IMPEL PROJECT: "*ENERGY EFFICIENCY IN PERMITTING AND INSPECTION*", EXCHANGE OF EXPERIENCES ON HOW THE ISSUES OF ENERGY EFFICIENCY AND REDUCTION OF GREENHOUSE GASES ARE DEALT WITH IN PERMIT PROCEDURES AND INSPECTIONS IN THE MEMBER STATES – DEVELOPMENT OF A TEMPLATE FOR DOCUMENTS AND DATA REQUIRED REGARDING ENERGY EFFICIENCY IN THE PERMIT APPLICATION (2011/2012)

2012/04/ANNEX 3

MANUFACTURE OF GLASS

SUMMARY OF ENERGY-RELATED INFORMATION FOR THE MANUFACTURE OF GLASS AND PROPOSAL FOR THE SECTOR SPECIFIC SUPPLEMENT TO THE DRAFT APPLICATION FORM FOR ENERGY EFFICIENCY

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European Union Network for
the Implementation and Enforcement
of Environmental Law

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1 Summary of Energy-related Information – Glass Sector

In Chapter 1, energy (efficiency)-related information has been extracted from the Draft BAT Conclusions for the Manufacturing of Glass, Draft BREF for the Manufacture of Glass as well as from an expert presentation (i.e. Association of the German glass industry). The main purpose of the summary is to create a basis for the development of a proposal for sector specific supplements to the Draft Application Form for Energy Efficiency in Chapter 2 of this document.

Where relevant, reference will be provided to the exact Chapter/Figure/Table of the abovementioned documents from which particular information has been taken.

1.1 Draft BAT Conclusions for the Manufacture of Glass (Energy Efficiency)

The Draft BAT Conclusions provide reference to other BREFs which are of relevance for the activities covered by the BAT Conclusions. Among these documents, the reference document on Energy Efficiency (ENE) has been pointed out.

1.1.1 General BAT conclusions for glass manufacturing

Unless otherwise specified, the **general BAT Conclusions** apply to all instillations. According to **Chapter 1.1.2 of the Draft BAT Conclusions**, BAT is to reduce the specific energy consumption by using one or a combination of the following techniques (see **BAT 2**).

	Technique	Applicability
i.	**Process optimisation, through the control of the operating parameters**	The techniques are generally applicable
ii.	**Regular maintenance of the melting furnace**	
iii.	**Optimisation of the furnace design and the selection of the melting technique**	Applicable for new plants. For existing plants, the implementation requires a complete rebuild of the furnace
iv.	**Application of combustion control techniques**	Applicable to fuel/air and oxy-fuel fired furnaces
v.	**Use of increasing levels of cullet, where available and economically and technically viable**	Not applicable to the continuous filament glass fibre, high temperature insulation wool and frits sectors
vi.	**Use of a waste heat boiler for energy recovery, where technically and economically viable**	Applicable to fuel/air and oxy-fuel fired furnaces. The applicability and economic viability of the technique is dictated by the overall efficiency that may be obtained, including the effective use of the steam generated
vii.	**Use of batch and cullet preheating, where technically and economically viable**	Applicable to fuel/air and oxy-fuel fired furnaces. The applicability is normally restricted to batch compositions with more than 50 % cullet

Table 1-1: General BAT Conclusions for the Glass Industry

Furthermore, **Chapter 1.1.4 of the Draft BAT Conclusions (i.e. BAT 5)** stipulates that BAT is to reduce energy consumption and emissions to air by carrying out a constant monitoring of the operational parameters and programmed maintenance of the melting furnace.

Technique	Applicability
The technique consists of a series of monitoring and maintenance operations which can be used individually or in combination appropriate to the type of furnace, with the aim of minimising the ageing effects on the furnace, such as sealing the furnace and burner blocks, keep the maximum insulation, control the stabilised flame conditions, control the fuel/air ratio, etc.	Applicable to regenerative, recuperative, and oxy-fuel fired furnaces. The applicability to other types of furnaces requires an installation-specific assessment

Table 1-2: Monitoring of parameters and maintenance of the melting furnace

In relation to **BAT 5** it has to, however, be noted that the described technique is only applicable to regenerative, recuperative and oxy-fuel fired furnaces. The applicability to other types of furnaces would require an installation-specific assessment.

