Integrated Burner Technology and Oxygen Supply for Glass Melting: A step towards sustainability and decarbonization

Michael J. Gallagher, Ph.D., Lead Engineer,
Combustion Glass Applications,
Air Products & Chemicals, Allentown, PA

Ashwin Vinod, Ph.D., Principal Research Engineer,
Combustion Glass Applications,
Air Products & Chemicals, Allentown, PA

James Carlson, Principal Project Leader,
Insulation Group Central Engineering,
CertainTeed Corporation, Malvern, PA

Presented during the 84th Conference on Glass Problems, held November 6-8, 2023 in Columbus, Ohio and republished with permission of The Glass Manufacturing Industry Council (www.gmic.org).

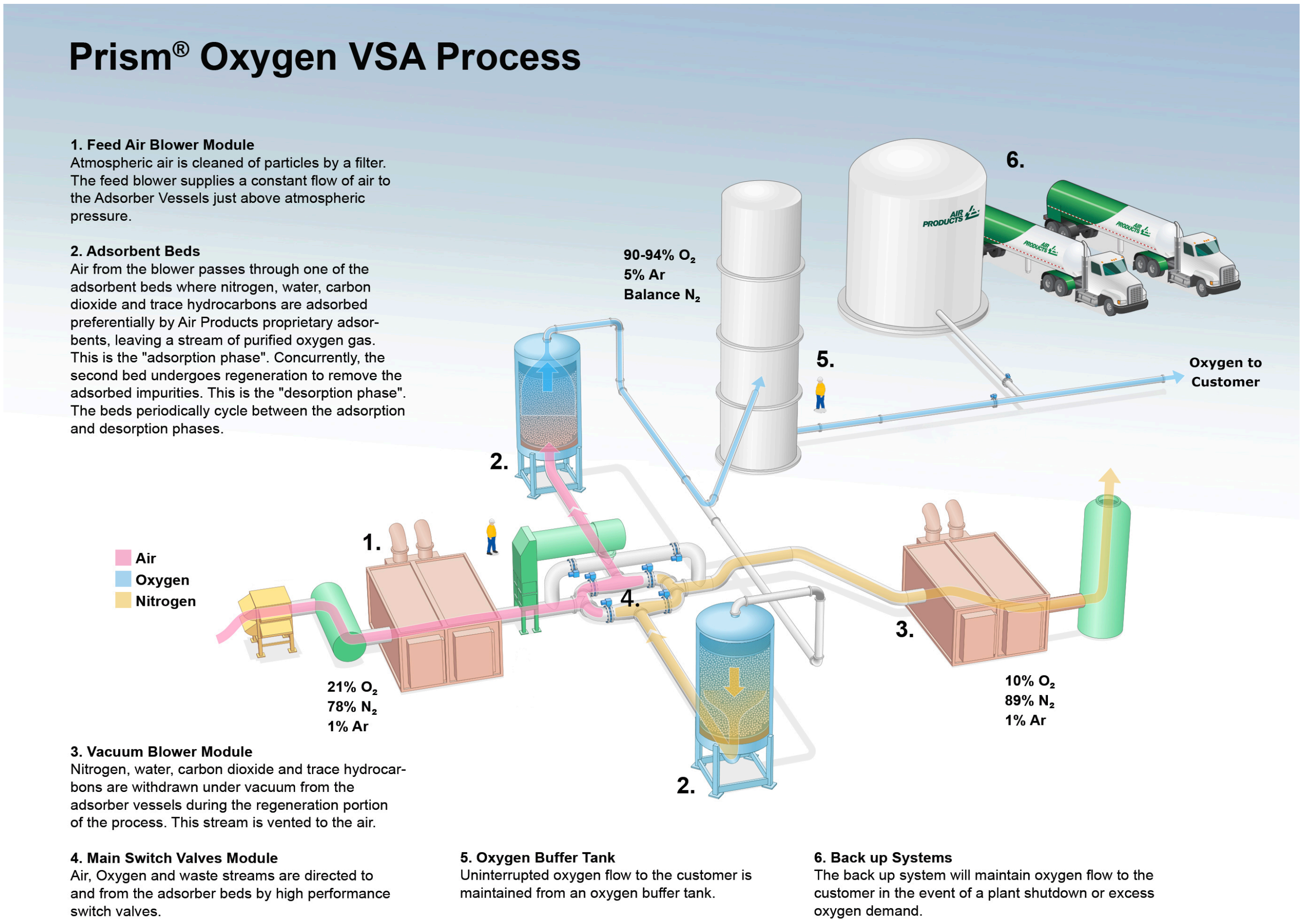
Abstract

Sustainability and decarbonization have become strong focus areas for the Glass Manufacturing industry over the past few years. Oxy-fuel combustion contributes to these goals because it provides 10-25% fuel savings over air-fuel combustion as well as a reduction in carbon emissions. Oxygen separation plants, however, do consume electrical power and therefore this must also be a factor in calculating the carbon footprint for each glass manufacturing facility. Many oxygen separation plants use vacuum swing absorption (VSA) technology, and they are designed to supply oxygen at pressures of approximately 1 bar (14.7 psi). A gaseous oxygen compressor is often used to achieve the required oxygen supply pressure, but this equipment can consume a significant portion of the total power supplied to the VSA and it requires periodic maintenance thus increasing VSA downtime. The reason for needing such high oxygen supply pressure is often due to the design of oxygen piping, flow skids, and the oxy-fuel burners. Air Products has developed a new burner configuration with an integrated