California Statewide Gas Emerging Technologies

Final Presentation: ET23SWG0009

Ultra-Low NOx Burner Field Testing

Venky Iyer, PhD.
Troy Edens
Anoushka Cholakath

05/21/2025

Agenda

- Project Objectives
- Test Set-Up and Approach
- Phase I and II Testing
- Results
- Conclusion
- Recommendation

Project Team

Anoushka Cholakath -ICF
Project Manager

Venky Iyer – ClearSign
Engineering Manager

Steven Long -ICF
Project Oversight

Troy Edens- Rogue
Combustion
Director

Project Objectives

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

Industry Standard ULNB - Mesh Burner

Emerging Technology

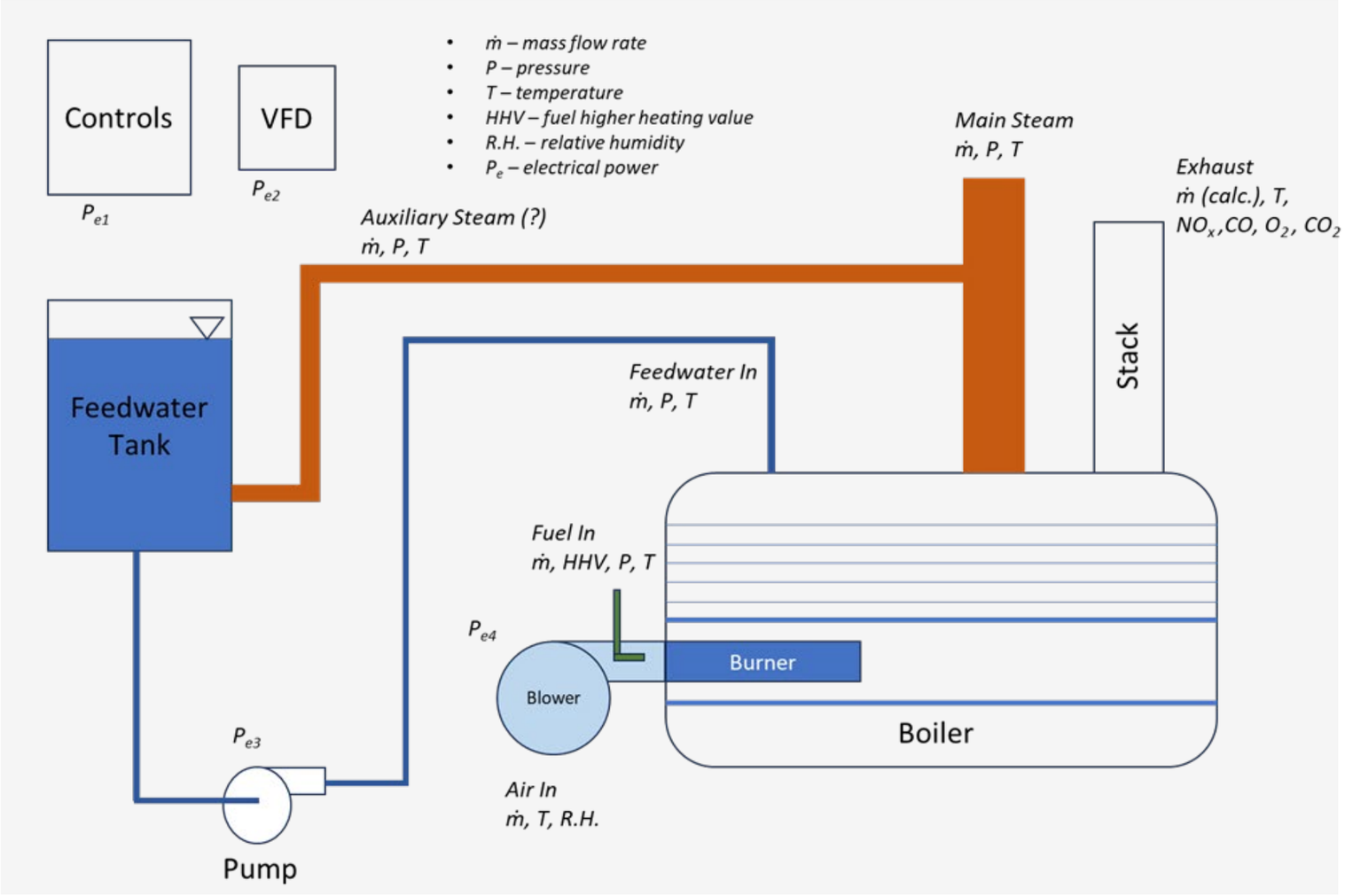
Rogue NZN Burner with ClearSign Core Technology

