water uses:
  - Hot water loads 190 - 230 °F
  - Converting steam equipment
  - Absorption chiller
- Site gas pressure and compression needs/power

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Performance Considerations

	Reciprocating Engine	Steam Boiler	Gas Turbine
Rated Electric Efficiency (HHV)	27-41%	-	24-36%
Rated Overall Efficiency (HHV)	77-80%	>80%	66-71%
Part Load Thermal Efficiency	Ok	Ok	Poor
Hot inlet air efficiency/output Impacts (rule of thumb)	**-1%** for every 10°F above 77°F*	**+0.25%** for every 10°F increase	**-4 to -5%** for every 10 to 12°F increase

*Certain engine sizes and configurations may have minimal derate

- Poor gas turbine part load performance
  - GTs can throttle power output by reduce reducing combustion temperature, which reduces efficiency and increases emissions.
- Increased inlet air temperatures degrade gas turbine performance
  - More power is required to compress hot, less-dense air
  - Electric prices are highest in the summer during lowest performance for CHP.

CHP Sizing Considerations

- Important to size CHP based on site thermal loads to maximize efficiency
- Thermal output typically represents 60-70% of the CHP inlet fuel energy
- HRSG duct firing for additional steam needs to offset boilers

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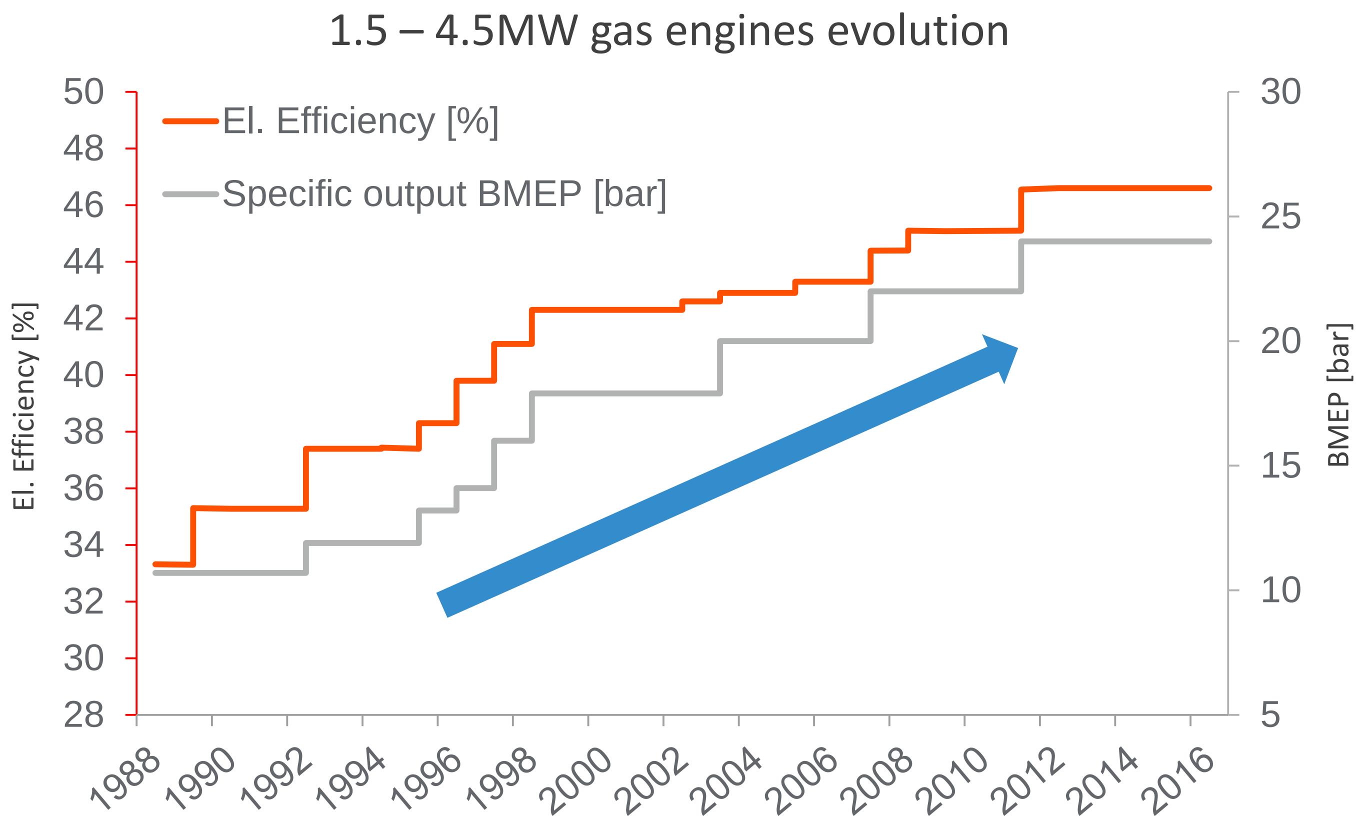
CHP Technology Evaluation Process

