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Presented by

Ultra Low NOx Burner Testing

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Project Objectives

- Test and measure efficiency of industry standard conventional ultra-low NOx burner
  - Sub-9 ppm NOx capable
- Test and measure efficiency of Rogue-ClearSign NZN burner
  - At comparable NOx level (sub-9 ppm or S9)
  - At unmatched near-zero NOx level (sub-2.5 ppm or NZN)

Metrics

- NOx Emissions
- CO Emissions
- Boiler Thermal Efficiency
- Fuel Gas Use
- Electrical Energy Use

Burner Technologies

Baseline Technology

Figure 1. Industry Standard ULNB – Mesh Burner

Emerging Technology

Figure 2. Rogue NZN Burner with ClearSign Core Technology

Boiler System Set-Up

Figure 3. Boiler System Set-Up

Test Approach

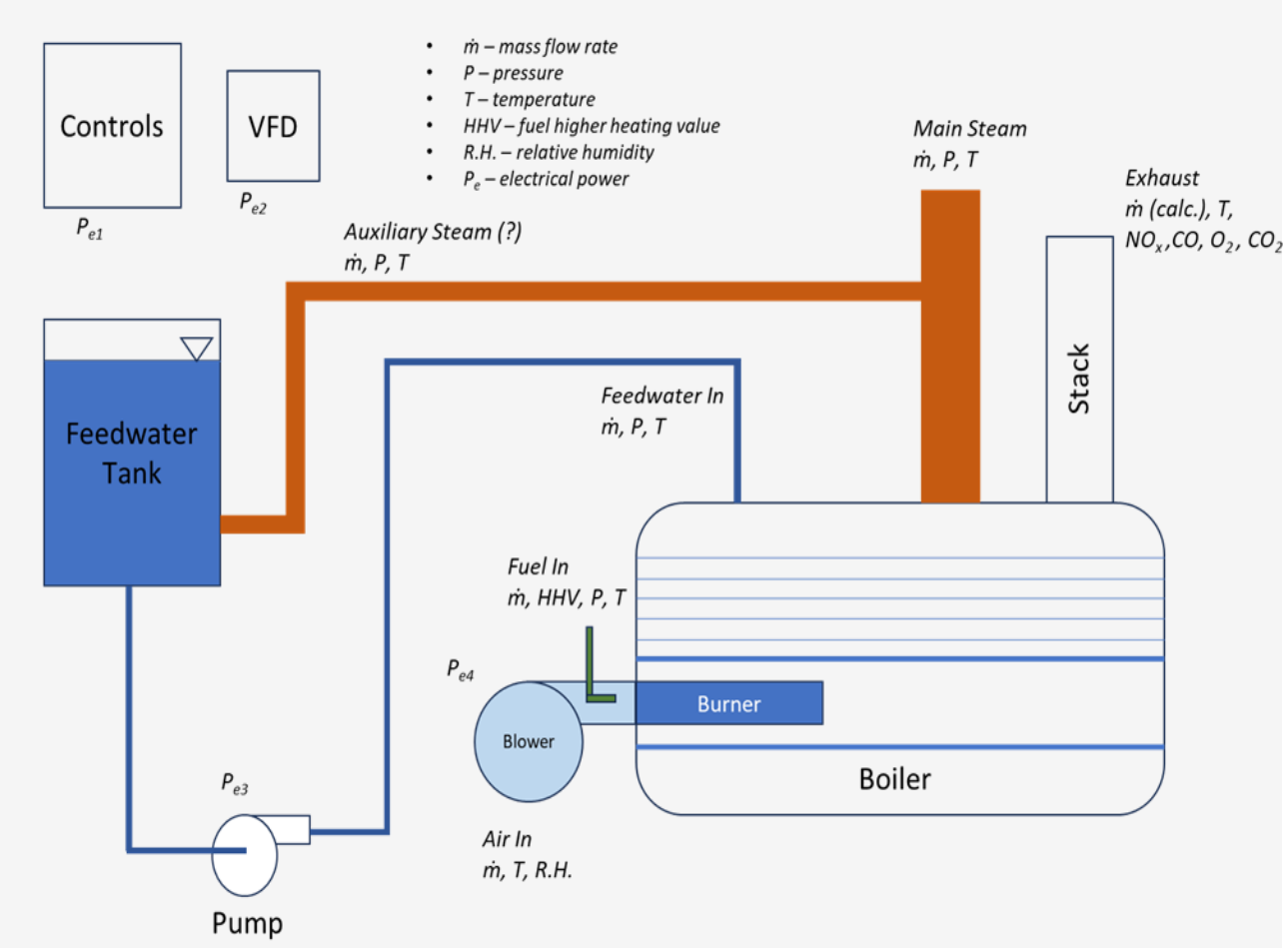


Figure 4. Boiler Burner Schematic

Figure 5. Instrumentation

Test Conditions

There will be two main phases of testing with an additional third phase of testing on the ClearSign burner:

- Phase 1: Baseline burner tuned to sub-9 ppm NOx
- Phase 2: Replacement ClearSign burner
  - A. ClearSign burner tuned to sub-9 ppm NOx
  - B. 2.2 ClearSign burner tuned to achieve lowest possible NOx (sub-2.5 ppm)

Table 1. Burner Firing Rates

	Baseline Burner	Rogue-ClearSign Burner
Firing Rates (Max. 5.0 MMBtu/h)	• 25% • 33% • 66% • 84% (Limited by Blower Capacity)	• 25% • 33% • 66% • 84% • 100%
NOx Level (corrected to 3% O_2)	• Sub-9 ppm	• Sub-9 ppm • Sub-2.5 ppm

Flame Appearance

Industry Standard ULNB – Mesh Burner

Rogue NZN Burner with ClearSign Core Technology

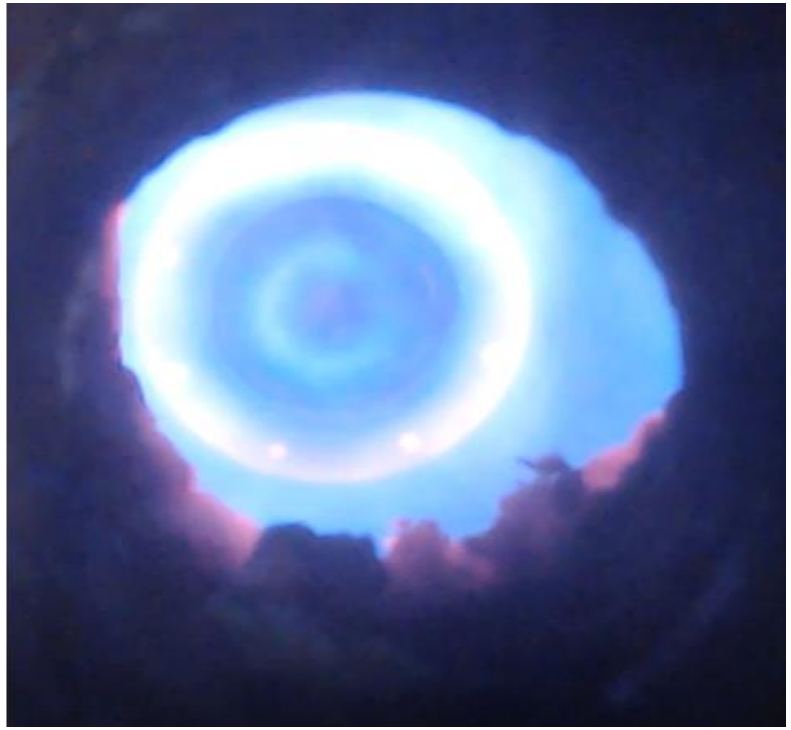


Figure 6. Flame Appearance

Results

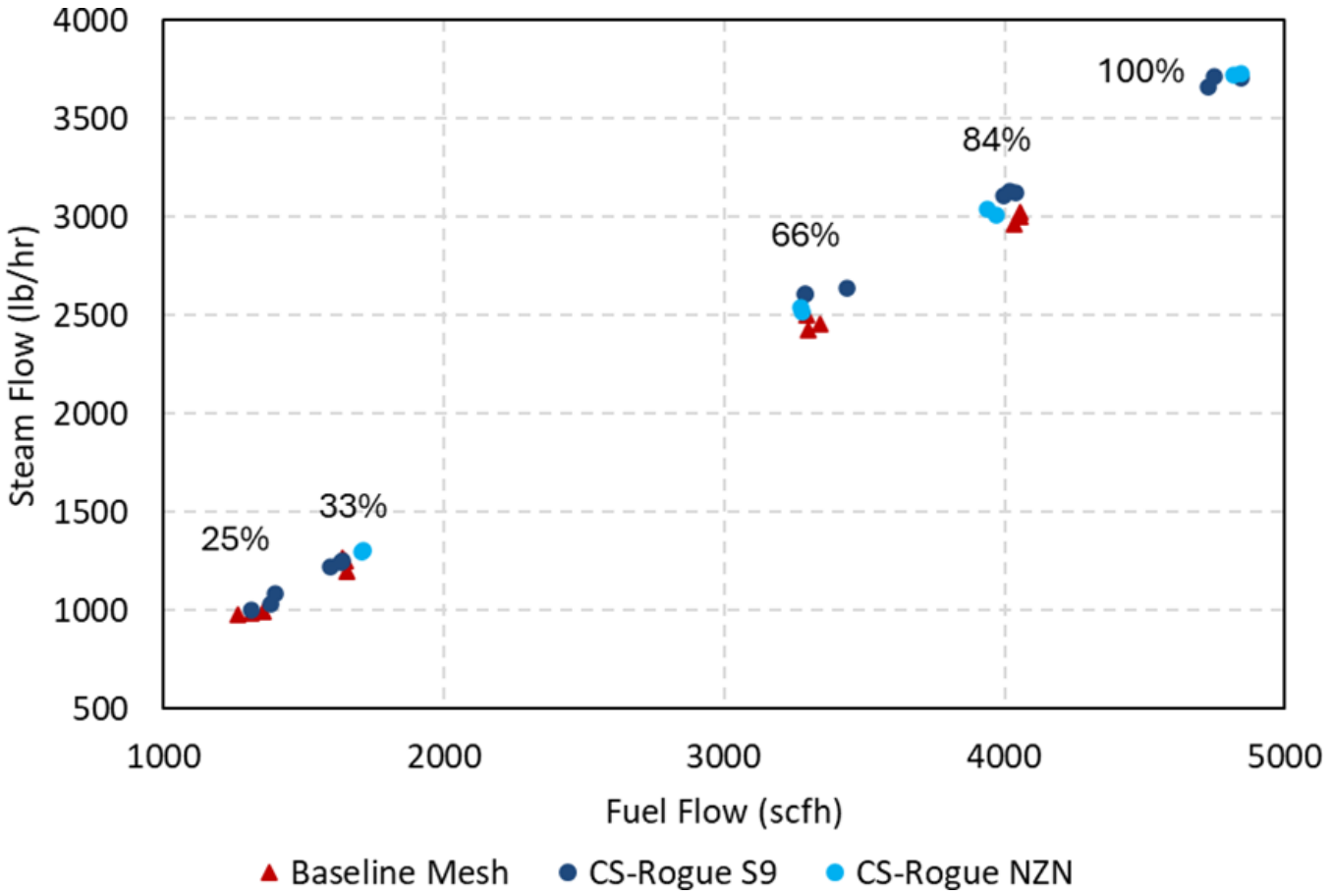
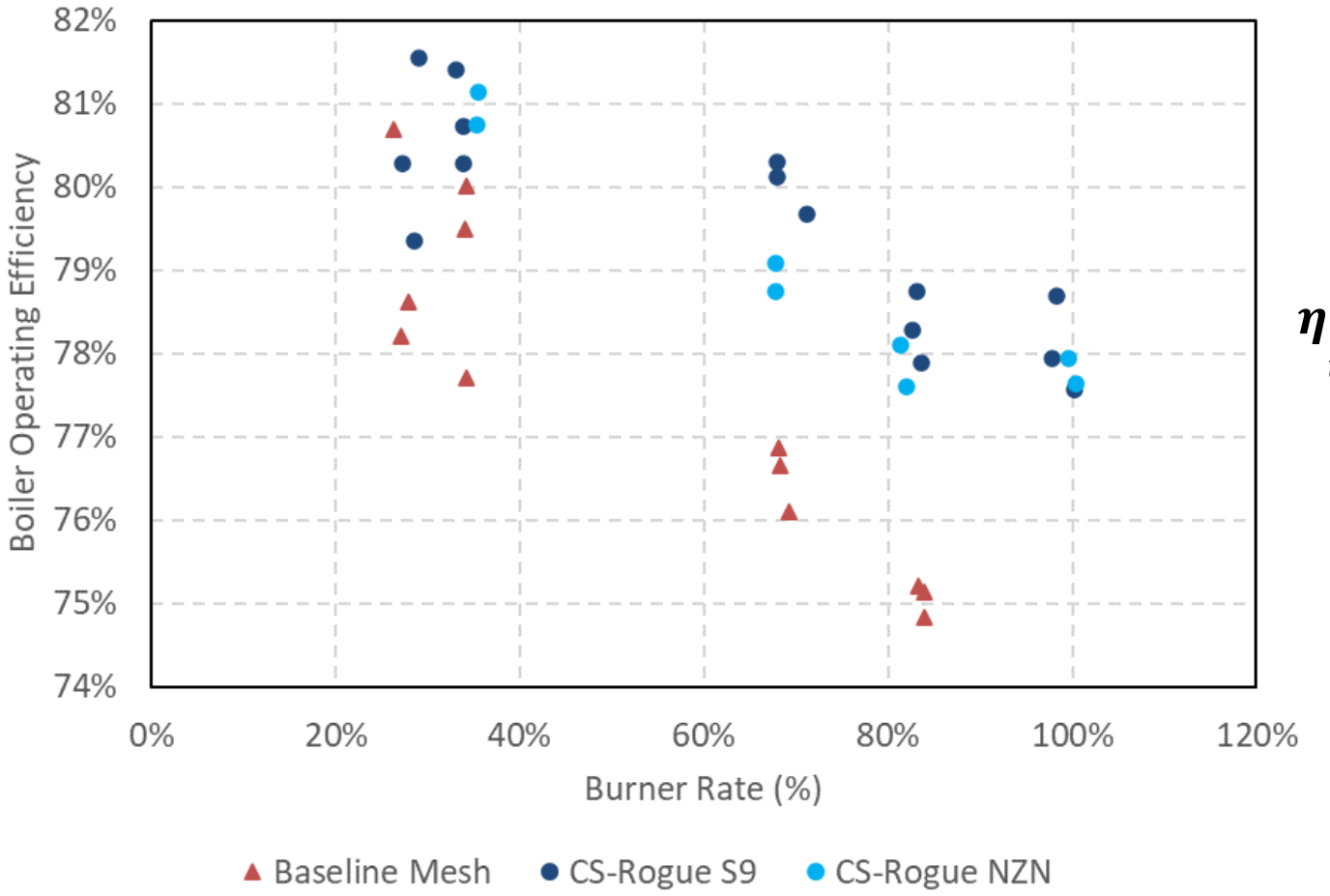