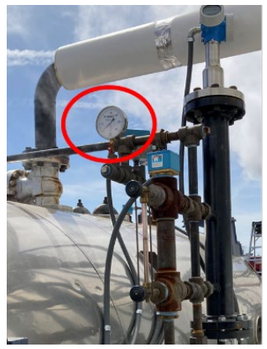
Test Set-Up and Approach

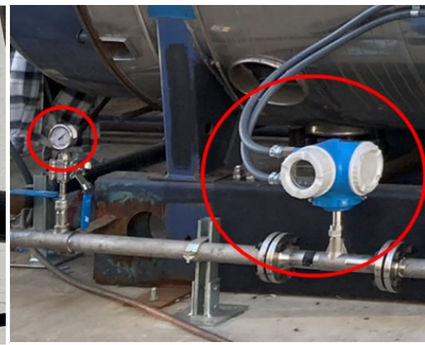
Boiler System Set-up

*Note that condensate is not recycled, 100% makeup water is used

Test Approach





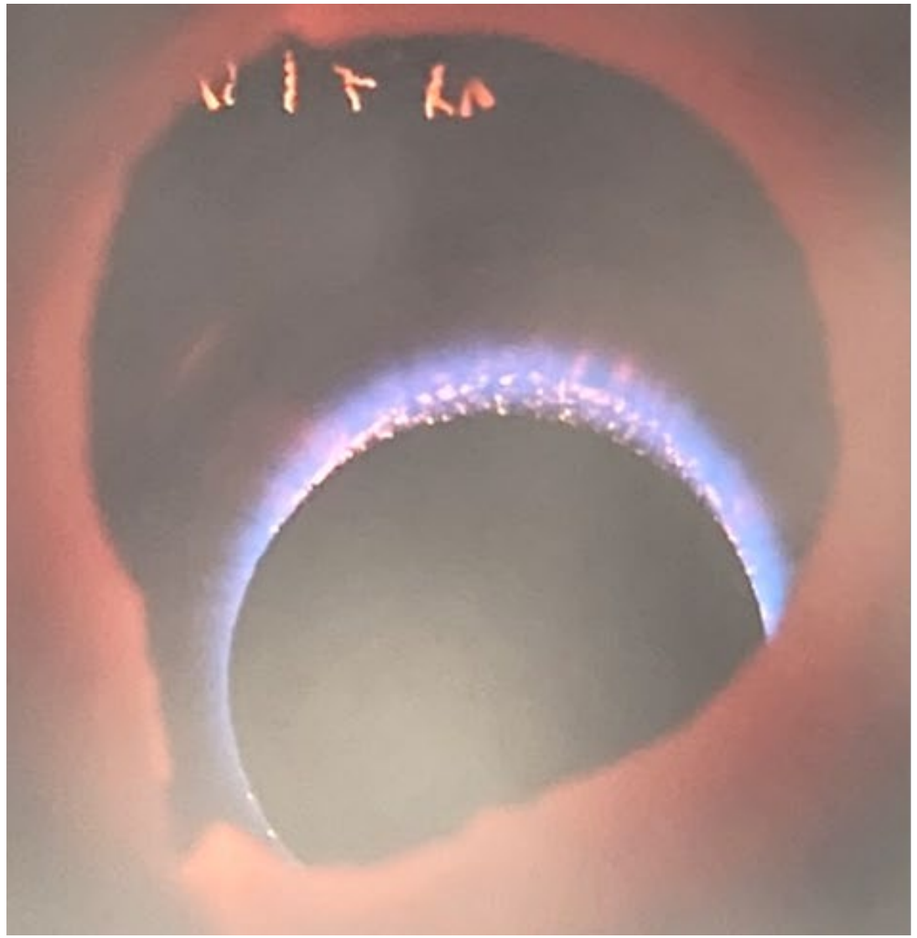


Test Conditions