- **Step 1** – Determination of thermal & electrical load profile of facilities or defined boundary to be served (define: min/max/base)
- **Step 2** – Define design/evaluation criteria of project
  - Financial, environmental, spatial, availability, redundancy, simplicity/operability
- **Step 3** – Align array of (thermal/electrical) outputs for selected technologies to efficiently satisfy dynamic profile of loads served considering constraints of respective connection to macro grid (feeder) & host facility

Gas Engine Technology

"Reciprocating engine technology has improved dramatically over the past three decades" – EPA CHP Partnership



- Electrical efficiency ↑13 points
- Power ↑120%
- Longer lifecycles & higher reliability
- Containerized/modular versions allow for faster & simplified installs

Today's engines' electrical efficiencies and power densities change rules of thumb for CHP w/ steam

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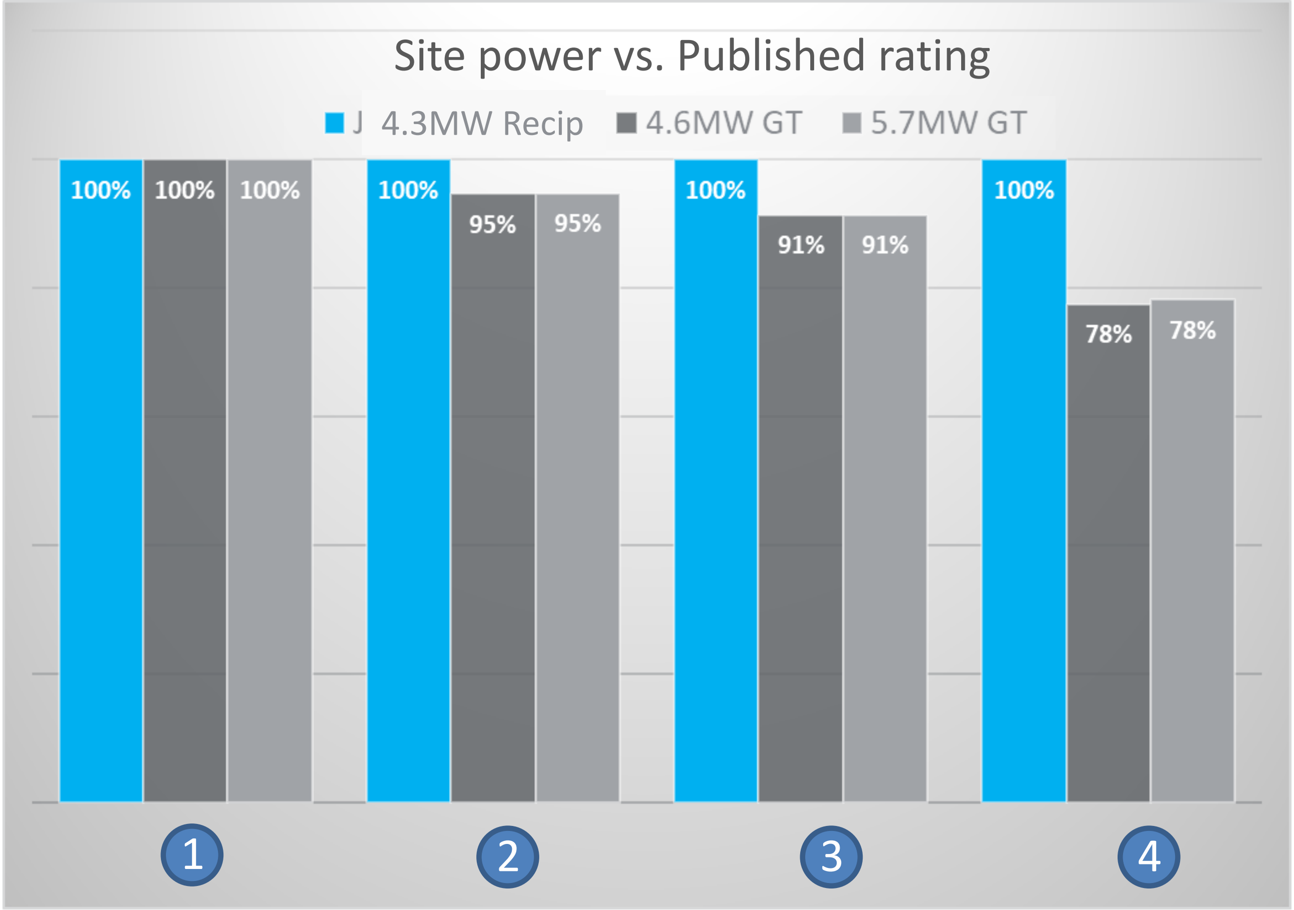
Published vs On-Site Performance

