LIFE Eco-HeatOx

Layman's report

July 2013 – December 2016

With the contribution of the LIFE financial instrument of the European Community

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Executive summary

The LIFE Eco-HeatOx project, co-funded by the EU LIFE+ programme, was launched in July 2013 by Pasabahce Bulgaria EAD (ex Trakya Glass Bulgaria EAD) (BU) and Air Liquide S.A. (FR). The aim of the Eco-HeatOx project was to implement hot oxy-fuel combustion in a medium sized glass furnace, which could significantly lower the environmental impact from glass-melting processes. The project covered the engineering, construction, demonstration and validation of this technology. The objective was to demonstrate the maturity and the full potential of the hot oxy-fuel combustion technology for medium sized furnaces.

In the first chapter of this Layman's report, the environmental challenges tackled by the LIFE Eco-HeatOx project as well as its main objectives and the project partners are described. In the second chapter the proposed innovative technology is described, and in the third chapter, the project activities and achievements are summarised. In the fourth chapter the related benefits are detailed.

The final chapter is dedicated to the long-term benefits of the project and to the replicability and transferability of the results.

1. Introduction

Environmental Challenge

Shortly after falling in 2009, carbon dioxide (CO2) emissions rose in 2010, following global financial crisis, to a record level of 30,6 gigatons, with a rise of 5% from the previous record year, 2008, when levels had stood at 29,3 gigatons. In 2011, global fossil fuel CO2 emissions set yet another record, increasing a further 1,0 gigaton, which made the total 31.6 gigatons. According to the latest IEA estimates, 2011 CO2 emissions in the sectors of energy, industry and transport were the highest in history.

The tableware glass production requires a lot of energy and produces a large amount of GHG. The oxy-fuel combustion as well as the waste heat recovery have already allowed a decrease of the environmental impact caused by large glass furnaces. In order to transfer the positive impact to small and medium sized furnaces, a new concept had to be developed. After successful implementation, the process could be adapted for other production processes that use similar melting furnaces all over Europe.

The recent increase of the GHG concentrations in the atmosphere is mainly due to the human activities and is almost certainly responsible for the global warming phenomenon that we have observed over the past years. This "anthropogenic" greenhouse effect is mainly caused by the emission of CO2: more than 50% of the anthropogenic GHG emissions are carbonic gas contributing to 75% of the anthropogenic greenhouse effect. This value is rising up to 90%, only considering the industrial emissions; industries have thus interest in reducing CO2 emissions as a priority. Industrial processes category represents one of the most critical business sectors responsible for CO2 emissions, which amounts to 7% of European emissions.

Moreover, the manufacturing processes of mineral products such as glass, lime, and cement are responsible for 50% of those emissions among industrial furnaces. For instance, together they emit more CO2 than chemical and metal production industries.

LIFE Eco-HeatOx addressed this issue with the objective to reduce GHG emissions from small and medium sized glass furnaces particularly, and the impact would be able to be transferred to other similar processes.

The LIFE Eco-HeatOx project: Objective and Expected results

LIFE Eco-HeatOx project goes one-step beyond from traditional oxy-fuel combustion (ColdOx) as it recovers some part of flue gas energy, otherwise wasted, by preheating natural gas and oxygen to 450°C. This energy recovery reduces natural gas consumption and consequently greenhouse gas emissions further from what is expected from typical oxy-fuel combustion.

LIFE Eco-HeatOx project aimed at implementing hot oxy-fuel combustion is an innovative technology based on oxy-fuel combustion. The technology could significantly lower the environmental impact of glass-melting processes, and is recognised as one of the most effective technologies in glass melting industries in terms of CO2 reduction through fuel savings, while maintaining NOx and dust emissions significantly low compared to air-fuel combustion.

The objective of the project was first to validate the technical feasibility through industrial demonstration, and then to widely disseminate its environmental benefits to small and medium sized furnaces.