1.1.2 Process-specific BAT conclusions for glass manufacturing

Process-specific BAT apply in addition to the above listed general BAT (e.g. BAT for container glass manufacturing, BAT for flat glass manufacturing, BAT for domestic glass manufacturing). However, with regard to energy (efficiency), no process-specific BAT are defined.

1.2 Expert presentation (Federal Association of the German Glass Industry)

During the 2nd **Expert Group Meeting**, Mr. Engelhardt from the Federal Association of the German Glass Industry introduced the glass manufacturing sector in general and presented energy-related information which can be utilised for the purpose of this document.

After a brief introduction to the glass industry in general and the presentation of key figures (e.g. energy end use: electricity 21.4 %, natural gas 66.1 % heavy fuel oil 11.9 % and light fuel oil 0.6 %) the main production processes were described in more detail.

In connection to energy efficiency, it was stated that the German glass industry nowadays has the highest energy efficiency ever. The specific energy consumption has reduced from 1928 up to now significantly (i.e. from >5,500 kWh/t to approximately 1,000 kWh/t). Since the 1960s, the glass manufacturing industry as a whole has reduced the specific energy consumption by approximately 1.5 % per year. Nowadays, this figure is lower as the thermodynamic limits are approached.

The typical energy demands in relation to different types of furnace (e.g. cross fired burner, regenerative 4,200 kJ/kg) and different types of glass produced (e.g. container glass, float glass) were summarised (see Table 1-3) and the **main drivers for energy efficiency** in the industry listed as:

- size of furnace: large furnaces are inherently more energy efficient due to the better surface to volume ratio
- heat recuperation: combustion air pre-heating (installed in all furnaces)
- waste heat use: cullet pre-heating, batch pre-heating (energy efficiency gains 5-10 %)
- throughput: the higher the better in terms of energy efficiency
- type of glass produced (e.g. colourless or coloured)
- age of furnace (the newer, the higher the energy efficiency)
- quality needed: higher quality means higher energy input
- quantity and quality of cullet (10 % more cullet leads to approximately 3 % less energy input)
- oxy-fuel-firing
- waste heat boilers

Furthermore, in relation to **typical energy demands**, the following Table was presented to the meeting participants (Source VDI 2578)

Type of furnace	Sort of glass	Contents [t]	Melting surface [m²]	Depth [m]	Capacity [t/d]	Energy [kJ/kg]
Cross-fired burner, regenerative	container glass	50-500	15-155	1,2-1,7	40-500	**4200**
U-flame, regenerative	container glass	50-500	15-140	1,2-1,7	40-450	**3800**
Recuperative furnace	container glass	50-650	up to 250	1,1-1,6	40-450	**5000**

Oxy-fuel furnace	container glass	390-600	110-154	1,3-1,7	350-425	**3050-3500**
Cross-fired burner, regenerative	float glass	300-2500	100-400	1,2-1,4	150-900	**6300**
Recuperative furnace	domestic glass	40-180	15-60	1,1-1,3	15-120	**6700**
Recuperative furnace	continuous filament glass fibre	50-200	15-110	0,8-1,5	30-350	**4300**

Table 1-3: Typical energy demands in relation to different types of furnace and glass produced

In addition, Mr. Engelhardt also summarised the main BREF-BAT techniques and discussed their applicability (e.g. optimisation of the furnace design and the selection of the melting technique which is applicable for new plants, for existing plants the implementation requires a complete rebuild of the furnace).