Electrical Power Ratings at Site Conditions, kWe

		4.3MW Recip	4.6MW GT	5.7MW GT
1	Published data, @ genset terminals, kWe	4373	4600	5670
2	At 1500' site altitude, 59F temp, kWe	4373	4355	5370
3	Site installed: 59F, 1500', air/exh losses, kWe	**4373**	**4205**	**5180**
4	Installed "Hot day" site conditions (95F), kWe	4373	3565	4435

Gas Turbines lose output when site electrical demands are often higher, and/or utility pricing is highest



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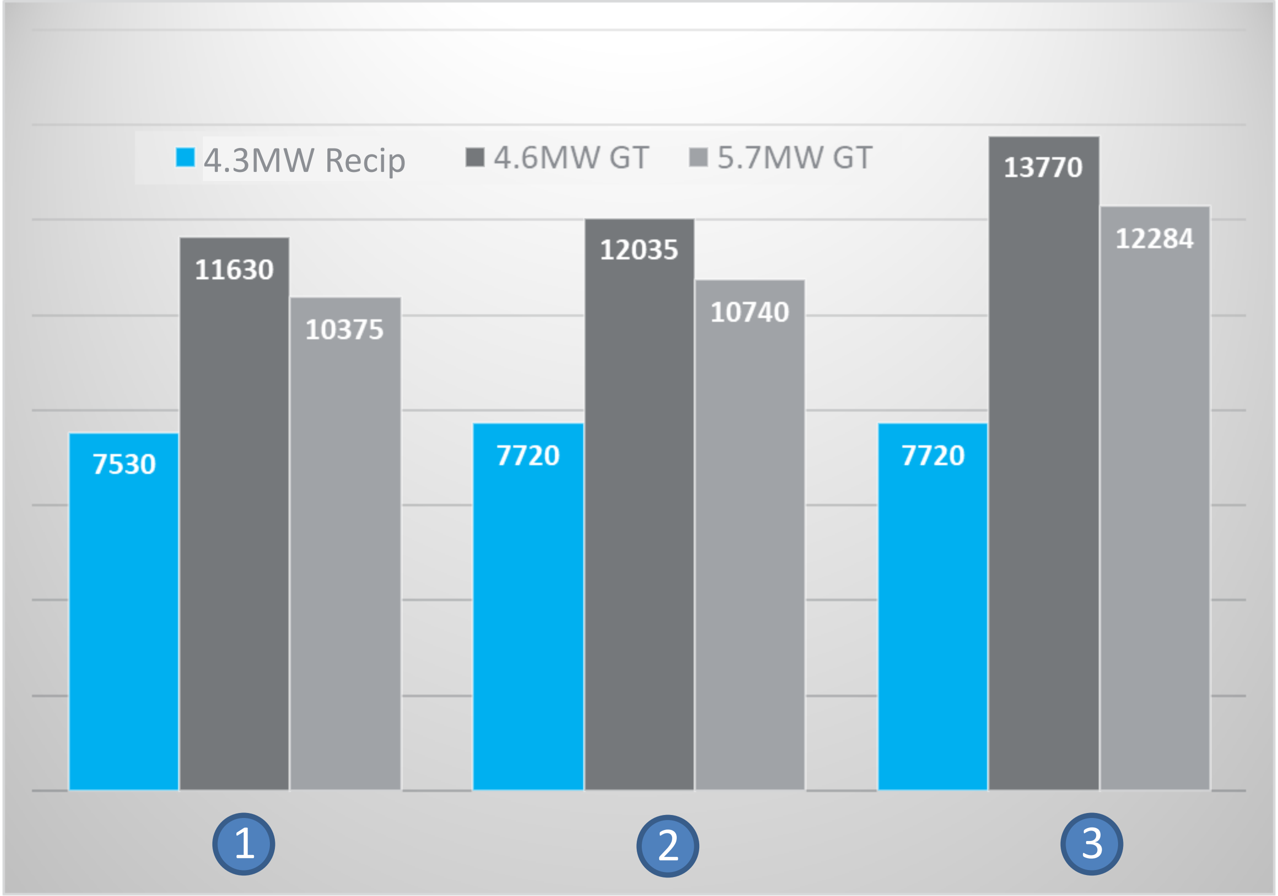
Published vs On-Site Performance

