LIFE CleanOx

After LIFE Plan

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

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1. Summary

After-LIFE plan includes the activities planned by the partners after the LIFE CleanOx project. These activities have many different purposes, in particular to industrialize the technology to bring it to the market and to disseminate the achievements and the technology potentials among targeted groups for a wider deployment.

Both the main and the communication activities selected for the continuation were found to be effective and successful in terms of implementation throughout the LIFE CleanOx project.

2. Project objectives and key achievements

Lowering GHG emissions and energy consumption are a recurrent challenge in the industry because the methods employed have to be environmentally sustainable and at the same time economically viable. In response LIFE CleanOx aims at facilitating the widespread implementation of waste heat recovery for oxy-fuel furnaces with an innovative heat recovery system. The project will focus on tableware glass. However, this technology, once validated, can be transferred to any industrial furnaces irrespective of a type of application as long as it operates at higher than 700°C, which represents the majority of active furnaces in Europe.

LIFE CleanOx consisted in demonstrating an innovative radiative heat exchanger (R-HX) based HeatOx solution.

The project had three main objectives:

- Reduction of GHG emissions linked to tableware glass production (compared to air combustion using a regenerative heat exchanger: 30% less CO2 and 90% less NOx emissions),
- Increase of thermal efficiency in tableware glass plants (compared to air combustion using a regenerative heat exchanger: 30% less),
- Significant CAPEX reduction (50-75%) compared to LIFE Eco-HeatOx.

<u>Regarding the GHG emissions:</u>

The on-site test demonstrated an increase in thermal efficiency of 17% relative to air combustion using a regenerative heat exchanger and 4% relative to cold oxy-combustion. These results are below the above targets. While we had hoped to improve upon LIFE Eco-HeatOx, in fact the results achieved were not as good. As described in the report on Final Project Performance Specific Indicators, this is attributable to the location of the CleanOx RHX on a bypass flue gas channel, in order to target high flue gas temperatures. This approach and location was found to be particularly challenging. Based on Eco-HeatOx experience, by implementing an RHX in a similar location to

Eco-HeatOx, achieving similar energy savings and emissions reductions can be expected. This will provide 23% less CO2 emissions and 90% less NOx emissions, relative to air combustion using a regenerative heat exchanger. The NOx emissions reduction is inherent in using oxy-combustion, even without heat recovery.

As to the thermal efficiency increase:

As above, by implementing an RHX in a similar location to Eco-HeatOx, an increase of 23% in thermal efficiency relative to air combustion using a regenerative heat exchanger can be expected.

Finally, for the CAPEX reduction:

The ceramic RHX installed at Paşabahçe was a demonstration unit connected to two burners (out of the 10 of the furnaces). It is impossible to make a meaningful comparison of its CAPEX with that of Eco-HeatOx. However, the basis of the CleanOx CAPEX reduction expectation was the reduction in the number of pieces of equipment. Indeed, we confirmed that it is possible to greatly reduce the number of heat exchangers by adopting radiative heat recovery. For Eco-HeatOx, one recuperator (flue-gas to air heat transfer), two air-natural-gas heat exchangers (one per side of the furnace) and two air-oxygen heat exchangers are needed. For the CleanOx pilot, one RHX provided both hot oxygen and hot natural gas. At scale, we expect that separate natural gas and oxygen RHX's will be preferred. Thus we confirm a reduction from 5 to 2 heat exchangers. This will be somewhat offset by the greater complexity of the RHX compared to the heat exchangers used in Eco-HeatOx. In addition, the RHX approach requires more hot O2 and NG piping where Eco-HeatOx has hot air piping. Detailed review of costs has concluded that a significant CAPEX reduction is achievable, but it is generally less than 50%.

We have also concluded that the reduction in footprint and in complexity achieved by CleanOx is an important advantage, one that was perhaps underestimated previously. As there is no need for air-O2 or air-NG heat exchangers, integration into an existing plant design is substantially easier.

3. Replicability and transferability plan

3.1. Market analysis

The glass production process is a capital intensive, high volume, continuous production process. A glass installation operates 24 hours a day, 7 days a week for uninterrupted periods of 10 to 18 years. The **energy** in the glass industry accounts for the largest share of manufacturing costs, representing on average about **14% of the total glass production costs.** Reducing it is an economic imperative for all glass manufacturers in order to remain competitive. As a consequence they are increasingly demanding in terms of return on investment, especially in mature markets like Europe.

At the end of the production cycle, the decision to rebuild a glass line is mostly dependent on the projected demand for products. Glass manufacturers invest to upgrade installations and will continue to apply best available techniques. In doing so, the industry is guided by existing legislation such as the EU Emissions Trading Scheme and the Industrial Emissions directive, but **remains driven by the economics of the sector.**

Production of **1 kg of glass in a gas-fired furnace generates approximately 0.60 kg CO2** (Scope 1 and 2, of which 0.40 kg for combustion).

Independently of the evolution of natural gas prices, the glass industry will remain a large consumer of energy and a large contributor to CO2 emissions, and will have to cope with stronger and stronger environmental constraints.
The links between economic growth, pulled by the rapid urbanization, the increase in infrastructural activities across the globe and **the glass market** have tightened.

Market is very consolidated and concentrated with barriers to entry mainly linked to investment capacity.