oxygen supply system that can supply oxygen at much lower pressures – as low as 0.34 bar (5 psi) at the VSA fence line with only 0.03 bar (0.5 psi) required at the burner. A trial of this technology was conducted at CertainTeed's Chowchilla, CA facility, and the results showed that the reduced oxygen supply pressure of the Integrated VSA/Cleanfire® HR_x™ System achieved excellent results such as lower NOx emissions and reduced energy consumption with no negative effects. The Integrated system also achieved approximately 30% power savings in the oxygen supply system, thus helping to reduce the Chowchilla facility's overall carbon footprint.

Introduction

The effects of climate change are increasingly apparent and have made decarbonization and sustainability key priorities for the glass industry going forward [1,2]. Although many options are being investigated on the path to decarbonization, blue and green hydrogen, renewable energy, or a combination of both are strongly looked upon as promising options to reduce and ultimately eliminate the dependence on carbon-based fossil fuels. While there have been significant efforts and investments made toward the development of a H_2 and green electricity supply chain, it is well understood that it will take several years before either could become economically available on a scale large enough to meet the needs of an energy-intensive industry like glass. In such an energy infrastructure, other technologies that promise lower energy consumption (and therefore a lower carbon footprint), without compromising quantity and quality of the glass produced, would serve as an ideal next step on the industry's path towards decarbonization.

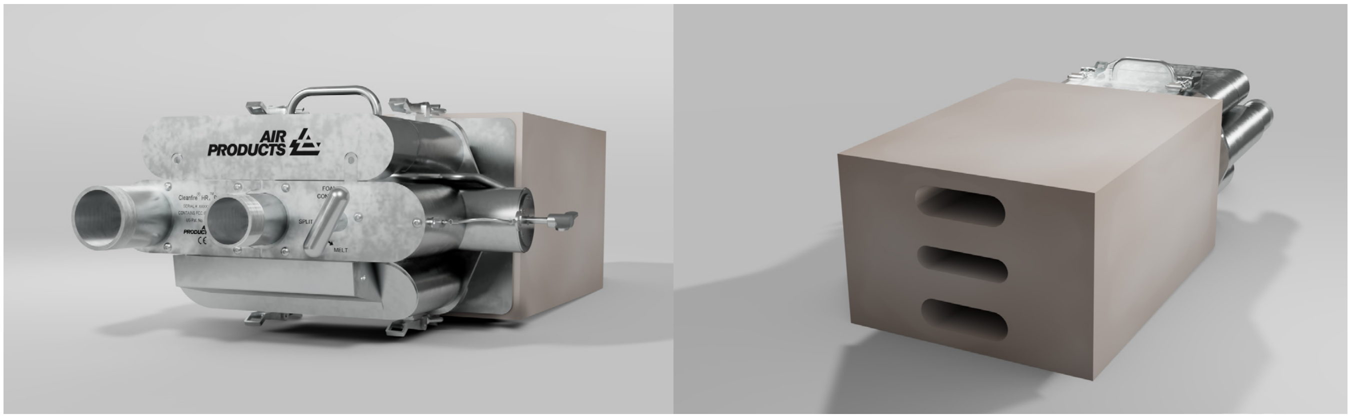
Figure 1: Schematic of the new low pressure VSA system



