Energy saving incentives for the European glass industry in the frame of the EU Emissions Trading Scheme

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Abstract
The European Emissions Trading Scheme (EU – ETS) covers approximately 45 % of European GHG and close to 12,000 installations. The EU ETS particularly affects the energy intensive industries while it imposes a significant risk of "carbon leakage", i.e. the risk of EU industry departing to countries with weaker restraints on GHG emissions. The EU Glass industry, being capital intensive and also requiring long investment cycles, is the world's largest glass producer with a market share close to one third of global production. Maintaining its competitiveness is of great significance since not only 80 % of its produced volume is traded in the EU but also 100,000 persons were occupied in the sector in 2012.

The approach proposed in the present paper will analyse the EU – ETS Glass Industry regarding the balance between allocated European Union emission Allowances (EUAs), verified CO_2 emissions and potential shortfall in allowances so as to determine the situation of glass industries and the extent of urge for energy saving activities towards the strengthening of their position within the requirements of the EU ETS phase III (second commitment period: 2013–2020). Projections of the EU market will be taken into account. Technological interventions for CO_2 specific reduction in the glass industry and in particular Waste Heat Recovery (WHR) are presented. The replication potential of WHR through batch preheating will be especially addressed since it is considered a promising technology according to the latest Best Available Techniques (BAT) Reference Document for the Glass Industry under Directive IED 2010/75/EU. The paper results into the conclusion that the incentives for energy reduction investments are to an extend only driven by the pressure from the EU-ETS however they are also imposed by other factors such as the cost of energy and the overall cost effectiveness of the installations which are configuring their competitiveness in the European context.

Introduction
The present paper aims to explore energy saving opportunities in the EU glass industry and to identify the role of the EU ETS in providing incentives regarding energy efficiency improvements in the sector. Among other, the EU ETS covers CO_2 emissions from the manufacturing of glass including glass fibre with a melting capacity exceeding 20 tonnes daily (Official Journal of the European Union, 2009). The costs of glass manufacturing are expected increase due to rising fossil fuel prices and the evolution of the EU – ETS. Currently EUAs cost around €5,5/tCO_2 however prices might well increase in the future. Therefore glass industries are driven to reduce CO_2 emissions mainly through reduced fuel consumption. As price volatility has a negative effect on investment potential, the investments are expected to be significantly linked to the prices of EUAs. However, up to now, generic studies (Mo J-L et al, 2016), (FTI Consulting, 2015),(Laing T.et al , 2013) have shown that emission trading schemes alone fail to support low carbon energy investments and that additional tools are needed in combination.

Glass manufacturing is a high temperature, energy intensive industry (JRC 2013). The highest proportion of energy is consumed in the furnace (EU Commission, 2009). As a result,

Table 1. Evolution of transaction volumes and values of the EU – ETS Market between 2005 and 2015 (POINTCARBON, 2012), (Carbon Market Monitor, 2016) (Carbon Finance, 2007, 2008, 2009, 2010, 2012), (Ellerman and Joskow, 2008).

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Tr/action Volume ($MtCO_2$)	321	1,104	2,060	3,093	6,326	6,789	7,853	9,025	8,092	6,942	4,960
Value (m€)	6,367	19,480	35,857	68,710	85,183	100,987	106,332	112,683	27,149	30,679	33,785

efforts are focusing on furnace energy reduction methods (R. Beerkens 2009). During the previous decades, these efforts focused on the use of recycled cullet, improvement of furnace design and combustion control, increased insulation, new process sensors and more effective regenerators.

The EU Emissions Trading Scheme

The European Emissions Trading System (EU – ETS) is an EU policy tool for reducing industrial greenhouse gas (GHG) emissions cost-effectively while maintaining the competitiveness of the industrial sectors involved. The concept concerns the free allocation and/or acquiring of emission allowances (measured in tons of CO_2eq) on the market of amounts equal to the annual emissions of the industrial sites concerned. In this manner, industrial operators can submit annually an amount of emission allowances equal to the amount of the site's emissions instead of paying a penalty for each tonCO_2eq exceeding the amount of available emission allowances. The scheme is a "cap and trade" one, i.e. a scheme that imposes an overall cap to the sum of emissions covered by it, as opposed to the other potential type, that of a "baseline and credit" type of scheme. The latter is based on emission intensity rather than emissions and is therefore characterised by a greater uncertainty as to the achievement of emission targets.

The EU – ETS was first introduced through its pilot scheme in 2005–2007 as a transition from traditional environmental policy characterized by the command-and-control approach on the way to market-based instruments for the achievement of environmental and energy targets. The second phase for the EU – ETS coincided with the Kyoto commitment period from 2008 to 2012. During this period all participating countries should cumulatively reduce six GHG including CO_2 by 5.2 % in comparison to 1990 levels (for CO_2,CH_4 and N_2O with some exemptions in some countries) and to 1995 (for fluorinated gases). For the European Union this target translated into an 8 % reduction, a target well achieved without even counting the additional reductions coming from carbon sinks (LULUCF) and international emission credits i.e. the final reduction averagely between 2008 and 2012 had been 11.7 % for the EU15 and 19 % for EU27 exempting Cyprus and Malta that did not have a target due to not being Annex I countries to the United Nations Framework Convention on Climate Change (UNFCCC) (DG for Climate Action, 2016). In fact, the actual verified emissions during the pilot (1st) and 2nd EU – ETS phase were lower than the annual emission cap during every year, except for the year 2008 (EEA, 2015). This means that both phases can be considered as periods of overallocation, although individual sectors (e.g. the electricity sector) or individual installations had experienced a shortfall in allowances. The third phase for EU – ETS concerns the period 2013–2020 during which cost-free allocation is being progressively withdrawn by auctioning of allowances while also a EU-wide cap instead of Member States caps on emissions have been introduced originally reducing annually by 1.74 %. The third EU – ETS phase reflects the EU 2020 target for an at least 20 % reduction of GHG compared to 1990 levels and covers i) CO_2 emissions from Power and heat generation, from energy-intensive industries including oil refineries, steel works and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals and Commercial aviation, ii) N_2O emissions from production of nitric, adipic, glyoxal and glyoxlic acids and iii) Perfluorocarbons (PFCs) from aluminum production. Emissions from these sectors are targeted to be 21 % below the levels of 2005.

