HOxyGas
Layman's report
June 2012 – January 2017

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

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Executive summary

The HOxyGas project, co-funded by the EU LIFE+ programme, was launched in June 2012 by AGC Flat Glass Czech a.s. (CZ) and AGC Glass Europe SA (BE). The aim of the HOxyGas project was to produce coloured automotive flat glass on a furnace equipped with an innovative combustion technology using hot oxygen (O2) (up to 550°C) and hot natural gas (NG) (up to 450°C) for combustion. 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-combustion technology.

It has to be noted that the current AGC systems using hot oxy-combustion are not compatible with 100% NG use. Compared to 100% gas air combustion technology (state-of-the-art technology, the proposed innovative technology targeted for the furnace an increase of energy efficiency by 19.7% and reaching the following emissions reductions: CO_2 emissions by 5.5% (CO_2 emitted by O_2 production included), NO_X emissions by 79.2%, SO_X emissions by 35.5%, and dust emissions by 67.7% if we consider a pull of 600 tons/day.

In the first chapter of this Layman's report, the environmental challenges tackled by the HOxyGas project, as well as its main objectives and the project partners are described. In the second chapter, the proposed innovative technology and the related benefits are detailed. In the third chapter, the project results and achievements are summarised.
The final chapter is dedicated to the long-term benefits of the project and to the replicability and transferability of the results.

As it is detailed within the next sections, it was originally foreseen to operate the technology for clear glass up to 600 T/day, however, actually, the clear glass has been replaced by light green glass at a pull of 500 T/day). Therefore the demonstrated environmental benefits have been the following ones, which are in line with our estimations considering a pull of 500 T/day:

- CO_2 emissions reduced by 5.5 +/- 3 % meaning up to 4,800 tons of CO_2 saved per year
- NO_X: specific emissions reduced by 85 %;
- SO_X: specific emissions reduced by up to 82 %;
- Energy consumption reduced by about 18.7 +/- 3 %.

1. Introduction

Environmental challenge

The recent increase of the greenhouse gases (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 last years. This "anthropogenic" greenhouse effect is mainly caused by the emission of CO_2: 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 a high interest in making the reduction of CO_2 emissions a priority. Industrial processes category represents one of the most important business sectors responsible for CO_2 emissions, being responsible for 7% of European emissions.
Indeed after falling in 2009, carbon dioxide (CO_2) emissions rose in 2010, due to the global financial crisis, to a record level of 30.6 GTons, with a rise of 5% from the previous record year, 2008, when levels had stood at 29.3 GTons. According to the latest IEA (International Energy Agency) estimates, CO_2 emissions in the sectors of energy, industry and transport were in 2010 the highest in history.

Moreover, the manufacturing processes of mineral products such as glass, lime, and cement are responsible for 50% of those emissions. For instance, together they emit more CO_2 than chemical and metal manufacturing industries.

Glass is a key element to many industries. In 2006, the world market for flat glass was estimated at around 42 millions of tonnes, which is equivalent to 4.2 billion square metres of glass with a thickness of 4 millimetres. Worldwide, the average yearly consumption is of 6 kg per person, which rises to 18 kg per person in Western Europe. Growth in the demand for flat glass has generally outpaced real GDP growth for the past 20 years.

