Air Products Technology for Glass Melting

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AIR PRODUCTS

Cleanfire® Burner Installations

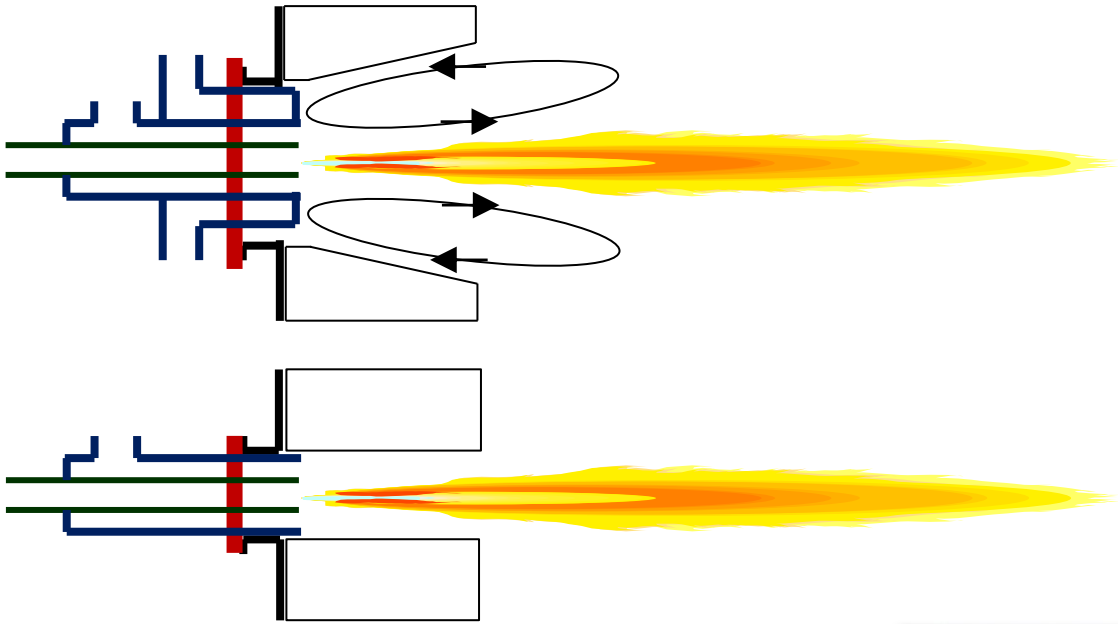
- All Burners Globally
  - Over 300 Furnaces
  - More than 2000 Burners

- HRi Natural Gas Burners
  - Over 125 Furnaces
  - More than 1000 Burners
- HRx Natural Gas Burners
  - 4 Furnaces
  - 43 Burners

Cleanfire® Burner Development History

- **Gen1™ Burner – 1991** → **1st Zero Maintenance, non Water-cooled Oxy-Fuel Burner**
  - Gen1™ Dual-Fuel Burner – 1993
- **HR™ Gas Burner – 1994** → **1st Flat-Flame Oxy-Fuel Burner with O_2 Staging**
  - AOF™ Burner – 1999
  - HR™ Oil Burner – 2000
- **HR*i*™ Gas Burner – 2004** → **Higher Radiation, Lower NOx Flat Flame Burner**
  - HR*i*™ Oil Burner – 2010
  - HR*e*™ Burner - 2015
- **HRχ™ Burner – 2017** → **Flat Flame with Below and Above Flame Staging for Maximum Radiation and Foam Control**

GEN I Burners
15% Fuel Savings vs Air
No Staging Capability



<u>Incumbent Design</u>:
Particulate from Furnace Recycled back to Burner Nozzle due to Divergent Precombustor

<u>Gen1 Innovation</u>:
Parallel Precombustor Eliminates Recycle and Need for Water Cooling

- Burners Sizes Available from 0.25 – 20 MMBtu/hr

AIR PRODUCTS

HR™ Burners: Flat Flame with O_2 Staging

- Benefits of Flat Flame
  - Greater Flame Area Facing Glass
  - Greater Flame Radiation to Glass
- Benefits of (Under-Flame) Staging
  - Creates Fuel-Rich Region of Flame Enabling Soot Production, Leading to Luminous Flame
  - Provides Ability to Control Flame Length and Momentum at Fixed Firing Rate
  - Lowers NOx Emissions
- Burner Sizes Available from 0.75 to 20 MM BTU/hr

Effect of Staging

Minimal staging

Maximized staging

Fuel Savings: GEN I vs HR

A Direct Comparison of Oxy-Fuel Burner Technology

John H. Tyler and James F. Booth
Techneglas, Inc.
Columbus, OH

Robert D. Marchiando and Kevin A. Lievre
Air Products and Chemicals, Inc.
Allentown, PA

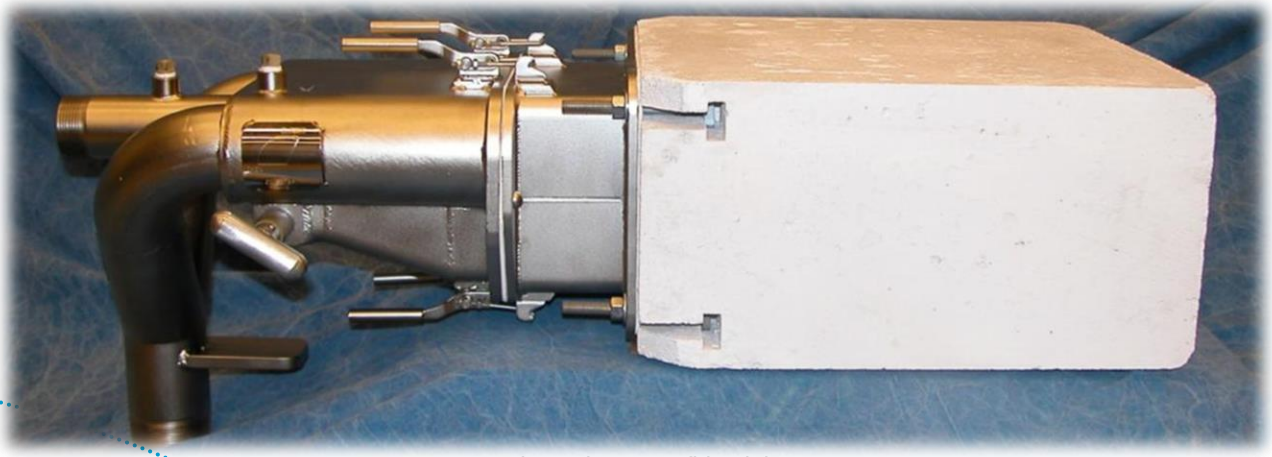
- Techneglas TV Funnel Furnace
- Columbus, Ohio
- On the fly conversion from GEN I to HR Burners
  - -9.2% improvement in MM BTU/T
  - -5% Reduction in Fuel Usage
  - -13 T/D increase in Furnace Pull