Figure 7. Steam Flow Rate Measured at Different Firing Rates

Results



$$\eta_{\substack{boiler \\ thermal}}(\%) = \frac{\dot{Q}_{out}}{\dot{Q}_{in}} \mathbf{X\ 100}$$

Figure 8. Boiler Operational Efficiency

Results

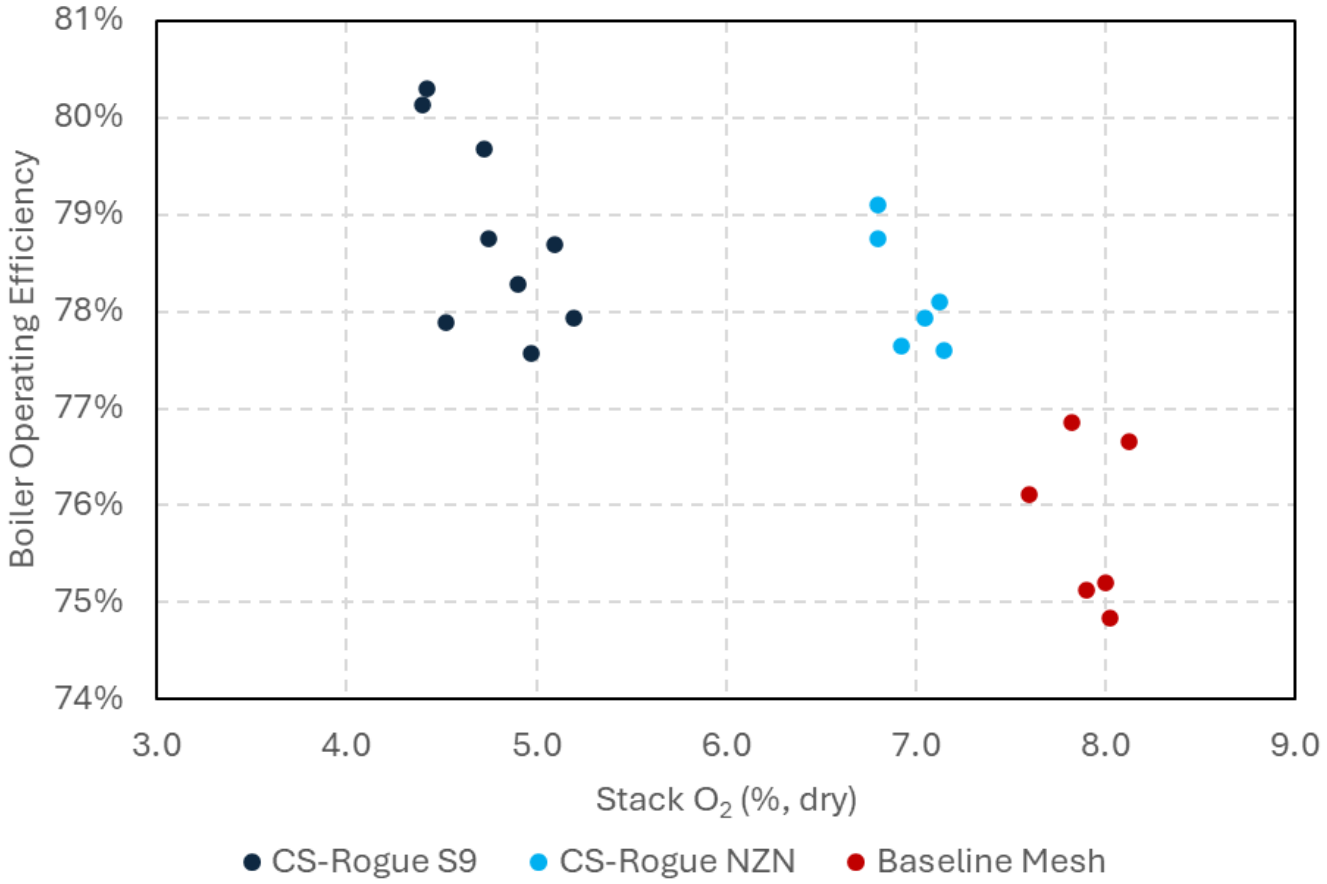


Figure 9. Boiler Operating Efficiency Dependence on Operating Oxygen

Results

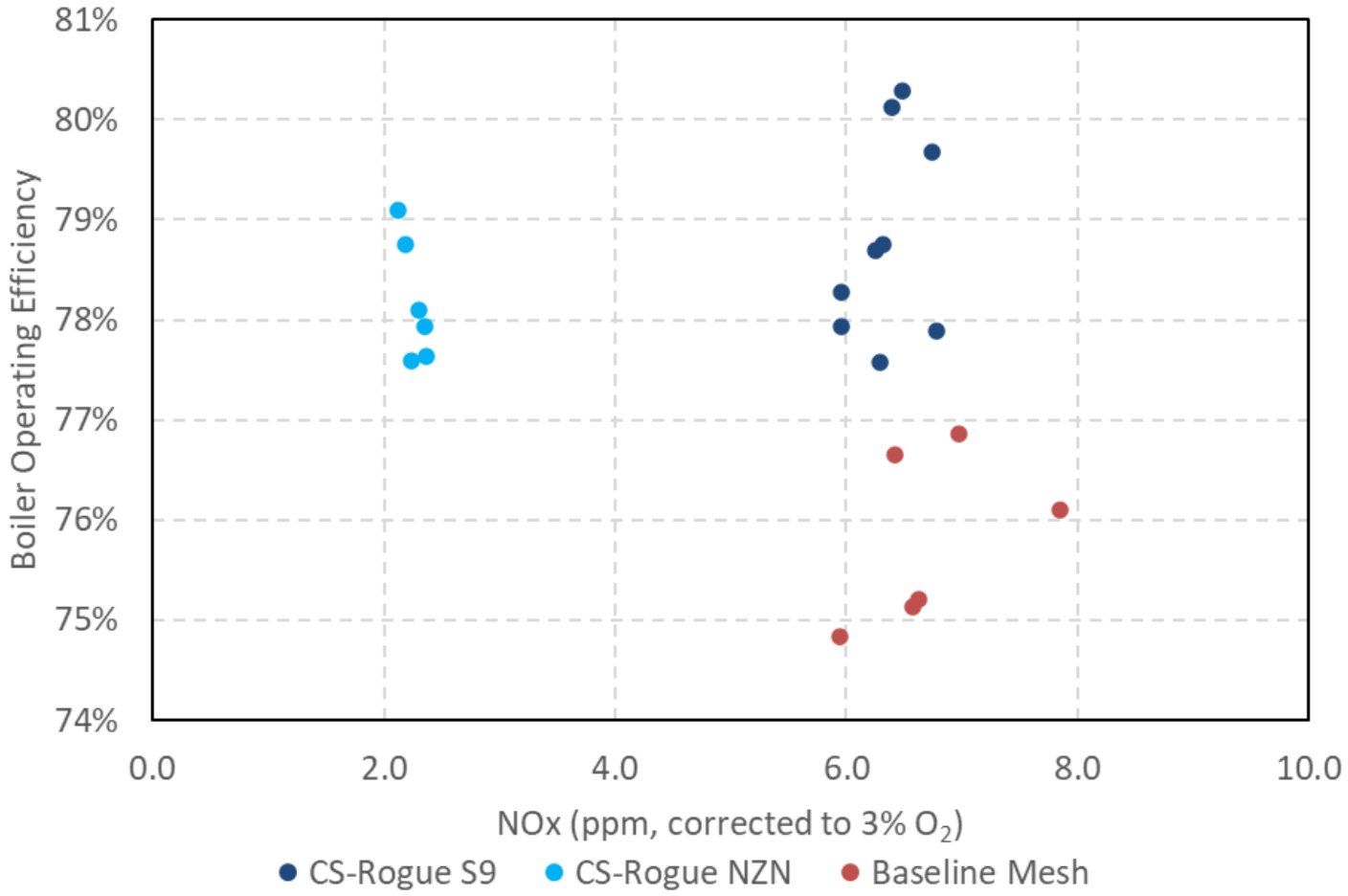


Figure 10. Boiler Operating Efficiency vs. NOx emissions