Finally, some of the **main obstacles to higher energy efficiency** were summed up as:

- melting processes are already optimised
- payback time for investments
- use of cullet: necessary volumes are not on the market, low quality cullet
- cullet and batch pre-heating: problem of 'concrete development' which is a danger to the production process
- oxy-fuel: high costs
- waste heat boilers (question remains what to do with the steam)
- higher energy demand for environmental protection technologies
- higher energy demand for higher product quality
- missing space for installations rebuilds or improvements

1.3 Draft BREF for the Manufacture of Glass (Version 24 June 2011)

The major environmental challenges for the glass industry are emissions to air and energy consumption. Glass making is a high temperature, energy intensive activity, resulting in the emissions of products from combustion and the high-temperature oxidation of atmospheric nitrogen; i.e. sulphur dioxide, carbon dioxide, and oxides of nitrogen. Total energy consumption by the glass industry was approximately 311 PJ (86.5 million MWh). Of the total energy, 15 % is consumed as electricity, 30 % as fuel oil and 55 % as natural gas.

Major environmental improvements have been made in flat glass production, emissions have been reduced substantially by means of primary and secondary measures and reductions of specific energy consumption have been achieved. From 1960 to 1995, energy consumption has been reduced by 60 %, while during the period 1996 – 2006; a further reduction of about 20 % was achieved. The **theoretical minimum for glass melting is 0.76 MWh/tonne** (equivalent to **2.74 GJ/tonne**) and significant development in technology would be necessary for further improvements [128, ECORYS 2008]. The **observed minimum values for specific energy consumption are about 5 GJ/tonne**, at the beginning of a furnace campaign.

1.3.1 Summary of general information for the whole glass sector

Chapter 3 of the Draft BREF document provides data and information concerning the environmental performance of installations within the sector in terms of current emissions, consumption and nature of raw materials, water consumption, **use of energy** and the generation of waste reflecting the situation in installations in operation at the time of writing. The input and output are discussed for the industry as a whole, followed by more specific consideration for each sub-sector.

Glass making is energy intensive and the choices of energy source, heating technique and heat recovery method are central to the design of the furnace. The same choices are also some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. **Thus, one of the most important types of input to the glass making process is energy, and the three main energy sources are fuel oil, natural gas and electricity.** The exception to this is the manufacture of stone wool where the predominant melting technique is the hot blast cupola, which is fuelled by coke. **The choice of energy source depends strongly on the individual energy strategies and/or policies of each Member State (e.g. promoting the use of fossil fuel instead of nuclear power).** The type of energy used has a direct influence on the emissions of air pollutants (e.g. SO_x from fuel containing sulphur, or NOx from natural gas containing significant amounts of nitrogen, etc.). It also influences whether the emissions will be emitted directly from the site or indirectly off-site.

In past decades, the predominant fuel for glass making has been fuel oil, although in several European countries natural gas is now the predominant fuel. There are various grades of fuel oil from heavy to light, varying in purity and sulphur content. Many large furnaces are equipped to run on both natural gas and fuel oil, and it is not uncommon for predominantly gas-fired furnaces to burn oil on one or two ports. It is also more and more common to mix fuel and gas in the same burner. The third common energy source for glass making is electricity, which can be used either as the only energy source or in combination with fossil fuels. Resistive electrical heating is the only technique to have found widespread commercial application within the glass industry. Indirect electric heating has only been used for very small tanks and pot furnaces or for heating part of a tank (e.g. the working end or the forehearth).

In general, the energy necessary for melting glass accounts for over 75 % of the total energy requirements of glass manufacture. Other significant areas of energy use are forehearths, the forming process, annealing, factory heating and general services. **The typical energy use for the container glass sector, which accounts for around 53 % of the EU output is for the furnace 79 - 82 %; the forehearth 6 %; the compressed air 4 %; the annealing lehr 2 %; and other 6 %.** Although there are wide differences between sectors and individual plants, the example for container glass can be considered broadly indicative for the industry. The main exception to this generalisation is the mineral wool sector where the fiberising operation and the curing oven are also major energy consumers. Within the container glass sector, the production of flaconnage represents a specific case, with about 50 % of the total energy consumption used for melting due to the particular quality requirements of the final product.

