



BURNS  **MCDONNELL**



Reciprocating Engine or Combustion Turbine?

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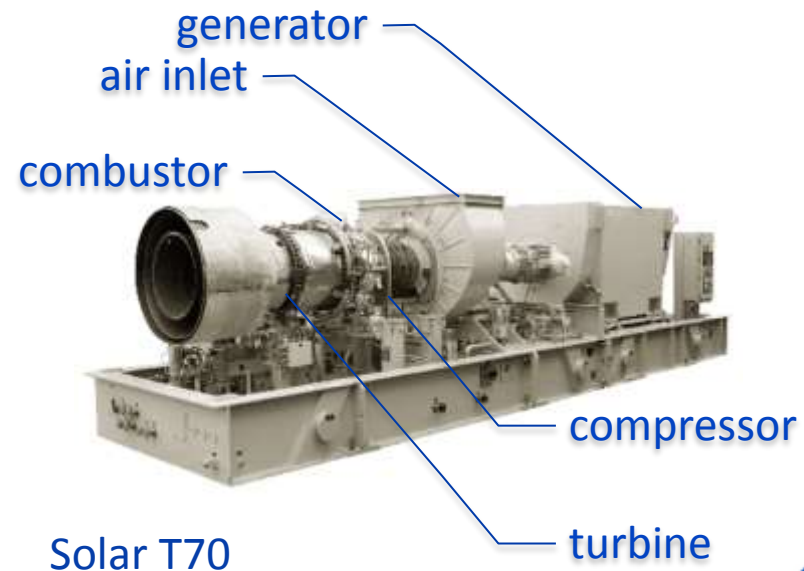
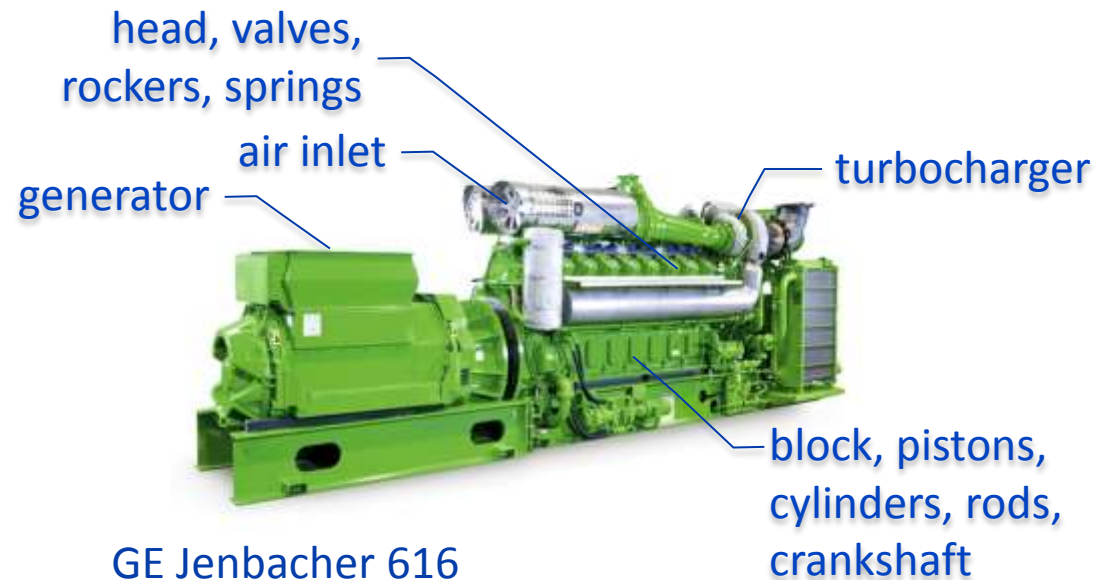


AGENDA

- ▶ Installations
- ▶ Technology Overview
- ▶ Footprint
- ▶ Performance
- ▶ Power to Heat Ratio
- ▶ Thermal Load Following
- ▶ Fuel Flexibility
- ▶ Emissions & Permitting
- ▶ Vibrations & Acoustics
- ▶ Capital Costs
- ▶ O&M Costs
- ▶ Decision Matrix
- ▶ Case Study