Shortcoming of HR Burner

- Staging Limited to ~ 50% of Incoming Oxygen Flow Rate in order to prevent burner block overheating and Carbon Grown on Nozzle Tip

Innovation of HR*i* Burner

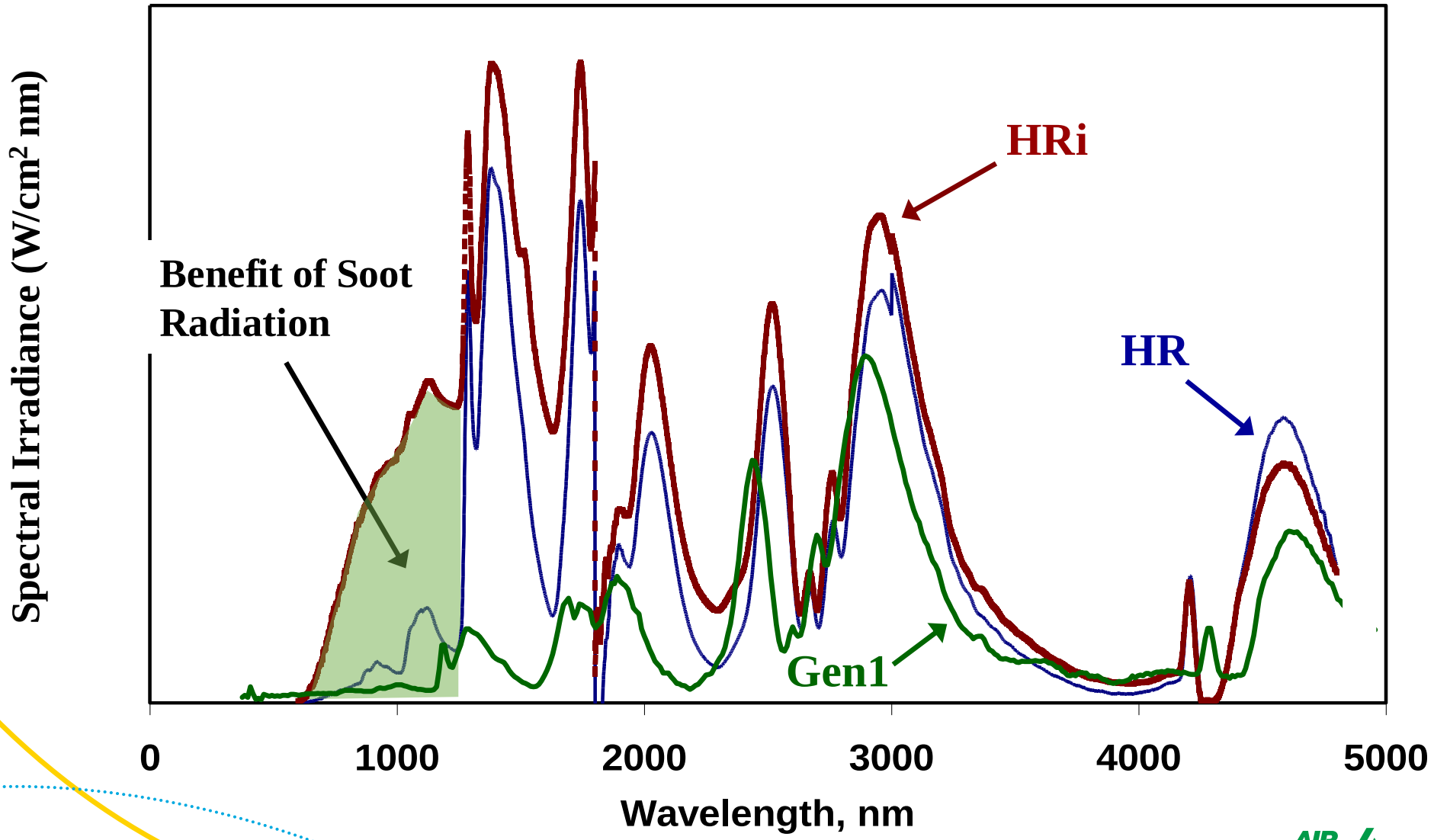
- Advancements in Nozzle Design Enable up to 70% Oxygen Staging without Burner Block Overheating or Carbon Buildup
- Leads to Higher Flame Radiation, Lower NOx Emissions and Greater Degree of Flame Length / Momentum Control



Fuel Savings
HR*i* vs HR Burner

- Techneglas TV Panel Furnace
- Pittston, Pennsylvania
- On the fly conversion from HR to HRi Burners
  - 3% Reduction in Fuel Usage
  - Fuel savings abandoned for Glass Quality Improvements