As discussed earlier, fuel oil and natural gas are the predominant energy sources for melting, with a small percentage of electricity. Forehearths and annealing lehrs are heated by gas or electricity, and electrical energy is used to drive air compressors and fans needed for the process. General services include water pumping, steam generation for fuel storage and trace heating, humidification/heating of batch, and heating buildings. Some furnaces have been equipped with waste heat boilers to produce part or all of the steam required

In order to provide a benchmark for process energy efficiency, it is useful to consider the theoretical energy requirements for melting glass. The theoretical energy requirements for the melting of the most common glasses from batch formulations without cullet recycling is given in Table 1-4 The calculation assumes all available heat is fully utilised and has three components:

- the heat of reaction to form the glass from the raw materials
- the heat required, enthalpy, to raise the glass temperature from 20 to 1500 °C and
- the heat content of the gases (principally CO_2) released from the batch during melting.

The theoretical levels given in Table 1-4 only relate to the energy required to melt the glass formulations. Additional energy will be required to refine, form and finish the glass, and for other ancillary services such as compressed air.

Type of glass	**Heat of Reaction [GJ/tonne]**	**Enthalpy of glass [GJ/tonne]**	**Enthalpy of gases emitted [GJ/tonne]**	**Theoretical energy [GJ/tonne]**
Soda-lime (flat/container glass)	0.49	1.89	0.30	**2.68**
Borosilicate (8 % B_2O_3)	0.41	1.70	0.14	**2.25**
Borosilicate (13 % B_2O_3)	NA	NA	NA	**2.4**
Crystal glass (19 % PbO)	0.40	1.69	0.16	**2.25**
Crystal glass (24 % PbO)	NA	NA	NA	**2.1**
Crystalline glass with Barium	1.02	1.91	0.31	**3.24**
NA = not available. *Source:* **[15, ETSU 1992] [102, ARC Energy requirement 2008]**				

Table 1-4: Theoretical energy requirements for the melting of common glasses from batch formulations without cullet recycling [Table 3.6, BREF GLS]

The actual melting energy requirements experienced in the various sectors vary widely from about 3.3 to over 40 GJ/melted tonne. This figure depends very heavily on the furnace design, scale, method of operation and type of glass. However, the majority of glass is produced in large furnaces and the energy requirement for melting is generally below 8 GJ/tonne. Energy consumption is considered further for each sector where information is available.

In general, energy is supplied to the melting furnace by:

- combustion of fuel
- preheating of combustion air
- electric power
- sensible heat of fuels, oxygen or excess air
- (preheated) batch

Because glass making is such energy intensive, high-temperature process, there is clearly a high potential for heat loss. **Substantial progress with energy efficiency has been made in recent years and some processes (e.g. large regenerative furnaces) are approaching the theoretical minimum energy consumption for melting, taking into account the inherent limitations of the processes.**

A modern regenerative container furnace will have an overall thermal efficiency of around 50 % (maximum 60 %), with waste gas losses of around 30 %, and structural losses making up the vast majority of the remainder. This efficiency compares quite well with other large-scale combustion activities particularly electricity generation which typically has efficiency in the range of 35 - 45 %. Structural losses are inversely proportional to the furnace size, the main reason being the change in surface area to volume ratio. **Electrically heated and oxy-fuel fired furnaces generally have better specific energy efficiencies than fossil fuel furnaces**, but have associated drawbacks which are discussed later in this document. A typical energy output distribution for the production of the most common industrial glasses is reported in Table 1-5.

Type of glass	Flat glass	Container glass
Type of furnace	Float, regenerative cross-fired	Regenerative, end-fired
Pull rate	600 tonnes/day	260 tonnes/day
Cullet	25 %	83 %
Total energy consumption (GJ/tonne melted glass)	6.48 GJ/tonne melted glass	3.62 GJ/tonne melted glass
Water evaporation (batch humidity)	1 %	1.5 %
Endothermic reactions	6 %	2.4 %
Sensible heat glass melt (net)	33 %	44.2 %
Wall heat losses	15 %	18.3 %
Cooling and leakage heat losses	9 %	3.7 %
Flue-gas losses from bottom regenerator	32 %	27.6 %
Regenerator heat losses (structure)	4 %	2.3 %
Source: [97, Beerkens Energy Balances 2006]		