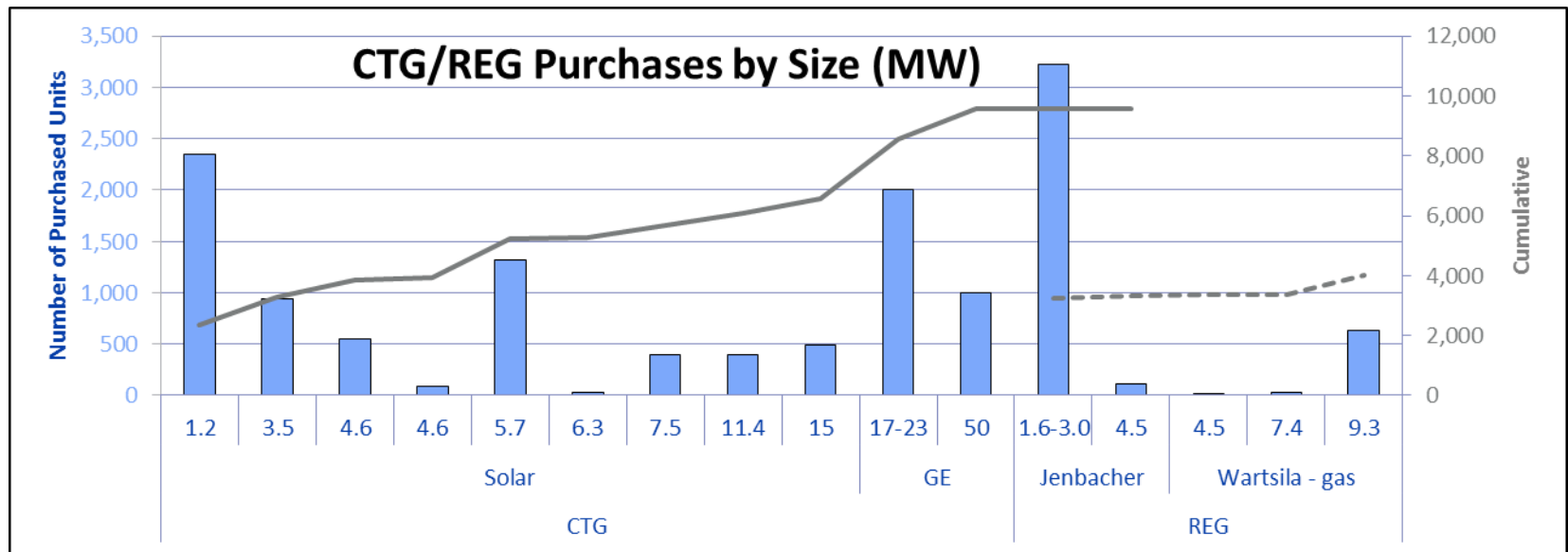
TECHNOLOGY OVERVIEW

- ▶ Gas turbines (4-50+ MW)
- ▶ Reciprocating engines (2-18 MW)