Heat Rate at Site Conditions, BTU/kWh (LHV)

		4.3MW Recip	4.6MW GT	5.7MW GT
1	Published data, @ genset terminals	7,530	11,630	10,375
2	Site installed: 59F, 1500', air/exh losses, "nominal" tolerance	7,720	12,035	10,740
3	Installed "Hot day" site conditions (95F)	7,720	13,770	12,284

Gas engine electrical efficiency advantage increases at installed & hot day conditions

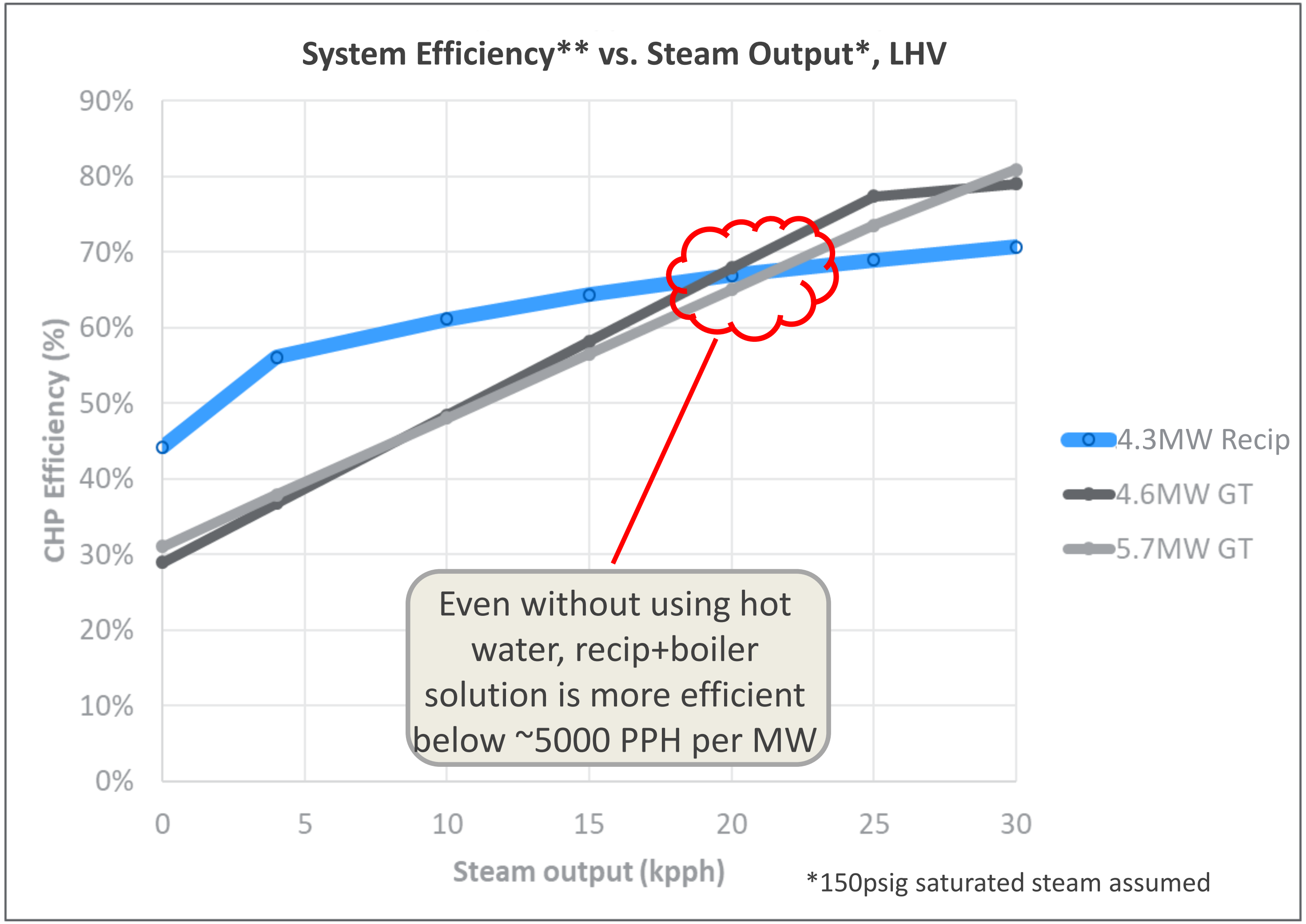


Whole System Efficiency – steam only CHP

	Steam production method	Feedwater heating method
4.3MW Recip	HRSG + aux boiler	Engine hot water circuit or Economizer