Flame Radiation Comparison



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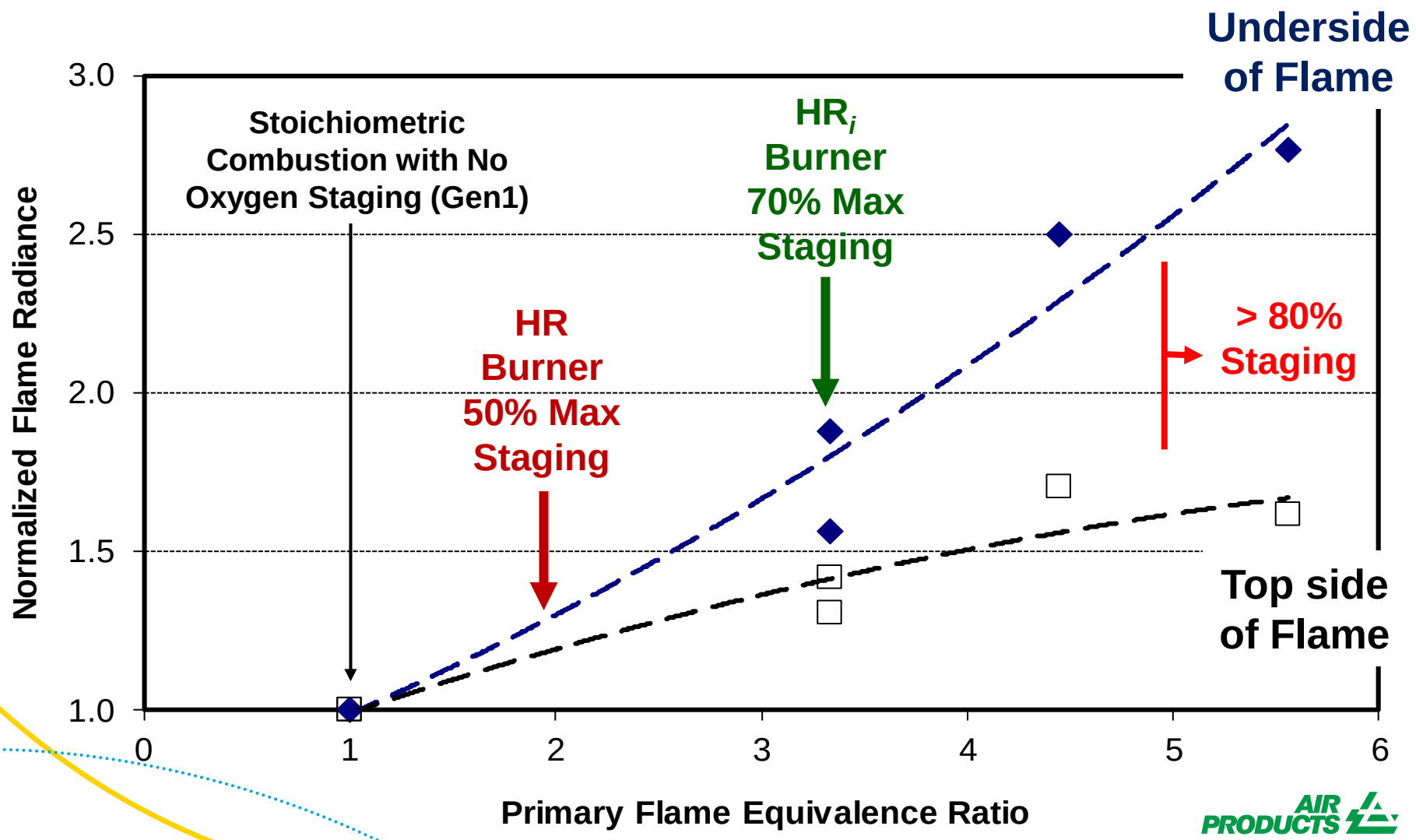
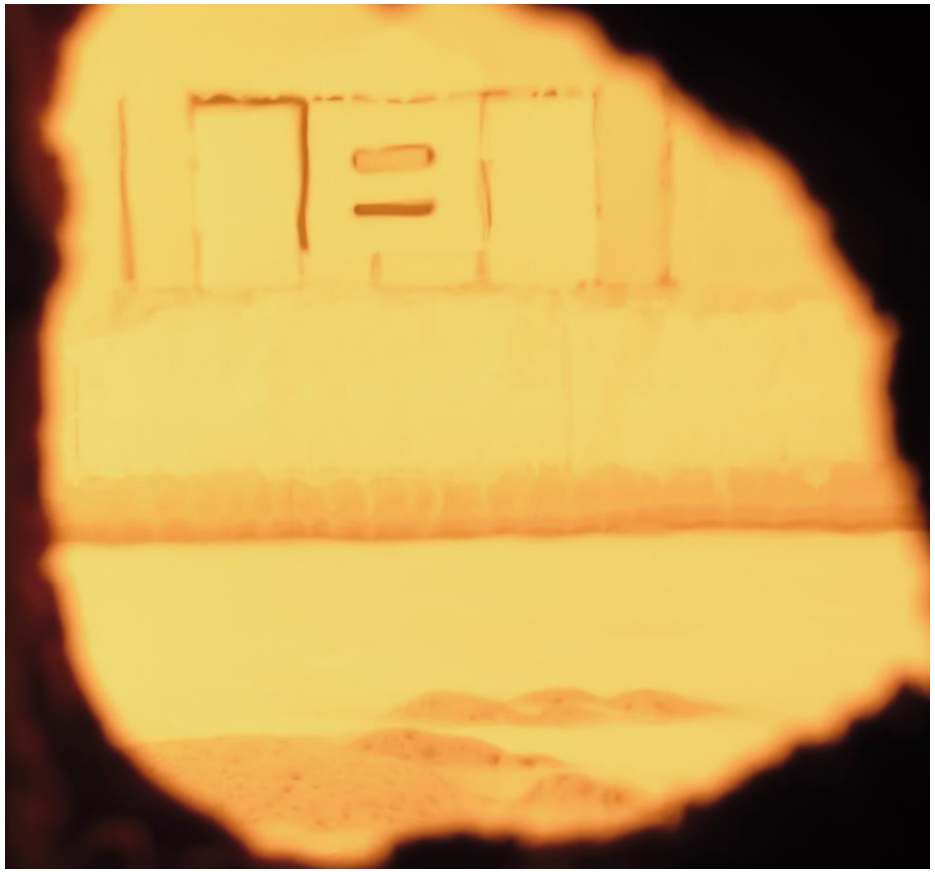
Path to HRx
Searching for Greater Flame Radiation