Following the research activities that had proven the basic methodology of the proposed concept, the project validated the technology with a full scale industrial demonstration on a furnace producing commercial tableware glass. The pollutant emissions were expected to decrease as follows (taking aging effect of furnace into account):

- **CO2**: specific emissions reduced by 23% and come from the following sources:
    - for ColdOx compared to air-fuel combustion, CO2 reduces from 294 kg/tg to 248 kg/tg, meaning 3 694 t of CO2 saved per year for 220 tpd furnace.
    - for Eco HeatOx compared to ColdOx operation CO2 reduces from 248 kg/tg to 225 kg/tg, meaning 1 847 t of additional CO2 saved per year for 220tpd furnace
- **NOx**: specific emissions reduced by 90% thanks to the use of pure oxygen instead of air as oxidizer in the production process, which limits the presence of nitrogen. NOX are indirect GHG and are also involved in acid rains. The quantitative reduction would be from 5,2 kg/tg to 0,52 kg/tg, meaning 376 t of NOX saved per year for 220tpd glass furnace.

This energy saving technology also entails lower dependence on energy price fluctuations. Financial viability of the technology and less additives consumption will also help the replication of the technology.

Project partners

<u>Coordinating beneficiary - Pasabahce Bulgaria EAD (ex- Trakya Glass Bulgaria EAD)</u>

Pasabahce is part of an industrial group, Şişecam, with the main activity fields of glass and chemicals production. The group is in a leading position in business lines covering all basic fields of glass such as float glass, glass household articles (tableware), glass packaging and glass fibre. Currently, Şişecam is the only glass manufacturer in the world that operates in all four of the aforementioned segments.

Pasabahce Bulgaria plant: LIFE Eco-HeatOx demonstration site

<u>Associated beneficiary – Air Liquide S.A.</u>

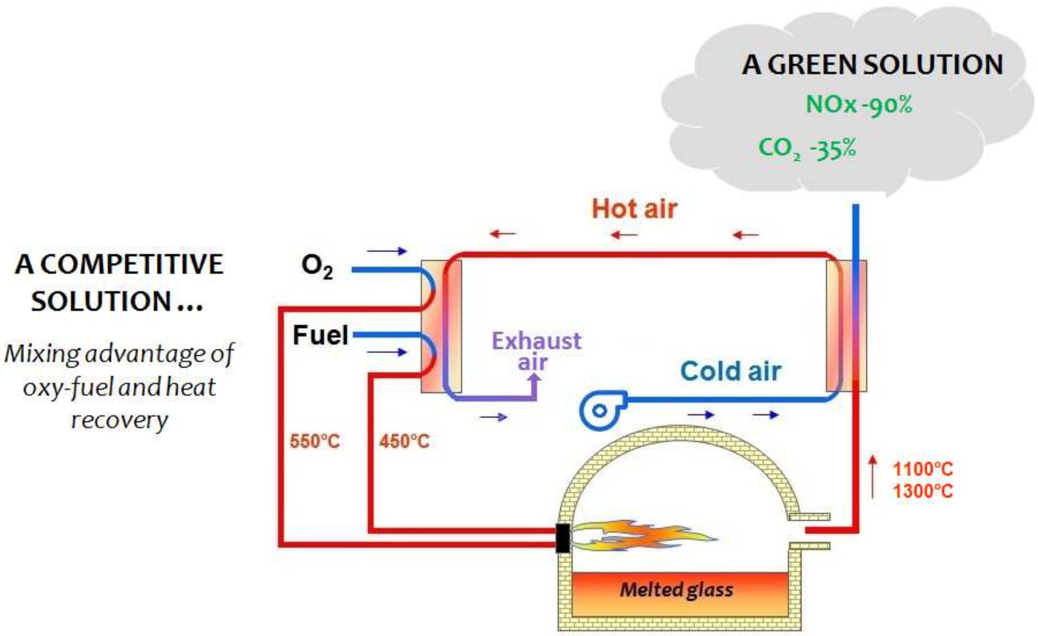
Air Liquide S.A. is a French multinational company which supplies industrial gases and services to various industries. It is the world's largest supplier of industrial gases in terms of revenues and has operations in over 80 countries. With over 50,000 employees worldwide and more than 16,000 M€ revenues, the company brought to the LIFE Eco-HeatOx project its industrial and manufacturing expertise.