4.6 MW GT	HRSG, HRSG + DF	Economizer
5.7MW GT	HRSG, HRSG + DF	Economizer

Recip Advantages:

- Flexible: Can "de-couple" thermal and electric production
- Higher total efficiency at low-mid steam demands (~2.3 tons/hr per MW)
- Ideal for variable steam loads (i.e. site thermal profiles result in partial utilization)



**ratio of total fuel input to electric output + thermal output (including boiler)

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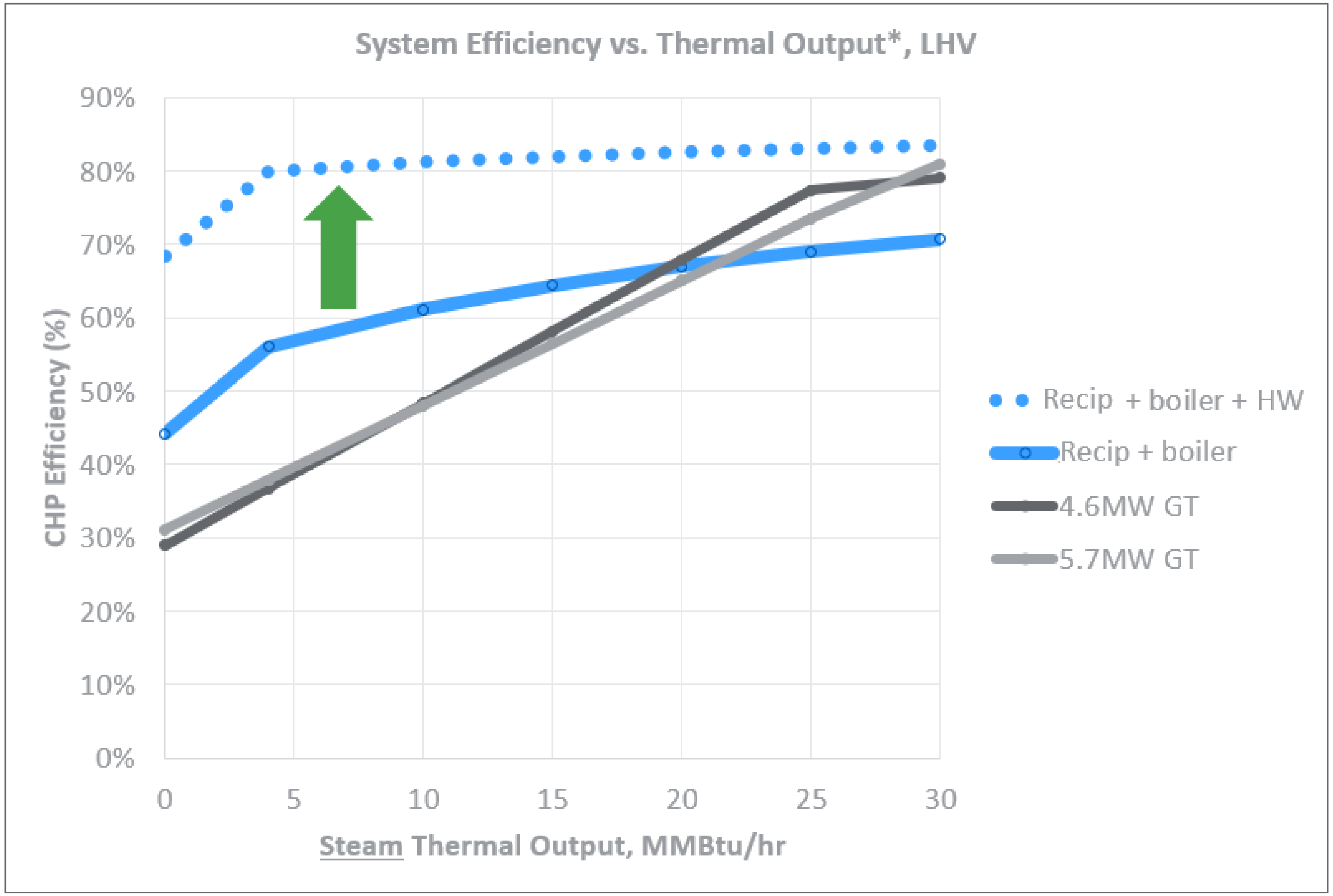
Whole System Efficiency – with Engine Hot Water

