LIFE12 ENV/BG/000756

FINAL Report

Covering the project activities from 01/07/2013 to 31/12/2016

Reporting Date

31/03/2017

LIFE Eco-HeatOx

Demonstration & validation of a heat recovery packaged solution for decreasing oxy-glass factories' environmental impact

Project Data

Project location	Bulgaria
Project start date:	01/07/2013
Project end date:	31/12/2016
Total Project duration (in months)	42 months
Total budget	4,416,633 €
Total eligible budget	3,379,974 €
EU contribution:	1,689,986 €
(%) of total costs	38.26
(%) of eligible costs	50.00

Beneficiary Data

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Executive Summary

Project objectives, key deliverables and outputs for the end of the project

The LIFE Eco-HeatOx project has two main objectives:
- Reduction of GHG emissions linked to tableware glass production (compared to air combustion using a regenerative heat exchanger: 23% less CO2 and 90% less NOX)
- Increase of thermal efficiency in tableware glass plants (compared to air combustion using a regenerative heat exchanger: 23% more)

LIFE Eco-HeatOx aims to incentivize implementing heat recovery systems for small and medium size furnaces using natural gas by introducing an innovative technology focusing on small and mid-size tableware glass furnaces. The natural gas and the oxygen consumptions will be reduced by preheating the reactants (natural gas & oxygen) up to 450°C using waste heat from furnaces.

The project aims firstly to demonstrate and validate the technical feasibility at an industrial scale, and then to assess and widely disseminate the environmental benefits of this improved industrial process dedicated to small and medium size furnaces.

Following the research activities that have validated the methodology proposed for an energy-efficient and environment-friendly operation, the aim of this project is to validate the technology with a full scale industrial demonstration on a furnace producing tableware glass.

The demonstration phases are summarized by the following key deliverables of the project:
- Ready to start-up review (pilot)
- Report of furnace operation with cold reactants
- Report of baseline case with cold reactants
- Report of start-up with hot reactants
- Furnace running with prototype and nominal pull rate
- Report on Hot Oxy-combustion

Summary per chapter for the reporting period

This final report covers the period from July 2013 until December 2016 and it presents the final results of the project. The activities performed during the whole duration of the project are summarized within the sections below.

Technical part

After 4 months of preparation and installation (Action B1) until November 2013, the furnace has been started the first week of December for working in cold operations. At this period, ASU was not working properly and oxygen was partially delivered by trucks. After main issues have been fixed and permits of exploitation agreed, the ready-to-start up review has been signed and Air Separation Unit has started to deliver its 2548 Nm3/h O2 as expected (Action B3).

Optimization of cold oxygen “Coldox” operation have been performed to improve efficiency gain and reach between 8% to 10 % compared to an air furnace used as a “reference”:
- By changing fire distribution in order to study foam,

- By optimizing fire distribution in order to reduce furnace temperature,
- By changing batch composition in order to reduce bubbles flow,
- By managing furnace pressure in order to reduce air ingress that are partially responsible of extra fuel consumption.

After the pilot development & building phases (Action B2) relating to cold operation was completed, developmental activities were focused on designing & integrating the HeatOx system to the pilot furnace. In this regard, many site visits, meetings and exchanges of data took place with the primary recuperator manufacturer for preparing the layout of the air heating system. In parallel, positioning of the secondary heat exchangers and routing of the hot operation piping between burner skids and burners were also defined in order to allow an on-the-fly installation. Nominal capacities of the secondary heat exchangers, which is important for operating the heat exchangers at peak efficiency, were set based on the most favorable fuel distribution as foreseen for the hot operation.

The final fuel consumption gain brought by reactant preheating has been measured at 9,4%.

Implementation of all sub-parts of HeatOx system occurred in 3 months in summer 2015 while furnace continuously produced glass. Especially, recuperator & burner installation was carefully led to minimize impact on production.
After commissioning and start-up, troubleshooting has been performed on various issues until summer 2016:

- Flue gas channel insulation
- Hot air leaks
- Flue gas cut-off damper sealing
- Clogging on interconnecting duct of recuperator
- Soot deposit on burner tip & block wear

Eight measurements campaigns (see Action C4) have been launched in order to:

- Support troubleshooting
- Measure NOx on Pilot and air furnace
- Audit the performance of the system

<u>Communication and dissemination actions</u>

Besides being focused on the technical aspects of the project, the partners are engaged in some dissemination activities. A dedicated website was set up and updated according to the EC remarks and requests following the Inception Report:

- A “News” section has been created,
- A “Home” button has been created for more navigability,
- A translation in Bulgarian has been created,
- It has been checked that writing “Eco-HeatOx” in Google displays the project website first,
- The link to access the project’s web-summary has been added: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4764

The information boards have been displayed on partner’s sites and at strategic places visible for the public as requested by the EC.

The LIFE Eco-HeatOx partners also attended some conferences and other events. They shared also some of their results in the frame of networking with potential customers and other project co-funding from European Commission: discussion with LIFE 11 ENV/CZ/000488 and exchange of website links with LIFE project lead by STARA GLASS (Action E.2: Networking with other projects). It is to be noted that the Strategic dissemination plan (Action D.4) has been prepared at the beginning of the project and the After-Life communication plan (Action E.3) and the Layman's report (Action D.3) have been prepared at the end.

The progress and results of the project have been disseminated in several events:

Presentation at GRTgaz	Industrial Conference	Sevres, France (Nov. 2013)
Presentation at AFRC conference	Scientific conference	Houston, USA (Sept. 2014)
Presentation at ATIV	Glass conference	Parma, Italy (Sept. 2014)
Presentation at Balkan Conference	Glass conference	Nessebar, Bulgaria (Oct. 2014)
IFRF conference	Seminar	Albi, France (Nov. 2014)
Presentation at Ceramic Society of Japan	Seminar	Tokyo, Japan (Feb. 2015)
TCO9 meeting (ESG conference)	Meeting with stakeholders	Bilbao, Spain (Apr. 2015)
Glassman Europe	Exhibitions	Lyon, France (May. 2015)
Presentation at 76th Glass Problems Conference	Glass conference	Columbus, US (Nov, 2015)
27th China International Glass	Exhibitions	Shangai, China (April, 2016)
Presentation at 24th International Congress on Glass	Conference	Shangai, China (April, 2016)
HVG-DGG	Conference	Goslar, Germany (June, 2016)
Presentation at 77th Conference on Glass Problems	Industrial Conference	Columbus, Ohio USA (Nov. 2016)
Presentation at ATIV 2016	Conference	Parma, Italy (Oct. 2016)
31st Glass Symposium	Industrial Conference	Istanbul, Turkey (Oct.2016)
Asahi Glass Company Visit of	Company Visit	Targovishte, Bulgaria (Apr. 2017)
Winner of the Stars Parade (Annual Sisecam Event)	Internal Award Ceremony	Istanbul, Turkey (May 2017)
Presentation at ‘‘EUnited for a better LIFE’’ International Networking Event by MoEW	Networking Event	Sofia, Bulgaria (May 2017)
Presentation at Furnace Solutions 12 by SGT	Industrial Conference	Stoke-on-Trent, United Kingdom (Jun. 2017)