	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

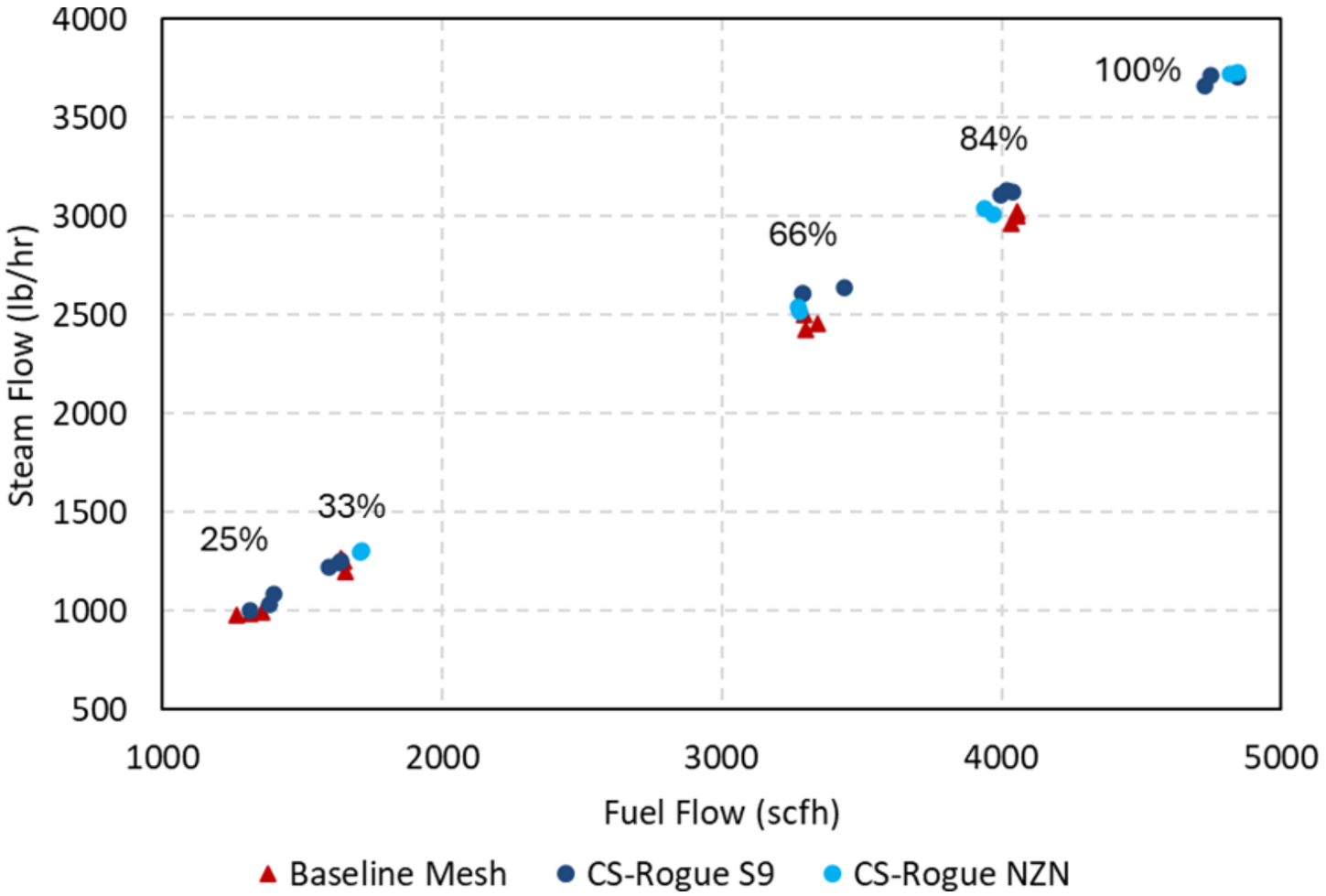
Industry Standard ULNB
– Mesh Burner



Rogue NZN Burner with ClearSign
Core Technology

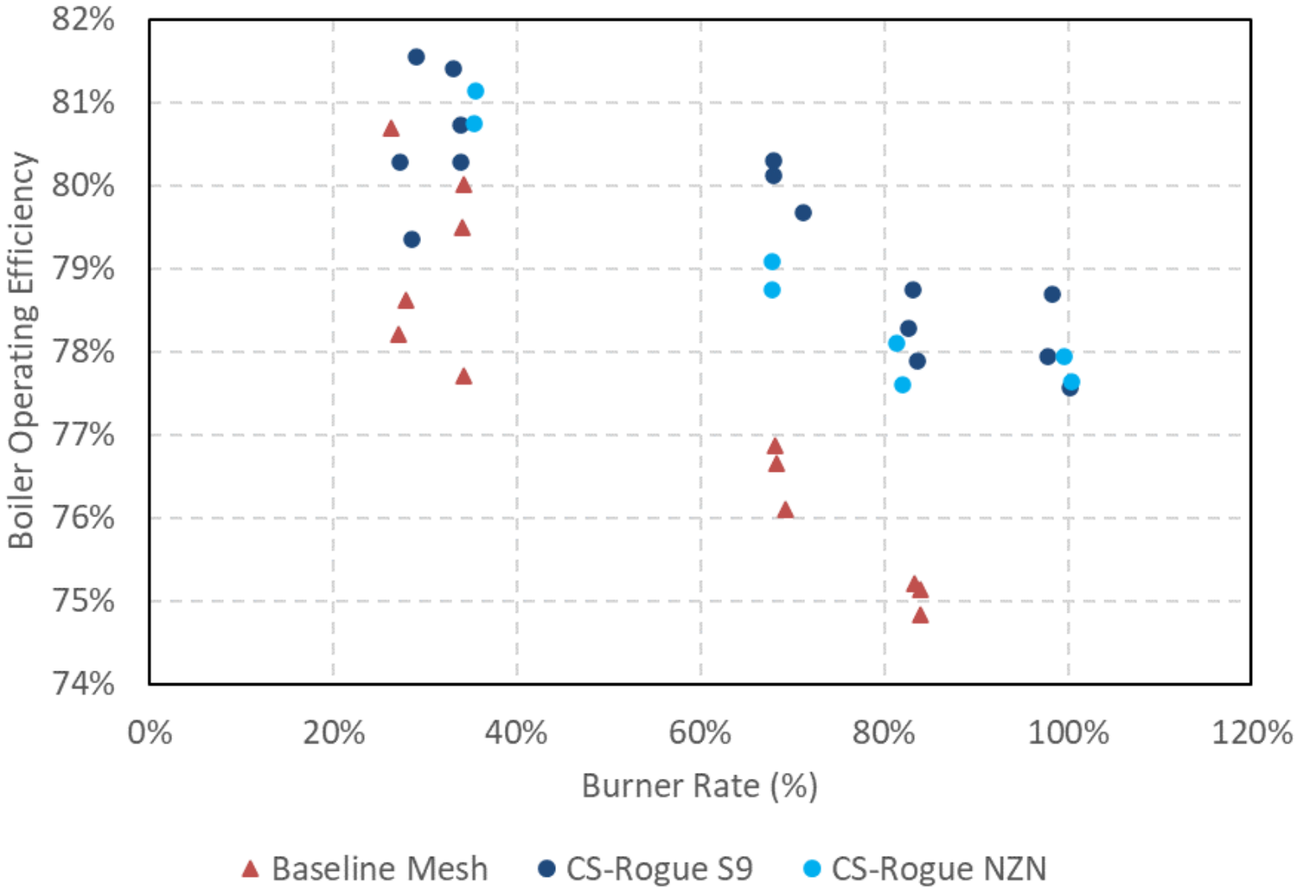
Results

Steam Produced