- Capturing hot water for additional site use can increase engine efficiency substantially



*150psig saturated steam, all engine HT circuit heat used

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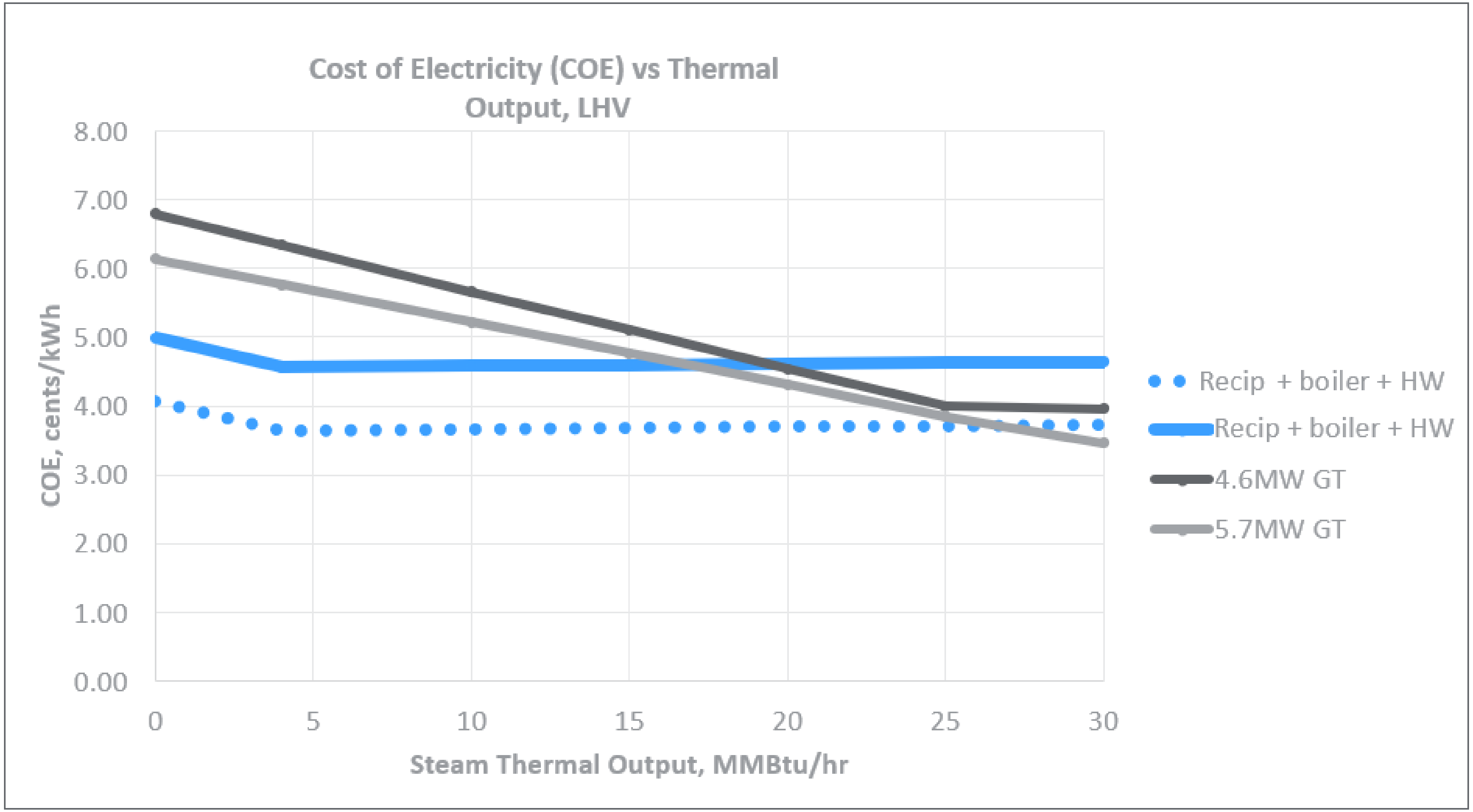
Self-Generation Cost Example – w/ Engine Water