An Integrated Burner Technology and Oxygen Supply System for Glass Melting

To facilitate immediate, sizable energy savings for a glass plant, Air Products has developed its Integrated Prism® O_2 VSA/ Cleanfire® HR_x™ Combustion System ("Integrated System"). The oxygen VSA (Vacuum Swing Adsorption) system is a modified version of the standard O_2 VSA with one key difference; the low pressure VSA system does not include the GOX (gaseous oxygen) compressor that delivers O_2 at high pressures to the customer (**Figure 1**). Removal of the compressor leads to certain operational benefits in addition to the reduced footprint of the system. The GOX compressor is an energy-intensive component of the system, and hence its removal offers the potential for significant energy savings. Additionally, the compressor is often the component of any VSA system that most often requires maintenance, and therefore its removal further improves the reliability, and reduces the likelihood of system downtime. The key challenge with a low pressure VSA is that, with the GOX compressor removed, the O_2 stream generated does not have the necessary pressure to operate in conjunction with standard flow skids and burners. The outlet pressure of the low pressure O_2 VSA is about 5 psi, as opposed to the 12-15 psi supplied by standard VSAs. To tackle this challenge, Air Products has successfully developed a line of low-pressure downstream components including flow skids and modified burners to function seamlessly with the new low pressure O_2 VSA.

Figure 2: Cleanfire HR_x burner in its burner block



The modified Cleanfire HR_x burners operate exactly like their standard pressure counterparts at back pressures <0.5 psi. The burner is a flat flame oxy-fuel burner with state-of-the-art features like extreme oxygen (O_2) staging up to 95%, low NOx emissions, foam reduction mode to destabilize surface foam [3], and optional sensors for remote performance monitoring [4]. The Cleanfire HR_x burner in its burner block is shown in **Figure 2**. The burner block has a central precombustor for initiating the combustion reaction, and upper and lower ports for staging O_2.

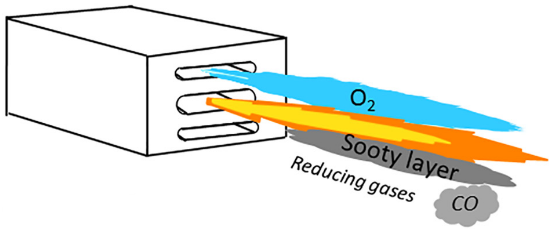
The Cleanfire HR_x burners have the unique capability to be operated in any of three distinct O_2 staging modes to optimize flame properties, depending on the burner's location within a glass furnace. **Figure 3** depicts the three different staging modes of the HR_x burner and their respective functionalities. In Split Mode, the staging O_2 is split evenly between the upper and lower staging ports producing a high momentum flame well suited for the more turbulent locations within a furnace. In Melt Mode, staging O_2 is directed to the lower staging port producing a long flame with a more luminous bottom that leads to increased radiation directed towards the melt below. In Foam Control Mode, all of the staging O_2 is directed to the upper staging port located above the flame. In this mode, the flame develops a sooty bottom layer with reducing gases such as CO, that effectively destabilize surface foam and thereby minimize inefficiencies in the melting process [5].