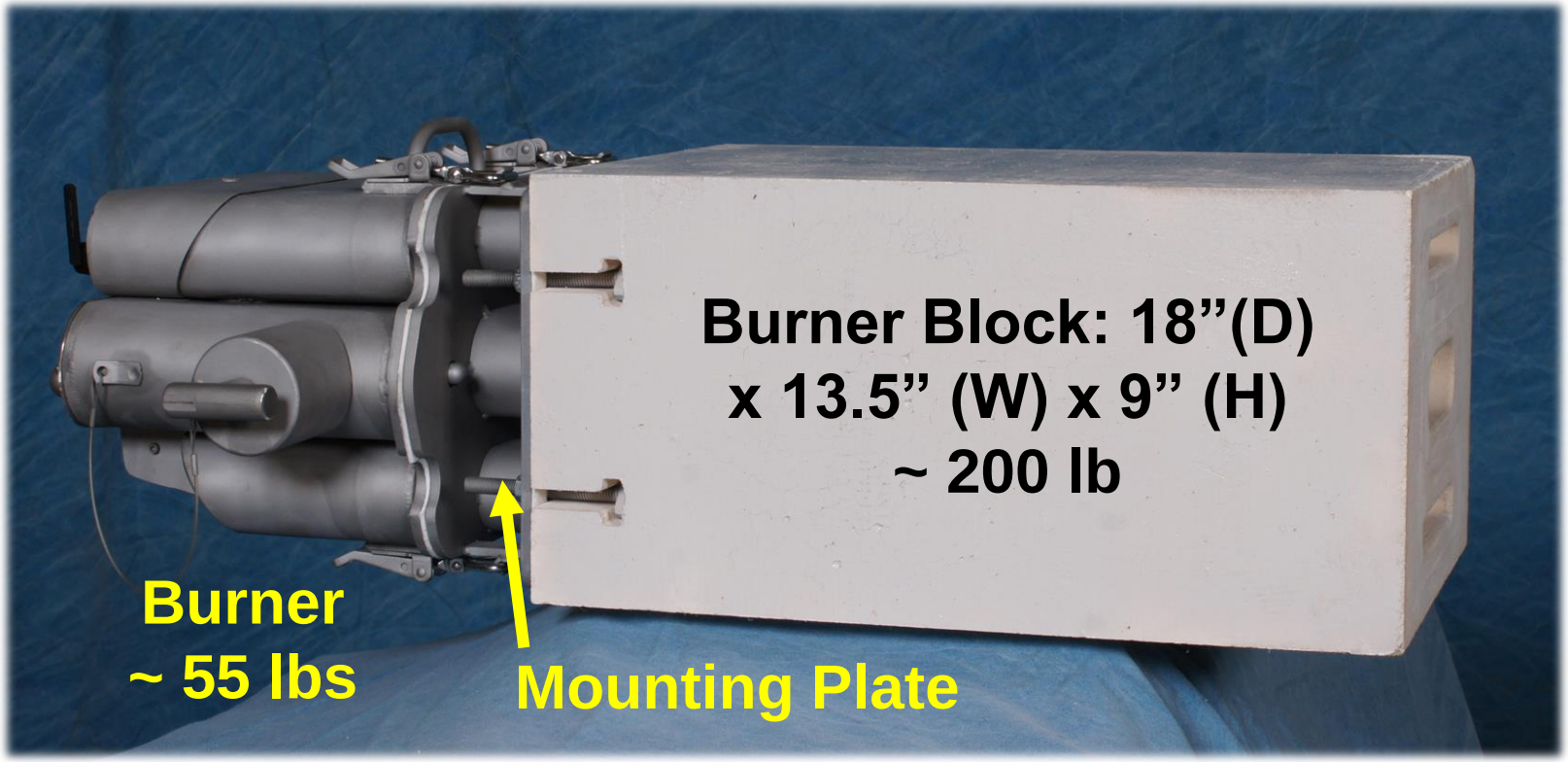


…and Tackling Foam Formation

- Effects of Foam
  - Reduced Heat Transfer to Glass > Increase in Fuel Flow
  - Weakening of Secondary Convective Flows in Glass Melt Leading > Increase in Glass Defects
  - Refractory Attack