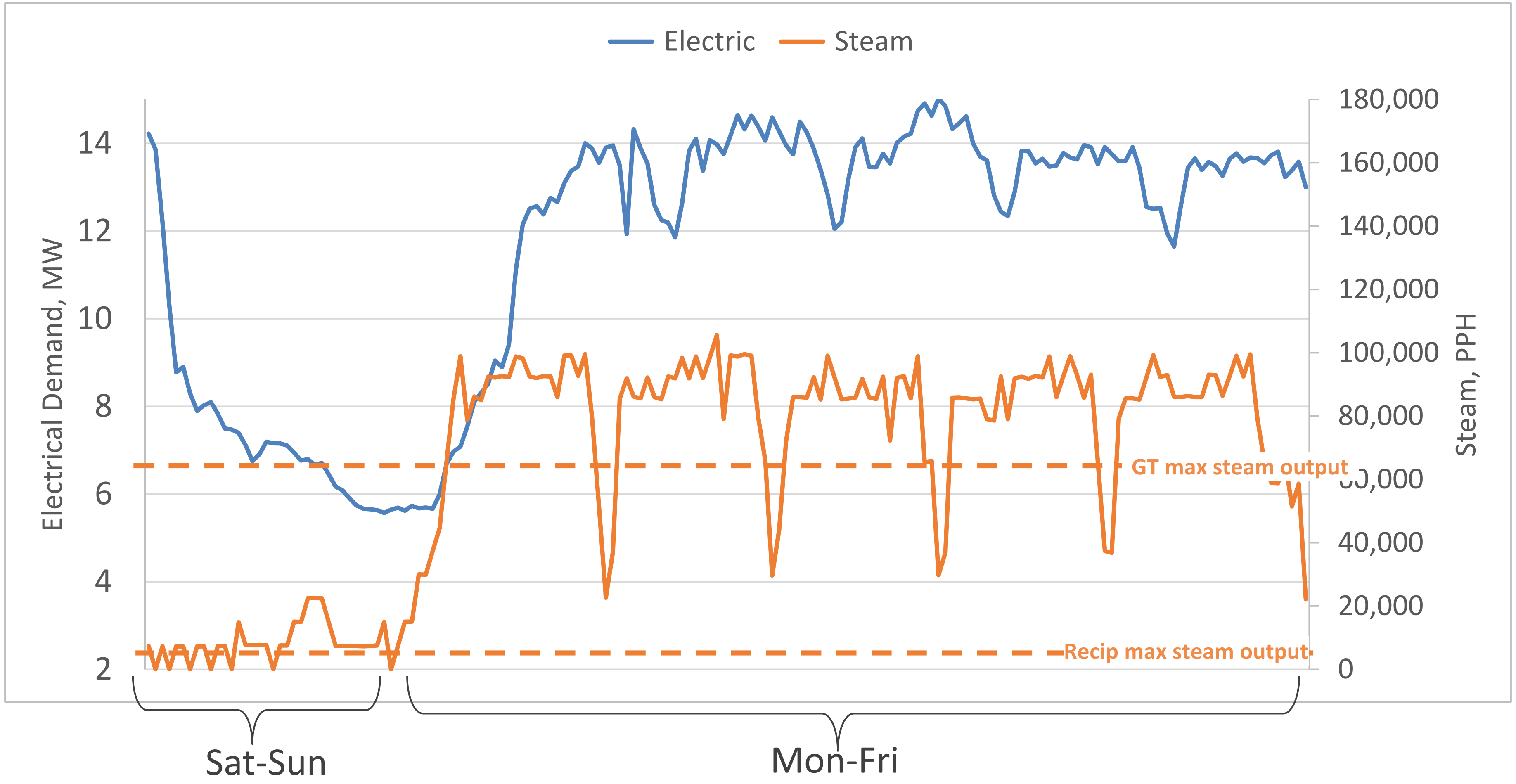


Example assumptions:

- O&M - 1.6cents/kWh (recip), 1.3cents/kWh (GT)
- O&M comparisons estimated from EPA CHP handbook
- $4/MMBtu NG price
- All engine HT circuit heat is used
- GT and boiler economizers not considered

For example purposes only – each case will vary based on project specific details

Data Analysis - Customer Example



Typical customer weekly electric & steam data shown, using hourly interval data

Site considerations:

- High utility demand charges