The burner also incorporates an O_2 staging control valve to adjust the split of combustion O_2 into primary O_2 and staging O_2. The higher O_2 flow through the primary port speeds up the mixing of O_2 and natural gas, thereby producing a high momentum flame. On the contrary, a completely closed staging valve allows only 5% of the combustion O_2 to flow through the primary port, whereas the remaining 95% is directed to the staging ports. High levels of O_2 staging yield multiple benefits including a longer flame, lower NOx, and increased flame luminosity.

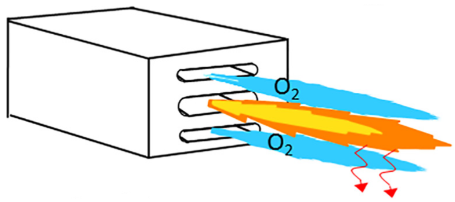
CertainTeed Chowchilla Installation Overview

The Integrated system installed at CertainTeed's Chowchilla, CA, 295 TPD fiberglass plant included the low pressure VSA system and 11 Cleanfire HR_x burners. The valve settings on each of the burners were optimized to have the flame properties best suited for their positions within the furnace. Prior to the Integrated system, the furnace operated with alternative oxygen supply and burner technology. In the following section, the performance of the Integrated system is compared to the prior installation in terms of VSA power consumption, furnace melting efficiency, NOx emissions, furnace crown temperature and furnace bottom temperature. Please note that most of the data presented herein are normalized with respect to the performance metric value prior to the installation of the Air Products system.

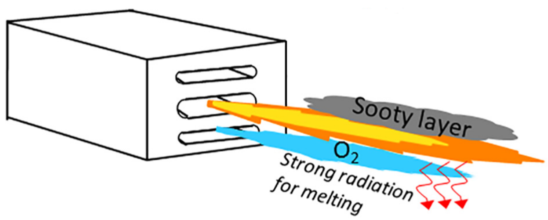
Figure 3: Various staging modes of the HR_x burner



Foam Control Mode
- Staging O_2 on top of primary flame
- Produces long, staged flame with sooty underlayer, containing reducing gases (CO)
- Will reduce foam on surface of glass



Split Mode
- Staging O_2 on top and bottom of primary flame
- Produces shorter, stable flame with high radiance
- Good for boosting applications and/or locations with high turbulence (near flue)

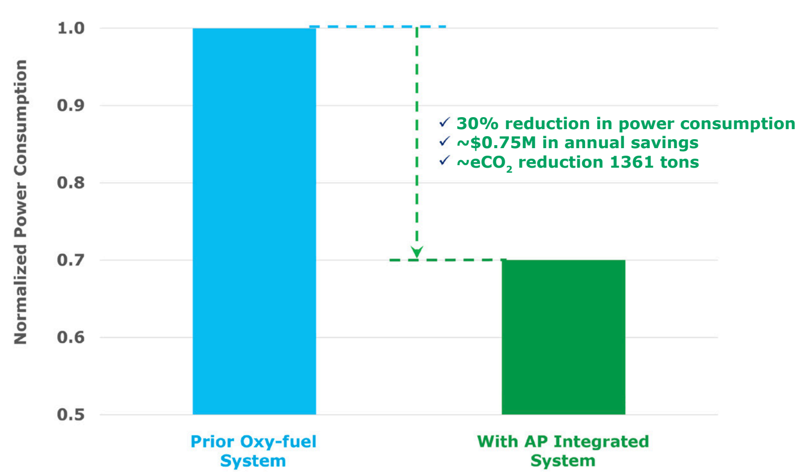


Melt Mode
- Staging O_2 on bottom of primary flame, similar to traditional HR_i burner
- Produces long, flame with high radiance on underside for faster melting

VSA Power Consumption

Power consumption of the O_2 VSA before and after the installation of the Integrated system was compared by estimating the annual energy usage of each in kWh. The data were normalized with respect to the energy consumption before the Integrated system was implemented and are presented in **Figure 4**. A significant 30% drop in energy consumption was noted with the new system. In the context of energy prices in the state of California, a 30% reduction in energy consumption would translate to close to 0.75 million US dollars in annual savings for the facility. Another key consequence of the reduced power consumption is the associated reduction in CO_2 emissions. Utilizing a conversion factor of 0.879 lbs. CO_2 per delivered kWh as prescribed by the Pacific

Figure 4: Normalized power consumption of the O_2 VSA



Gas and Electric Company carbon footprint calculator [6], the above noted savings in energy consumption amounts to 1361 fewer tons of CO_2 emitted each year by the O_2 VSA alone.