Higher rates of steam produced for Rogue-ClearSign burner compared to Baseline

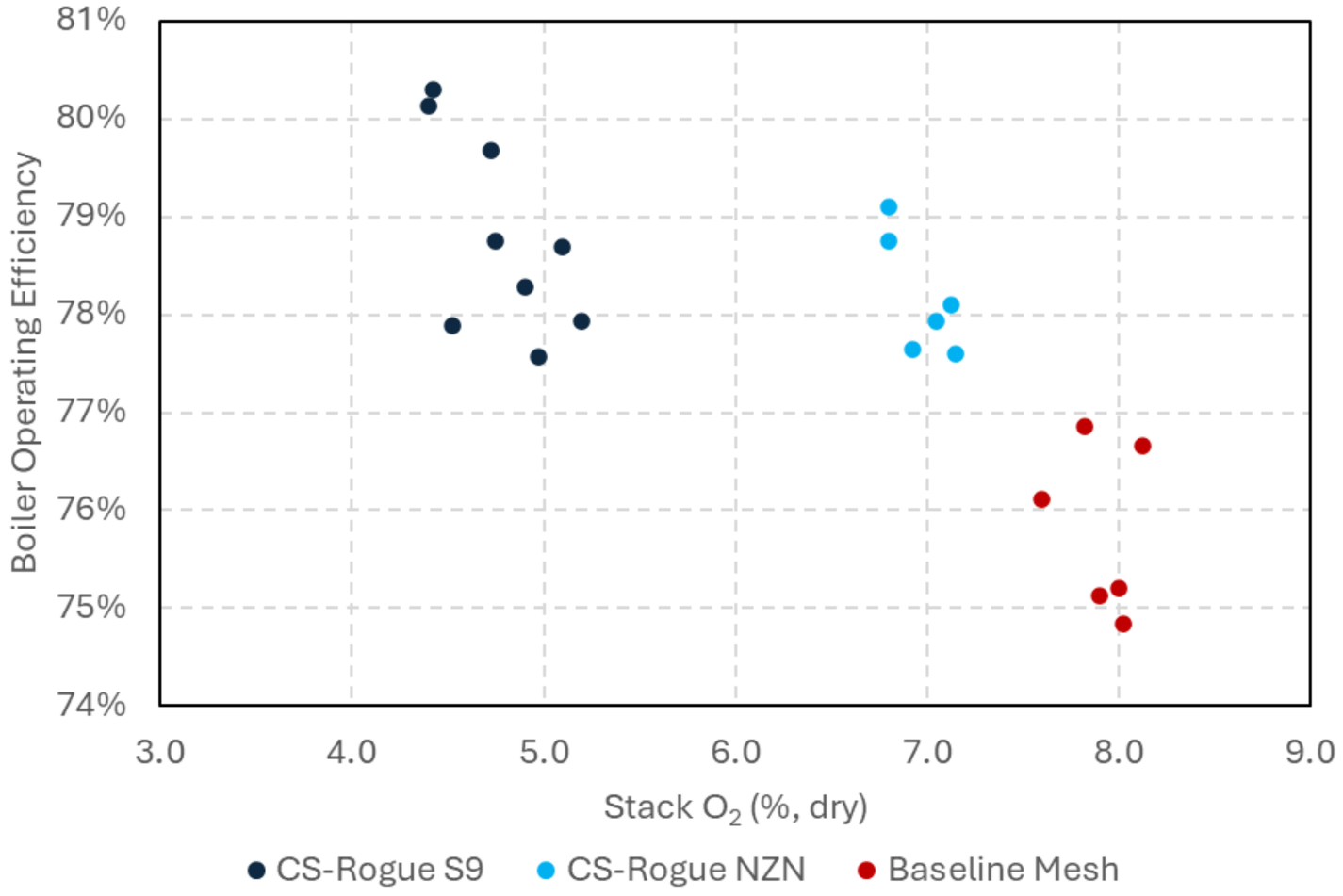
Boiler Operational Efficiency



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

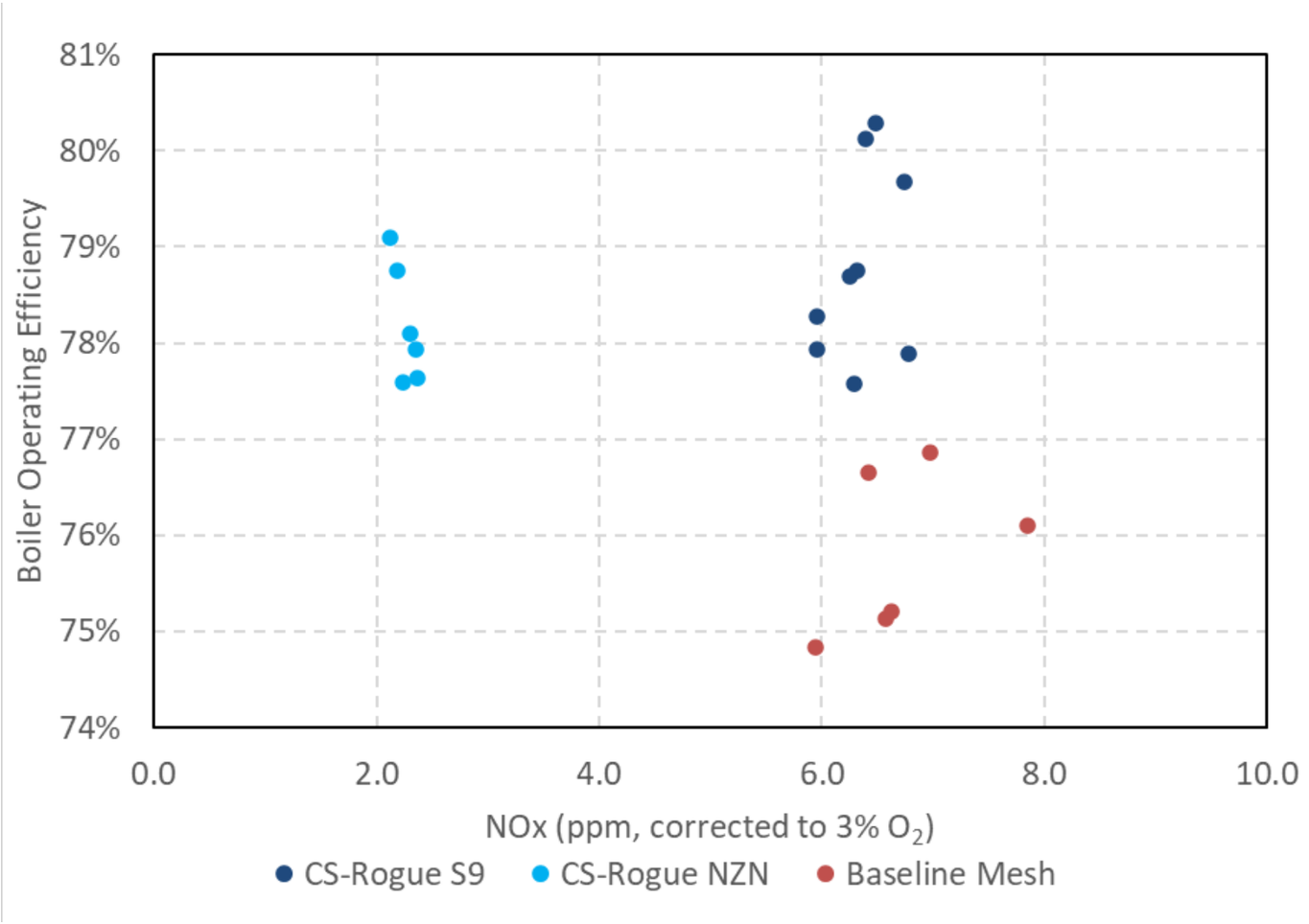
Highest thermal efficiency for Rogue-ClearSign S9 followed by NZN