1 Introduction

The tableware glass production requires a lot of energy and produces a large amount of GHG. The oxy-combustion as well as waste heat recovery have already allowed a decrease of the environmental impact of the large glass furnaces. To ensure a lower impact for the environment of small and medium size 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.

In 2006, the production of tableware glass was 1,470,000 tons in the EU countries. It represents 4% of the total glass production. There are approximately 300 tableware plants in the European Union. Most of them (240) have a daily production under 20 tons while 19 have a daily production above 100 tons. These numerous plants with relatively small production will be particularly interested by the solution with a few equipment proposed by PB and AL. In 2008, FEVE (European Federation of glass packaging and glass tableware makers) countries' total tableware production was 1,131,900 tons.

During the LIFE Eco-HeatOx project, current and future regulatory frameworks for climate change and pollution (CO2, NOX, energy consumption) are taken into account for their compliance and override. This will allow to formulate challenging and relevant environmental impact goals that could be realized through this project.

As the currently available hot oxy-combustion technologies are dedicated to large furnaces, no suitable comparisons can be made with an air-combustion furnace which is the currently used technology for tableware glass furnace in PB's plant. A comparison for the new technology with cold oxy-combustion is also planned in order to highlight the interest of heat recovery in small and mid-size furnaces.

According to each partners' expertise and with the support of AL, PB/TGB's teams of the plant of Targovishte were directly involved in the validation of the pilot furnace. In parallel, AL performed the demonstration and conducted in-depth analyses for the factors impacting the validation of the pilot furnace and its environmental results. PB also supportedAL through its scientific expertise in table glass production.
LIFE Eco-HeatOx devotes a specific attention to burners, furnace performances, emissions and glass physical properties evolutions.
The main technical challenge lies in the use of hot oxy-combustion. This step is essential for the understanding of the hot-oxy combustion technology dedicated to small and medium size furnaces. Indeed, this is the stage that allows to validate the technology.

The expected outcome is the validation of innovative environmentally friendly processes for tableware glass plants. The initial objective is to reduce specific energy consumption up to 23% compared to furnaces operating in air combustion with regenerative heat exchangers. Air combustion with regenerative heat exchangers is known to be one of the most efficient air combustion technology.
Objectives in terms of energy consumption: 23% of natural gas saved compared to air-combustion and 9% compared to cold oxy-combustion, and, in relation to this, 1 052 000 kWh a year saved in oxygen production (54 272 tons of oil equivalent given that in Bulgaria almost 60% of electricity come from fossil energy).

2 Technical part

<u>Actions B: Implementation</u>

<u>Action B.1: Pilot furnace and piping development</u>

Description of performed activities

Pilot furnace, which is sized for a medium capacity (200 ton/day) tableware production, was so developed as to integrate the HeatOx system on the fly without any disturbance to ColdOx operation. Areas were identified to maximize re-use of the existing infrastructure and the material. One example is the common use of the existing chimney originally built for the regenerative furnace commissioned in 2005. Also, surplus steel and insulation material left over from the old furnace were identified to be re-used on the pilot furnace. This action was completed by the end of August 2013.

Layout and piping development were carried out with utmost attention to minimize pressure and thermal losses. Also, in order to prevent any dispute between piping layout and the civil work that would require an extensive re-work and violation of safety aspects, a close coordination between the engineering, civil work and he environmental departments was maintained. Contract awards to licensed subcontractors were issued by the end of September 2013.

Air Liquide has externalized the activity of piping drawing and development to ensure quality of the process diagram.

The final layout of the secondary heat exchangers (SHx) to be positioned between burner skids and burner blocks was discussed and agreed upon with Air Liquide in light of the interferences of the civil works around the furnace. Nominal capacities of SHxs, which is important for operating the heat exchangers at peak efficiency, were set based on the most favourable fuel distribution as foreseen for the hot operation.

Waste gas quantity and temperature at the inlet of primary heat exchangers (PHx) were reviewed with AIT, and TGB pledged that the required waste gas temperature (1150^{o}C min-1200^{o}C max) demanded by AIT at the inlets will be guaranteed through extra insulation on the vertical flues. Due to limitations posed by support structure under the furnace, double holes to be drilled on the horizontal flue roofs downstream of the vertical flue was determined as the best positions for the primary heat exchangers. Although this constraint in layout led to a more complex solution not foreseen before, it proved to be the only viable option for the installation of the secondary heat exchangers. Following this, TGB was tasked with job of cleaning all interfering pipe & ducts in the available shaft through which heavy PHx parts was planned to be lowered via plant roof.

Air Liquide has run a safety analysis based on an internal industrial process that consists in:

1. Making an ARA (Analysis of Risk Anticipated)
2. Identifying responsibilities
    - Defining interfaces between the elements of the technology

    - Defining design authorities for each element
3. Performing an HAZOP (HAZardeous OPerations)

Particular attention is paid to the switch from natural gas to Liquified Petroeleum Gas and to potential leak of natural gas in the air loop.

Action B.2: Pilot building

Before the pilot building started, The Ministry of Environment was officially contacted for the categorization of the new technology and the determination of the new emission limits and the update of the exploitation permits were sought. After the building permission was granted, pilot building was initiated with the selected teams of contactors and the overseers and was completed by the mid of November 2013.

Between July and December 2015, the technology of natural gas and oxygen preheating has been implemented on the plant of Pasabahce at Targovishte without stop of the furnace or glass quality issue or safety issue. This erection had involved between 10 to 30 workers on site during 3 months with 2 supervisors full time.