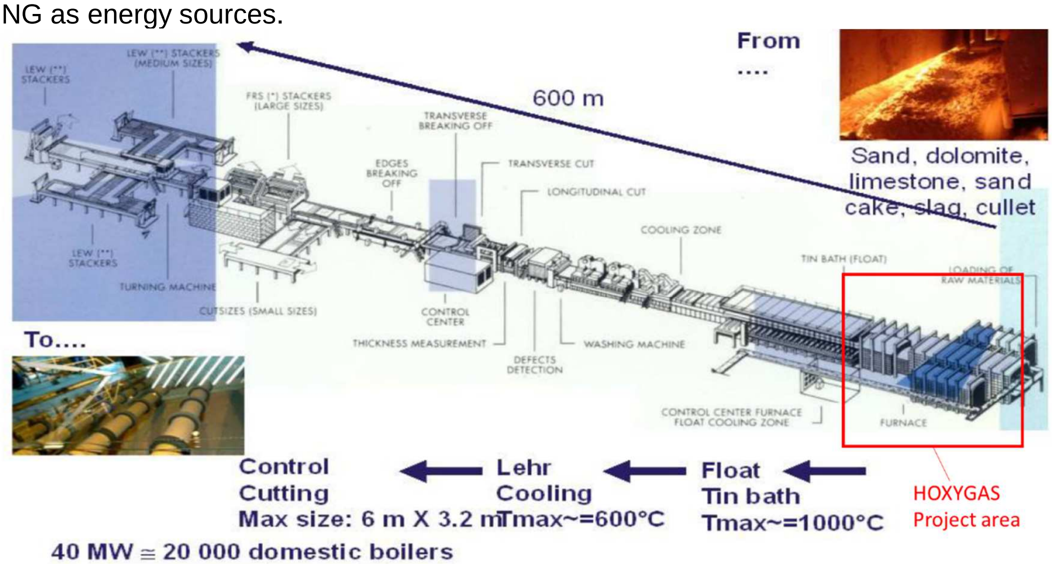
More specifically, the automotive flat glass production requires a lot of energy and produces a large amount of GHG.
Despite a lot of efforts have been made over the last decades to reduce the energy need: a reduction by 10 % of energy consumed per ton of glass from 1880s. The current figure is still from 6 to 7 GJ per ton of glass while the theoretical minimum energy level required would be between 2 to 3 GJ per ton of glass – the energy necessary for materials needed in the glass composition to melt.
To ensure a perfect production, with the high level of quality of this specific glass production, while reducing as much as possible the related environmental impact, a new concept of furnaces using oxy-combustion technology was targeted by the project. After successful implementation, the process could be adapted for other production processes that use melting furnaces, such as the steel industry or the cement industry, which is known for its vast CO_2 emissions.

In this context, the main environmental challenge targeted by the HOxyGas project is the reduction of the CO_2 emissions and energy consumptions for producing automotive glass through the above-mentioned innovative oxy-combustion technology using only preheated oxygen as oxidiser and preheated natural gas as fuel.

The HOxyGas Project: Objective and expected results

The HOxyGas project focused on 2 main targets: the reduction of the consumption of fossil fuel and the reductions of emissions of GHG linked to automotive glass production processes. Therefore, with this project we aimed at limiting the impact of industrial activities on climate change.
Limiting energy consumption and gas emissions has always been a challenge in the industry. For instance, during the last 5 years, the glass industry has reduced the use of oil. Thus, nowadays, the number of furnaces that operate fully on gas has increased to at least 95%. With this project, we proposed an innovative process, based on the use of only hot natural gas, oxygen, and the hot oxy-combustion technology to produce glass. The project has been focused on automotive glass, nevertheless, this technology, if validated, can be transferred to all other glass applications. The process will have a lower environmental impact than all currently existing technologies.

The figure below represents full float glass production line. The HOxyGas project has been focusing on the furnace part, by implementing and demonstrating an innovative oxy-combustion technology operating with only NG as energy sources.



The HOxyGas project aimed at demonstrating the maturity and potential of the new technology by producing high quality automotive colour glass (which has higher quality requirements than architectural glass), using only natural gas as a combustible (more corrosive atmosphere, more foaming on glass surfaces).
Compared to a state-of-the-art reference (which is 100% gas air combustion technology), the following quantitative results were expected at high and low pull:

Pull	High pull (clear glass): 600 T/day	Low pull (coloured glass): 500 T/day
Melting energy reduction	19.7%	18.3%
CO_2 emissions reduction (including emissions related to Oxygen production)	5.5 %	5.5 %
NO_X emissions reductions	79.2%	79.2%
SO_X emissions reductions	34.5%	34.5%
Dust emission reduction	67.7%	67.7%

It is worth noting that, contrary to what was originally foreseen, clear glass has not been produced, due to automotive market needs during the project and has been replaced by light green coloured glass during the project. Therefore during the project the furnace has only operated at "low pull".