Boiler Operating Efficiency vs Operating O_2



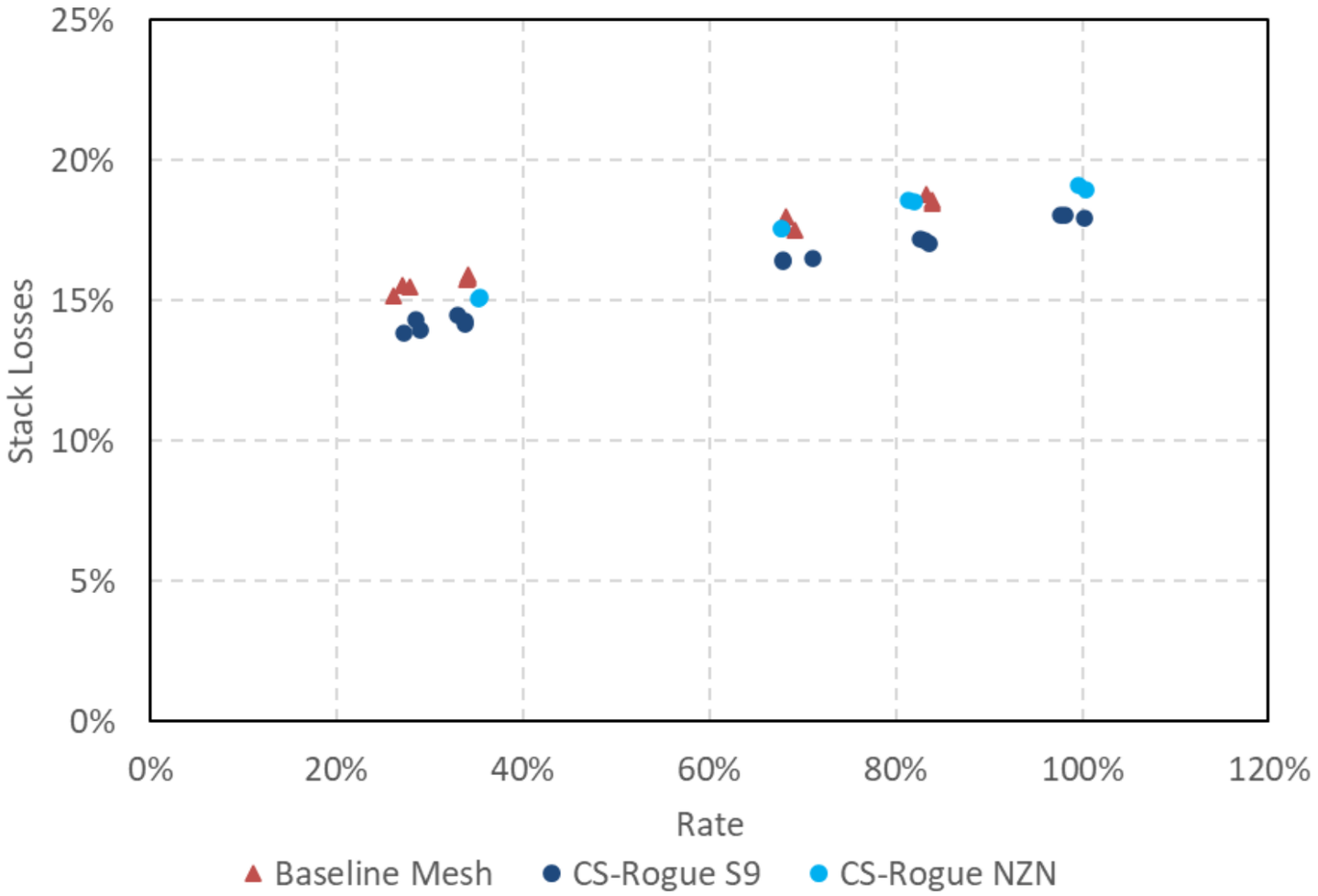
Efficiency increases at lower operating O_2 levels

Boiler Operating Efficiency vs NOx Emissions



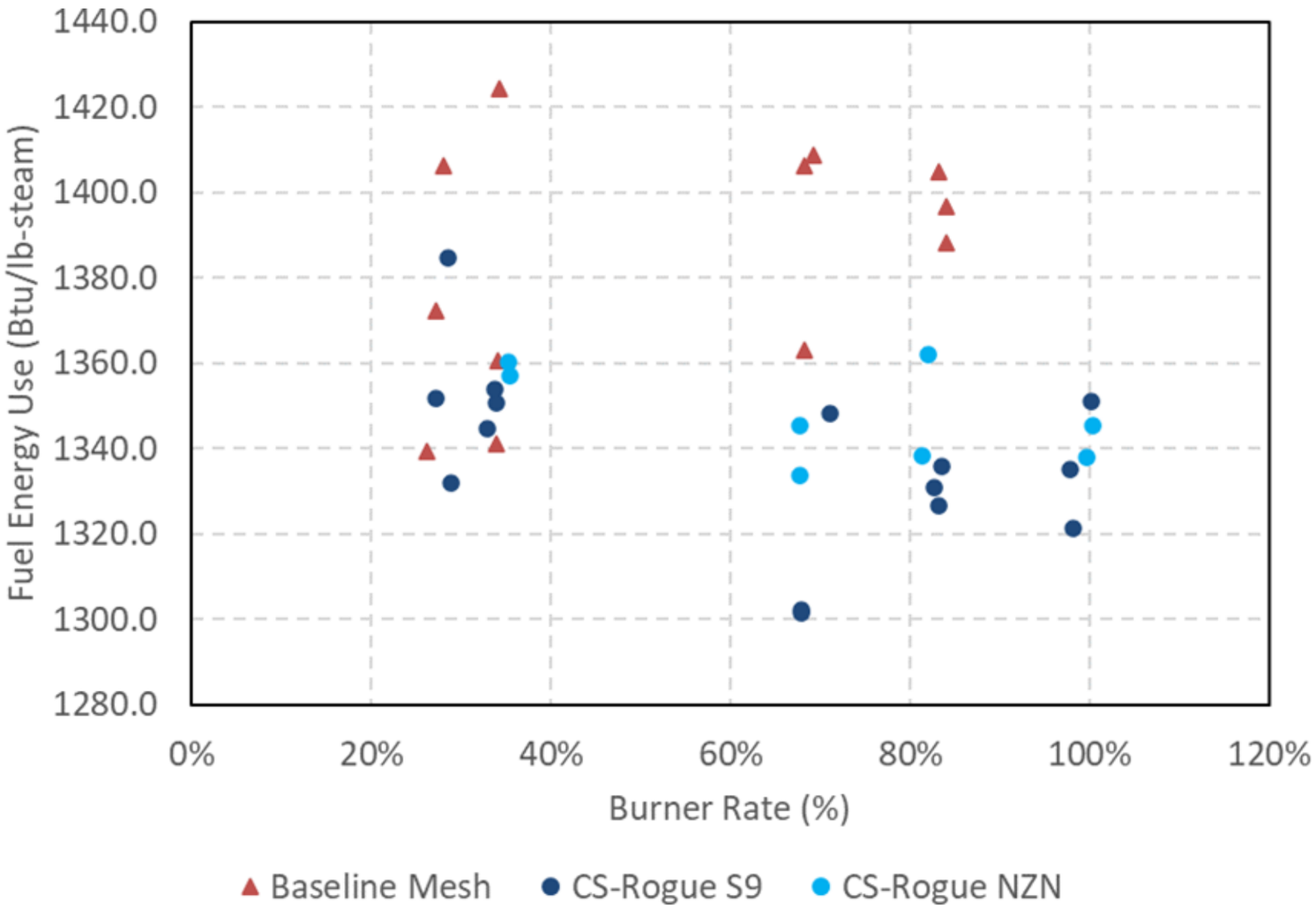
Rogue-ClearSign Burner provides higher efficiency with SCR-level NOx