To avoid any perturbation on glass production, HeatOx burner had been installed one by one with a specific weekly sequence

Commissioning had then been performed with leak test of piping and all process control check including safety interlock. A detailed start-up review has been fulfilled. Commissioning has requested a team of 10 peoples during 3 weeks.

Action B.3: Launch and Implementation of the cryogenic device for O2 production

The Air Separation Unit has been installed during Q4 2013. Production Plant is mechanically completed and commissioned, demonstrating the capability of nominally production with proper quality.

Action B.4: Launch and implementation of the pilot furnace

Around the mid of November 2013, heat up burners were commissioned to get the pilot furnace from room temperature to 1550ºC in a gradual manner to avoid stress and cracking in the refractory structure. Glass pull occurred in the first week of December. During 10 days testing at low pull rate (120-130 ton/day), gas and oxygen flows to burners were checked to see the ratios set at the central control system were correct. Also, test of the pressure boundaries prerequisite for safety operation of the pilot furnace was done.

Foam generation on glass furnace at nominal pull (200 ton/day) was more excessive than expected and necessitated a re-adjustment of fining agents and raw materials to mitigate this problem. Also, ratio of oxygen and natural gas was checked by extractive measurements for each burner and oxygen leakage control was made to see if there was any crack on the burner blocks.

In 2014 and 2015, the work has been focused on three main activities:

- Reducing foam by playing on fire distribution,

- Changing batch composition in order to measure effect of bubbles,
- Installation one Heatox burner for qualification before full conversion of furnace.

Foam was identified as the main contributor to the higher-than-expected fuel consumption in cold operation. Therefore, activities have centered on mitigating the foam's adverse effects on energy performance. Model studies were performed by Air Liquide to optimize the fuel distribution so as to lessen the effect of foam on energy performance. In line with model outputs, some part of fuel on the large capacity burners near doghouse were transferred to downstream burners. It was noticeable through close observations that this shift in fuel distribution helped decrease the foam thickness under upstream burners.

Another way to play on foam consists in changing batch composition. Reducing fining agents' quantity is a way to reduce number of bubbles. This induces a change of equilibrium Fe^{2+}/Fe^{3+} that can only be mastered by adding decolorizing agents. However, there is a limit because bubbles appears in the glass melt when fining agents are reduced too much. Trials have been performed several times by TGB but it is not possible to decrease below a certain amount of fining agents: glass quality was jeopardized.

In order to prepare full conversion to Heatox technology, one burner was decided to be installed about a year earlier (2014).
The first HeatOx burner was installed in September 2014, after some update of the design the burner did not show any issues for a year of operation.

Starting in July 2015, the installation of HeatOx system was completed in Sept 2015, followed by commissioning/start-up with NG/O2 temperature around 350°C. Since we could not reach the design O2/NG temperature (450ºC), a lot of efforts have been made to increase O2/NG temperature through the activities described below. Also carbon deposit on HeatOx burner tips, which was thought to be due to the lower NG temperature (lower velocity) than designed, have been solved.

Flue gas channel insulation and air ingress
Flue gas temperature was found to be 100-200ºC lower than the design temperature (1150ºC) with significant amount air ingress. In order to minimize heat loss and air ingress, it was decided to insulate the flue gas channel.

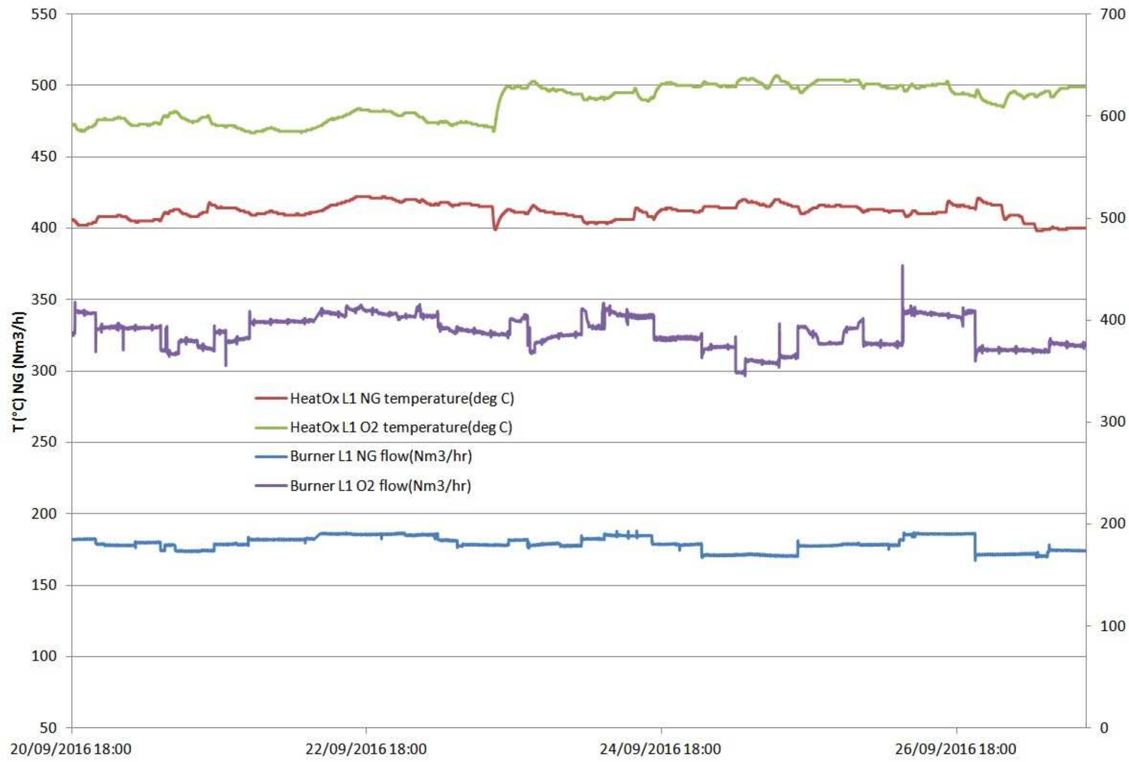
Bypass damper installation
The role of the bypass damper was critical in that it dictated flue gas flowrates to the primary recuperator. The failure of the original damper led to significant less flue gas flowrate to the recuperators. Therefore, different damper designs were tried to have more robust operation.