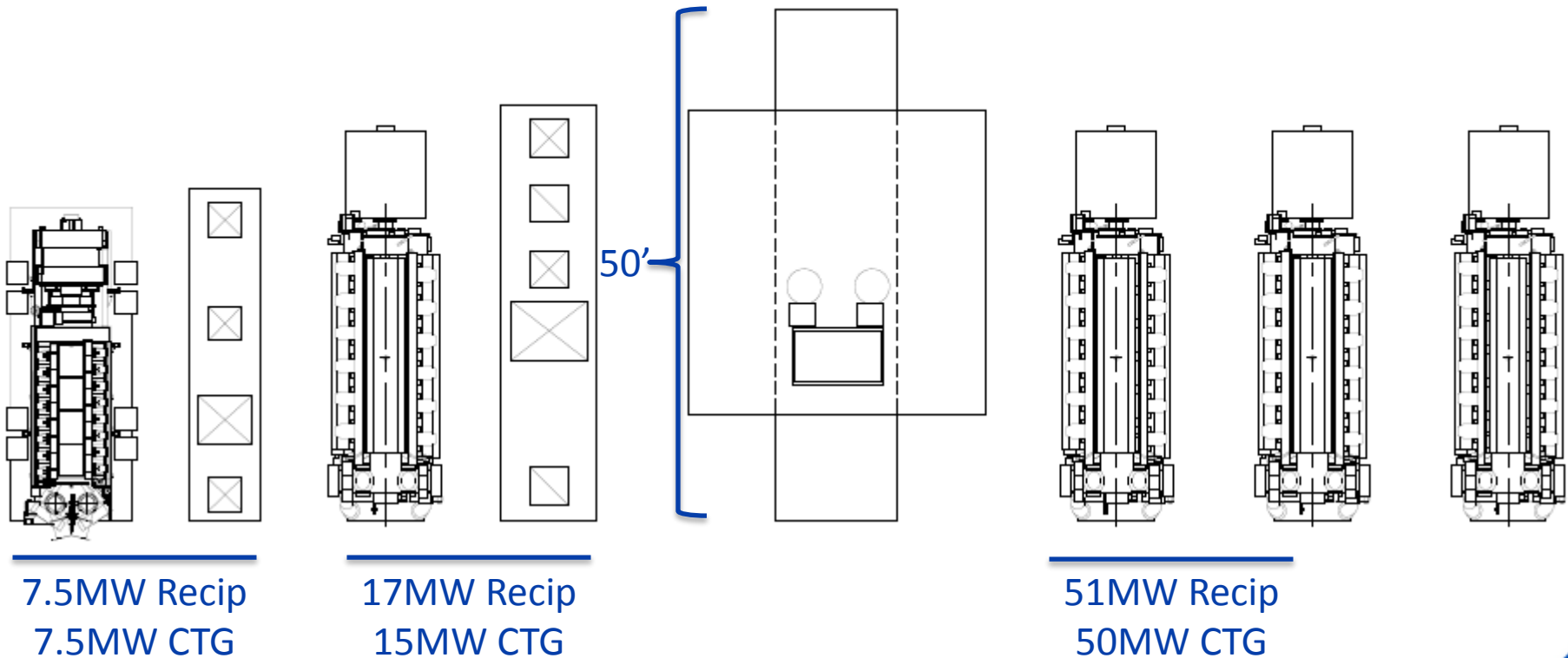
CTG/REG INSTALLATION

- ▶ CTG installation more abundant
- ▶ Large REG installation popularity growing, still significant number of installations
- ▶ CHP market in US dominated by turbines



FOOTPRINT

- ▶ For smaller applications footprints are similar
- ▶ For larger applications, footprint of CTG smaller than REG



PERFORMANCE

Considering the previous REG/CTG comparisons:

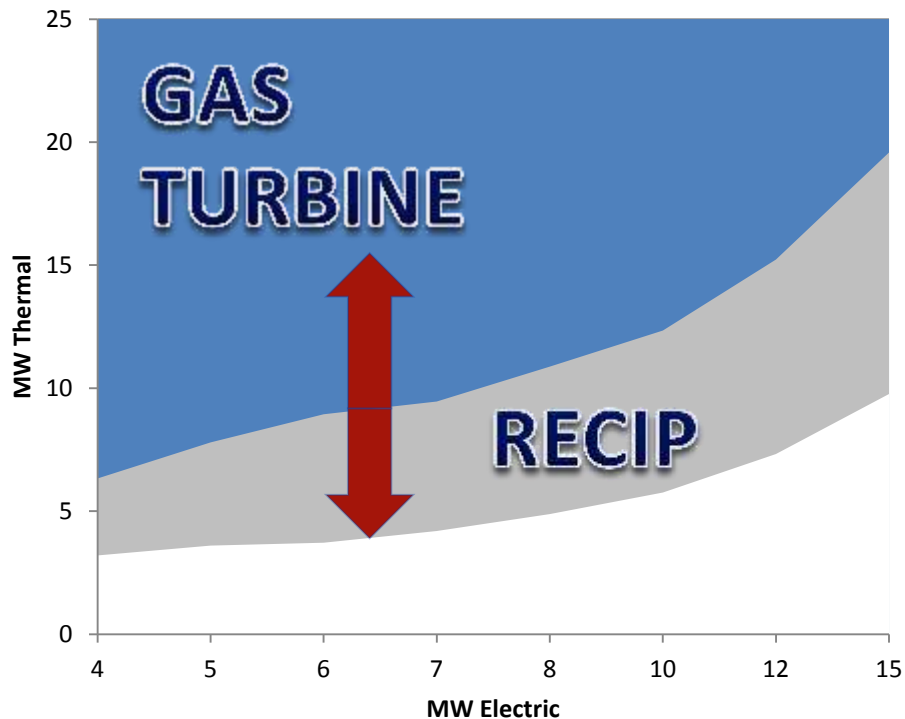
| Unit | Power Output (MW) | Heat Rate (BTU/kWh, LHV) | Exhaust Gas Flow (lb/hr) | Exhaust Gas Temperature (°F) |
|---------------|-------------------|--------------------------|--------------------------|------------------------------|
| 7.5 MW REG | 7.5 | 7,400 | 94,000 | 734 |
| 7.5 MW CTG | 7.5 | 10,100 | 214,000 | 960 |
| 17 MW REG | 17 | 7,100 | 246,000 | 707 |
| 15 MW CTG | 15 | 9,700 | 395,000 | 940 |
| 3 x 17 MW REG | 51 | 7,100 | 737,000 | 707 |
| 50 MW CTG | 50 | 7,100 | 1,100,000 | 890 |