Project partners

Coordinating Beneficiary – AGC Flat Glass Czech, the largest glassmaker in Central Europe

Based in Teplice (North Bohemia), AGC Flat Glass Czech is the largest producer of flat glass and its applications in Central Europe. It manages production plants in the Czech Republic, trade agencies in Central Europe and processing plants in the Czech Republic, Slovakia and Poland.

In addition to processing facilities for manufacturing architectural glass, mirrors and decorative glass, the Czech operations rely on 3 float plants located in Teplice and an automotive glass plant in Chuderice. AGC employs around 4,500 people in Czech Republic and is regularly ranked in the Top 5 of best employers in the country.

Associated Beneficiary – AGC Glass Europe, a leader in flat glass

Based in Louvain-la-Neuve (Belgium), AGC Glass Europe produces, processes and distributes flat glass for the construction (external glazing and interior decorative design), the automotive and the solar sectors. It is the European branch of AGC, the world's largest flat glass producer.

Its baseline "Glass Unlimited" reflects the possibilities offered by:

- Glass as a material to meet a growing variety of needs (comfort, energy control, health & safety, aesthetics);
- Innovation in products and processes, derived from sustained research in advanced glass technology;
- Over 100 sites throughout Europe, from Spain to Russia;
- A worldwide marketing network;
- Its 16,000 employees.

2. The innovative melting technology proposed in the HOxyGas project

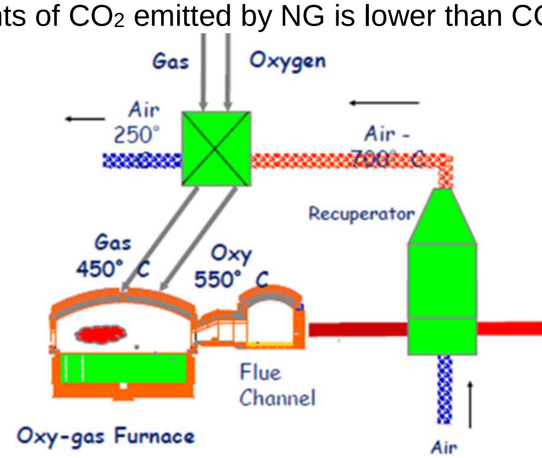
Usual automotive flat glass process is based on regenerative air combustion: the oxidizer used is thus air composed by 21% of O_2 and 79% of N_2. The related natural gas (NG) combustion (mainly composed by methane CH_4) can be expressed through the following reactions:

$$CH_4 + 2\,(O_2 + 3.76\,N_2) \rightarrow CO_2 + 2\,H_2O + 7.52\,N_2$$

CO_2 and H_2O released by this combustion will participate to the heat transfer to the glass while the nitrogen (N_2) will only be "a heated load" then lost by the fumes at the melter outlet. In classical air combustion melter technology, regenerators done by refractory honeycomb will be used on each side of the furnace to recover energy losses by the hot fumes and will transfer a part of the energy to the combustion air. Nevertheless, the efficiency of such process remains quite low since there is still up to 35-40% of the useful energy lost.

On top of being a source of energy losses, it is worth noting that N_2 will at very high temperature (as it is the case inside the burner's flame) produce NO_X pollutant.

In order to optimise the process efficiency and to limit the related environmental impact of the standard air combustion, AGC investigated as potential solutions to improve simultaneously energy consumption and environmental footprint the use of pure oxygen instead of air and natural gas as combustible (amounts of CO_2 emitted by NG is lower than CO_2 emitted by heavy oil).