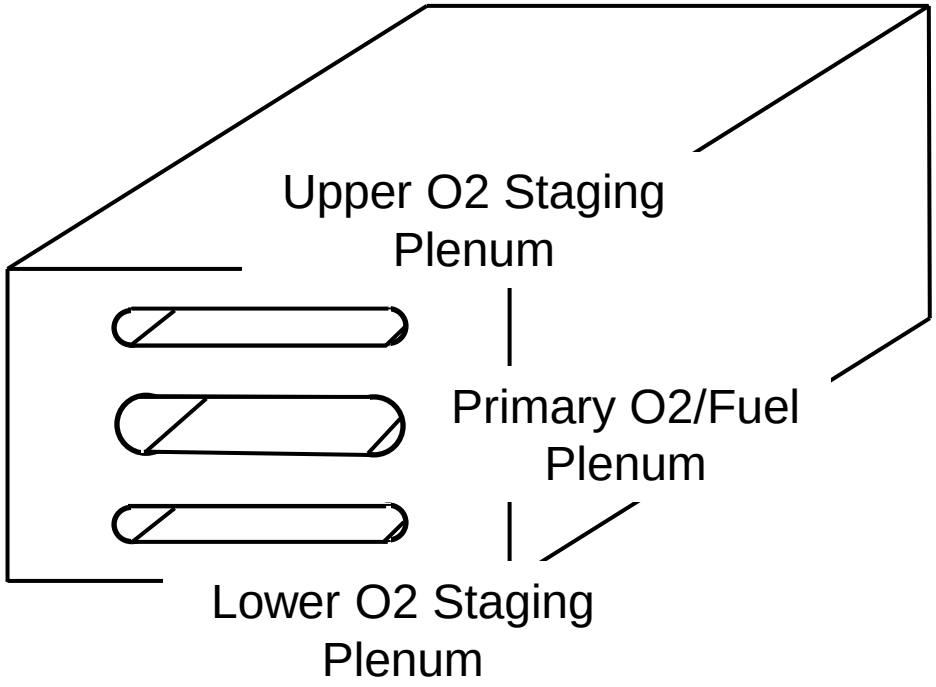
Cleanfire® HRx Burner



3 Sizes Cover Range from ~ 1 – 12 MMBtu/hr

HRx Burner Design and Operating Principles

- Enable oxygen staging below AND above primary flame
  - **Below flame (Melt Mode):** Enhance downward radiation to glass while shielding crown
  - **Above flame (Foam Control Mode):** Reducing gases adjacent to glass surface for foam reduction.
  - **Combination above and below flame (Split Mode):** Shortens flame & maximizes flame momentum while preserving luminosity



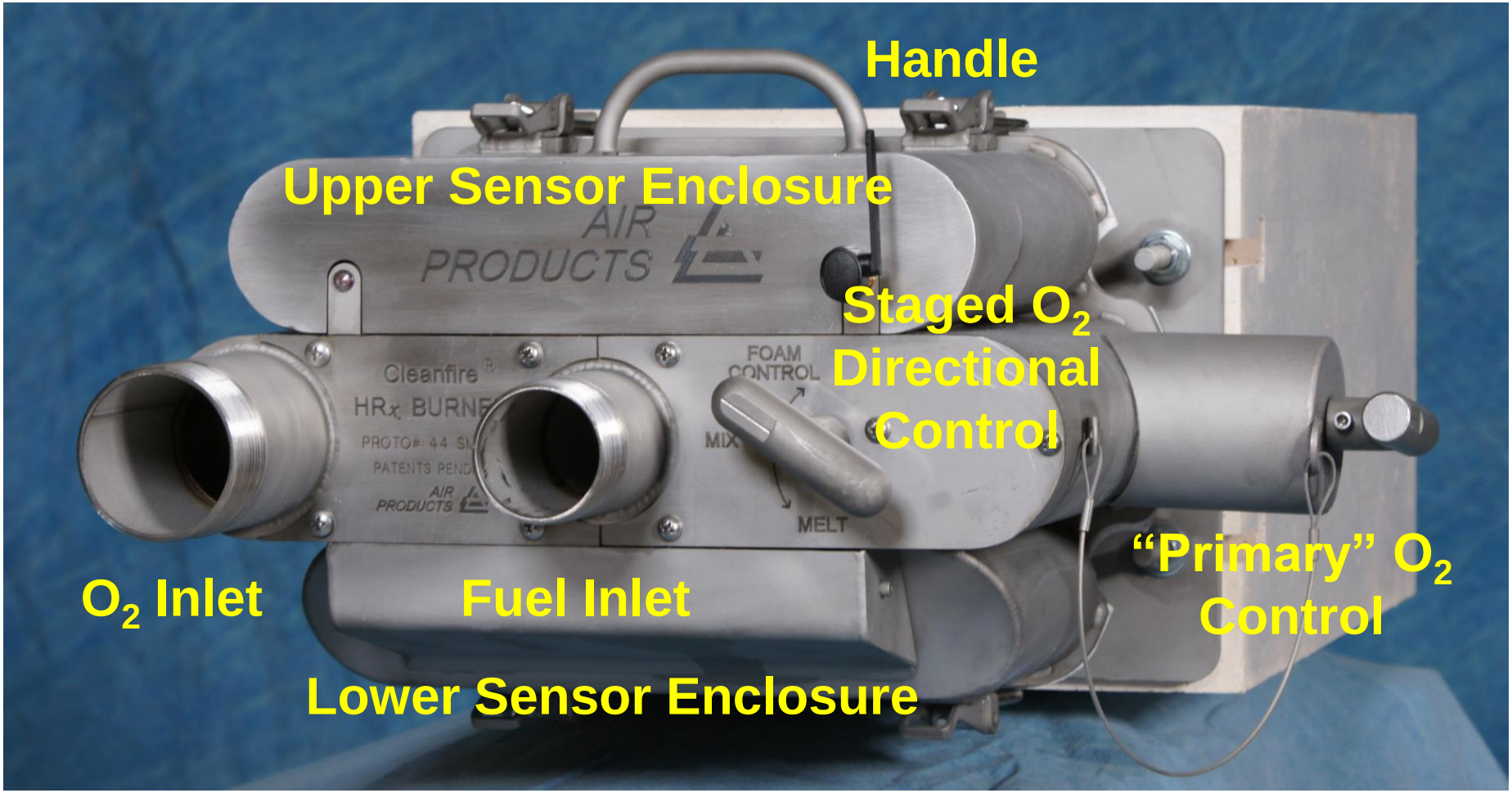
HRx Gas Burner in Different Operating Modes