Table 1-5: Examples of energy output distribution for the production of the most common industrial glasses [Table 3.7, BREF GLS]

Some of the more general factors affecting the energy consumption of fossil fuel fired furnaces are outlined below. For any particular installation, it is important to take account of site-specific issues which will affect the applicability of the general information given below. These factors also affect the emissions per tonne of glass of those substances which relate directly to the amount of fossil fuel burned, particularly CO2, SO2 and NOX. **The main site-specific issues are given below**.

a. **The capacity of the furnace significantly affects the energy consumption per tonne of glass melted**, because larger furnaces are inherently more energy efficient due to the lower surface area to volume ratio.
b. **The furnace throughput is also important**, with most furnaces achieving the most energy efficient production at peak load. Variations in furnace load are largely market dependent and can be quite wide, particularly for some container glass and domestic glass products.
c. **As the age of a furnace increases, its thermal efficiency usually declines**. Towards the end of a furnace campaign, the energy consumption per tonne of glass melted may be up to 20 % higher than at the beginning of the campaign.
d. **The use of an electric boost improves the energy efficiency of the furnace.** However, when the cost of electricity and the efficiency of electrical generation and distribution are taken into account, the overall improvement is lower (or even negative). An electric boost is generally used to improve the melting capability of the furnace rather than to improve energy efficiency.
e. **The use of cullet can significantly reduce energy consumption because the chemical energy required to melt the raw materials has already been provided.** As a general rule, every 10 % increase in cullet usage results in an energy savings of 2 – 3 % in the melting process.
f. **Oxy-fuel firing can also reduce energy consumption, particularly in smaller furnaces.** The elimination of the majority of the nitrogen from the combustion atmosphere reduces the volume of the waste gases leaving the furnace by 60 – 70 %. Therefore, energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames; most oxy-fuel furnaces are not equipped with heat recovery systems.

The site-specific issues reported above do not take into account some important off-site issues which affect the applicability of the different melting techniques, in particular the cost of electricity and the efficiency of electrical generation and distribution.

Table 1-6 gives examples of specific energy consumption for a range of modern, energy efficient glass furnaces.

Tank furnace type	Glass type	Melting area (1) (m^2)	Glass bath depth melting end (mm)	Tank capacity melting end (t)	Length/width ratio of the tank bath	Output (t/d)	Specific output (t/m^2d)	Specific energy consumption (2) (kJ/kg glass)
Cross-fired furnace with regenerative air preheating	**Container glass**	15 – 155	1200 – 1700	50 – 500	1.9 - 3.0:1	40 - 500	2.5 - 4.0	**4200**
Regenerative end-fired furnace	**Container glass**	15 – 140	1200 – 1700	50 – 500	1.9 - 2.5:1	40 - 450	2.5 - 4.0	**3800**
Recuperative furnace	**Container glass**	Up to 250	1100 – 1600	50 – 650	2.0 - 2.8: 1	40 - 450	2.0 - 3.0	**5000**
Oxy-fuel fired furnace	**Container glass**	110 – 154	1300 – 1700	390 – 600	2.0 - 2.4:1	350 - 425	2.3 - 3.5	**3050 – 3500(3)**
Cross-fired furnace with regenerative air preheating	**Flat glass**	100 – 400	1200 – 1400	300 – 2500	2.1 - 2.8:1	150 - 900	2.3 - 2.7	**6300**
Cross-fired furnace with regenerative air preheating	**Television tube glass (screen)**	70 – 300	900 – 1100	160 – 700	2.0 - 3.0:1	100 - 500	1.1 - 1.8	**8300**
Furnace with recuperative air preheating	**Tableware**	15 – 60	1100 – 1300	40 – 180	1.8 - 2.2:1	15 - 120	1.0 - 2.0	**6700 – 11000(4)**
Cross-fired furnace with regenerative air preheating	**Tableware**	30 – 40	800 – 1000	65 – 100	2.0 - 3.0:1	40 - 60	1.2 - 1.6	**8000 – 11000**
Regenerative end-fired furnace	**Tableware**	45 – 70	800 – 1800	100 – 250	1.8 - 2.2:1	120 - 180	2.0 - 3.0	**5000 – 6000**
Furnace with recuperative air preheating	**Glass wool**	15 – 110	800 – 1500	50 – 200	2.8:1	30 - 350	3.4	**4300 – 6500**