*Heat rate of REGs generally much lower than CTG counterpart

*Thermal (exhaust) output of REGs generally much lower than CTG counterpart

PERFORMANCE

- ▶ Power to heat ratio
- ▶ Selecting the appropriate prime mover allows the best utilization of capital with the ability to base load the equipment.



| REG | | |
|-----|----------------|--------------|
| MW | Total Heat MWt | Power / Heat |
| 4.0 | 3.8 | 1.041 |
| 4.5 | 4.2 | 1.071 |
| 5.4 | 3.7 | 1.456 |
| 6.5 | 5.8 | 1.123 |
| 7.4 | 4.9 | 1.523 |

| CTG | | |
|-----|----------------|--------------|
| MW | Total Heat MWt | Power / Heat |
| 3.5 | 6.3 | 0.553 |
| 4.6 | 7.8 | 0.590 |
| 5.7 | 8.9 | 0.638 |
| 6.3 | 9.5 | 0.666 |
| 8.0 | 10.9 | 0.736 |

PERFORMANCE: THERMAL LOAD FOLLOWING

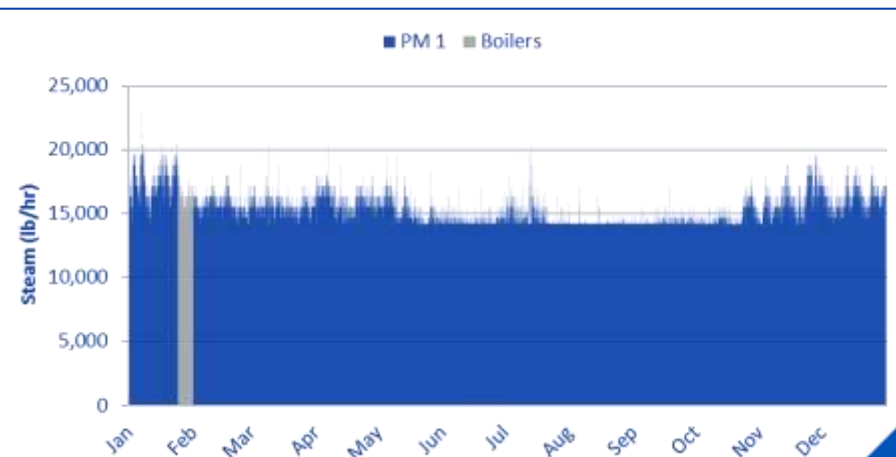
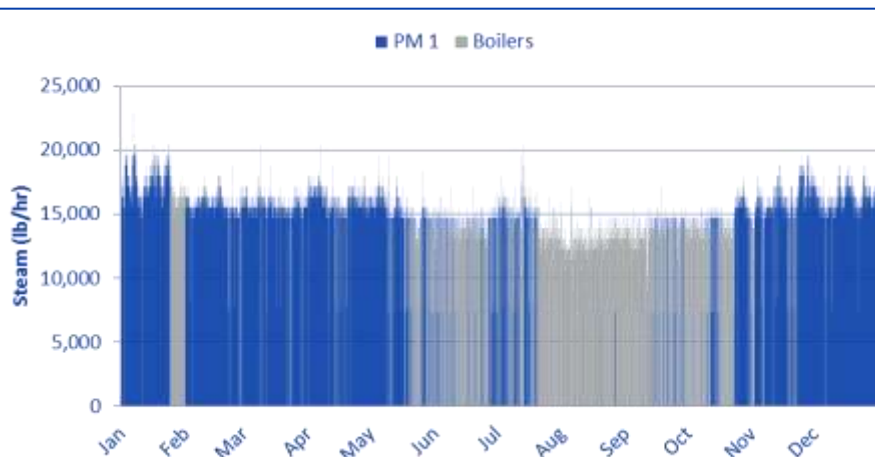
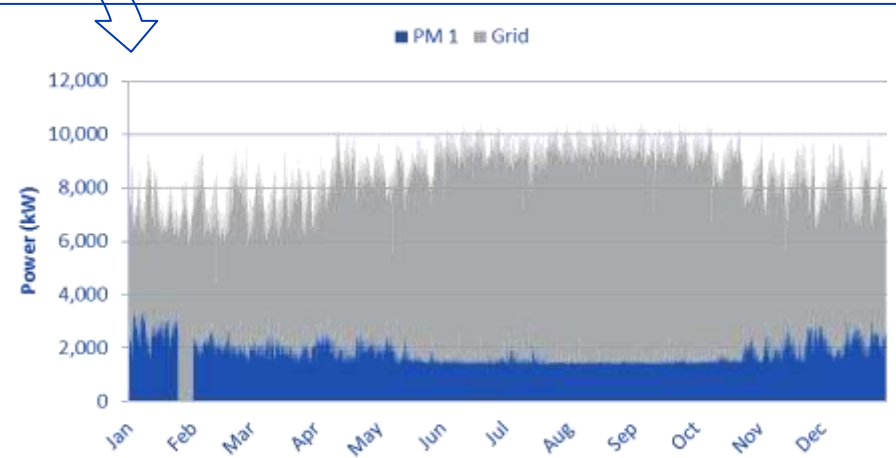
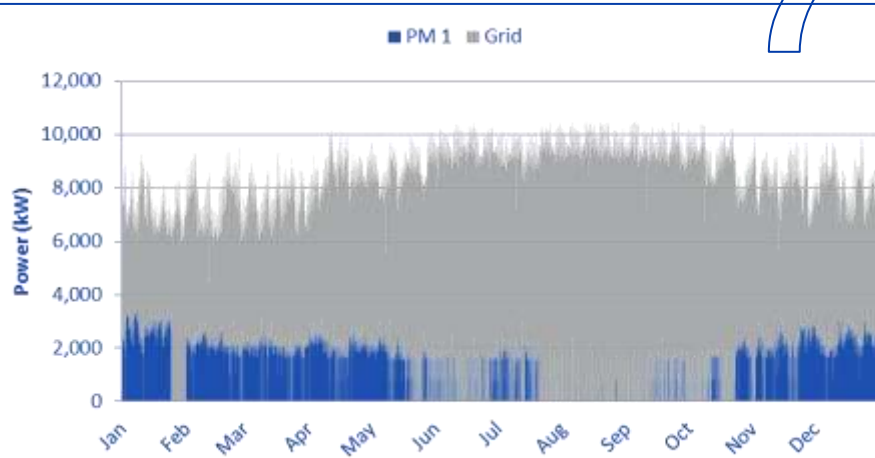
- ▶ Exhaust gas bypass damper:
- ▶ CTG: on/off, REG: modulating