Stack Energy Losses



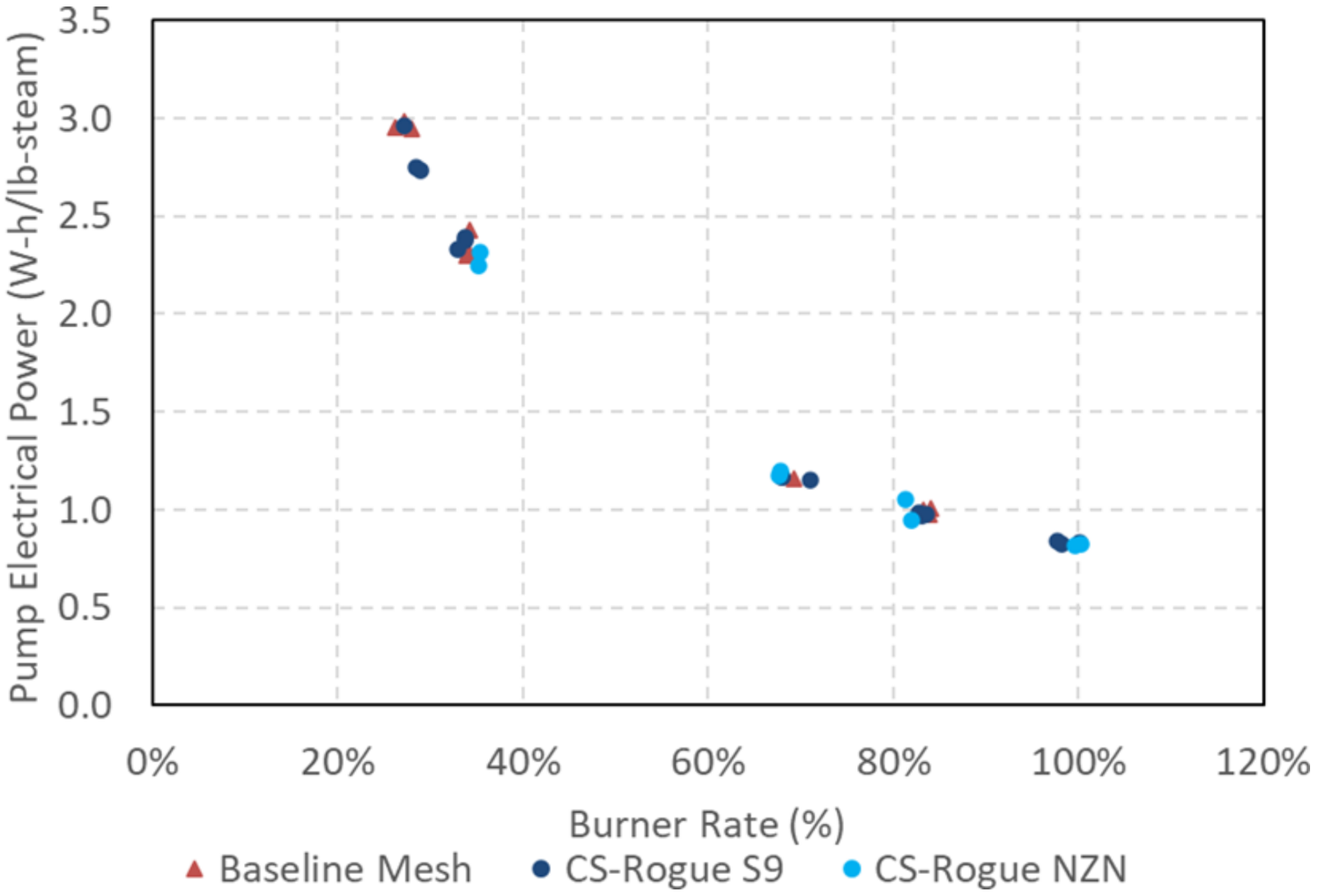
Lowest stack energy losses for Rogue-ClearSign S9 case