2. The innovative technology proposed in the LIFE Eco-HeatOx project

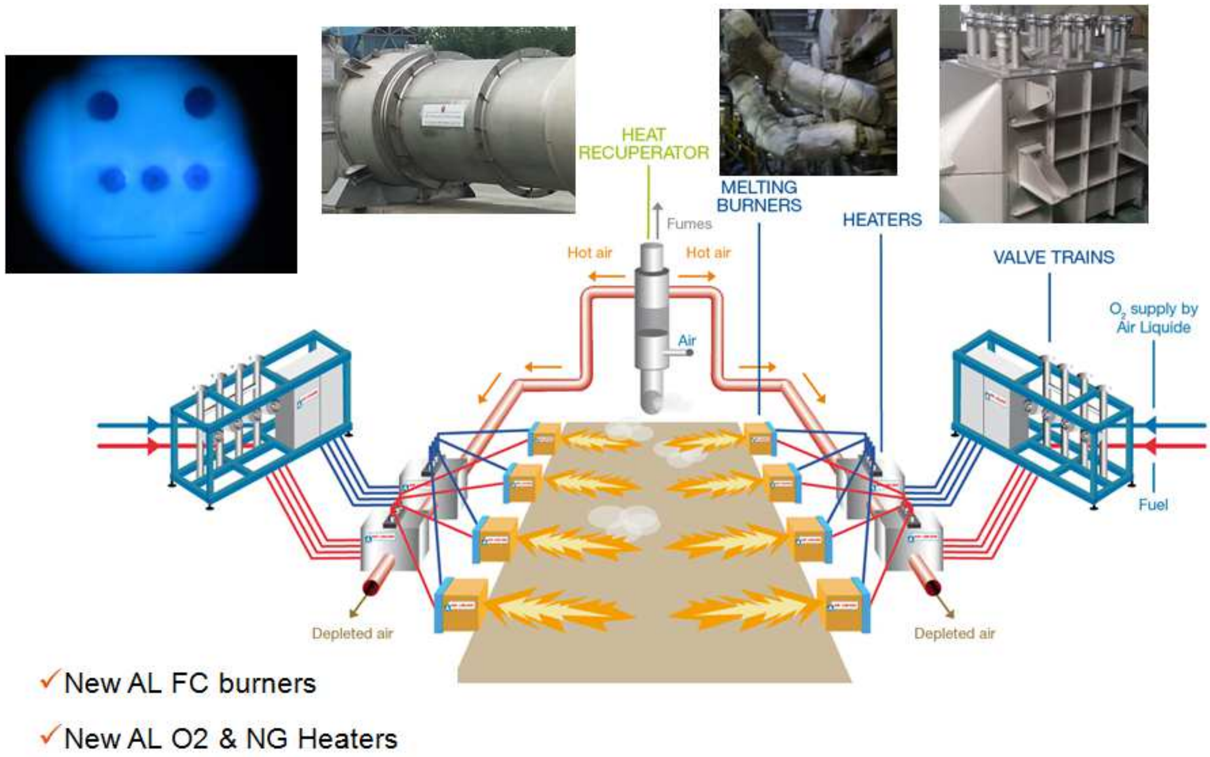
CO2 is major greenhouse gas emitted during glass production. The CO2 emission comes mostly from combustion of natural gas or other form of hydrocarbons and the decomposition of raw material during glass melting processes.

Air is commonly used in glass melting furnaces as a source of oxygen. Oxy-fuel combustion uses oxygen as oxidizer without nitrogen so that flue gas has much less volume than air-fuel combustion, resulting in higher efficiency. Oxy-fuel combustion is proven technology for significant reduction of carbon dioxide (CO2) and nitrogen oxide (NOx) emissions, which are both detrimental to humans and the environment.

Over the past years, Air Liquide has developed the Eco-Heat Oxy-fuel combustion (Eco-HeatOx) technology. Eco-HeatOx is an innovative technology which makes oxy-fuel combustion more attractive than traditional oxy-fuel combustion by preheating pure oxygen and natural gas using intermediate heat transfer fluid (air) heated by waste energy from flue gas. The traditional oxy-fuel combustion is operated with ambient temperature O2 and NG (ColdOx). HeatOx with 550°C oxygen and 450°C natural gas lowers O2 and NG consumption by 10% compared to ColdOx, and even up to 40% compared to air-fuel combustion with recuperative furnaces. This means CO2 reduction is also expected to be up to 40%. In addition, thanks to the absence of nitrogen, NOx (NO and NO2) reduction is expected to be up to 90%.