CBPG HRSG with Bypass, Ex Louver Shown

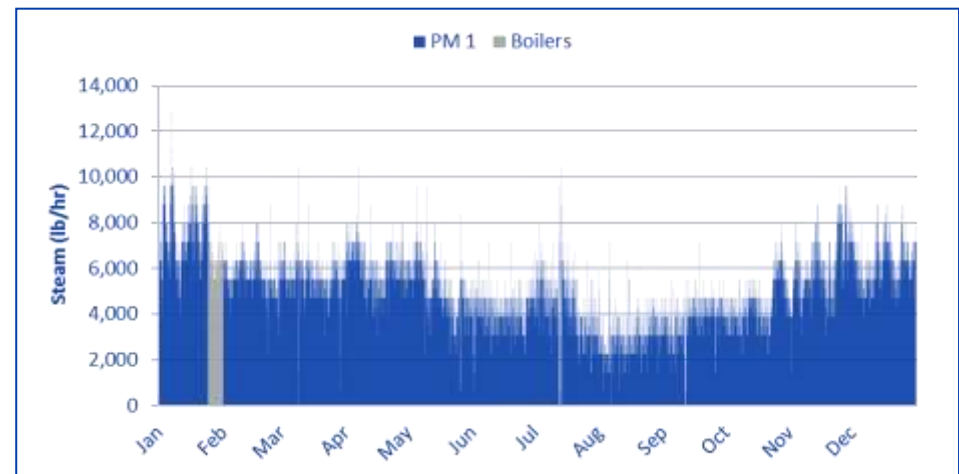
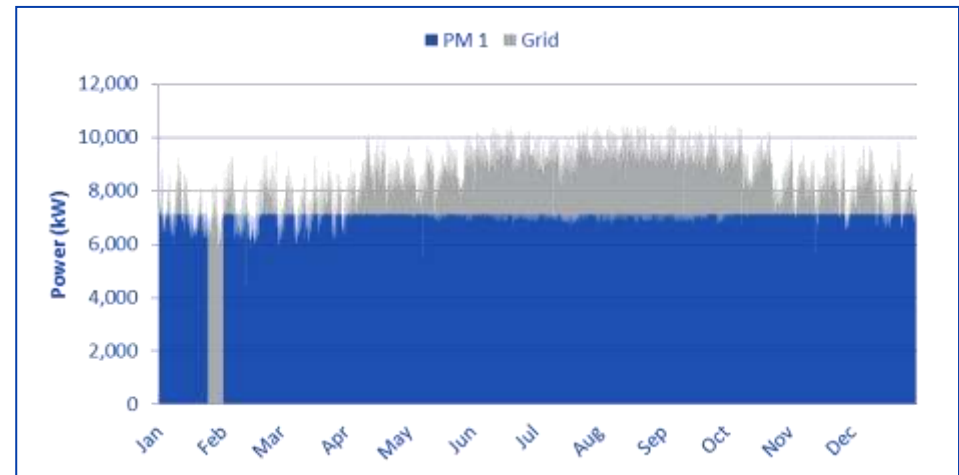
PERFORMANCE: THERMAL LOAD FOLLOWING CTG