The glass industry is composed of three major segments:

1. **Flat glass** (float glass) for the automotive and construction industries. 75% of float glass is produced in developing economies with more than 50% of all worldwide in China
2. **Container glass** for resilient local industries: food, beverages, cosmetics, pharmaceuticals and perfumery
3. **Technical glass** including glass fiber, tableware, lighting glass, Flat Panel Display (FPD), Plasma Display Panel (PDP), and Liquid Crystal Display (LCD). **Technical glass is the fastest growing segment (CAGR 6.5%).**

Climate change and consumer awareness initiate a strong change over the recent past years. This major inflection point as the world continues on the sustainable route towards a low carbon economy, will be amplified with the coming up of new furnace generations and technologies with low carbon footprint and high energy efficiency.

3.2. Business plan

Oxy-combustion in the glass industry already helps **reduce NO_x** emissions by removing nitrogen contained in air **and reduces CO_2 emissions** by lowering the need for fuel (e.g. natural gas) thanks to the better efficiency of oxy combustion compared to air combustion. It represents about 10% of global market production today.

Based on these market fundamentals, the glass industry is increasingly making use of oxygen for combustion, driven by two factors:

1. **Demand increases for technical glass with energy intensive and pollutant emitting melting processes** for which operating **oxy-firing is cleaner and already economically profitable**. Examples include Glass wool and fiber for insulation in the construction industry, or products for various new applications in composites markets for automobile frames, equipment in aircrafts and for electronics products TFT-LCD. Fiber and speciality glass account for about 13% of the WW glass production.

2. Energy transition drivers trigger a growing conversion towards **a more efficient, flexible and productive melting process** to ensure the long-term sustainability of this industry: **oxy-fuel** is accepted **as the solution** combining performance, flexibility and emission reduction, this last aspect being on the critical path of the glass market strategic position in the years to come.
   More specifically on the financial aspects: Oxy-combustion can **counterbalance the rising cost of increasing environmental constraints**.

The major segments, containers and flat glass sectors account for about 81% of the WW glass production.

With these segments, for Oxy-combustion w/o energy recovery, taking into account CO2 emissions related to Oxygen production and compared to combustion with air, the CO2 emissions are not significant.

3.3. Technical activities

The pilot CleanOx technology has been implemented to a tableware glass furnace but, the CleanOx technology project could be very beneficial to other glass furnaces. Also, the technology is convenient for other industries having high temperature processes.

The radiative heat exchanger could work with any type of glass and fuel so it could be implemented to glass furnaces with ease. At the end of a furnace's lifetime, when the investment decision is made to rebuild the furnace, CleanOx technology can possibly be implemented thanks to its financial viability. Then, in 15 years, oxy-boost technology could be applied to a major part of oxy-combustion furnaces.

More and more glass makers may choose to implement CleanOx technology in accordance with the business plan to reduce their environmental impact. 23 % reduction in energy and CO2 emissions from combustion are expected. In this scope, simulation and design change studies are carried out. After investment decision is made, next steps that will apply are defined in below:

- Application for the required permits for oxygen production and use in the glass furnace
- Determination of upstream and downstream process limitations to eliminate the imposing effects of unrelated technical limitations on the environmental benefits of the projects.
- Measuring and validating an accurate baseline level of process functionality prior to the implementation of an oxygen boosting system to monitor all of the indicators including thermal, mechanical, and environmental.
- Investigation of the furnace capacity increase, glass quality improvement, production and energy efficiency improvement to better understand and predict the furnace's behavior.
- Implementation of the radiative heat exchanger, burners, piping and O2 generator into furnace
- Definition of optimum operating conditions and operation of different production cases to establish transitional and steady state operating practices for changing operating and product requirements.

Prior to any deployment of the technology, the industrialization work will be performed by Air Liquide in 2023 in order to review and optimize the design of the equipment (lessons learned from the CleanOx project). This work has already been initiated by Air Liquide during the course of the project execution. The expected outcome of this industrialization work is to get specification for the R-HX and design tool that can be used in order to perform feasibility studies with glass makers regarding the benefits of implementing the CleanOx technology in their furnaces.

3.4. After LIFE actions

Timetable of the After-LIFE actions per beneficiary is summarized below.

After-LIFE Actions	Responsible Beneficiary	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Industrialization of the CleanOx technology	Air Liquide											
Contacts with stakeholders and targeted groups for deployment of the technology	Air Liquide											
Elaboration of dissemination materials	Air Liquide											
Update of the website presenting the project's results	Air Liquide											
Presentation of the project's benefits in national and international conferences and seminars	Air Liquide & Paşabahçe											
Organization of meetings with stakeholders and targeted groups interested to replicate the developed technology	Air Liquide											

All the actions described in the above table will be carried out with the project's partners' own resources. There will be no external input from grants or subsidies. The partners are confident that the cost-effectiveness of the project will be used to deploy the CleanOx technology effectively.

4. Conclusion

The CleanOx project was designed, developed and implemented with the purpose of contributing to the environment for a low energy and low carbon economy. This after-LIFE plan outlined the next steps to carry out this mission by bringing the newly developed technology to the market and disseminating its achievements.

There is great potential in the glass and other sectors like cement and steel to apply this technology. Dissemination of this technology to other furnaces will provide a significant contribution to reducing energy consumption and emissions.