The Air Liquide patented **HeatOx technology** aims at covering broad types of glass furnaces ranging from container and tableware to technical glass.



This innovative technology is composed by the following five technology bricks:

1. **Primary heat exchanger (recuperator)**, allows heating air up to 700°C by using energy available on fumes coming out of glass furnace. This equipment should be fully integrated on exhaust furnace ducts.
2. **Secondary proprietary heat exchanger**, allows preheating oxygen up to 550°C and natural gas up to 450°C with hot air coming from primary heat exchanger.
3. **NEXELIA HeatOx proprietary burners**, specially developed to operate cold or hot oxygen and natural gas.
4. **Valve trains, skid of equipment,** able to control and measure oxygen and natural gas flow rate of every burner installed on the furnace.
5. **Air preheater** (not shown on drawing above), allows preheating ambient air by recovering energy still available on discharged air from the secondary heat exchangers after preheating oxygen and natural gas, thereby reducing the size of the primary heat exchanger.

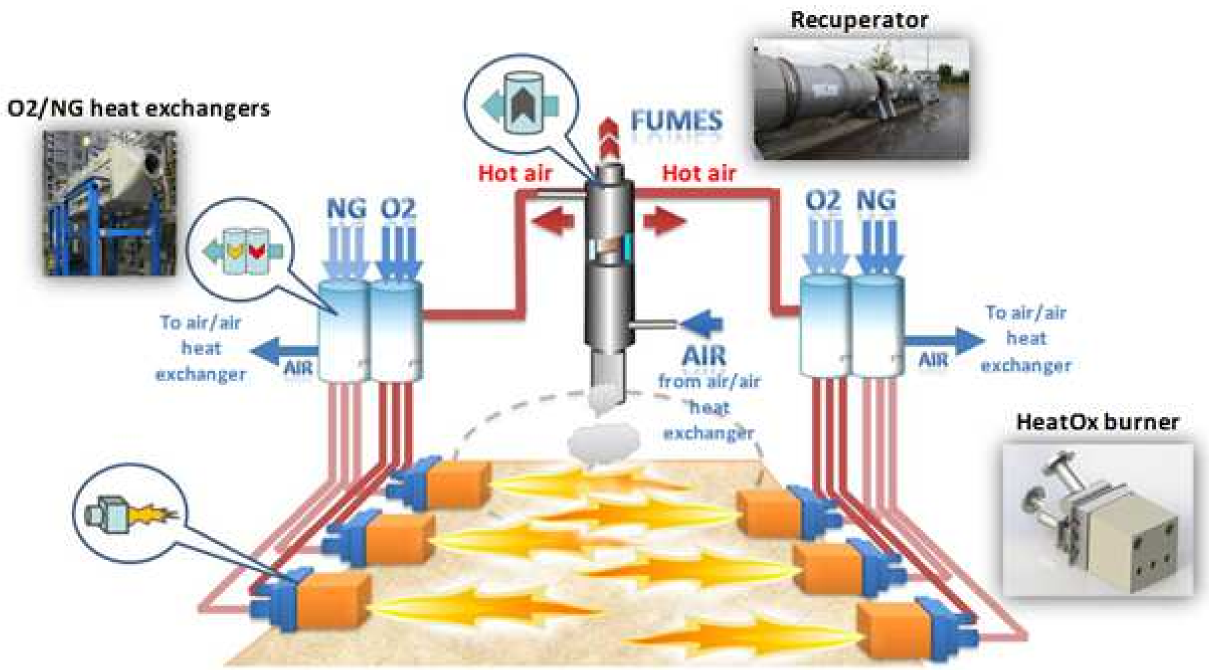
The use of an air preheater allows increasing primary heat exchanger shell skin temperature, this helps to maintain fumes at a higher temperature level, thereby avoiding condensation of corrosive species coming from the glass (or other corrosive products). The use of air preheater also enhances primary heat exchanger lifetime.

3. Main project activities and achievements

HeatOx system installation

Main challenge of the HeatOx system installation was that the furnace wasn't designed to accommodate the HeatOx system originally. Therefore, most of the modifications to the furnace had to be performed when the furnace was in operation, which was not a trivial task at all.