The next phase of the EU – ETS will reflect the EU target of a minimum of 40 % domestic reduction in GHG emissions by 2030 compared to 1990 (EU Council 2014) as well as the long-term aim of maintaining the increase in global average temperature to well below 2 °C above pre-industrial levels. This goal is expected to enter into force in 2020 and has been preliminary agreed by 195 countries at the 21st session of the Conference of the Parties (COP21) of the UNFCCC Climate Conference in Paris in December 2015. In order to achieve this target the annual EU – ETS cap will be reducing annually by 2.2 % from 2021 during the fourth EU – ETS phase (2021–2030).

The evolution of the EUAs price between 2012 and 2016 is shown on Figure 1, derived by data from the European Energy Exchange (EEX).

Nowadays the EU – ETS constitutes the world's largest emissions trading system and the first and still largest international trading system for carbon dioxide emissions. At present, it operates in 31 countries (EU 28 plus Iceland, Liechtenstein and Norway) and it covers approximately 45 % of total EU emissions, corresponding to more than 11,000 industrial installations and additional air-flight operators (since 2012). Emissions from stationary installations in 2014 appeared to have already decreased (EEA, 2015) by 24 % compared to 2005 to 1,813 Mt CO_2-eq.

The European Glass Industry

The glass industry is extremely capital-intensive and energy intensive (EU Economic and Social Committee, 2015). The European EU glass industry is comprised by approximately 1,000 industries while more than 80 % of glass is produced by less than a dozen multinationals each employing more than 1,000 people (ILO, 2015). The other companies are small or medium-sized. In 2014 the EU 28 produced more than 33 million tonnes of glass. In the same year the whole industry (comprised by multinationals and the small and medium-sized industries) employed slightly over 180,000 people (incl. processors), which corresponds to a continuous decrease since 2005 (close to 240,000 employees) by (GAE, 2016) 25.3 %. Respectively the production of glass in 2005 had been 35.8 million tonnes.

The largest subsector in the glass industry is the container glass production. The glass container market was led by the alcoholic beverages industry with around half of its share in 2014. The market is driven by factors like the fact that end use industries are growing and by the light weighting industry trend which has reduced glass bottles weight by 40 % during the last decade. Raw material prices and logistics can hinder the increase of the sector's market share (Ceramicindustry, 2016), i.e. higher raw material prices or more expensive logistics lead to increased production costs which in its turn may cause the reduced interest of potential buyers.

From the demand side, the EU glass containers market was worth 14.30 billion USD in 2014 (Research and Markets, 2015). For a global comparison, world container glass demand is led by the Asia Pacific region (37 %) while the EU represented 33 % of the world container glass demand in USD (ILO, 2015).

The world market for flat glass has reached approximately 65 million tonnes in 2014 with 50 % covered by China which at the beginning of the 90's only had a 20 % share (Glass for Europe, 2016). In Europe, flat glass production is the second largest glass production sector with an approximate 30 % of total.

The world glass packaging market volume, has reached 47,000 kt in 2013. The leader in this market is the Asian – Pacific region followed by Europe (Packaging Today, 2016). The glass packaging market volume is expected to reach 60,847 kt by 2020, growing at a compound annual growth rate (CAGR) of 4 % from 2014 to 2020. Concerning short term projections the glass market in Europe is foreseen to grow at a CAGR of 3.56 % (by revenue) and 4.13 % (by volume) over the period 2014–2019 (Glass Market, 2015), (Infiniti Research, 2016). Regarding in specific the glass packaging market, the European Union is the second largest market in glass packaging market volume in the world and is expected to further grow (Packaging Today, 2016). Long-term projections show, that although for the non-metallic minerals sector in overall (ICF, 2015) the production will be slightly declining until 2050, the Glass and Cement sectors will have a stable production.

Generally, projections for the container glass sector show a growth of 1 to 2 % annually according to estimations of the EU Container Glass Federation (FEVE, 2016). Yearly production of glass containers is projected to reach 17.74 million metric tons by 2020 with a CAGR of 3.32 %. From the demand side, the glass containers market is forecasted to reach 17.59 billion USD by 2020 at a CAGR of 3.51 % for the period (Research and Markets, 2015). The flat glass sector is in a different position than the container glass sector. Up to now, approximately 12 out of 62 plants have ceased production recently in the EU. By contrast, new sites were built between 2008 and 2012 in neighboring to the EU regions due to cheaper labour, energy and raw materials, and "carbon leakage" issue while more new investments were planned by 2016 (EU Economic and Social Committee, 2015). Future short-term estimations showed that the world flat glass market will grow by a CAGR of 7.3 % between 2014 and 2019 with the Construction sector being the major end-user of flat glass, with an estimated 83.4 % of market demand in volume. Demand is expected to rise due to increased demand for solar glass panels and electronic displays (Research and Markets, 2016). However for Europe the aforementioned issues ("carbon leakage", labour costs, energy and raw material costs) prohibits growth.