Melt

Mixed

Foam Control

Cleanfire® HRx Layout and Features



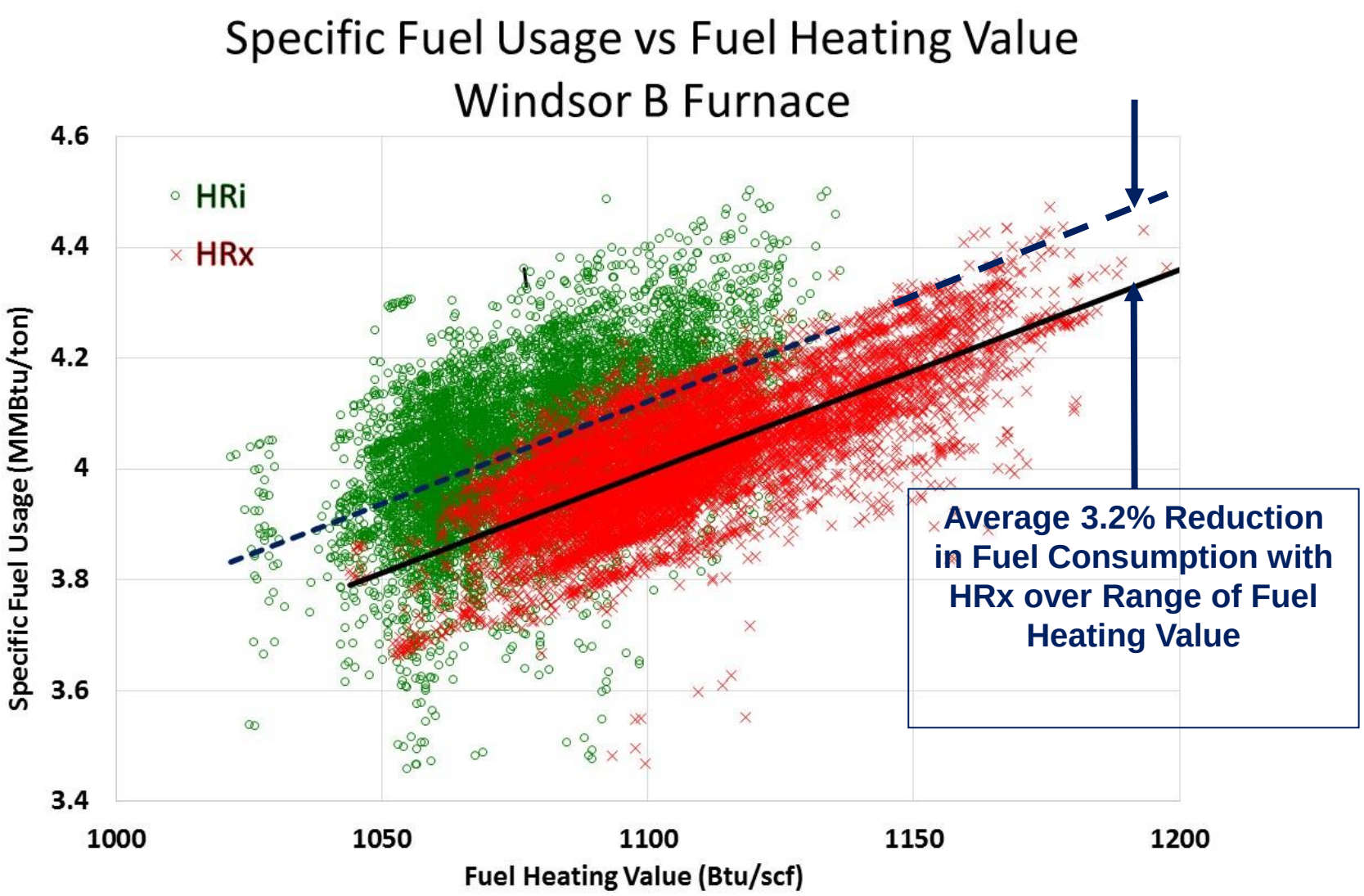
1st Demonstration of HRx Burner at Owens-Illinois Windsor B Furnace

- 400 TPD
- Amber Glass
- Equipped with HRi Burners

Pre-Conversion Goals

- Reduce energy consumption
- Improve glass quality through reduction of surface foam
- Lower NOx Emissions

Key Results: Energy Efficiency


Specific Fuel Usage vs Fuel Heating Value
Windsor B Furnace
HRi
HRx
Specific Fuel Usage (MMBtu/ton)
4.6
4.4
4.2
4
3.8
3.6
3.4
1000
1050
1100
1150
1200
Fuel Heating Value (Btu/scf)
Average 3.2% Reduction in Fuel Consumption with HRx over Range of Fuel Heating Value