Fuel Energy Use



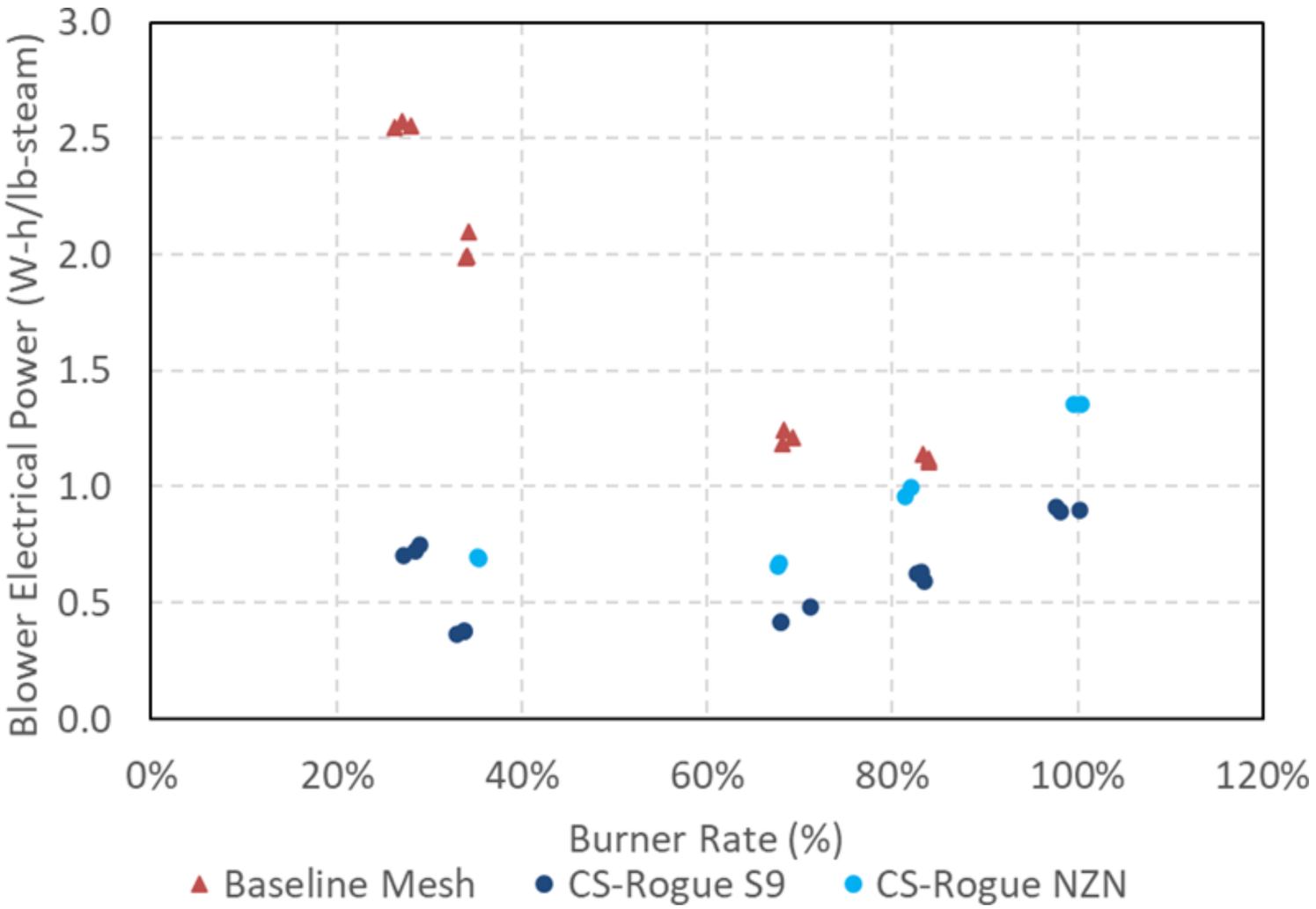
Rogue–ClearSign Burner provides savings in fuel use

Feedwater Pump Electrical Energy Use



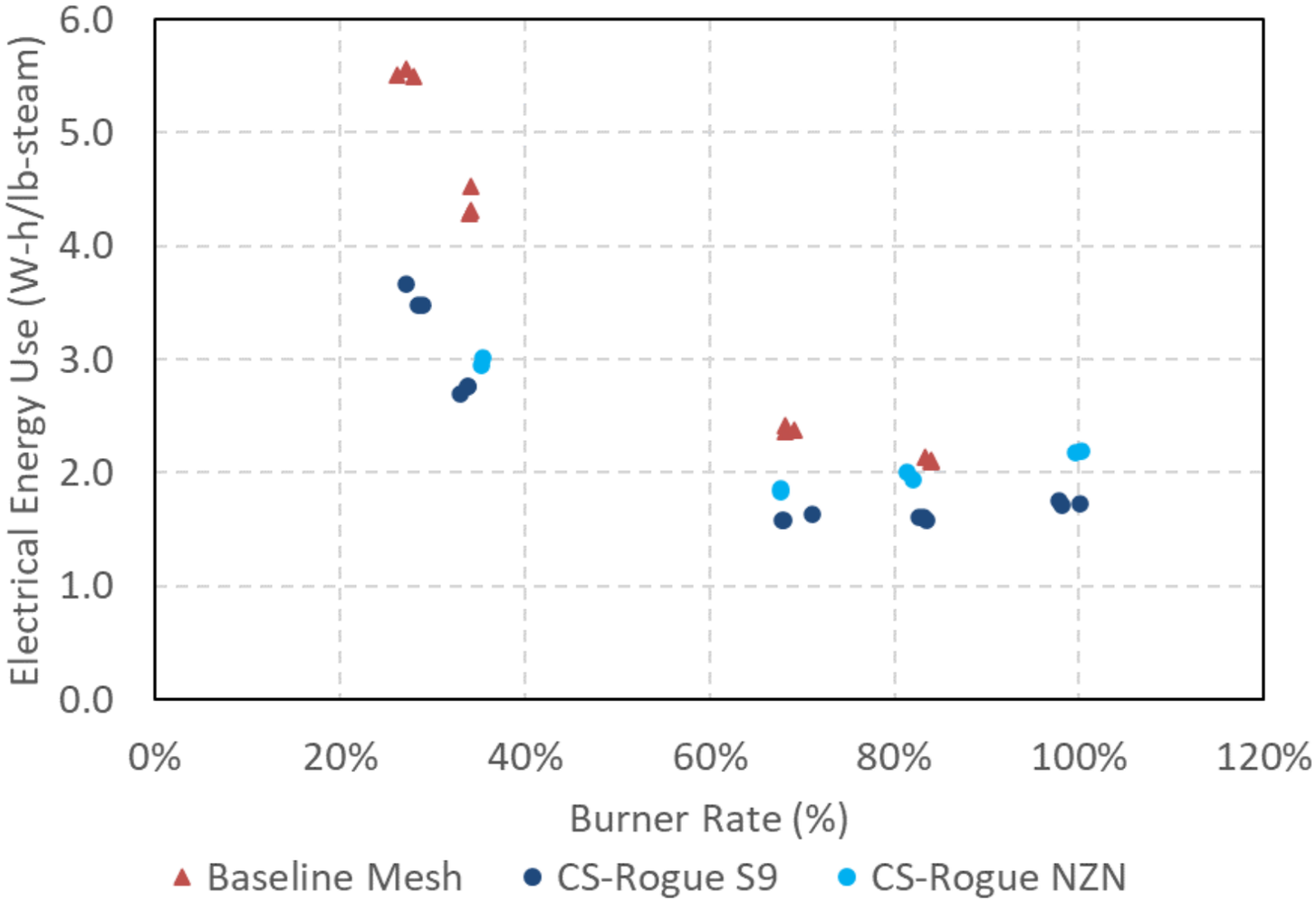
Similar electrical energy use for feedwater pump across all cases