THE GLASS INDUSTRY IN THE FRAME OF THE EU ETS

During the 1st and 2nd EU – ETS phase (years 2005–2012), the Glass manufacturing sector has presented a surplus, i.e. verified emissions were in overall less than allocated emissions. However some installations have experienced shortfalls. The position of the Glass manufacturing sector within the EU – ETS involved 360 entities in 2014 with total verified emissions 18 $MtCO_2eq$ corresponding to 3 % of total emissions originating from industrial installations (596 $MtCO_2eq$). Among these 360 entities only one installation may be characterized as "large", emitting annually more than 500 $ktCO_2$. A number of 165 were medium sized enterprises with emissions between

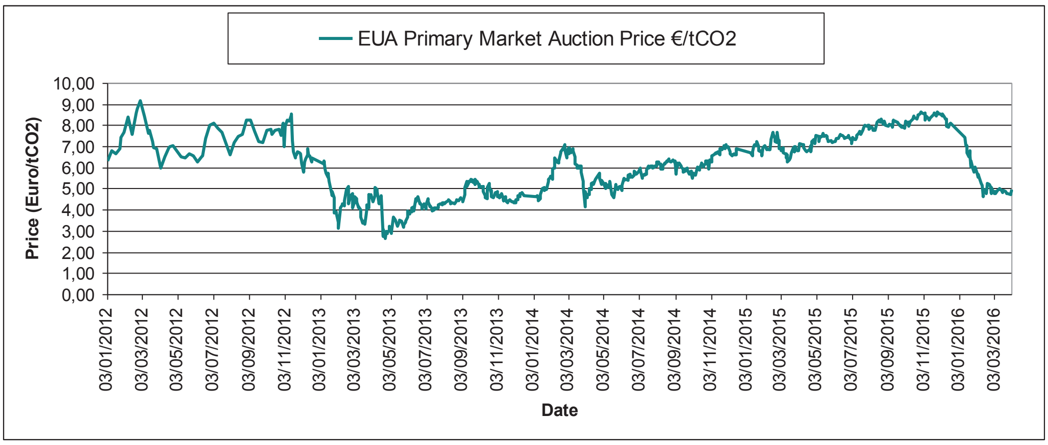

Figure 1. EUAs primary market auction price [EEX data, accessed 4/2016].

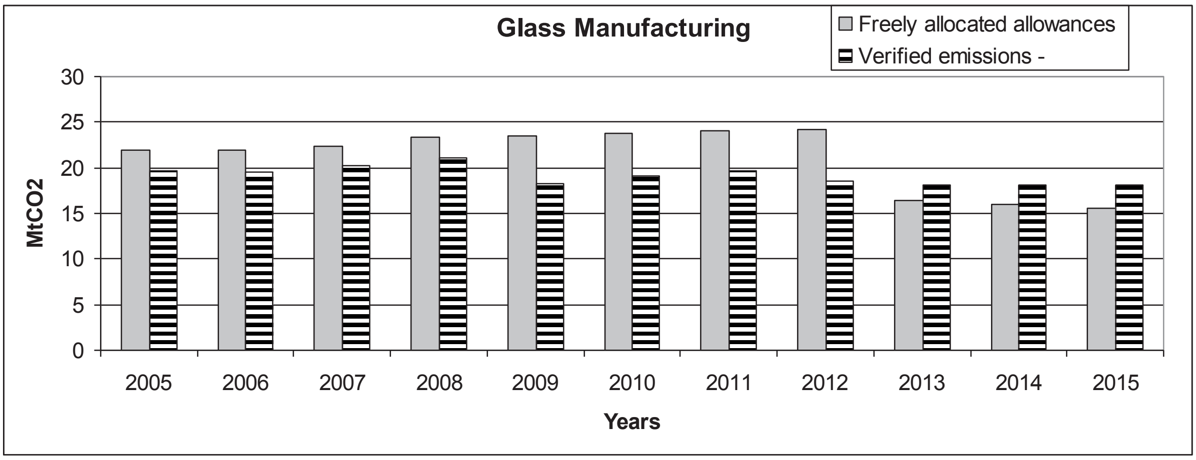

Figure 2. Allocated Allowances and Verified Emissions for the EU-ETS Industry in the years 2005–2015 (EEA, 2016).

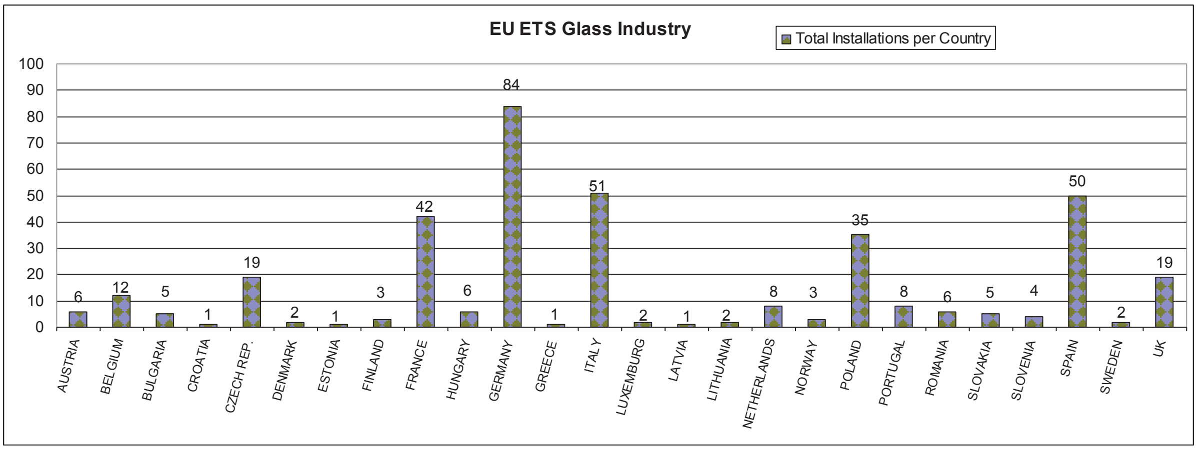

Figure 3. EU – ETS operative glass production installation (EUTL, 2016).