Results

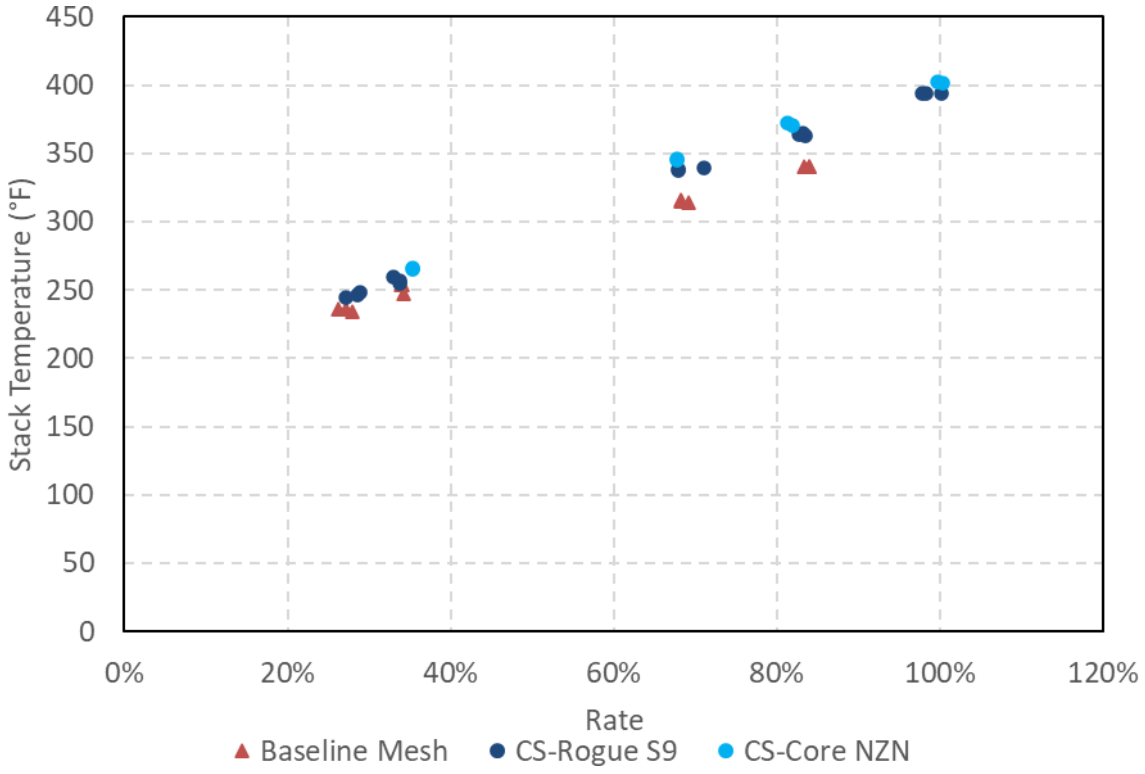


Figure 11. Stack Outlet Temperature

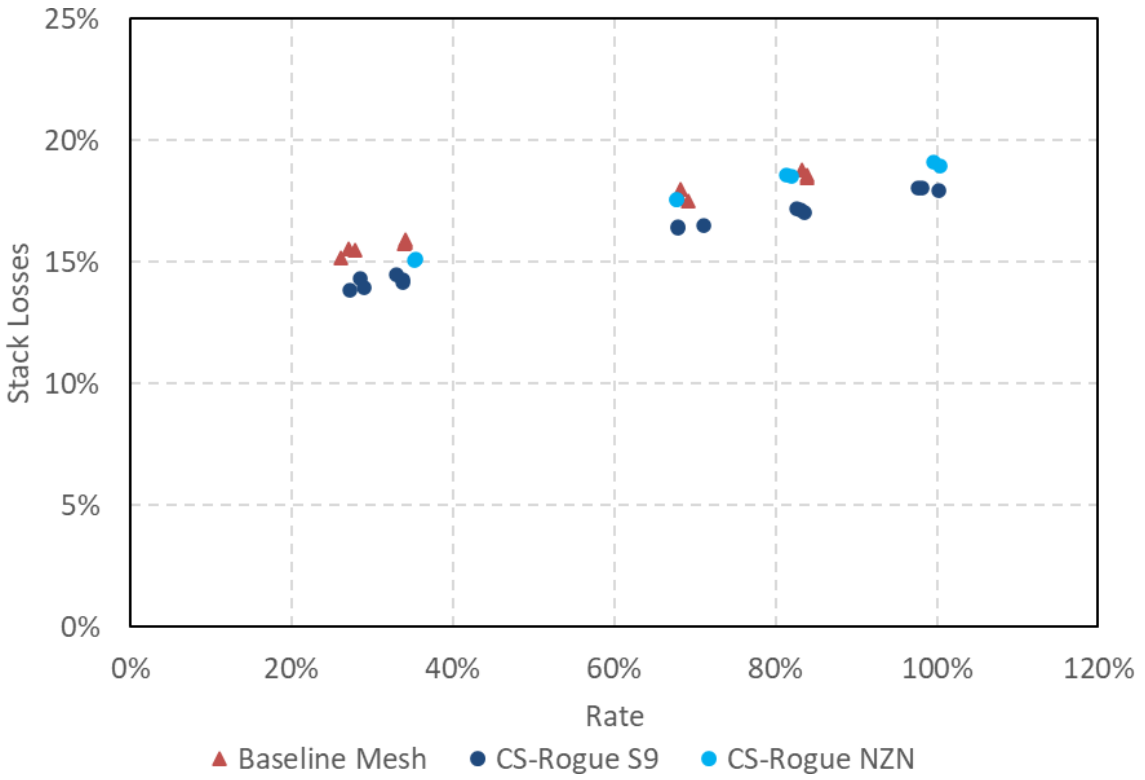


Figure 12. Stack Energy Losses (% of burner heat release)