Intermediate channel De-Clogging
Due to the bypass damper failure, we experienced the plugging of the intermediate flue gas duct connecting the two recuperators.

NG gas lance / burner replacement
Due to the carbon deposit issue, designs of NG lances has been updated to mitigate the low NG temperature impact. Information about burner follow-up are described in more details in Actions C. All burners versions (500 kW - 1000 kW - 2000 kW) are now running well

without carbon deposit or need of maintenance and with a flame shape satisfying the glass melting process.

After completion of work on fumes duct, damper and interconnecting piece of recuperator, the system performances were much better, and NG/O2 reached respectively temperatures around 400°C and 500°C close to design condition, ie fumes temperature at inlet of recuperator close to 1150°C.



Actions C: Monitoring of the impact of the project

Action C.1: Monitoring of pilot furnace development

With the participation of Sisecam Design Group (BTM), 6 site visits & meetings were organized in Targovishte to review the progress of the project. In addition, there was continual exchange of data between project partners. Air Liquide made several site visits to give information on the development progress of the hot oxy combustion.

Action C.2: Monitoring of pilot building and implementation

In order to monitor the furnace, two main actions have been launched in 2015:

- Numerical simulations have been performed to understand the effect of foam on furnace temperature (Sub-action C2.1)
- Endoscopy of the furnace have been performed to check if furnace and burner blocks are damaged (Sub-action C2.2)

GLASS1D program developed by Air Liquide has been used. It shows how to adapt the fire distribution in order to reduce foam.

Three endoscopic campaigns have been prepared and have shown that furnace and burner blocks were not damaged by oxygen combustion.

In February 2016, another endoscopy campaign was performed to investigate the condition of the burner blocks. Images show no structural damage of the furnace superstructure but slight deposition on burner block, which is cleaned by operators periodically. Blocks where it was difficult during hot installation to set spacer brick properly around are suffering of an accelerated wear.

Action C.3: Monitoring of pilot operation

Sub-action C3.1: Since the beginning of the furnace, quality of glass has been tracked with a lot of attention. The main quality parameters of a tableware glass are the seed count per unit mass and the position on a-b diagram. There has been no difference in seed content or in color quality between oxy combustion B furnace and A furnace, which is of regenerative air combustion type.

Sub-action C.3.2: In order to be able to assess fuel consumption of B-Furnace 6 campaigns have been performed with full furnace audit:

- measurements of flue gases temperature and concentration on A-furnace,
- measurements of temperature and composition of flue gases all along the chimney of B-furnace,
- Helium tracking technique in order to quantify the fumes flow rates.
- Heat & mass balance of furnace A & B

Sub-action C3.3: Monitoring of heat exchanger & burner

To be able to perform an accurate heat & mass balance of the various heat exchanger, manual air flow measurement has been led by AL during two dedicated campaigns following an agreed methodology. This data made more consistent the heat & mass balance of the HeatOx system.

Thermal expansion of heat exchanger and associated piping have been monitored by regular measurement of deviation of the position from the original value. Thermal expansion had not created any stress on the mechanical structure or piping thanks to proper design of the devices (spring-hanger, sliding plate, bellows) managing the thermal expansion of the system.

Outlet temperature of heat exchanger was recalculated with the actual conditions of the operation. Discrepancy between measured values of and calculated values of outlet temperature are lower than 10°C. Therefore it was concluded that heat exchangers were performing almost as expected.

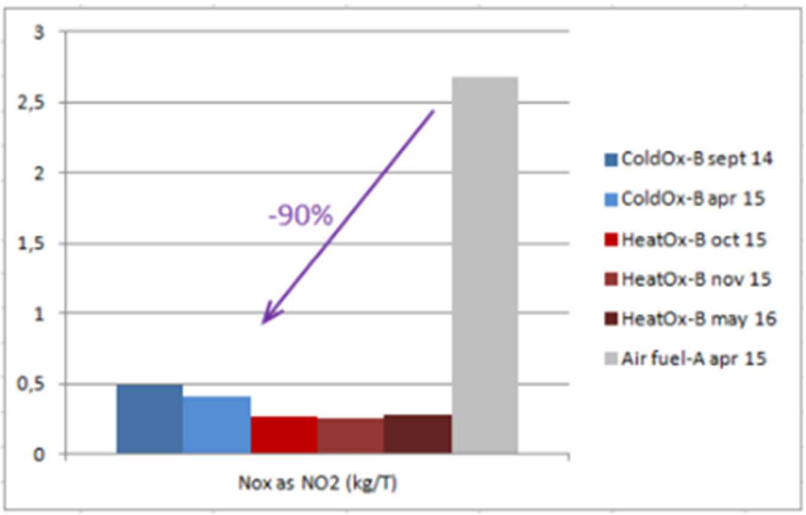
When system switched to HeatOx, soot deposits have been identified on the burner tip after a few weeks of operation. The issue was more apparent for 1MW burners and especially when they were operated at very low power (~600kW). The soot deposit was different from the massive failure for the original burners in that the burner tips were intact. After detailed investigations and tests of various lance design an updated design of 1MW burners has been implemented and successfully solve the soot deposit issue.

Action C.4: Monitoring of environmental parameters and socio-economic impact

Description of performed activities

The environmental impacts of the project have been measured in coldox and HeatOx operations during 10 campaigns made by AL and TGB and compared to furnace A representative of regenerative furnace. Oxy-fuel furnace B exhibits NOx emissions reduced by 90% compared to air furnace A whatever the temperature of O2 and NG.

Besides the various campaigns of fumes measurement have clearly demonstrated that despite the preheating of the reactant, NOx emissions are equivalent to the coldox operation around 0,3 kg/Tglass below the regulation (0,5-1,5 kg/tglass).



A methodology has been agreed to correct the effect of electrical boosting and cullet ratio. All data are corrected at 25% of cullet ratio and without electrical boosting
Energy savings between Cold oxy-fuel and air end-port regenerative have been evaluated around 8% to 10% in average at designed pull (220 tpd) during the first two years of operation. Taking into account the aging effect of 0,5% per year for oxy-fuel furnace and of 1% per year for end-port furnace (figure from state of the art), its energy savings would become close to 14% after 10 years. This value is under the intermediate target of 15% mainly because foam still remains important despite AL & PB efforts.