500 $ktCO_2$ and 50 $ktCO_2$eq. Lastly, 87 were small entities emitting between 25 and 50 $ktCO_2$ annually while 107 entities with annual emissions below 25 $ktCO_2$.

During 2013 and 2014 the EU – ETS glass manufacturing sector in total experienced a shortfall in emission allowances in the range of almost 12 % (3.8 $MtCO_2$). According to the latest available data (EUTL, 2016), for the first three years of phase III of the EU – ETS, EU – ETS Glass Industries had an allocation of 48 $MtCO_2$. Respective verified emissions were in the range of 54 $MtCO_2$ since some installations have not yet reported their verified emissions. A 70 % of the glass production installations (270 installations) concerned only glass manufacturing whereas an additional 30 % (108 installations) included glass fibre manufacturing. The distribution of these installations per country is shown in Figure 3.

European glass industries are exposed to the risk of "carbon leakage" i.e. the risk of relocating to locations outside the EU where no strict environmental targets are in place. More specifically, a sector or sub-sector is deemed to be exposed to a significant risk of carbon leakage if a) the extent to which the sum of direct and indirect additional costs induced by the implementation of the directive would lead to an increase of production cost, calculated as a proportion of the Gross Value Added, of at least 5 %; and b) the trade intensity (imports and exports) of the sector with countries outside the EU is above 10 %. Also if i) the sum of direct and indirect additional costs is at least 30 %; or ii) the non-EU trade intensity is above 30 %. Evidence that installations within the sector have been relocated exists. Enterprises were about 10,000 over 2000–2003 and declined at a steady rate to around 8,000 in 2010, because production became concentrated. Data have shown that although the overall number of enterprises in the manufacturing sector rebounded in 2010 when demand recovered, the number of glass producing enterprises fell further (ECORYS, 2013). Flat glass, hollow glass and other glass including technical glassware production were first included in the carbon leakage list of the Decision of the European Commission in 2010 (EU Commission 2010). Subsequently product benchmarks have been set (EU Commission 2011) while later on (EU Commission 2012) the manufacture of glass fibre has been added. These four subsectors of glass manufacturing were also included in the second carbon leakage list for the period 2015–2019 (EU Commission 2014). Only if an installation achieves to meet the benchmarks will it actually receive all the necessary emission allowances. In the opposite case, it receives the emission allowances respectively and up to the amount covered by the product benchmark. The benchmark is derived by comparison to the average GHG emission performance of the 10 % best performing installations in the EU producing the specific product (DG for Climate Action – b).

Energy conservation at the EU Glass Industry

Projections for the non-metallic minerals sector overall (ICF, 2015) show that energy intensity is expected to remain flat until 2030 whereas a gradual decline in energy consumption is expected to appear through 2050. Glass manufacturing in particular requires large amounts of energy since typical glass furnaces operate constantly at temperatures around 1,600 °C in order to heat and melt the mix of raw materials. In fact the largest amount of energy during the process of glass manufacturing is consumed in the furnace. That is why usually energy conservation methods focus on furnace energy reduction methods (Beerkens, 2009). Throughout the previous decades, these efforts targeted on the utilisation of recycled cullet, improvement of furnace design and combustion control, increased insulation, new process sensors and advanced regenerators.

Energy intensity for the sector is 8 GJ/tonne nowadays as in contrast to 35 GJ/tonne in 1960 (Glass Alliance Europe, 2016). More specifically the average fuel and emissions intensity of the European glass industry (EU25) was 7.8 GJ per tonne of saleable glass and 0.57 tCO_2 per tonne of saleable glass respectively in 2007 (Smitz et al., 2011). For the container glass industry the average fuel and emissions intensity of the European glass industry (EU25) was 6.4 GJ per tonne of saleable glass and 0.48 tCO_2 per tonne of saleable glass respectively in 2007. Respective figures for flat glass were about 40 % higher.

Apart from the restrictions on CO_2 emissions imposed by the Emissions Trading Directive, the EU glass industries have to comply with the emission limit values for nitrogen oxides and sulphur oxides imposed by the Industrial Emissions Directive (IED) and determined in the sector's Best Available Techniques (BAT) reference document (ResearchandMarkets, 2016 – b).

In order to decrease the specific energy consumption and consequently the CO_2 emissions during the glass production process, a widely proven method considers the utilization of the exhaust gases. Those have typically a heat content that reflects 25–30 % of the furnace energy input (Hibscher C., et al., 2009), (Barklage-Hilgefort H., 2009), (Rue D. et al, 2014), (Herzog J. et al, 2008), (Campanaa F. et al., 2013) . The exhaust gas temperature downstream the air regenerators lies in the range of 400–500 °C and can arrive at 700 °C or higher with recuperators of air-fired furnaces whereas at oxygen-fired glass melting furnaces it achieves temperatures higher than 1,100 °C.

Waste Heat Recovery options suitable for the glass industry include electricity generation, steam or hot water generation, thermochemical recuperation, natural gas preheating and batch/cullet preheating.

It has been concluded that Organic Rankine Cycle Systems is an option with important opportunities in heat recovery in energy intensive industries including the glass industry (Campanaa F. et al., 2013). In particular the evaluation of energy balance at a glass plant has revealed that for heat source temperature of approximately 450–500 °C, Organic Rankine Cycle (ORC) systems and water steam Rankine cycle systems have an electric efficiency of 15–19 % (Zourou K., et al., 2013).

Steam or hot water can be produced during suitable heat exchangers for internal or external utilization, such as building heating and cooling or for industrial processes in neighboring facilities (Biščan D et al, 2012), (Rezaie, B et al., 2012).