The two main innovative aspects (see the figure above) introduced by the hot oxy-combustion technology are:

1. Combustion with only oxygen as oxidisers limiting energy losses and NO_X production;
2. Pre-heating of both oxygen (up to 550°C) and natural gas (up to 450°C) to increase the overall furnace efficiency using a two-step approach:
   i. Air/fumes recuperator: energy is transferred between hot fumes coming out of the furnace and an air flow
   ii. Air/Reactants exchangers: preheated airflow will be distributed on each burner between two heat exchangers
      i. Air/oxygen
      ii. Air/Natural gas

Finally, the preheated reactants will flow up to the burners through insulated flexible.
The two-step approach is justified by safety to avoid any risk of fumes (can contain non-burned fuel) mixing with oxygen in case of leakage in the final heat exchanger.

1st Industrial application: hybrid combustion (heavy oil + NG)

A first industrial application took place in Boussois, France, and started in 2008 with the aim at validating the feasibility of producing good quality clear glass for architectural applications with a hybrid combustion, using partially heavy oil and partially natural gas and not only natural gas as it was the case within HOxyGas.

During this first experience, AGC Glass Europe evaluated and validated technical components. These included technology design and material selection (furnace, burners, refractory); safety issues linked to hot oxygen use; glass melting settings (fire curve, internal furnace atmosphere and foam management).

The environmental as well as the energy interests have also been assessed.

This first project was funded by the European Commission Environment - LIFE+ Programme – HotoxyGlass - LIFE07 ENV/F/000179.

Specific additional challenges addressed by HOxyGas Project

Contrary to the first experiment performed in Boussois, the HOxyGas project, which took place in the Czech Republic at Retenice plant, had as major objective to demonstrate the environmental benefits of a hot oxy-combustion using only natural gas as fuel. The main specific challenges that would have to be overcome in order to achieve the expected results were thus the following:

- Higher water content in the furnace atmosphere (~ 1/3 CO_2v; 2/3 H_2Ov) due to oxygen and natural combustion (no dilution by nitrogen):
  - The higher water content in furnace atmosphere in contact with hot glass surface will enhance evaporation of corrosive chemical species as NaOH. Moreover since the combustion fumes flow is lower with such innovative technology in comparison with a traditional furnace, the concentration of all chemical species will be higher.
  - The diffusion of water from atmosphere inside hot glass will modify some glass properties as bendability temperature. Moreover, in higher water content, conditions inside glass, the chemical reaction will be modified generating a thick foam layer on top of the glass bath. This foam layer will have an impact on quality and energy consumption since it will act as an insulation layer. Finally, the diffusion exchange will be also enhanced downstream the furnace as in the tin bath.
  - Due to heat transfer from the flame generated by the new technology and the adapted design of the furnace, new fire curve and temperature profile in furnace need to be adopted to ensure quality requirements of the product.
- Automotive glass production:
  - The automotive market has more severe quality requirements and a larger range of products than architectural market. In fact automotive market is requiring coloured glass (from light colour to dark colour) on which will be applied a big range of post process (temper and/or lamination) for manufacturing the final products. Each glass colour leads to new adjustments of the melting technology to reach the best thermal regime and quality requirements.

3. Main project activities and achievements

The HOxyGas was successfully performed between June 2012 and January 2017. To achieve the objectives of the project the two following main phases were completed:

1. Design and Building phase (June 2012 – April 2014);
2. Heating-up, start-up and operating phase (March 2014 – January 2017).

Design and Building phase

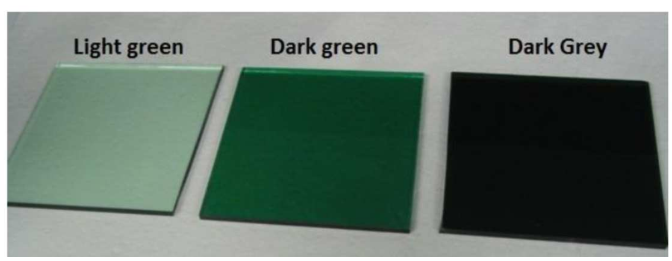
The design and building of the furnace structure (civil work, metallic structure and refractory) finished by mid-March 2013 and all required permits were obtained. However, in April 2013, the launch of the furnace had to be postponed to April 2014 considering the economic situation on the flat glass market.
The cryogenic device (O_2/N_2 production) was completed and was launched with the furnace (April 2014).
In order to prepare the second phase of the project, the following activities were also performed by AGC Glass Europe R&D within this phase:

- Numerical models development for furnace behaviour prediction and definition of fire curve for start-up phase for different glass colour;
- Heating-up conditions of the furnace, including refractory analyses;
- Definition of raw material compositions for start-up;
- Glass quality tracking methodology analysis development.

Heating-up, start-up and operating phase

The heating-up of the furnace and tin bath started in March 2014 and the full-furnace operation was launched on April 22, 2014. After 3 weeks of operation with cold reactants, the furnace has started to operate in hot oxy-combustion in May 2014 with the lightest green colour.

After intensive activities aiming to optimise the process as well as to ensure the production of high quality glass fully in line with automotive market requirements, the pilot furnace is now fully operational in hot oxygen / hot Natural Gas combustion at a pull of 500-520 tons/day of glass. It has been validated for 7 different colours (from light to dark green, dark grey and very dark grey) for thickness from 2.1 to 10 mm (laminated and tempered).



The savings achieved by the innovative technologies are summarised in the table below and are globally higher than the expected results.

% savings vs Air-gas	Energy savings	CO_2*	NO_X Green glass	SO_X	Dust
Expected results at low pull (500 T/d)	18.4%	5.5%	79.2%	35.5%	67.7%
Actual Results at low pull	18.7% +/-3%	5% +/- 3%	85%	82%	83%

4. Project long-term benefits and next steps

Environmental Benefits

During the HOxyGas project, both partners have demonstrated the following high environmental benefits of the technology, especially in terms of fuel and CO_2 emissions reductions:

- 5.4 MNm^3/year natural gas saved;
- Up to 4,800 T CO_2/year saved (including CO_2 emitted for O_2 production);
- 745,000 T NO_X/year (glass without nitrate)
- 220,000 T SO_X/year.

Economic Benefits

From an employment perspective, the project has led to the creation of 67 jobs and allowed securing on the long-term numerous jobs for both entities.

The implemented innovative systems allow significant savings in terms of NG consumptions. Therefore, in terms of cost efficiency and payback time, the innovative oxy-combustion is highly depending on the required resources prices as natural gas and oxygen.

Next steps: Replicability & transferability

In order to facilitate a wide replication and transfer of the innovative hot oxy-combustion technology, both entities will continue to perform intensive dissemination activities to promote the highly positive environmental benefits of the technology:

- Participation to events such as: conferences, exhibitions, fairs;
- The project website: http://www.agc-hoxygas.eu/index.htm;
- Networking activities in particular with industry associations, standardisation activities.

In terms of replicability, the oxy-combustion technology is evaluated at each cold repair on both technical and economical points of view as alternative to state-of-the-art air-gas combustion. Nevertheless, as mentioned above, it has to be noted **that economical relevance of the technology is closely linked to local energy prices (gas, electricity).**

In particular, one furnace of Boussois AGC plant, will be re-started in April 2017 (after stand by period of 3 years due to market crisis) in hot oxy-combustion using 100% natural gas thanks the activities performed during the HOxyGas project.

This technology would be theoretically replicable to all flat glass manufacturing plants (outside AGC groups), the dissemination activities performed by AGC will encourage other glass makers to investigate on such environmental-friendly technologies leading to CO_2 emissions and fuel consumption reductions as well as economic benefits.

In terms of transferability, such technology is theoretically transferable to various other applications in the glass sector (other kinds of glass) but also in cement, steelmaking and ceramics industries after some R&D and engineering studies. AGC as glass producer will not be directly involved in the transfer to such applications but the dissemination of the HOxyGas project results (see above) will pave the way to a wide transfer of such innovative environmental-friendly technology.