Furnace Melting Efficiency

The melting efficiency of the furnace was assessed in terms of the thermal energy consumed per ton of glass produced. For a particular period of interest, the total natural gas consumption was estimated, and the associated total energy was divided by the total tonnage of glass produced during the same period to obtain the specific fuel consumption in MMBTU/ton of glass. Though the furnace pull rate remained nearly constant before and after the installation of the Integrated system, the proportion of cullet present in the batch was noted to be higher after the installation of the Integrated system. Therefore, a compensation factor was applied where a 2.9% decrease in energy consumption was assumed for every 10% cullet used [7]. The change in specific fuel consumption with the installation of the Integrated system, accounting for the effect of increased cullet is shown in **Figure 5**. The decreased fuel consumption per ton of glass produced was found to be 8%, which, when translated into reduced CO_2 emissions, amounts to a total of 1760 tons annually. It is also important to note that the installation of the Air Products system coincided with a furnace rebuild and the installation of a new insulation package, the effects of which cannot be neglected. Drawing from previous experiences with oxy-fuel furnace rebuilds and HR_x related performance improvements, it is estimated that 50% of the reduction in fuel consumption was a result of the Air Products system and the remaining 50% was the result of the furnace's new insulation package.

Figure 5: Normalized specific fuel consumption

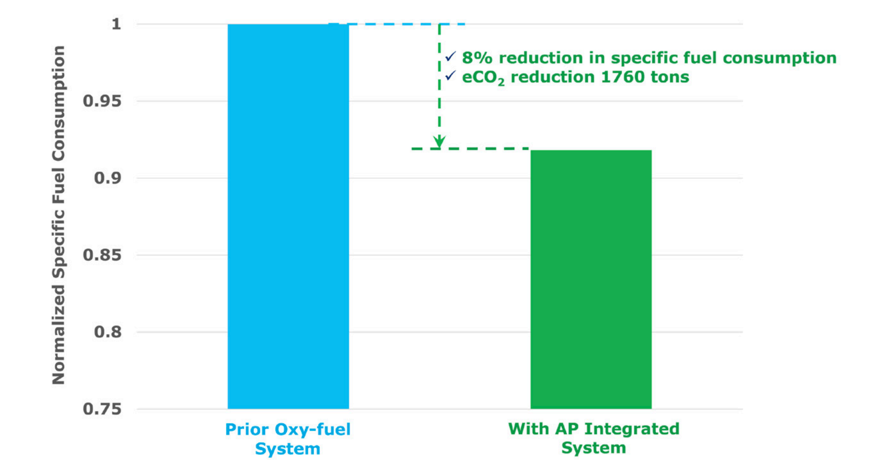
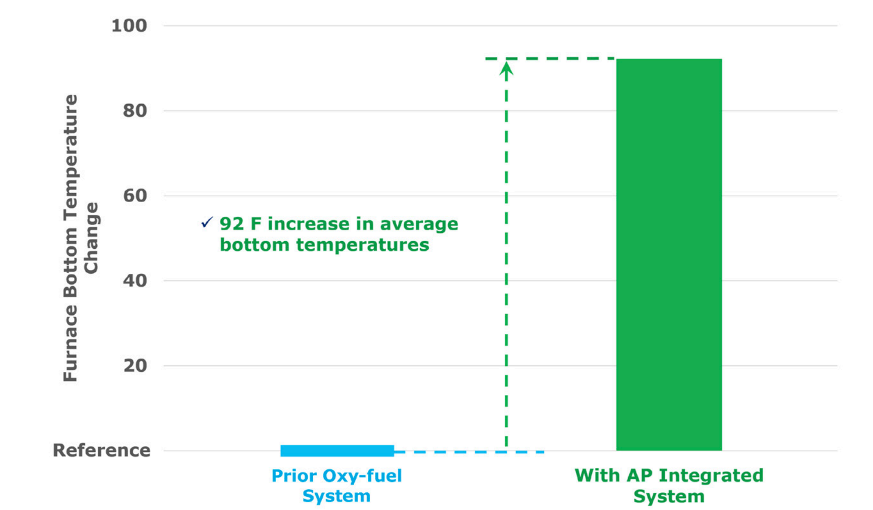