Performance test of a couple of weeks at various pull rate highlights an average of 8% of energy savings compared to best operation in cold oxy-fuel and up to 9,4% at design conditions, ie fumes temperature close to 1150°C. Because of issues about insulation on vertical flue gases channel, fumes temperature is sometime below the desired temperature reducing O2 and NG temperature and thus savings down to a minimum of 7%.

HeatOx energy efficiency compared to air-fuel regenerative end-fired furnace has thus been measured at 16%. To compare with the initial objective, aging effect has to be taken into account and by doing so, energy efficiency of HeatOx compared to air-fuel regenerative end-fired furnace would reach 19% in the middle of the campaign.

The results are summarized in the table below:

Savings (Taking into account aging effect)	Objectives Eco-HeatOx vs Air	Results Eco-HeatOx vs Air
Energy Consumption (GJ/ton)	22,60%	19,00%
O2 consumption (Nm3/h)	-	-
Dust (kg/ton)	61,54%	-
NOx (kg/ton)	90,00%	90,00%
CO2 from combustion (kg/ton)	23,47%	19,00%
CO2 from raw material (kg/ton)	-	-
Total CO2 (comb + raw) (kg/ton)	15,44%	14,00%
CO2 from O2 production (kg/ton)	-	-
Total CO2 process (kg/ton)	11,71%	10,00%

- Operation of the pilot furnace with hot natural gas and oxygen has been demonstrated compared to traditional air regenerative end-port
  - energy consumption is reduced by 19%
  - direct pollutants emissions are reduced by 19% for CO_2 and 90% for NOX
- Project has validated that while the pilot furnace operates in hot oxy-combustion:
  - energy consumption is 19% lower than an air-combustion furnace
  - pollutants emissions are reduced by 14% for CO_2 considering the CO_2 coming from raw material and by 10% considering O_2 production

3 Dissemination actions

3.1 Objectives

Different actions are dedicated to the communication and the dissemination of the progress and results reached during the project in order to ensure they will be communicated as broadly as possible:

- **D.1 Project website:** The objective of this action is the development of a project website to ensure a dissemination of the project via electronic media with a specific focus on its environmental benefits, both during the project lifetime and after its termination.
- **D.2 Life + information boards:** The objective of this action is the preparation of LIFE+ information boards describing the project.
- **D.3 Layman's report:** The objective of this action is the issuing of the Layman's report at the end of the project that will report all the objectives, actions and results of the project.
- **D.4 Strategic dissemination plan:** The objective of this action is to prepare a plan to ensure an appropriate dissemination of the project to the different targeted audiences.
- **D.5 Other dissemination:** The objective of this action is to ensure an appropriate

dissemination of the project, with a specific focus on its environmental benefits, both during the project lifetime and after its termination. The aim is to diffuse communication tools in order to maximize the targeted audience, including creation of brochures and posters, articles in specialized press, conferences and seminars, fairs and exhibitions, guided visits to show pilots.

- **E.2 Networking with other projects:** The objective of this action is to ensure an effective networking with other projects, to a mutual benefit of both, not only during the project duration but also after its termination. The main objective is the transfer of knowledge and information exchange with professionals of the area and of the LIFE programme.
- **E.3 After-Life communication plan:** The objective of this action is the definition of an action plan to pursue the dissemination and communication of the project's results after its end.

3.2 Dissemination: overview per activity

Actions D: Communication and dissemination

Action D.1: Project website

Description of performed activities

The website has been carried out with support of an external assistance. The website is composed of five pages:

- Homepage,
- Partners,
- Technology,
- Results,
- News.

The website is hosted by an internal Air Liquide platform which allows managing the evolution of the website by project manager. It has been updated according to the EC remarks and requests following the Inception Report:

- A "News" section has been created,
- A "Home" button has been created for more navigability,
- A translation in Bulgarian has been created,
- It has been checked that writing "Eco-HeatOx" in Google displays the project website first,
- The LIFE logo has been added on the pages where it was missing ("Partners" and "Technology"),
- The name of the project coordinator has been updated,
- "Sisecam" has been replaced by "Pasabahce Bulgaria",
- "Eco-heatox" has been replaced by "Eco-HeatOx",
- The link to access the project's web-summary has been added: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=4764

Action D.2: LIFE+ information boards

Description of performed activities

Five large size information boards have been installed. One at the main entrance of the plant, one on the main road near the plant, one at the Pilot Furnace, one at Vabel district and one near the center of city of Targovishte for the local people to easily see, upon approval from Municipality of Targovishte. Moreover, three small size information boards have been installed in the administrative building of Pasabahce Bulgaria plant. Also, a poster paper about the project's objectives was given at a symposium organized by Sofia University.

Targovishte City center

Pasabahce plant indoors

Action D.3: Layman's report

Description of performed activities

A Layman's report was produced at the very end of the project summarizing the main project achievements and highlighting the main environmental benefits of the innovative oxy-combustion technology developed and demonstrated during the LIFE Eco-HeatOx project. This Layman's report will target a very large audience and has been done in 3 languages (EN, BG and FR). The three versions can be downloaded from the website.

Action D.4: Strategic dissemination plan

Description of performed activities

Both partners have defined an overall dissemination strategy and the role of each entity. This strategy includes the following activities:

- printing of informational material
- publishing in specialised press
- participation to seminars and conferences
- participation to fairs and exhibitions
- project website

Partners have also identified specific actions to address stakeholders such as:

- guided visits to show pilots
- Layman's report
- press releases

The strategic dissemination plan was an ever evolving document that was updated when the consortium has new dissemination opportunities.