Assessment of Fuel Efficiency Improvement

- More Luminous HRx flame leads to higher rate of flame-to-glass heat transfer

HRi

HRx

Breast wall temperatures are same for 2 Photos

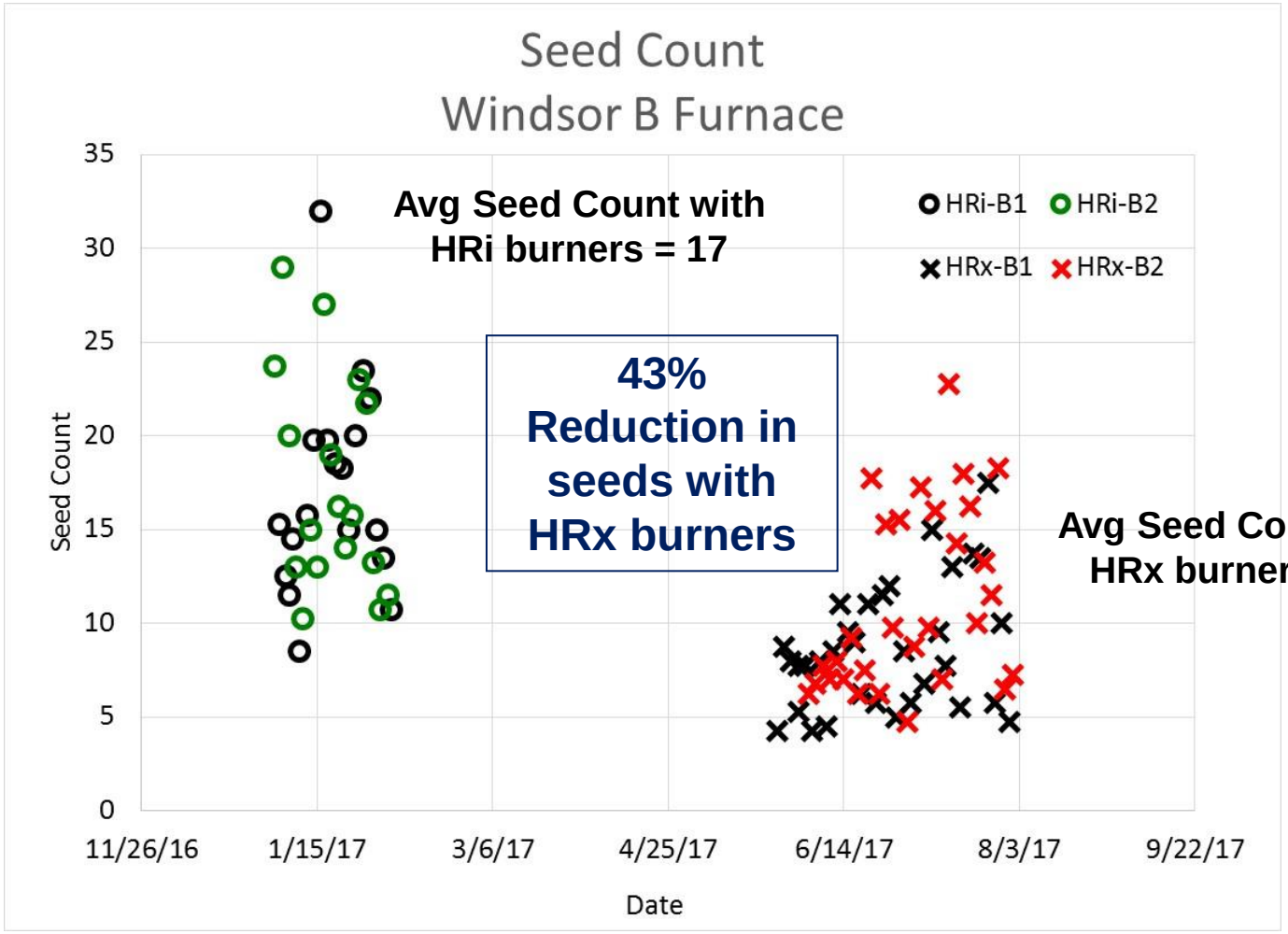
Fuel Efficiency Improvement, cont'd

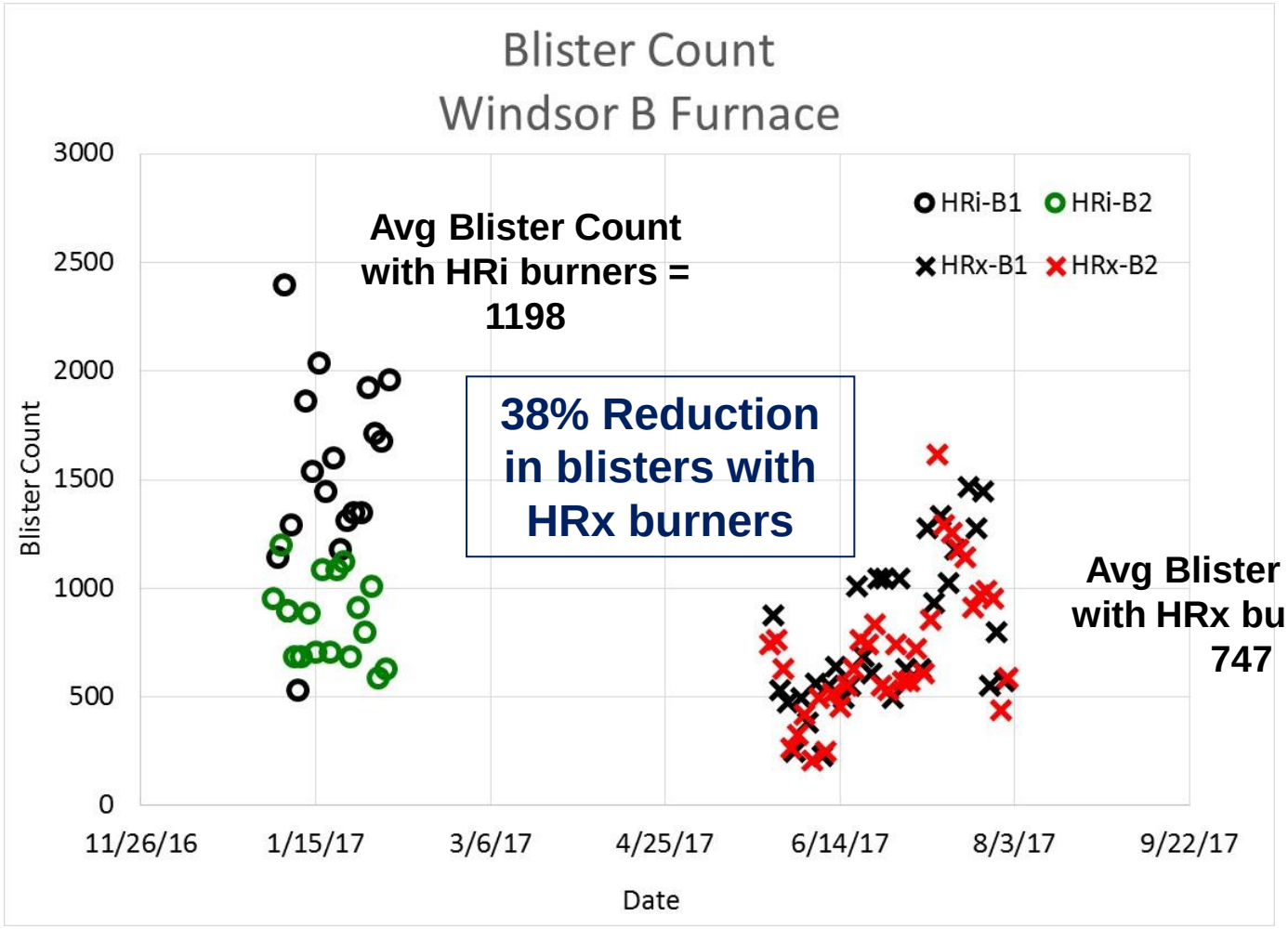
- Another factor is reduction of surface foam, which allows higher penetration of flame energy into glass, for more efficient melting