Results

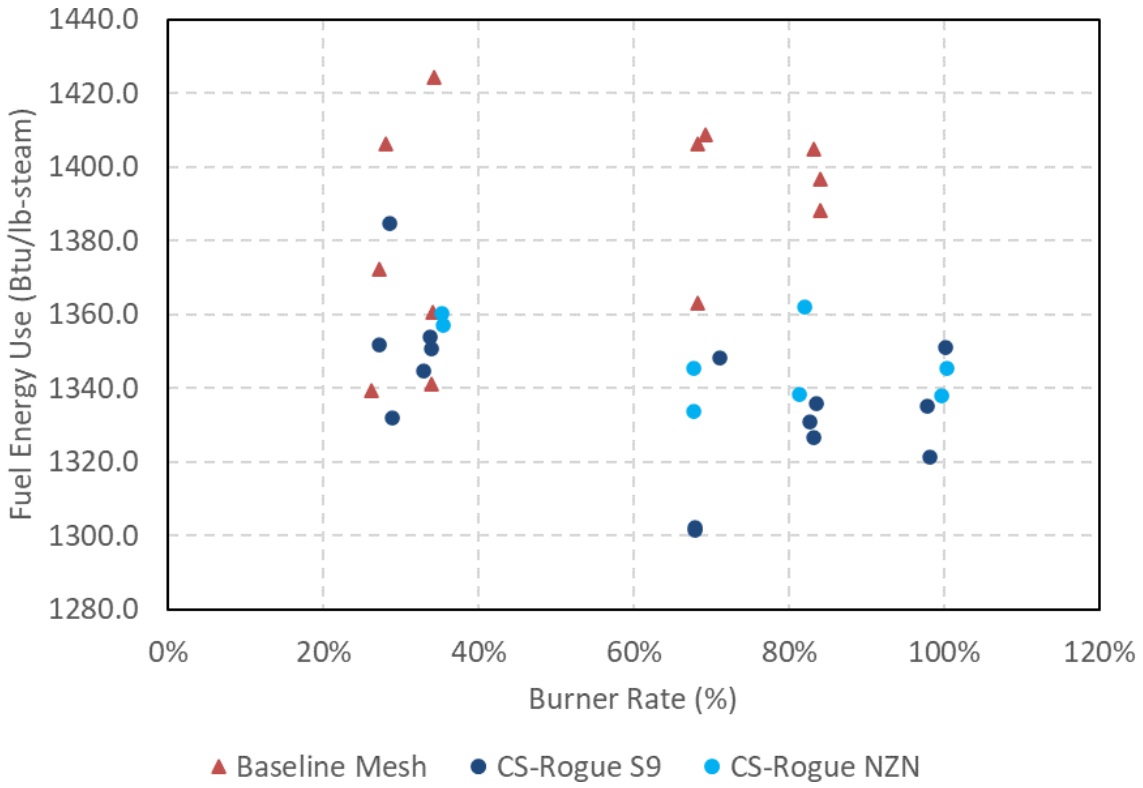


Figure 13. Fuel Energy Used per lb of Steam Produced

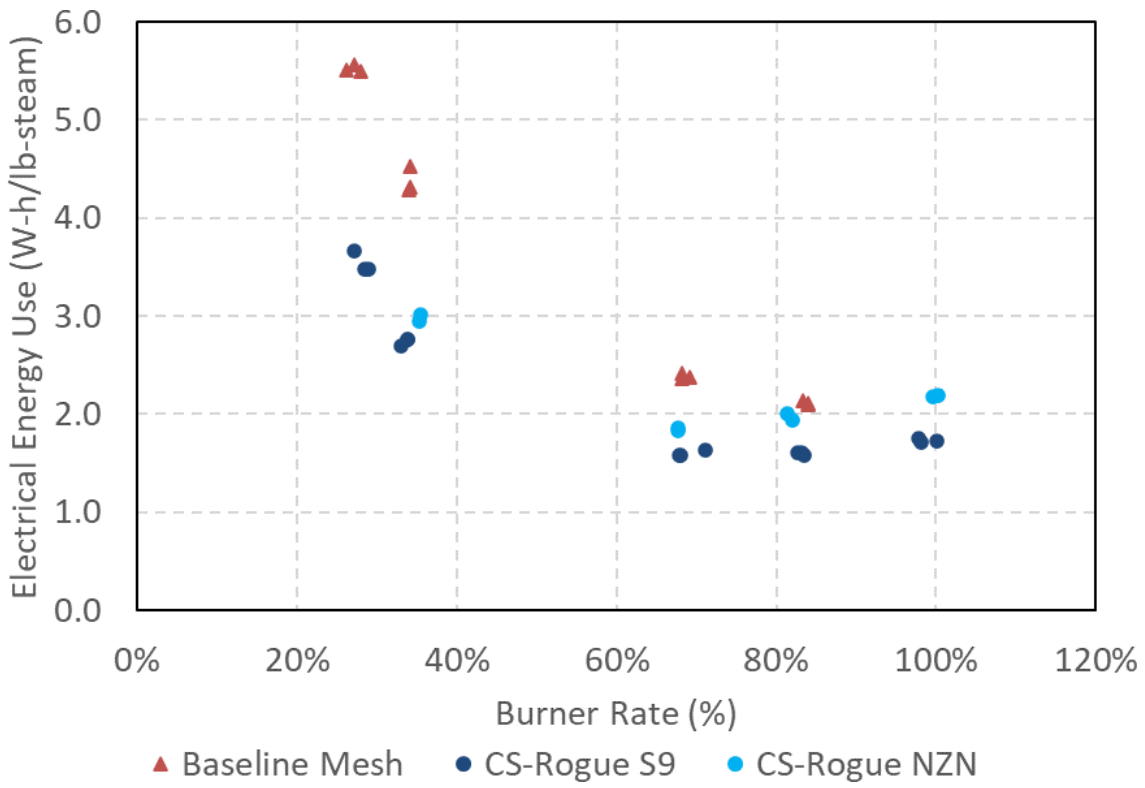


Figure 14. Electrical Energy Used per lb of Steam Produced

Results

Table 2. Fuel and Electrical Energy Used per lb of Steam Produced at 66% Firing Rate

Burner	Fuel Energy/lb-steam (Btu/lb-steam)	Savings (%)	Electrical Energy/lb-steam (W-h/lb-steam)	Savings (%)
Baseline Mesh	1392.65		2.38	
CS-Rogue S9	1317.23	5.4%	1.60	**33%**
CS-Rogue NZN	**1339.52**	**3.8%**	**1.85**	**25%**

Table 3. Fuel and Electrical Energy Used per lb of Steam Produced at 84% Firing Rate

Burner	Fuel Energy/lb-Steam (Btu/lb-steam)	Savings (%)	Electrical Energy/lb-steam (W-h/lb-steam)	Savings (%)
	Btu/lb-steam	%	W-h/lb-steam	**%**
Baseline Mesh	1396.69		2.11	
CS-Rogue S9	1330.98	4.7%	1.59	**25%**
CS-Rogue NZN	**1350.20**	**3.3%**	**1.98**	**7%**

Conclusion

- The ClearSign-Rogue burner demonstrated higher thermal efficiency, fuel savings, as well as electricity savings not only at comparable NOx levels as the baseline mesh burner but also when operating at sub-2.5 ppm NOx
- Savings in electricity ranged from 7% at sub-2.5 ppm NOx to 25% at sub-9 ppm NOx compared to the baseline mesh burner

Recommendations

- No-cost techno-economic analysis (TEA) for existing operations to provide capital funding justification
- Demonstrate operation on Hydrogen fuel with near-zero NOx
  - Up to 30% natural gas replaced with H2
  - 100% H2

This project was conducted through the ICF implemented, SoCalGas administered California Statewide Gas Emerging Technologies Program.

The project report can be found on cagastech.com

For more information, contact get@caenergyprograms.com

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