(1) Surface area of glass furnace for glass melting and refining; normally the area between the doghouse and the throat; in the case of float glass furnaces, without the unheated conditioning area.
(2) Specific energy consumption without working end and feeder during start-up and nominal load operation (energy consumption will generally increase by 0.1 to 0.2 % per month, due to ageing of the furnace, without electrical boosting, melt preheating and secondary waste heat utilisation) is standardised to:

- 70 % cullet for container glass
- 20 % cullet for float glass
- 40 % cullet for television tube glass and tableware.
- energy savings per cent of additional cullet used: 0.15 to 0.3 %.

The specific energy consumption figures given are approximate guide values for new medium-size and large plants. They are not suitable for energy balance considerations owing to the large differences which occur in individual cases. The effective specific energy consumption is dependent not only on the cullet content and the tank age, but also, '*inter alia*', on batch composition, air preheating, specific tank loading, insulation of the tank and the required glass quality standard.
(3) The data indicated are based on the operating experience with two commercial plants using oxy-fuel technology. The energy required for oxygen production is not included in the specific energy consumption.
(4) The lower range of specific energy consumption for recuperative furnaces may be related to a lower quality standard of the glass produced. In general, regenerative furnaces present lower specific energy consumptions than recuperative furnaces.
Source: [42, VDI 1997] [136, EURIMA 2008] [137, Domestic glass 2008]

Table 1-6: Examples of energy consumption for a range of glass furnaces [Table 3.8, BREF GLS]

1.3.2 Summary of specific information for each sub-sector

Container Glass

For the mainstream bottle and jar production sector, the energy necessary for melting glass accounts generally for over 75 % of the total energy requirements of container glass manufacture. For flaconnage production, melting energy may only represent 50 % of the total energy consumed on site due to the low production speeds and weights, and the specific techniques applied, such as flame polishing and decoration. Other significant energy use areas are forehearths, the forming process (compressed air and mould cooling air), the annealing lehr, factory heating and general services. The typical energy used by each process step is given in Figure 1-1.

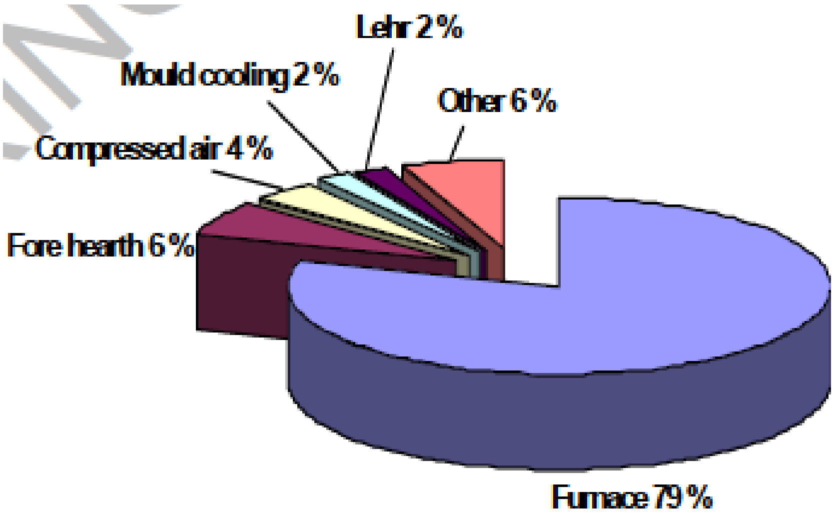

Figure 1-1: Energy usage in a typical bottle/jar container glass plant (not representative for perfume/cosmetic ware production) [Figure 3.3, BREF GLS]