Thermochemical recuperation systems (Hibscher et al., 2009) utilise recovered heat for converting natural gas to hot synthesis gas, that mostly contains CO and H_2 and has a higher energy content than natural gas. The conversion reaction is highly endothermic while the installation of such a system is most fitting for oxy-fuel or recuperative furnaces because the temperature required inside the reformer lies in the range of 800 °C to 900 °C. Preheating of natural gas at a temperature of about 350–400 °C has already been applied in a few industries, especially in oxy-fuel furnaces while the installation of this application leads to specific energy savings in the order of (Van Limpt H., et al., 2013) 3 %.

Batch/cullet mixture preheating is an additional option of recovering waste heat. As an option it is known since the 80s however it has not been much utilized due to the problems associated with it. Those concerned high investment costs and technical side effects. First generation systems were characterized by the evaporation of batch moisture and the dehydration of soda ash (Glüsing A. K., 2009), causing agglomerations and blocking problems of the batch flow in the preheater. To achieve the consequent requirement for minimization of the water content, it was obligatory to use cullet ratios above 50 %. An additional downside was the increased dust carry-over from the combustion area into the regenerator as well as from the batch preheater to the stack given that batch was completely dried. In the current days the dusting and humidity problems have been solved due to developing technologies and in the Best Available Techniques reference document (Scalet B. M., et al.2013) issued for the Glass Industry in 2013, batch preheating is included within the "promising technological innovations".

According to the Best Available Techniques reference document, batch preheating systems can be installed at any existing glass melting furnace with a cullet ratio of more than 50 % while one installation is reported to have been operating at 30 % cullet ration. Energy savings achieved with batch/cullet preheating reach levels of 12–20 % (Beerkens R., 2009-b). The batch/cullet mixture is preheated to approximately 300 °C and flue gases are cooled down by 200–250 °C. Specific energy consumption is decreased by combining reduced fuel input and, in the case of electric boosting, reduced electricity consumption with an increased glass pull so that air emissions levels are reduced. In addition, despite relatively high investment costs, payback times of less than 5 years have been reported (Scalet B. M., et al.2013), (Beerkens R., 2009-b), (Worrell, Ernst, 2008).

Emissions reduction is achieved subsequently to energy savings since 70–90 % of the CO_2 emissions are linked to fuel combustion (Ross C. P., 2009). Therefore, batch/cullet preheating also consequences CO_2 emissions decrease. In the same manner, as combustion air is reduced, NO_x emitted is also reduced (Beutin E. et al. 2009) .

BATCH AND CULLET PREHEATING

There are various types of batch and/or cullet preheating systems applied in the glass industry or still in testing phase. At cullet – only preheaters, cullet is preheated by direct contact with either the flue gases or steam. At combined batch and cullet preheaters, heat can be transferred through direct or indirect contact between the batch and the hot flue gases. Batch can also be introduced inside the preheater in the form of pellets.

Important restrictions have to be applied when installing a batch preheater. At first, the entry temperature of the flue gases must not exceed 600 °C so as to avoid the deformation of structural materials. This is also the temperature where cullet begins to stick and cause plugging problems. Although batch humidity is necessary to avoid batch de-mixing during transportation, water content of the batch needs to be reduced to a minimum as well, due to problematic water removal from the preheater. This is the reason of first generation preheating systems operating with a cullet percentage of 50 % or more, where, as cullet content increases the required moisture is decreased. Well-known manufacturers of preheat systems are Interproject, Praxair (originally Edmeston), Sorg and Zippe. Some of the installed systems are described below.

Interprojekt batch preheater (Beutin E. et al. 2009) is a direct contact heat exchanger presented in Figure 4. Hot flue gases flow downstream the air regenerator through the preheater in several layers (8–10) of ducts which are situated horizontally across the preheater and are open at the bottom side, allowing direct contact with the batch. Flue gases pass in cross and counter flow through the preheater from the bottom with a temperature of about 400–500 °C to the top with a temperature of 200–250 °C. The flue gas ducts have been appropriately designed in order to minimize the pressure losses, to provide a longer residence rime of the gases inside the heat exchanger and to limit carry-over entrainment of dust. Typical flue gas velocities range between 6 and 8 m/s. Batch and cullet are mixed before entering the preheater according to a preferred recipe and then conveyed to the top of the preheater. The batch moves slowly due to gravity with a typical speed of 1–3 m/h ensuring adequate heat transfer and practically no wear of the ducts and the walls. The batch is completely dried and heated to a temperature of about 300 °C. Nienburger Glas (now REXAM) has installed its first unit in 1987 in furnace no. 4 and replaced it with an improved version in 1999 using the Interprojekt system (Barklage-Hilgefort H, 2009). The original system was installed in a green glass regenerative furnace operating at pull rates of 260 - 310 t/d using more than 80 % cullet content in the batch. The specific energy consumption was 3,367 kJ/kg glass including the electric boosting, achieving an energy saving of about 16 %. Another batch preheater was also installed in Nienburg furnace no. 1 which produced flint glass. This furnace was operating without electric boosting and was using lower cullet content than the green glass furnace (40–70 %). The average specific energy consumption was 3,870 kJ/kg glass.

Praxair and Edmeston (Barrickman L. et al. 2009) have developed a hybrid direct cullet only preheater for oxy-fuel furnaces, combined with an electrostatic precipitator for dust removal.

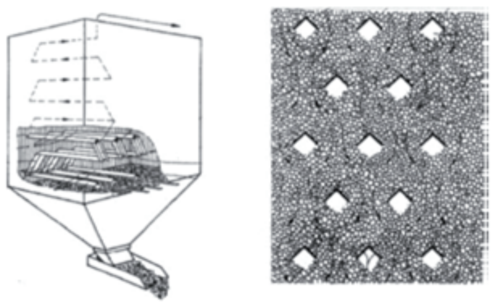

Figure 4. Basic concept of the batch preheating system "Nienburger" type (Barklage-Hilgefort H, 2009).