Openings of the flue gas channels were made to accommodate a two stage recuperator (primary heat exchanger) in each flue gas channel. When one flue gas channel was being modified, all the flue gas flowed through the other in order not to impact glass production. Furnace pressure was carefully monitored during this step to prevent pressure overshoot.



Oxygen and natural gas heat exchangers were located in a way to minimize the complexity of hot oxygen and natural gas piping. The thermal expansion was properly considered in the hot piping design and monitored during the HeatOx start-up.

HeatOx burner installation required significant efforts because a burner block needs special attention when installed to a furnace in operation. Each HeatOx burner was installed one after another, and the total eight HeatOx burners were installed on-the-fly during the 3 month long erection period.

Newly designed process and safety logics were programmed to the existing PLC. During the commissioning, all the safety logics went through hard simulation, which means the logics were confirmed with physically activation.

Troubleshooting

After commissioning and start-up, we have performed troubleshooting on various issues and major ones are the followings:

Flue gas channel insulation: As soon as flue gas temperature was found to be lower than expected, the flue gas channel from the furnace exit to the recuperator was adequately insulated. This insulation provided higher temperature flue gas inlet temperature to the recuperators and also minimized air ingress into the flue gas channel.

Hot (process) air leaks: Hot air leaks out of the process air channels were minimized and thermal expansion issues were fixed.

Flue gas by-pass damper: The role of the flue gas by-pass dampers was critical because it allowed flue gas to flow through the recuperators. During the initial test campaign, as the damper was losing its mechanical integrity, the overall performance was also deteriorated. Therefore, a few different damper designs were tested in order to minimize flue gas leak through the by-pass damper, and the current refractory dampers proved to be robust.

Clogging in flue gas interconnecting ducts: An early discovery during the operation phase was clogging in flue gas ducts connecting the two stage recuperators. Clogging creates elevated pressure drop and accordingly undesirable loading on the downstream induced draft fan. Differential pressure measurements were performed followed by an endoscopy campaign to visualize clogging. Laboratory analyses of the deposit samples pointed to sodium sulfate (Na_2SO_4) condensation. The estimated cause of the enhanced clogging is believed to be twofold: i) aerodynamically unfavorable flue gas flow path between the recuperators due to architectural limitations, ii) transitional effects such as low velocity and temperature in flue gas ducts during early operation phase, which are known to enhance deposition through build-up, agglomeration and condensation. To mitigate this issue, design changes are incorporated into the flue gas duct that enables declogging without interruption to HeatOx operation and with minimal impact to HeatOx performance.

Soot deposit on burner tips: Two HeatOx burners out of the eight installed showed soot deposit on their NG lance tips. Therefore, AL provided new design to Paşabahçe which successfully resolved the issue.

As mentioned before, the main challenge of the HeatOx system installation was that the furnace wasn't designed to accommodate the HeatOx system originally. Nevertheless, aforementioned issues were resolved by both teams' hard work and strong commitment under challenging conditions during the troubleshooting period.

Current status

Process logics and safety interlocks have been robust and make the system very easy to operate. However, heat recovery performance is slightly lower than what was expected due to the lower O2/NG temperature resulting from lower air temperature. This lower air temperature was specific to the particular configuration, where the recuperators were designed to accommodate the architectural constrain. Given O2/NG temperature, HeatOx performed as expected, that is, approximately 1% saving by 100˚C reactant temperature increase.

Dissemination activities:

To increase public and industrial awareness, several dissemination activities were held. Billboards either in the city center or the plant area were posted to increase public and employee attention and awareness.

In addition to this, several internal/external conferences and exhibitions were attended.

Conferences:

04/11/2013: GRT Gaz (Sevres, France)
20/09/2014: AFRC (Houston, US)
22/09/2014: ATIV-ESG Conference (Parma, Italy)
01/10/2014: 6th Balkan Conference on Glass (Nessebar, Bulgaria)

15/05/2015: ICG Conference (Bilbao, Spain)
04/11/2015: 76th Glass Problems Conference (Columbus, US)
11/04/2016: ICG (China)
07/06/2016: DGG (Goslar, Germany)
21/10/2016: ATIV 2016 (Parma, Italy)
08/11/2016: 77th Glass Problems Conference (Columbus, US)
08/06/2017: Society of Glass Technology Furnace Solutions 12, (Stoke-on-Trent, UK)

The "Michael Garvey Award" – for the most outstanding presentation of the day, at the Furnace Solutions conferences is presented to Dr. Tunç Görüney from Şişecam. This award is presented in memory of Michael Garvey – a previous speaker, who sadly died soon after presenting a paper at the 2008 conference. It is sponsored by Guardian Industries by whom Michael Garvey had been employed. The Award is specially commissioned piece of glass artwork.