Thermally limited: add steam drive chiller (or other steam sink)



PERFORMANCE: THERMAL LOAD FOLLOWING REG

- ▶ Modulating exhaust gas bypass damper prevents shutdown due to lack of thermal load



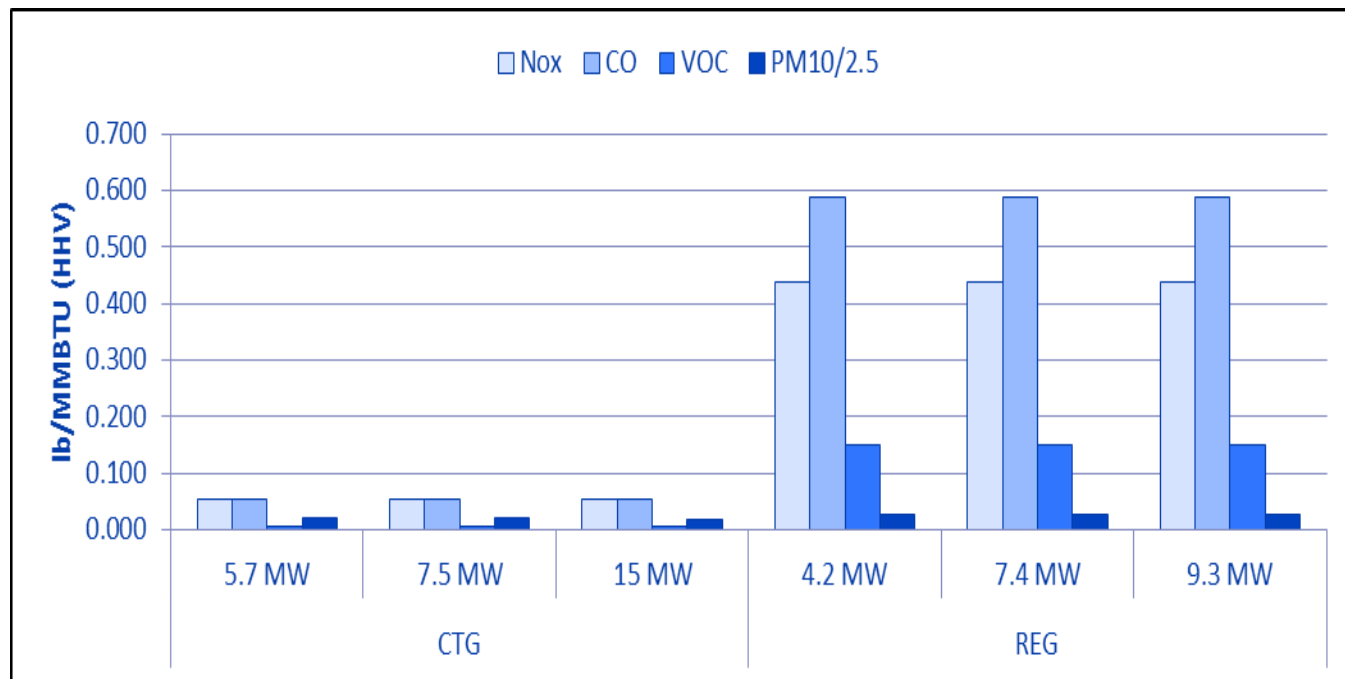
FUEL FLEXIBILITY

- ▶ Generally, REG's only operate on gaseous or liquid fuel; fuel type specifies machine type.
 - Few units available to operate on gaseous and liquid fuel
 - Propane operation requires 25%+ electrical derate
- ▶ Generally, CTG's capable of consuming wide variety of gaseous/liquid fuels
 - Certain fuels may dictate
higher emissions
combustors

| Gaseous | Liquid |
|-----------------|---------------------|
| Natural Gas | Light Fuel Oil |
| Propane | Heavy Fuel Oil |
| Syngas | Crude Oil |
| Landfill Gas | Fuel Water Emulsion |