External cullet from market recycling and internal cullet from defected products of the factory are treated separately. External cullet enters the pyrolizer where organic matter is vaporized after being in contact with a hot stream of flue gases and then this stream is mixed with hot flue gases from the furnace. Next step of the process deals with stream flow into an ionizer where dust particles are electrically charged and then passes through a main cullet preheater which is filled with both internal and preheated external cullet. In this main preheater, cullet is dried and further preheated while the dust particles are captured by the surface of the cullet due to an electrostatic field created by a built-in high-voltage electrode.

Sorg has also developed the so-called LoNOx-Melter furnace which is combined with a direct cullet preheater. The first installation was installed at Wiegand Glass, in Steinbach, Germany. Estimated energy savings by cullet preheating is (Herzog J. 2008) 15–20 % for recuperative furnaces based on 85 % cullet.

Zippe has developed a cross counter flow indirect preheater in which there is no direct contact between the flue gases and the batch (Glüsing A. K. 2009). The system is constructed by individual heat exchange modules stacked up vertically. Compared to a direct preheater, the advantage of using closed ducts is that no chemical reactions between the flue gas and the batch occur, there are no contaminations of the flue gases and no dust carry-over. The drawbacks of this system are the decreased heat transfer rates that lead to bigger constructions and the difficulty to remove batch moisture. Due to the moisture of the descending batch, the flue gas ducts at the top of the preheater comprise a drying zone. In order to remove the steam produced, de-vaporization modules were designed and installed between the individual modules. These funnels create hollow spaces inside the preheater in which steam can be trapped and subsequently withdrawn when added to the flue gas stream. Four such systems have been built (Beerkens R., 2009) in the 1990s for both regenerative and recuperative container glass furnaces. Typical height of the preheater varies between 20–25 m and energy savings range between 12–20 %. It is also reported that Zippe has developed a 2nd generation advanced batch preheating system that constitutes a hybrid between the indirect and the direct preheating system, combining both close and open-bottomed ducts (Zippe P., 2011,) while the first batch preheater in Africa, that can handle up to 400 tons/day, was successfully commissioned for Nampak Glass in South Africa during 2015 (Zippe, 2016).

Case Study for batch preheater installation

A case study based on one of the most energy-efficient end-port fired regenerative container glass furnace (Beerkens R., 2009-b) has been constructed. At first, furnace characteristics, that originally operates without a batch preheating system, are presented and the exhaust gases waste heat recovery potential is calculated. Consequently, assuming that a preheater is installed, three cases are examined based on different configurations with effect on fuel consumption and glass pull. The preheater dimensions are taken as 4.2 m long, 4.7 m wide while its effective height is 16.9 m. A 3-dimensional computational model (Dolianitis I. et al. 2016,) is used in order to simulate the mass and heat flows inside the proposed batch preheater while specific energy consumption and CO_2 emissions are

Table 2. Regenerative furnace energy balance without batch preheating.

Heat flows	kW	kJ/kg Glass	%
Heat input			
Fuel	10,893.5	3,620.0	98.7
Batch	51.5	17.1	0.5
Air	94.1	31.3	0.9
Heat output			
Water evaporation + soda dehydration	177.7	59.1	1.6
Endothermic reactions	262.7	87.3	2.4
Heat carried by glass	4,883.7	1,622.9	44.2
Flue gases downstream the regenerator	3,043.5	1,011.4	27.6
Conduction through furnace walls	2,016.8	670.2	18.2
Cooling and leakage	404.6	134.4	3.7
Regenerator losses	249.5	82.9	2.3

determined. Subsequently, a sensitivity analysis is performed where the length of the preheater is altered in order to estimate specific fuel consumption variation.

Energy balance calculations using 0 °C as reference temperature are given in Table 2. The basic data of the process without batch preheating are a glass pull of 260 t/d, an 83 % cullet in mixture, a 2 % batch humidity, energy consumption of 3,620 kJ/kg and no electric boosting. Assuming natural gas lower heating value of 46 MJ/kg and 2.6 kg of CO_2 emissions for every kg of natural gas combusted, the fuel derived CO_2 emissions are 0.205 kgCO_2/kg glass (53.2 tCO_2/day). The composition of the batch is: 83 % cullet, 10.5 % silica sand, 2 % limestone, 2 % dolomite and 2.5 % soda ash. Limestone emits 44.8 % of its mass as CO_2 while the mass loss percentage for dolomite and soda ash is 46.8 % and 41.9 % respectively (Ross C. P., 2010) . For a glass pull of 260 t/d, the process derived CO_2 emissions are 0.029 kgCO_2/kg glass (7.5 tCO_2/day) and overall CO_2 emissions are 0.232 kgCO_2/kg glass (60.3 tCO_2/day). The calculated flue gas volume flow downstream the regenerator is 14,223 Nm^3/h assuming 3.5 % oxygen content and its temperature is 476 °C, based on mass and energy balance of the initial configuration of the plant, as illustrated in Table 2.

FUEL REDUCTION CASE (CASE 1)

At the first case, glass pull is kept constant and fuel consumption is reduced. According to the model, batch is preheated to 322 °C and flue gases are cooled down to 209 °C. From the flue gas an amount of 1,379.8 kW is recovered and the efficiency of the preheater is 55.1 %. The specific energy consumption is 2,988 kJ/kg, reduced by 17.5 %. Specific energy consumption is reduced as both the mass and the temperature of the exhaust gases decrease. CO_2 emissions are 0.196 kgCO_2/kg glass (51 tCO_2/day), reduced by 15.4 %.