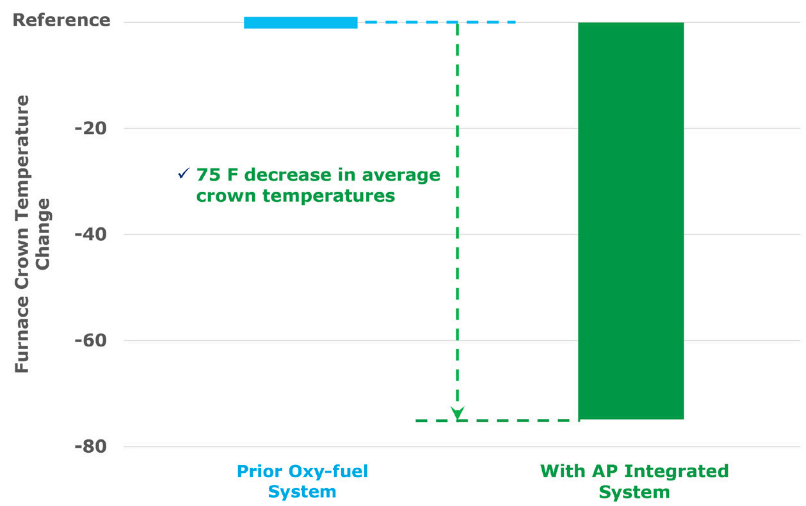
Figure 6: Difference in furnace bottom temperature



Furnace Crown and Bottom Temperatures

Temperature changes experienced at the furnace bottom as well as the crown were also studied. The average of the temperatures measured across all bottom and crown thermocouples during the periods of interest are presented in **Figures 6 and 7** respectively. For confidentiality, the temperatures are presented as a temperature difference with respect to the operation prior to the installation of the new Integrated system. As shown in **Figures 6 and 7**, with the installation of the new system, the average of the furnace bottom thermocouples increased by 92˚F and the average of the furnace crown thermocouples dropped by 75˚F. Both the changes are favorable from a furnace efficiency and longevity standpoint. The Cleanfire HR_x burners produce, long, luminous, high-momentum flames that are inherently resistant to lofting and turbulence-related disturbances. This enables them to direct more heat, more evenly, into the glass melt thereby raising furnace bottom temperatures and lowering crown temperatures.

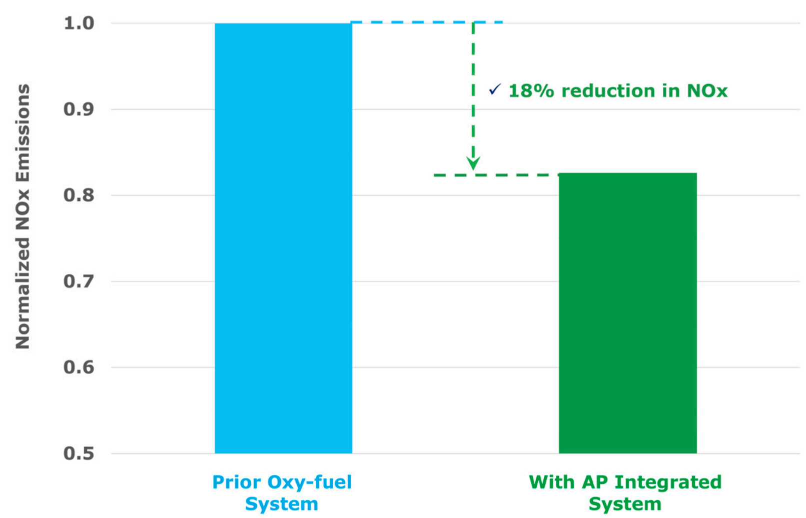
Figure 7: Difference in furnace crown temperature