| Process Off Gas | Liquid Biofuel |
| Digester Gas | |

EMISSIONS & PERMITTING

- ▶ Generally, CTGs offer lower emissions than REG counterparts
- ▶ SCR can reduce CO, No_x by 80-90%



Peerless SCR

VIBRATIONAL & ACOUSTICAL

▶ CTG Vibration

- Typically manageable

▶ Sound

- Sound-attenuating enclosures
- Intake air silencers
- Exhaust gas silencers

▶ REG Vibration

- Anti-vibration mounts
- Isolating pads

▶ Sound

- Smaller units enclosed
- Intake air silencers
- Exhaust gas silencers



Anti-vibration mount



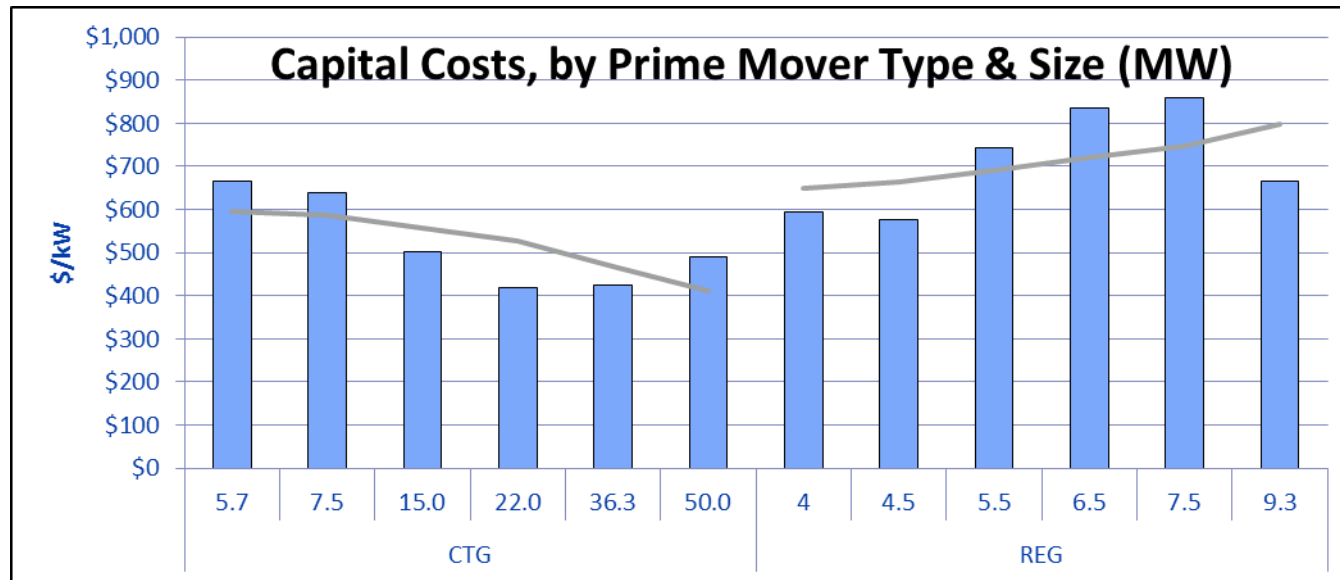
IAC Exhaust Silencer



CTG Enclosure

CAPITAL COSTS

- ▶ Among smaller options (<5 MW), capital costs are similar between CTGs, REGs (no BOP considered).
- ▶ Among larger options, capital costs of CTGs are less.