INCREASED PULL CASE (CASE 2)

At this second case fuel consumption remains constant while batch throughput is increased. It is suggested (Alexander J. C. 2009) that the pull rate of a furnace is limited due to one of the following reasons: forming machine capacity, cold-end equipment handling capacity, batch plant capacity, furnace design for refining, exhaust gas pollution emissions and energy input limitations for melting. Assuming that the first four limitations don't actually restrict an increased pull, heat transfer and heat balance calculations show that glass pull reaches 344 t/d, raised by 32.3 %. Batch is preheated to 302 °C and flue gases are cooled down to 209 °C. From the flue gas an amount of 1,702.4 kW is recovered and the efficiency of the preheater is 55.9 %. The specific energy consumption is 2,736.4 kJ/kg, reduced by 24.4 %. Even though fuel consumption is unchanged, specific energy consumption is reduced due to the decrease of the exhaust gas temperature and the increased glass pull. Specific CO_2 emissions are 0.184 kg CO_2/kg glass, reduced by 20.8 %.

COMBINED FUEL REDUCTION AND INCREASED PULL RATE CASE (CASE 3)

Since an increase in glass pull by 32.3 % is not always possible, at this third case, glass pull is set to 286 t/d, raised by 10 %. According to heat transfer and heat balance calculations the specific energy consumption is reduced by 20 % and fuel consumption is reduced by 12 %. Flue gases are cooled down to 210 °C and batch is preheated to 313 °C. From the flue gas an amount of 1,478.9 kW is recovered and the efficiency of the preheater is 55.2 %. Specific energy consumption decreases due to the increased glass pull and the reduction of the exhaust gas temperature and mass. Specific CO_2 emissions are 0.193 kgCO_2/kg glass, reduced by 17 %. The calculated energy flows for each case are presented in Table 3.

SENSITIVITY ANALYSIS

At a specific batch preheating installation, the available heat content of the incoming flue gases is determined by the furnace – air regenerator operation and is considered as constant. In order to increase the temperature of the preheated batch and consequently the amount of the energy recovered, the residence time of the batch inside the preheater has to be raised. Residence time can be raised by changing the preheater dimensions, as far as the batch flow is assumed constant. In the following analysis the variation of the preheater's length was examined with respect to batch residence time.

A sensitivity analysis has been carried out where four designs of the preheater (A, B, C and D) are examined based on the regenerative container glass furnace data presented in Table 2. The length of each design A, B, C and D is 1.5 m, 3 m, 4.2 m and 6.75 m respectively, while every other designing parameter remains unchanged. Two different configurations are investi-

Table 3. Energy balance of the furnace – batch preheater system.

Heat flows	**Case 1**		**Case 2**		**Case 3**	
	kJ/kg Glass	%	kJ/kg Glass	%	kJ/kg Glass	%
Heat input						
Fuel	2,988.1	98.6	2,736.4	98.5	2,894.9	98.6
Batch	17.1	0.6	17.1	0.6	17.1	0.6
Air	25.8	0.9	23.9	0.9	25.0	0.9
Heat output						
Water evaporation + soda dehydration	59.1	1.9	59.4	2.1	59.4	2.0
Endothermic reactions	87.3	2.9	87.3	3.1	87.3	3.0
Heat carried by glass	1,622.9	53.5	1,622.9	58.4	1,622.9	55.3
Flue gases downstream the regenerator	336.3	11.1	309.4	11.1	328.2	11.2
Conduction through furnace walls	670.2	22.1	506.6	18.2	609.3	20.7
Cooling and leakage	134.4	4.4	101.7	3.7	120.7	4.1
Regenerator losses	82.9	2.7	62.7	2.3	75.4	2.6
Preheater losses	37.9	1.3	27.4	1.0	33.8	1.2

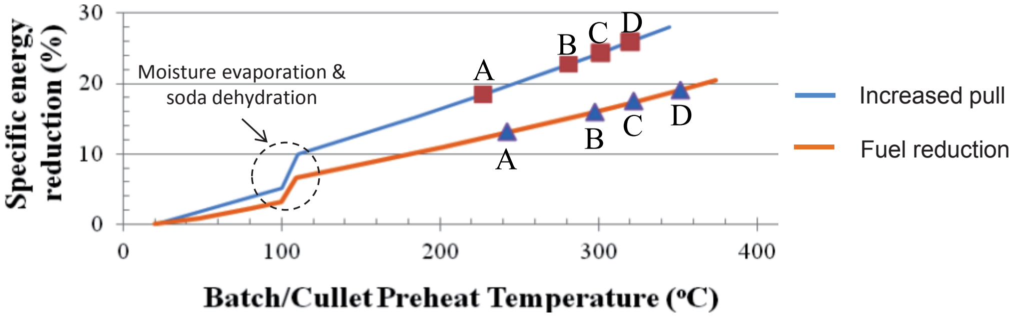

Figure 5. Effect of preheated batch temperature on specific energy consumption in a regenerative glass furnace by examining designs A, B, C and D with varying length.