NOx Emissions

NOx emissions were evaluated in terms of pounds of NOx emitted per ton of glass produced. As with the other parameters of interest, lbs. NOx/ton was averaged over the entire period of interest and normalized with respect to the value before installation of the new system. The data is presented in **Figure 8**. It was observed that NOx emissions per ton of glass produced was 18% lower with the Integrated system. As discussed earlier, the Cleanfire HR_x burners are capable of extreme O_2 staging; that is, approximately 95% of combustion O_2 is separated from the main flame and passed through an adjacent port. This creates a fuel-rich primary flame that has a lower core flame temperature and thus less NOx is produced as a result. A staged flame is also considerably longer than an un-staged flame and releases heat over a larger volume thereby increasing heat transfer to the glass surface.

Figure 8: Reduction in NOx emissions



Summary and Conclusions

The Integrated O_2 VSA – Cleanfire HR_x combustion system has proved to be an efficient, cost effective and reliable step on the path to decarbonization. The integrated system benefits two key subsystems of a glass plant; the O_2 generation system as well as the melter, both of which have a significant impact on the carbon footprint of the facility. The system significantly reduced the power consumption of the O_2 VSA by 30%, which saved the Chowchilla facility ~$0.75 million annually. The integrated system also increased furnace efficiency, by transferring more heat into the glass melt. This is evident by the lower furnace crown temperature and higher bottom temperatures. In addition, NOx emissions were reduced by 18% on average. Overall, the integrated system was estimated to lower the CO_2 emissions at the CertainTeed's Chowchilla facility by ~3100 tons annually. To date, Air Products has 10 of such integrated systems globally.

References

1. SAINT-GOBAIN NET-ZERO CARBON BY 2050, 9/24/2019. https://www.saint-gobain.com/en/news/saint-gobain-net-zero-carbon-2050

2. O-I Receives Approval for Science-Based Emissions Reduction Targets. https://www.o-i.com/news/contributing-to-a-healthier-world

3. M. D'Agostini, W. Horan, "Optimization of Energy Efficiency, Glass Quality, and NOx Emissions in Oxy-Fuel Glass Furnaces Through Advanced Oxygen Staging"; 79th Conference on Glass Problems (GPC), 2018.

4. Hendershot, Reed. "First smart burner for the glass industry." Glass Worldwide, Issue 64, 2016.

5. Laimbock, P. R. "Foaming of glass melts.", Ph.D. Dissertation, Technical University of Eindhoven, (1998). ISBN 90-386-0518-8.

6. Pacific Gas and Electric Company Carbon Footprint Calculator Assumptions https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf

7. Kovacec, M., A. Pilipovic, and N. Stefanic. "Impact of glass cullet on the consumption of energy and environment in the production of glass packaging material." Recent Researches in Chemistry, Biology, Environment, and Culture. Monteux, Switzerland (2011).

For more information, please contact us at:

Corporate Headquarters
Air Products and Chemicals, Inc.
1940 Air Products Blvd.
Allentown, PA 18106-5500
T 800-654-4567
info@airproducts.com

Canada
Air Products Canada Ltd
2233 Argentia Rd., Suite 203
Mississauga, ON L5N 2X7
T 800-654-4567/905-816-6670
info@airproducts.com

Europe
Air Products PLC
Hersham Place Technology Park
Molesey Road
Walton-on-Thames
Surrey KT12 4RZ
UK
T +44(0)800 389 0202
apukinfo@airproducts.com

Asia
Air Products
Floor 2, Building #88
Lane 887, Zu Chongzhi Road
Zhangjiang Hi-Tech Park
Shanghai, 201203, P.R.C.
T +021-3896 2000
F +021-5080 5585
Sales hotline: 400-888-7662
infochn@airproducts.com

AIR PRODUCTS

tell me more
airproducts.com

© Air Products and Chemicals, Inc., 2023 (46144) 337-24-001-US