This was also published in the Glass International Magazine on June 13, 2017 at the top line, and can be accessed via the following links:
http://www.glass-international.com/news/view/sisecams-tunc-goruney-wins-furnace-solutions-award
https://mxm.mxmfb.com/rsps/m/YZwMFzd62hnhmtpHuuz2Q-y7DXbI2eRLIKjrZN7Jytc

Meeting with stakeholders:

18/11/2014: IFRF French section (Albi, France)
06/02/2015: Glass conference in Ceramic society of Japan (Tokyo, Japan)
04/09/2015: TC09 Meeting (Bilbao, Spain)

Exhibitions:

08/05/2015: Glassman Lyon (France)
11/04/2016: 27th China International Glass

Internal promotions:

07/11/2014 Presentation in Şişecam 29th Glass Symposium (İstanbul)
2014/2015 Presentation to visitors (10 visits) (France)
21/10/2016 Presentation in Şişecam 31st Glass Symposium (İstanbul)
Visits on site (Şişecam, AL Bulgaria)
Meeting in April 2017 with another branch of Şişecam
12/05/2017 Internal Award and Recognition (Stars Parade, best corporate wide project)

Other dissemination activities

AL management of Eastern Europe visit in 2015
Asahi Glass Company visit of the HeatOx system in April 2017
AL Japanese team visit in April 2017

Per invitation of the Bulgarian Ministry of Environment and Water to the 'EUnited for a better LIFE International Networking Event', a presentation was made to share best practices of the LIFE Eco-HeatOx project. The event also enabled networking with two other LIFE projects and national policymakers.

4. Project long-term benefits and next steps

Environmental benefits

Table 1 shows overall achievement in terms of environmental impact. Eco-HeatOx was able to reduce about 8% of CO2 from combustion as opposed to the objective of 9,27%. The lower O2 and NG preheating temperature, 400°C or below, was the main reason for this lower performance, but the original estimation of 1% savings by 100°C increase of either combustion reactant was met. Therefore, we should be able to meet the objective, 9,27%, when we reach 450°C O2 and 450°C NG as designed.

ColdOx combustion did not outperform the air-fuel combustion to the extent of what was promised (8% energy efficiency reached vs 10% expected). Considering furnace aging effect, energy efficiency of the end-fired furnace is improved by 19% thanks to HeatOx and global CO2 reduction is estimated at 10% against air-fuel combustion, which is lower than the objective, 11,7%. This result, however, is not specific to Eco-HeatOx technology but to the plant condition. We strongly believe that the objective of HeatOx can be achievable once learnings from the Eco-HeatOx project are applied to the new furnace design.

	OBJECTIVES		RESULTS	
SAVINGS (taking into account aging effect)	Eco HeatOx vs Air.	Eco HeatOx vs ColdOxy	Eco HeatOx vs Air	Eco HeatOx vs ColdOxy
Energy Consumption (GJ/ton)	22,64%	8,89%	19%	8%
O_2 Consumption (Nm^3/h)	-	9,00%	-	8%
Dust (kg/ton)	61,54%	-	-	-
NOx (kg/ton)	90,00%	-	90%	-
CO_2 from Combustion (kg/ton)	23,47%	9,27%	19%	8%
CO_2 from raw materials (kg/ton)	-	-	-	-
Total CO_2 (comb+raw mat.) (kg/ton)	15,44%	5,74%	14%	5%
CO_2 production from O_2 (kg CO_2/ton glass)	-	7,50%	-	8%
Total CO_2 Process (kg/ton)	11,71%	5,81%	10%	5%

Table 1. Overall environmental results: Objectives with 450°C O2 and NG temperature and Results with 400°C or below O2 and NG temperature

More detail information on NOx emissions can be found in Table 2 and 3. NOx emissions were measured for different glass pull rates, and the NOx levels were corrected to the reference level of 8% oxygen in flue gas (dry). Compared to air-fuel combustion, NOx emissions of ColdOx were consistently lower by 83-93%. Also, NOx emissions of HeatOx were measured to be 86-91%, which is as good as ColdOx despite higher temperature of combustion reactants. These results validate the Eco-HeatOx target of 90% NOx reduction compared to the state of the art air-fuel combustion.