Action D.5: Other dissemination activities

Description of performed activities

Partners have participated to several seminars and conferences being the occasion to present the objectives and then the results of the Eco-HeatOx project:

Presentation at GRTgaz	Industrial Conference	Sevres, France (Nov. 2013)
Presentation at AFRC conference	Scientific conference	Houston, USA (Sept. 2014)
Presentation at ATIV	Glass conference	Parma, Italy (Sept. 2014)
Presentation at Balkan Conference	Glass conference	Nessebar, Bulgaria (Oct. 2014)
IFRF conference	Seminar	Albi, France (Nov. 2014)
Presentation at Ceramic Society of Japan	Seminar	Tokyo, Japan (Feb. 2015)
TCO9 meeting (ESG conference)	Meeting with stakeholders	Bilbao, Spain (Apr. 2015)
ICG Conference	Conference	Bilbao, Spain (May. 2015)
Glassman Europe	Exhibitions	Lyon, France (May. 2015)
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31st Glass Symposium	Industrial Conference	Istanbul, Turkey (Oct.2017)
Asahi Glass, Electronics Comp.	Company Visit	Targovishte, Bulgaria (Apr. 2017)
Stars of the Year (Annual Sisecam Event)	Internal Award	Istanbul (May. 2017)

It is to be noted that partners are continuing disseminating project's results after the end of the project (see the last two lines of the above table).

During the first two years, guided visits of the plant were dedicated to the AL and TGB Management and to the Monitoring team. After the installation of the heatox furnace, partners organized guided visits for other stakeholders as well (see above table).

8 contacts have been initiated with glass makers interested in the HeatOx technology.

Before the installation of Heatox the furnace has been visited by:

- Sisecam CEO: Prof. Ahmet Kirman (April 2015)

- Sisecam R&D President: Prof. Dr. Sener Oktik (April 2015)
- AL Management team of AL Bulgaria: Ioannis Merkos (June 2015)
- Sisecam R&D Management team: Attila Unsal (June 2015)
- Neemo: Stoyan Yotov (June 2015)
- Sisecam CEO of Tableware Group: Mr. Cemil Toker (June 2015)
- Sisecam Vice President of Tableware Production: Ahmet Okan (July 2015)

Air Liquide is also highly promoting the technology internally by making presentation of Eco-HeatOx to all visitors of Combustion group.

It is also to be noted that news in internal website of Air Liquide has been published.

Action E.2: Networking with other projects

Description of performed activities

Partners performed networking activities with Stara glass (Italy) which is also implementing a LIFE project on glass:
- Telephone conversation with Erneste Catteneo following the conference ESG /ATIV (21/24 september 2014)
- Upcoming meeting with PrimeGlass by end of 2017 to discuss results of projects and exchange of experience on dissemination

It is also to be noted that a presentation of the LIFE Eco-HeatOx project is provided on the LIFE PrimeGlass website.

Pasabahce networked with two other Bulgarian NAT projects at ‘‘EUnited for a better LIFE’’ international networking event in Sofia on May 22, 2016 (Lesser Kestrel Recovery - LIFE11 NAT/BG/000360 and Save the Raptors - LIFE07 NAT/BG/000068).

Partners also performed networking with local authorities:
- Compliance needed with EU reference methodology for NOx calculation of oxy-fuel flue gases
- Current setup (oxy-fuel flue gas treated in air-fuel DeNOx system) creates unnecessary treatment cost for Paşabahçe Bulgaria
- EC assistance requested to initiate discussion with local authorities (Q4 2016)
- Pasabahce networked with MoEW representatives at ‘‘EUnited for a better LIFE’’ international networking event in Sofia on May 22, 2016 regarding the best practices of LIFE Eco-HeatOx project.

Şişecam group is considering potential applications of the Eco-HeatOx technology in other locations such as Kırklareli and Eskişehir.

It is also to be noted that partners are currently exploring how to work together on developing and deploying next version of HeatOx technology with improved CAPEX and OPEX. A new LIFE proposal to go beyond the LIFE Eco-HeatOx has been submitted in 2016 and has been approved by the EC (Grant Agreement already signed). This new project will allow replicating the technology widely thanks to its improved financial viability.

Action E.3: After-Life communication plan

Description of performed activities

An After-LIFE communication plan was elaborated. This plan summarizes the main communication action that will be performed upon key stakeholders (glass producers, public authorities, standardization bodies, etc.) in order to ensure a good dissemination of the LIFE Eco-HeatOx project and on the environmental benefits of the technologies demonstrated to this research. These actions will also deeply pave the way to the implementation of more environmental-friendly furnace technologies in EU but also across the world, first for glass applications but also for other applications such as ceramics, steel, cement.

The main activities that will be performed will include:

- Participation to dissemination events: fairs, exhibitions, conferences;
- Maintain the website until 5 years after the end of the project;
- Networking activities with standardisation bodies or within industry associations or EU technology platforms.

4 Evaluation of Project Implementation

Methodology applied

The project methodology is that described in the Grant Agreement. It started with the modelling of a single LIFE Eco-HeatOx burner within part of combustion chamber to evaluate the flame shape. Detailed burner design was included in the CFD (Computational fluid dynamics) model. Commercial software Fluent was used for this work.

Then, the project consisted in modeling all (LIFE Eco-HeatOx) burners within the combustion chamber. Temperature profile and flue gas flow pattern in the combustion space have been obtained. Detailed design of combustion chamber and the oxygen and fuel flow rates of all burners were required inputs. The batch/glass surface temperatures were also needed as the boundary condition. Commercial software Fluent have been used for these CFD simulations.

Finally, the idea was to simulate all (LIFE Eco-HeatOx) burners within the entire glass melting furnace (the combustion chamber and glass tank) to study the flames in the combustion space and at the same time the heat transfer from the flame to the batch/glass surfaces. Flue gas temperature and velocity profiles in the combustion space have been obtained. The glass melt temperature distribution and flow pattern were also available. Advanced coupling models were used for these simulations because the entire glass melting and heat transfer from the combustion space to the glass needed to be calculated. Detailed design information of glass melting furnace, and the oxygen and fuel flow rates of all burners, as well as batch flow rate and thermal physical properties of glass melt were required. Commercial software TNO, Fluent and AL in-house code Athena have been used for this CFD simulations.

The furnace's structure has also been analysed by performing endoscopy visual check on refractories. Analysis of glass samples was also required in order to check the quality of the pilot furnace's production.

The energy efficiency of the pilot furnace has been analyzed by measuring the heat losses using thermography, thermocouples, and optical pyrometers. A laboratory, authorized by the Bulgarian legislation, in accordance with EU law, measured NOX, SOX, CO, total particles, etc. Continuous on-site measurement of NOX, and CO emissions have also been performed. The CO2 emissions have been calculated based on gas and raw material consumption, in accordance with the approved Monitoring plan in the EU ETS. These elements were key to the success of the project. All these activities aimed at validating the industrial tableware glass production process implemented in the LIFE Eco-HeatOx project.