HRi

HRx

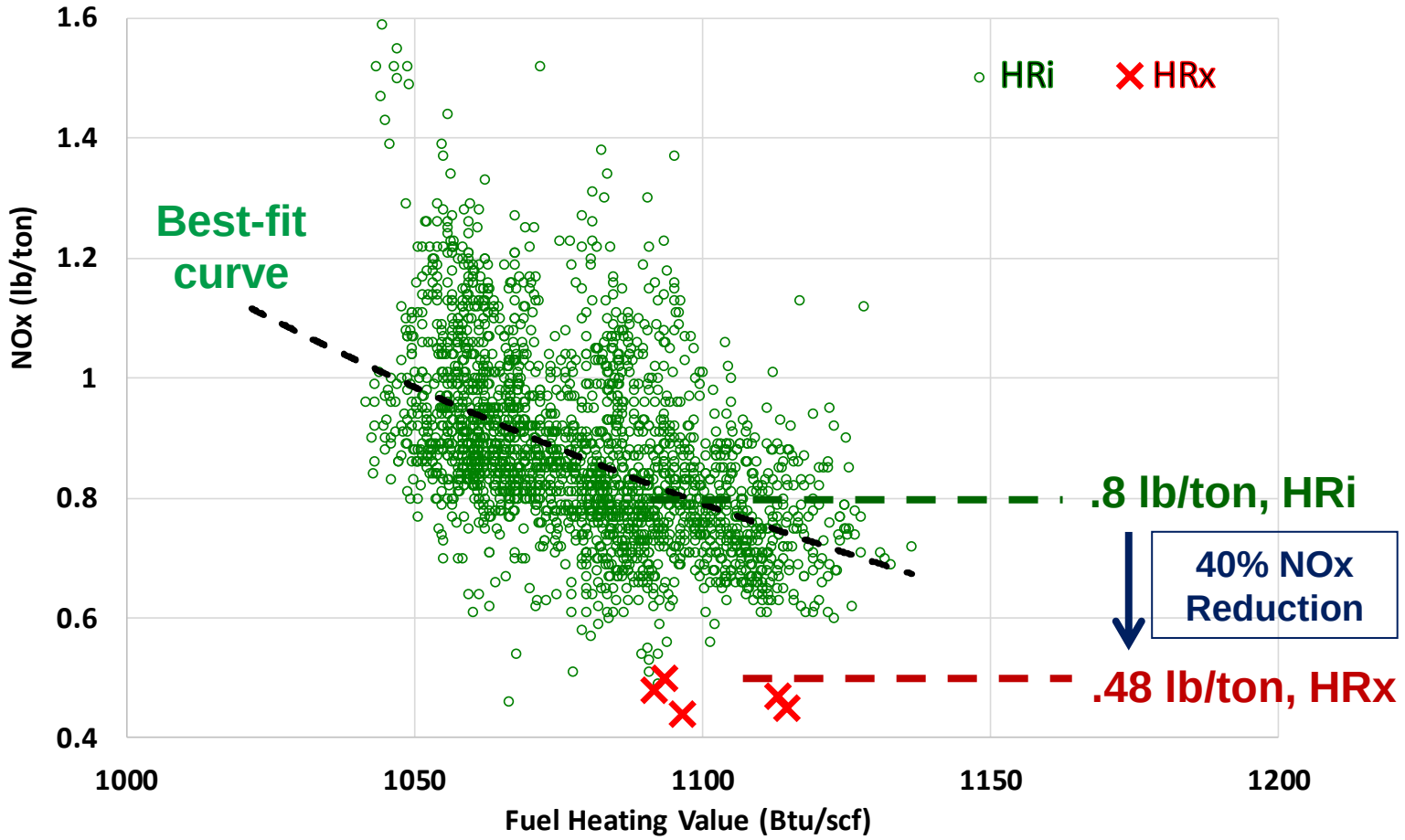
Key Results: Glass Quality


Seed Count
Windsor B Furnace
Avg Seed Count with HRi burners = 17
HRi-B1
HRi-B2
HRx-B1
HRx-B2
43% Reduction in seeds with HRx burners
Avg Seed Count with HRx burners = 10
Seed Count
0
5
10
15
20
25
30
35
11/26/16
1/15/17
3/6/17
4/25/17
6/14/17
8/3/17
9/22/17
Date


Blister Count
Windsor B Furnace
Avg Blister Count with HRi burners = 1198
38% Reduction in blisters with HRx burners
Avg Blister Count with HRx burners = 747
HRi-B1
HRi-B2
HRx-B1
HRx-B2
Blister Count
3000
2500
2000
1500
1000
500
0
11/26/16
1/15/17
3/6/17
4/25/17
6/14/17
8/3/17
9/22/17
Date

Key Results: NOx Emissions

NOx vs Fuel Heating Value
Windsor B Furnace



Assessment of NOx Reduction

- New nozzle design for HRx burner capable of achieving a maximum O2 staging level greater than 95% of total burner oxygen vs a maximum of 70% for HRi burner.

Summary

- Cleanfire Burner Technology > Proven Track Record of Innovation, Low Maintenance and Reliability
- Successive Burner Advancements have led to Continual Increases in Glass Melting Efficiency
  - Gen1 to HR ~ 6 – 8%
  - HR to HRi ~ 3%
  - HRi to HRx ~ 3%
- HRx Burner adds Mechanism for Additional Glass Quality Improvement + Deep NOx Reduction
- Beyond HRx
  - Cullet Preheating
  - Furnace Design Improvements
  - Low-level O_2/Fuel Preheating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To make glass better
...put us in the mix.

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