O&M COSTS

- ▶ Variable O&M
 - Minor maintenance
 - Lube Oil Consumption (REGs)
 - SCR Reagent Consumption
 - Major Maintenance
- ▶ Fixed O&M
 - Plant Operations

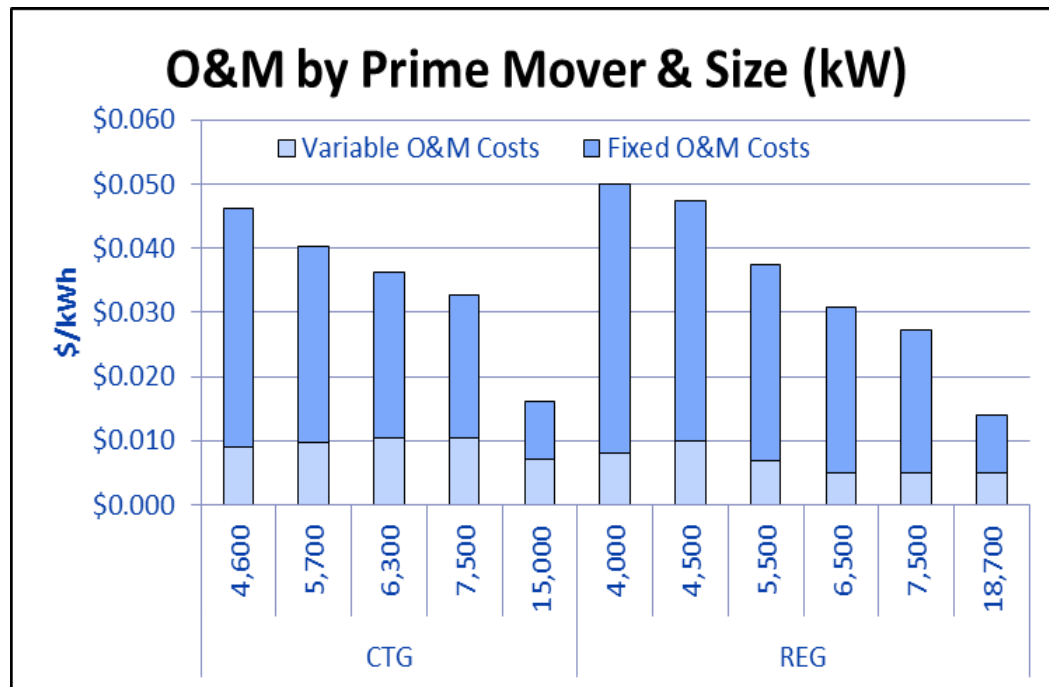


O&M COSTS

O&M Cost Differences

► Variable O&M

- Overhaul may fall under separate contract for REGs
- Trained plant operators may perform minor REG maintenance
- REG O&M costs vary largely between manufacturers



► Variable O&M costs:

- REG \$0.005/kWh-\$0.010/kWh
- CTG \$0.007/kWh-\$0.011/kWh

DECISION MATRIX

| Points | Criteria | REG | CTG |
|-----------------------------|---|-----|-----|
| Weight: [5] Range: 0-5 | Q: What is the power to heat ratio? (kW * 3412) / (BTU/H). Score: Ratio of 1.0 to 1.5+, all points to REG Ratio of <0.55 to 0.74, all points to CTG | | |
| Weight: [] Range: 0-5 | Q: What is the impact of space? Score: If greenfield site or size < 20 MW REG & CTG = 50% * Weight. If existing site, size > 20 MW, tight plant arrangement REG = 25% * Weight, CTG = 75% * Weight | | |
| Weight: [] Range: 0-5 | Q: What fuel diversity is required? Score: If gaseous and liquid fuel desired REG = 25% * Weight, CTG = 75% * Weight. Else REG & CTG = 50% * Weight | | |
| Weight: [] Range: 0-5 | Q: What startup time is required? Score: If less than five minutes all points to REG. Else REG & CTG = 50% * Weight | | |
| Weight: [] Range: 0-5 | Q: What level of emissions is desired? Score: If permitting process difficult and tight emission tolerances required CTG = 75% * Weight. Else REG & CTG = 50% * Weight | | |
| Weight: [] Range: 0-5 | What concern is plant vibration and acoustics? Score: If plant vibration and acoustics are major concerns CTG = 75% * Weight. Else REG & CTG = 50% * Weight | | |
| | Totals | | |



QUESTIONS

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