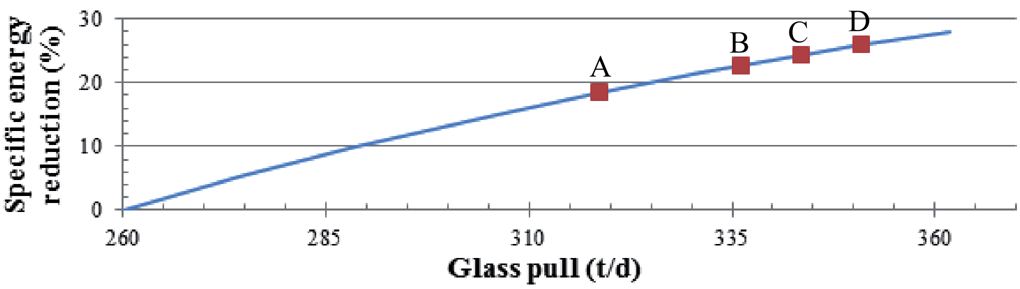

Figure 6. Effect of increased glass pull on specific energy consumption in a regenerative glass furnace with batch preheating operating with 10.9 MW energy input by examining designs A, B, C and D with varying length.

gated. At the first configuration (as case 1), glass pull is kept constant at 260 t/d and fuel consumption is reduced. At the second configuration (as case 2), fuel consumption remains constant and glass pull is accordingly increased. The effect of the preheated batch temperature on the specific energy consumption is examined for both configurations and presented in Figure 5 for each one of the four designs. The effect of an increased glass pull while energy inputs remain constant, examined at the second configuration, on the specific energy consumption is presented in Figure 6. It is expected that, as the length of a preheater increases, the overall surface of the ducts is proportionally increased and the velocity of the batch that moves down the preheater decreases. As a result, the residence time of the batch inside the preheater increases, the efficiency of the preheater increases and the specific energy consumption of the entire glass production plant is reduced.

Energy reduction incentives: To what extend are they driven by the EU ETS?

Emission Allowances' allocation above actually verified emissions is perceived as a lower incentive for abatement, since in this case, there is no urge for a EU – ETS operator to pursue emission reductions by means of emission abatement measures. Nevertheless, abatement that may be linked to energy efficiency improvement is considered, in the case of a moderate carbon price uncertainty. In fact, there are profits under such circumstances. A study (Sander de Bruyn et al., 2016) calculated the additional profits that sectors and companies have made from the EU ETS from 2008 to 2014 for 19 countries and 15 sectors including flat glass (NACE code 23.11), hollow glass (NACE code 23.13) and "other glass" (NACE code 23.14). Three types of profits were examined: profits from overallocation of free emission allowances conducted by selling the surplus in the market, profits from using CDM/JI credits for compliance which have a mean lower price than the allocated EUAs and profits from passing through the opportunity costs of freely obtained allowances in product prices (windfall profits).

Currently, it is not easy to quantify the exact rate of costs passed through to the final product due to the restrictions imposed by the EU – ETS per sectors or products. Yet, indicative figures for Glass industries have appeared in publications (EU Commission, 2015). In general, sectors capable of passing through costs only up to a limited extent, and therefore tolerating most of the carbon costs, are understood to face a higher risk of "carbon leakage". Viewing at the minimum cost pass-through values found in literature (EU Commission, 2015) out of six sectors, the glass sector had the second lowest minimum in the case of container glass (20 %) and third lowest minimum (30 %) in the case of hollow and other glass. Respective maximum percentages reported were 50 % for container glass being the lowest among the sectors and 80 % for the hollow and other glass being the second higher percentage among the examined sectors. A more recent study conducted, aiming to separate emission abatement reasons to those attributable to the EU – ETS and those attributable to the economic crisis that hit the EU in 2008/09 (Bel et Joseph 2015). This study showed that the reduction in emissions is mainly due to the economic recession rather than to the EU ETS and that studies prior to the crisis overestimated the potential of the EU – ETS for GHG emissions reduction, since the conditions that finally prevailed could not be foreseen.

The energy reduction potential through batch – preheating has currently not been exploited significantly, presumably due to high investment costs, space limitations and the overall position of the glass industries i.e. the difficulties that have to be faced due to the economic recession and the competition from outside EU. In addition it has only been relatively recently announced as a BAT in the glass sector. For the three first years of the third phase of the EU ETS i.e. 2013–2015, a rough shortfall in the range of 6,5 million emission allowances has appeared for the sector. This can be considered a significant incentive for the application of the batch preheating technique. In overall, the structure of the EU-ETS in its 4th phase from 2021 to 2030 which is currently at stake (DG for Climate Action 2016 – c) and in particular the move towards better targeted carbon leakage rules will clarify the picture concerning the foreseen carbon market and the potential for investments in the glass manufacturing sector.

Conclusions

Reducing energy consumption is an economic imperative and constant goal for all glass manufacturers (Glass for Europe, 2016). The utilization of batch preheating is still limited although the technology is now mature and problems such as dust carry-over and material plugging can be overcome according to current experience. Batch preheating is one of the best available techniques leading to high energy savings and potentially increasing production rates, as well as reducing CO_2 emissions. Concerning the issue of CO_2 emissions reduction, currently allocated emission allowances for the years 2013–2020 for the operating EU – ETS glass industries are estimated (EUTL, 2016) to approximately 120 million EUAs. Considering a 2 % of annual increase in glass production in the participating EU ETS countries, the amount of emissions for the years 2016–2020 is expected to be approximately 96 $MtCO_2$. A shortfall in emissions allowances in the range of 24–30 million EUAs for the years 2016 to 2020 is expected. This shortfall reflects a representative one without considering any additional actions that the installations might have taken through selling/buying/lending allowances or making forward contracts. Carbon dioxide emissions in the case study presented above were reduced by a range of 15.4 % to 20.8 % indicating that the glass sector can reduce its level of emissions by increasing energy efficiency. In the hypothetical case were the specific WHR application of batch preheating would be applied for the years 2016–2020 to a group of installations that emit 15 % of the total verified emissions (14,5 Mt of verified emissions) and considering a modest 12 % reduction of CO_2 emissions due to specific fuel consumption decrease, this would result into reduction of 1.7 Mt CO_2. At EUA prices in the range of 5 to 10 Euro per EUA this could interpret into a modest estimation of savings of 9–17 million Euros for the 5-year period from 2016 to 2020.

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