Blower Electrical Energy Use



Lower Blower Electrical usage due to lower excess air operation and use of VFD

Electrical Energy Use



Savings in Electrical Power due to lower excess air operation and use of VFD

Fuel & Energy Savings

Fuel & Electrical Energy Used per lb of Steam Produced:

Burner	Fuel Energy /lb-steam	Savings Against Baseline	Electrical Energy /lb-steam	Savings Against Baseline
	Btu/lb-steam	*%*	*W-h/lb-steam*	**%**
At 66% Firing Rate				
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%**
At 84% Firing Rate				
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%

Up to 5.4% Savings in Fuel and 33% Electricity with Rogue-ClearSign Burner

Burner Advantages

- Up to 5.4% Fuel Savings when operating at same level of NOx as industry standard burner
- Nearly 4% Fuel Savings in Near-zero NOx mode
- Unmatched NOx performance of sub-2.5 ppm (corrected to 3% O_2)
- Up to 33% Electricity Savings compared to industry standard burner

Conclusion

Conclusion

- The ClearSign-Rogue burner demonstrated higher boiler operating 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.
- The ClearSign-Rogue burner in S9 mode had the least stack losses as it operated at the lowest excess air or O2 levels The fuel savings ranged from 3.3% when the ClearSign-Rogue burner was operating at sub-2.5 ppm NOx to 4.7% at sub-9 ppm NOx at high fire.
- 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

Recommendation

Recommendations

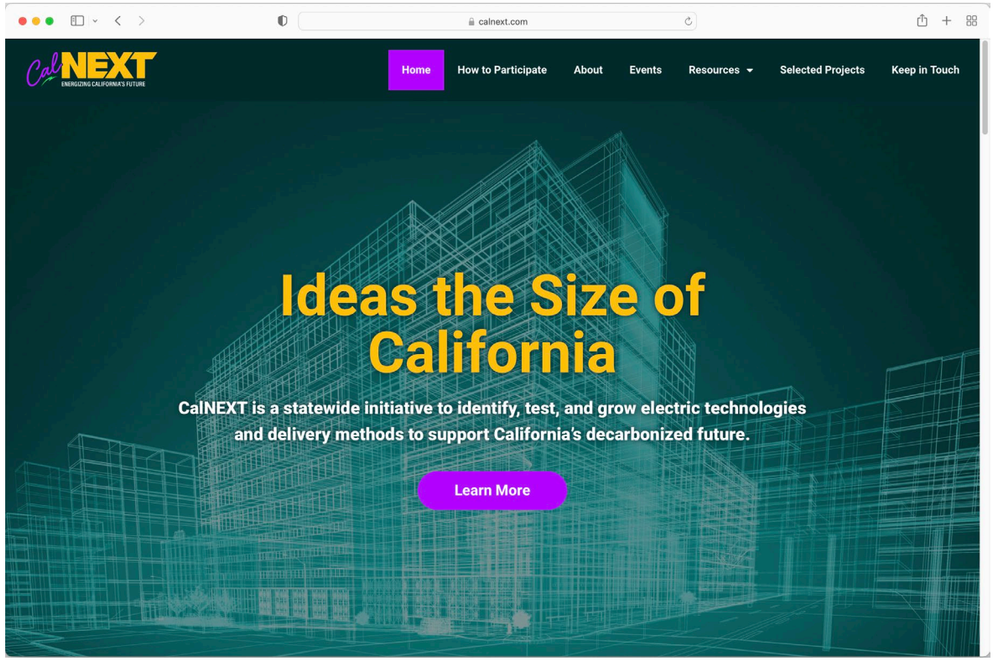
- No-cost techno-economic analysis (TEA) for existing operations to provide capital funding justification
- Demonstrate operation on Hydrogen fuel with near-zero NOx
    - Up to 30% natural gas replaced with H2
    - 100% H2

Thank you

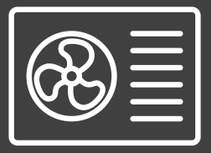
CalNEXT

CalNEXT's vision is to identify emerging electric technologies across six priority areas and bring them to the IOU energy efficiency programs portfolio.

To learn more and sign up for our email list, please visit **calnext.com**

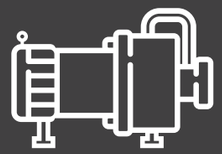


Appliances & Plug Loads



HVAC

Lighting



Process Loads

Water Heating

Whole Buildings

Get in touch with us:

Ava Donald

Program Manager
Ava.Donald@icf.com

Follow GET on LinkedIn: linkedin.com/cagastech

Visit: cagastech.com

icf.com

linkedin.com/company/icf-international/

twitter.com/icf

https://www.facebook.com/ThisIsICF/

About ICF

ICF (NASDAQ:ICFI) is a global consulting and digital services company with over 7,000 full- and part-time employees, but we are not your typical consultants. At ICF, business analysts and policy specialists work together with digital strategists, data scientists and creatives. We combine unmatched industry expertise with cutting-edge engagement capabilities to help organizations solve their most complex challenges. Since 1969, public and private sector clients have worked with ICF to navigate change and shape the future.