Mode	**ColdOx-B**	**ColdOx-B**	**ColdOx-B**	**ColdOx-B**	**Air-fuel Comb**
NOx as NO2 (kg/T)	0,424	0,459	0,410	0,181	2,677
Glass Pull Rate (TPD)	202	196	182	192	215

Table 2: NOx measurement **ColdOx vs Air-fuel Combustion**

Mode	**HeatOx-B**	**HeatOx-B**	**HeatOx-B**	**HeatOx-B**	**Air-fuel Comb**
NOx as NO2 (kg/T)	0,238	0,280	0,364	0,374	2,677
Glass Pull Rate (tpd)	200	198	204	208	215

Table 3: NOx measurement **HeatOx vs Air-fuel combustion**

Socio-Economic benefits

Air Liquide has employed 5 full time employees for HeatOx world wide deployment and 2,5 FTE of subcontractors is expected for each new project as needed during the erection of this pilot. This number does not include indirect employment for the technology development and support so actual employment should be larger. So far 8 AL and 18 PB employees have been trained and three of them were at managerial levels.

This project has enhanced public awareness of Paşabahçe Bulgaria as a green company. Paşabahçe networked with policy makers to emphasize importance of increasing public awareness on environmentally friendly production Technologies (BREF BAT compliance) and consulted with policy makers (Bulgarian Ministry of Environment and Water) to define best way of communicating to general public. Eco-HeatOx information board at Targovishte city center was placed with the approval of the Mayor.

This socio-economic benefits can be broadly realized only through the proliferation of the solutions. However, the current historically low NG price makes the situation less favourable to the technology. Plans are underway to further improve the performance and economic viability of the technology.

5. Next steps: replicability & transferability

In terms of replicability, it is estimated that about **628 furnaces** are operating in Europe for production of 43 Million of ton of every kind of glass per year. A majority, **490 units,** are regenerative or recuperative furnaces, which melt glass by air-fuel combustion with liquid or gaseous fossil fuel.

Type of glass	Total Number of glass furnaces EU-27 estimated
Domestic glass (tableware)	300 *(60 above 20 tonnes/day)*
Flat glass (float glass) *	58
Container glass*	175
Technical glass and fiberglass and others	95
Total*	628

Table 4: Number of EU glass furnaces

**Source: Best Available Techniques (BAT)*

Reference Document for the Manufacture of Glass Industrial Emissions: EC Directive 2010/75/EU (Integrated Pollution Prevention and Control)

Today, about **35 furnaces** are operating with oxy-fuel combustion in EU, for fiberglass and technical glass production mainly. Tank capacity in domestic (production above 20 tonnes/days), container and float glass production, represent nearly 82% of glass production in tonnage. Those account for **293 units** and can be potentially converted to HeatOx.

Since HeatOx could work with any type of glass and every fuel type, it could be implemented to any new furnaces.

At the end of a furnace's usual lifetime (7 to 12 years), when investment decision is made to renovate, HeatOx can possibly be implemented. Then, in 15 years, following the technology deployment in the market, a number of air glass furnaces could be converted to heat oxy-fuel combustion.

Even with very unfavorable natural gas price, there are quite a few glass companies considering HeatOx technology as a green solution.

In addition, Şişecam, who has hands-on experience in the technology, is considering the replication of HeatOx for float and fiber glass furnaces worldwide.

Air Liquide is also investigating into the transfer of HeatOx to other industrial applications such as cement, non-ferrous and enamels.

Again, lower replication rates than expected is due to the historically low natural gas price, which does not seem to recover in the near future according to various projections. In order to make HeatOx more attractive, all the equipment is under cost optimization. Moreover, plans are underway to further improve the performance and economic viability of the technology.