Cost-efficiency of actions has been ensured by regularly following expenditures. Moreover, financial discrepancies are justified in Sections 6.1 and 6.5. Some deviations in terms of expenditure have been explained with a request of amendment and have been accepted by the European Commission.

Results achieved

The project was progressing well until delays appeared for the installation of the Primary Recuperators onto flues. Due to the complexity of the existing layout and having to make the integration on-the-fly without any interruption to production entailed many meetings and site visits to finalize final layout and installation schedule.

Table 2 shows a summary of the tasks (only implementation since dissemination are discussed lately) performed within the project and an evaluation (expected results well achieved).

Table 2: Project progress vs. timing foreseen in the Grant Agreement

Task	Foreseen in the revised proposal	Achieved	Evaluation
General layout of the pilot furnace building (B.1; C.1)	August 2013	August 2013	The pilot furnace has been designed
Layout of the ASU(Air Separation Unit)-distance to furnace building (B.1; C.1)	August 2013	August 2013	ASU supplies oxygen at correct O2 purity and pressure
Flow charts of the system and drawings of the technical parts (B.1; C.1)	March 2014	March 2014	All flow charts and drawings are achieved
Getting necessary permits for civil work and stack emissions (B.2; C.2)	July 2013	July 2013	All required permits for civil work and stack emissions have been obtained
Completion of detailed engineering drawings: refractory, steel, ducts, civil works (B.2; C.2)	August 2013	August 2013	All engineering drawings are achieved (highly confidential documents)
Detailed layout and diameters of O2 pipework from ASU (Air Separation Unit) to safety skid to burner skids to heat exchangers to burners (B.2; C.2)	August 2013	August 2013	O2 pipework from the Air Separation Unit to the pilot furnace has been designed as foreseen.
Detailed layout and diameters of natural gas pipework from pressure regulating station to safety skid to burner skids to heat exchangers to burners (B.2; C.2)	September 2013	September 2013 June 2015	Natural gas & O2 pipework from the pressure regulating station to the pilot furnace has been designed as foreseen. Hot piping from burner skid to heat exchanger designed later in June 2015
Detailed layout and diameters of ductwork from primary recuperator to heat exchangers (B.2; C.2)	November 2013	April 2015	Ductwork from primary recuperator to heat exchangers has been designed as foreseen.
Completion of all civil works (B.2; C.2)	September 2013	September 2013	Civil works have been performed allowing the installation of the pilot.
Installation of all the equipment to the furnace exhaust and auxiliary equipment (B.2; C.2)		September 2015	All equipment for heatox operation have been installed at mid-September 2015
Pilot able to operate and produce: - Quantity: 2548Nm3/hr of O2 - Quality: 95% purity and 0.46kWh/Nm3 (B.3)	November 2014	April 2014	The ASU is able to operate in the required conditions
Completion of all assembly work (refractory, steel and duct work, combustion system and pipework) (B.4)	October 2013	December 2013	All assembly work has been performed and the furnace started with coldox in December 2013
Meeting all safety criteria required	October	December	CE label on valve trains. Safety

by OEM (combustion equipment) and local authorities (B.4)	2013	2013	check and commissioning in December 2013
Validation of the cold oxygen operation in production conditions (B.4)	March 2014	Yes	Coldox operation has been validated in production conditions
O2 temperature above 450°C for nominal flowrates (~2150Nm3/hr) (B.4)	June 2015	June 2016	HeatOx start-up at right temperature
NG temperature above 450°C for nominal flowrates (~1070Nm3/hr) (B.4)	June 2015	June 2016	HeatOx start-up at right temperature
Glass quality analysis (C.3)	December 2016	October 2016	Analysis of Glass quality
Heat balance in the furnace (C.3)	December 2016	October 2016	Continuous inspection from Oct 2015 to end of project
Inspection of the new burners (C.3)	December 2016	December 2016	Continuous inspection from Oct 2015 to end of project
Inspection of heat exchangers evolutions (C.3)	December 2016	December 2016	Continuous inspection from Oct 2015 to end of project
Validation of energy consumption and pollutants' emissions reductions in cold oxy-combustion and Analysis of potential cost savings per ton and per year of production (C.4)	August 2014	December 2015	All measures have been performed and the related deliverable has been finalized in December 2015
Validation of energy consumption and pollutants' emissions reductions in hot oxy-combustion and Analysis of potential cost savings per ton and per year of production (C.4)	June 2016	October 2016	First results in October 2016
On the field flue gases analysis: O2 measurements, CO2 concentration and flue gas temperature measurements (C.4)	December 2016	December 2016	Continuous monitoring all along the project
Evaluation of the socio-economic impact of the project actions on the local economy and population (C.4)	December 2016	December 2016	

Effectiveness of the dissemination

The partners have set up a website with information about the project, and have displayed Information boards on sites. The partners have participated to conferences and other events. Persons/companies interested in this technology are encouraged to contact the partners and discuss their experiences.

As it has been mentioned above, direct contacts have been taken with other companies (Stara Glass, AGC, etc.), which may be interested in implementing the Eco-HeatOx technology now that the efficiency and benefits of the technology have been assessed.

Within the Table 3, is summarized the progress or the project actions in terms of dissemination activities vs. objectives set-up in the Strategic Dissemination plan.

Table 3: Dissemination actions performed vs. Strategic dissemination plan

Action	Task	Status
D.1	Website creation	Website has been created and modified upon EC request. It has been regularly updated based on the progress of the project and will be maintained for 5 years.
D.2	Information Boards	Information boards have been created and are implemented in the partners' premises and near the center of Targovishte.
D.3	Layman's report	Layman's report prepared in Q4 2016 in English, Bulgarian and French.
D.4	Strategic dissemination plan	Strategic dissemination plan prepared in Q2 2014.
D.5	Participation in fairs and exhibitions	Partners have participated to 2 exhibition for the dissemination of the Eco-HeatOx project. A presentation has been done at Glassman Lyon with European actors of glass market and at China International Glass.
D.5	Participation in conferences and seminars	Partners have participated to 11 conferences and seminars for the dissemination of the Eco-HeatOx project (Italy, Spain, France, US, Japan, Bulgaria, China, Germany, Turkey)
D.5	Guided Visits	Several visits have been organised with the management teams of both partners and with end-users.
D.5	Printing of dissemination materials	Two different leaflets have been created (one on the technology, one on the burner) and posters have been used when participating to conferences.
D.5	Articles and press release	One internet article has been published and one article in the specialized press (Glass International).
D.5	Meetings with stakeholders	Partners have met stakeholders such as decision makers in glass (TC09 ICG committee), gas industries (GRT gas), glass manufacturers, Bulgarian authorities, etc.