- <100psi gas pressure
- Steam only – no hot water
- Variable electric & steam loads – favors smaller power nodes & turndown flexibility

Further review of annual hour-by-hour data reveals best customer fit may be recips…

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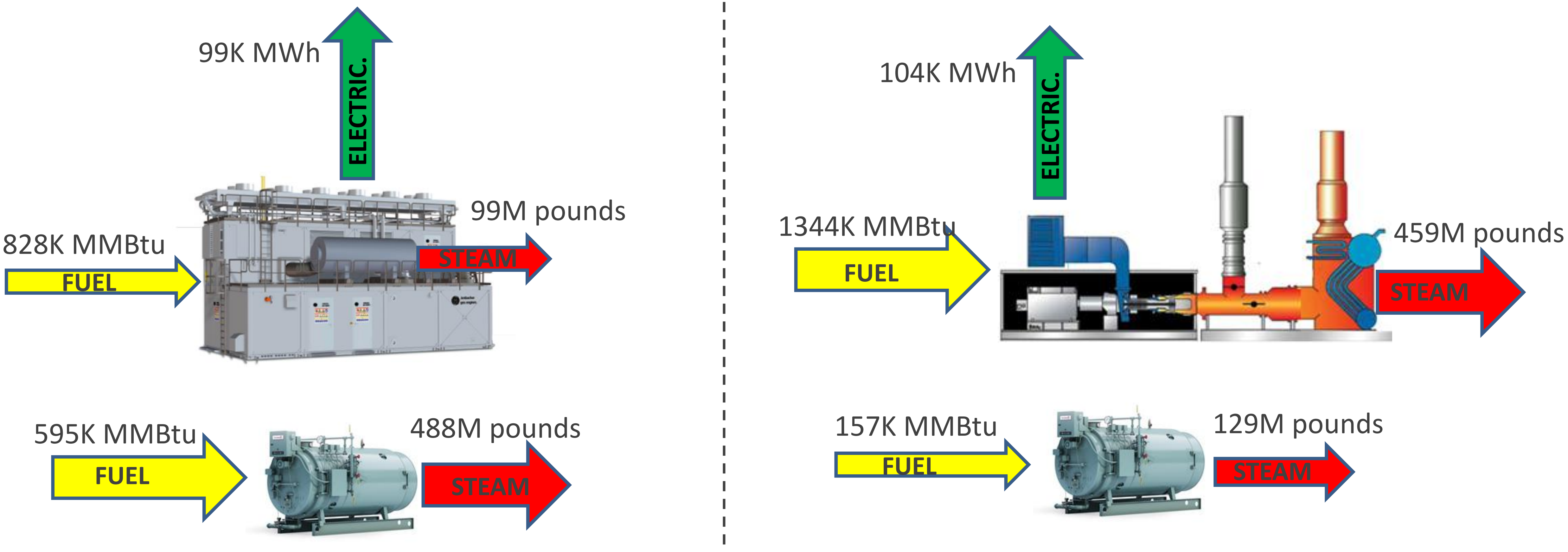
Customer Example – Annual Summary



Analysis showed recip solution saves >70,000 MMBtu of fuel annually

Thank you.

Questions?

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