5 Analysis of long-term benefits

Environmental benefits

This project complies with the European environmental objectives as it promotes a technique that requires less energy than BATs and which significantly reduces the emissions of pollutants.

The performance of the solution enabled us to extrapolate energy consumption reduction to 19%, compared to state of the art air combustion, which, in turns, leads to significant CO2 reduction. In addition, the technology also confirmed 90% NOx reduction.

The results of this project will therefore contribute to reach the objectives set in the following treaties and directives:

- Paris Agreement - Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels; Increasing the ability to adapt to the adverse impacts of climate change; Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development - 12 December 2015
- Treaty of Lisbon – Active as of 1 December 2009, the Treaty of Lisbon amends the existing treaties of the EU. The common European Policy for energy is given a new legal basis, aimed to ensure functioning of the European energy market, ensure safety of energy supply in the EU, promote interconnection of energy networks, and also to promote energy efficiency and saving, and the development of new and renewable sources of energy.
- Copenhagen Accord – December 2009: the European Union confirms the objective of the previously mentioned directive at an international level: a reduction of GHG emissions of 20% in comparison with the 1990 levels, and by 30% provided that other developed countries commit themselves to comparable emissions reductions.
- An Exploratory Opinion of the European Economic and Social Committee on the 'Roadmap for a low carbon energy system by 2050' (2011/C 107/08) of 6 April 2011.
- COM 26/5/2010 – Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage.
- COM 09/03/2010 - International climate policy post-Copenhagen: Acting now to reinvigorate global action on climate change.
- IED - Industrial Emissions Directive (Directive 2010/75/EU) (ex-IPPC (Directive 2008/1/EC)): stipulating that the industries including glass have to respect different environmental conditions regarding their emissions in pollutants such as CO2, NOX, SOX and Dust

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.

These 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.

The sustainability of the technology is mainly dependent on financial viability. Due to the historically low NG price, the solution became less attractive. In response Air Liquide have performed cost optimization on all the HeatOx equipment and up to 30-40% of CAPEX reduction seem feasible. In addition, Air Liquide and PB proposed new breakthrough technology to LIFE+ (CleanOx), which is based on Eco-HeatOx and can reduce CAPEX significantly while increasing efficiency gain even higher.

Replicability, demonstration, transferability, cooperation

It is to be noted that this technology can be transferred to all small and medium size furnaces regardless the sector as long as it operates at higher than 700°C, which, in fact, represents the majority of active furnaces in Europe.

In the framework of this project, PB and AL have set-up and implemented a furnace pilot technology using hot oxygen and natural gas in a glass furnace producing tableware glass. The technology implemented in this demonstration furnace requires less equipment, and hence lower capital cost, than the existing system at Boussois, which is dedicated to large float glass furnaces. The lower amount of equipment allows this new technology to be more broadly applied to medium and small glass furnaces.

Considering the benefits of the Eco-HeatOx technology in terms of energy savings and reduced CO2 emission, its demonstration at full scale (performed during the project) is very useful in order to facilitate the breakthrough of this technology among other technologies, less environmental friendly. Thanks to dissemination activities, partners are currently contacting other companies (mostly current customer) in order to present them the principle of the technology. The objective is to understand if glassmakers are ready to move to this technology. Such initiative constitutes the first step in view of preparing the replicability and the transferability of the Eco-HeatOx technology.

The current assessment shows that the technology will be difficult to be accepted to tableware/container glass furnaces due to low NG price unless O2 is provided at very low price, which is site specific. The first target would be the glass furnaces which already use oxy-fuel combustion such as fiber glass furnaces. Also, a hybrid furnace such as LCD glass furnaces is even more interesting in that it uses oxygen and hot air both so that it has a recuperator to generate hot air. Therefore, significant CAPEX for a hot air generation system can be avoided for HeatOx resulting in much favorable Return On Investment (ROI).

To maximize the environment and economic impact of the technology, other high temperature industrial processes such as copper, aluminum, cement and steel reheating are being investigated. These processes will require more compact and lower cost equipment.

Best Practice lessons

It is emphasized that compliance is needed with EU reference methodology for NOx calculation of oxy-fuel flue gases. Current setup (oxy-fuel flue gas treated in air-fuel DeNOx system) creates unnecessary treatment cost for Paşabahçe Bulgaria. Contact with Bulgarian Ministry of Environment and Water (MoEW) representatives at is believed to help harmonizing the methodology for calculating GHG emissions in Europe.

Innovation and demonstration value

Thanks to EU funding, PB/TGB and AL have set-up and implemented an innovative furnace technology using hot oxygen and natural gas in a glass furnace producing tableware glass.

Following the research activities that have validated the methodology proposed for an energy-efficient and environment-friendly furnace for glass production, the aim of this project was to validate the technology with a full scale industrial demonstration.
Indeed, it would not have been relevant to test the innovative technique with a pilot (small scale) furnace. In order to produce tableware glass, it is necessary to build and use a full scale, industrial furnace due to the specificity of tableware glass production.

A fundamental aspect of this demonstration project was to continuously assess the progress of environmental improvements with respect to the initial targets. These targets are related to pollutants and GHG emissions and energy consumption without negative impact on glass production to ensure the technology dissemination.

EU funding allowed dedicating all the required resources to implement, monitor and eventually validate this first full scale application.

Long term indicators of the project success

HeatOx validated 19% energy consumption reduction by extrapolating the current results, which gives 11,71% CO2 reduction. Since the numbers are calculated for entire furnace campaign considering furnace aging effect, the long term environment impact will be the number of replication times the current CO2 reduction. Approximately 24kg CO2 per year reduction for one ton of glass is expected. European annual glass production is about 43 million tons per year so that 1 million tons of CO2 per year reduction is expected if the entire furnaces are switched to HeatOx. If we consider 20% HeatOx penetration, 0,2 million tons of CO2 yearly reduction and 12900 tons per year of NOx are expected.