For the melting process, fuel oil or natural gas are the primary energy sources, sometimes with a percentage of electrical boost (up to 5 %). There are a few examples of all electric melting but these are rare. Electricity or natural gas are used for heating the forehearths and annealing lehrs. Electrical energy is used to drive air compressors and fans needed for the process. Energy is required for general services, which include water pumping and, usually steam generation for fuel oil storage and trace heating, humidification/heating of the batch and sometimes heating buildings. In some cases, mainly for larger furnaces, waste heat boilers are installed to produce part or all of the steam required.

The energy consumption of the process will depend on many factors, and the main ones are those outlined in Section 3.2.3 of the BREF GLS. Table 1-7 shows data concerning the total direct energy consumption of the manufacturing process per net tonne of product from the FEVE survey for bottle/jars and flaconnage production; both the full range (100 % data) and the mid-90th percentile (5 % - 95 % of data) are presented.

Product type	Reported data	N° values	Specific total energy usage (GJ NCV (1) /net tonne products		
			Mean	Min.	Max.
All product types	100 %	65	**8.7**	3.7	31.5
	5 - 95 %	57	**7.7**	5.3	16.8
Bottle and jar production	100 %	52	**6.9**	3.7	13.4
	5 - 95 %	46	**6.9**	4.7	8.5
Flaconnage production	100 %	13	**16.1**	7.2	31.5
	5 - 95 %	11	**15.5**	8.3	30.9
(1) NCV= net calorific value for fossil fuels and electricity as consumed (without taking into account the equivalent primary energy usage). *Source*: [126, FEVE 2009]					

Table 1-7: Total direct energy consumption (plant) per net tonne of product from the FEVE survey for bottles/jars and flaconnage production [Table 3.21, BREF GLS]

The range of energy consumption encountered within the sector is extremely wide. Flaconnage (speciality bottles and jars for perfume, cosmetic and pharmaceutical use) has much higher specific energy consumption than mainstream bottles and jars. The higher temperature and longer residence time required for melting high quality glass (flaconnage or perfume containers) increases the energy consumption. These glass products are generally produced with rather small furnaces which are by nature less efficient compared to large capacity melters. In addition, for these products, energy is needed for specific finishing operations, such as flame polishing or enamel decoration, carried out in the plant but also to low cullet rates and to smaller furnace sizes and a lower ratio of net production/glass melted caused by higher quality constraints. Finishing operations may also be carried out within mainstream bottle and jar plants, giving the upper values of the energy consumption ranges. Lower values correspond in particular to plants having access to higher quantities of suitable external cullet.

A similar range can be seen in Table 3.13 and Figure 3.4 of the Draft BREF GLS, which report energy data related to the melting process only. Energy consumption increases with the age of the furnace, due to a deterioration of the insulation and a lower efficiency of the heat recovery from the furnace waste gases. **For a well maintained regenerative furnace, the increase in energy consumption due to ageing can be estimated at between 1.5 and 3 % yearly**, the lower value being related to well maintained furnaces [96, TNO-TPD Energy efficiency benchmarking 2003].

Figure 1-2 shows statistical data on melting energy (GJ per tonne melted glass corrected to 50 % cullet) **by furnace type and size range.** This figure clearly indicates higher consumption for smaller furnaces, in particular for pull rates below 100 tonnes/day, although this effect is compounded with the product type which is usually associated with smaller furnaces, i.e. high quality glasses for flaconnage. For a given size range, end-port furnaces appear slightly more energy efficient than cross-fired furnaces, which would correspond in particular to the slightly greater surface for structural heat losses. Data for oxy-fuel fired furnaces, including the electrical energy necessary for oxygen production, indicate equivalent energy efficiency to that of regenerative furnaces in the larger size range.

The percentage of cullet used in the batch composition has a high and systematic influence on the furnace energy consumption. To enable comparison of different furnace types under comparable conditions, their consumptions have been standardised to 50 % cullet.

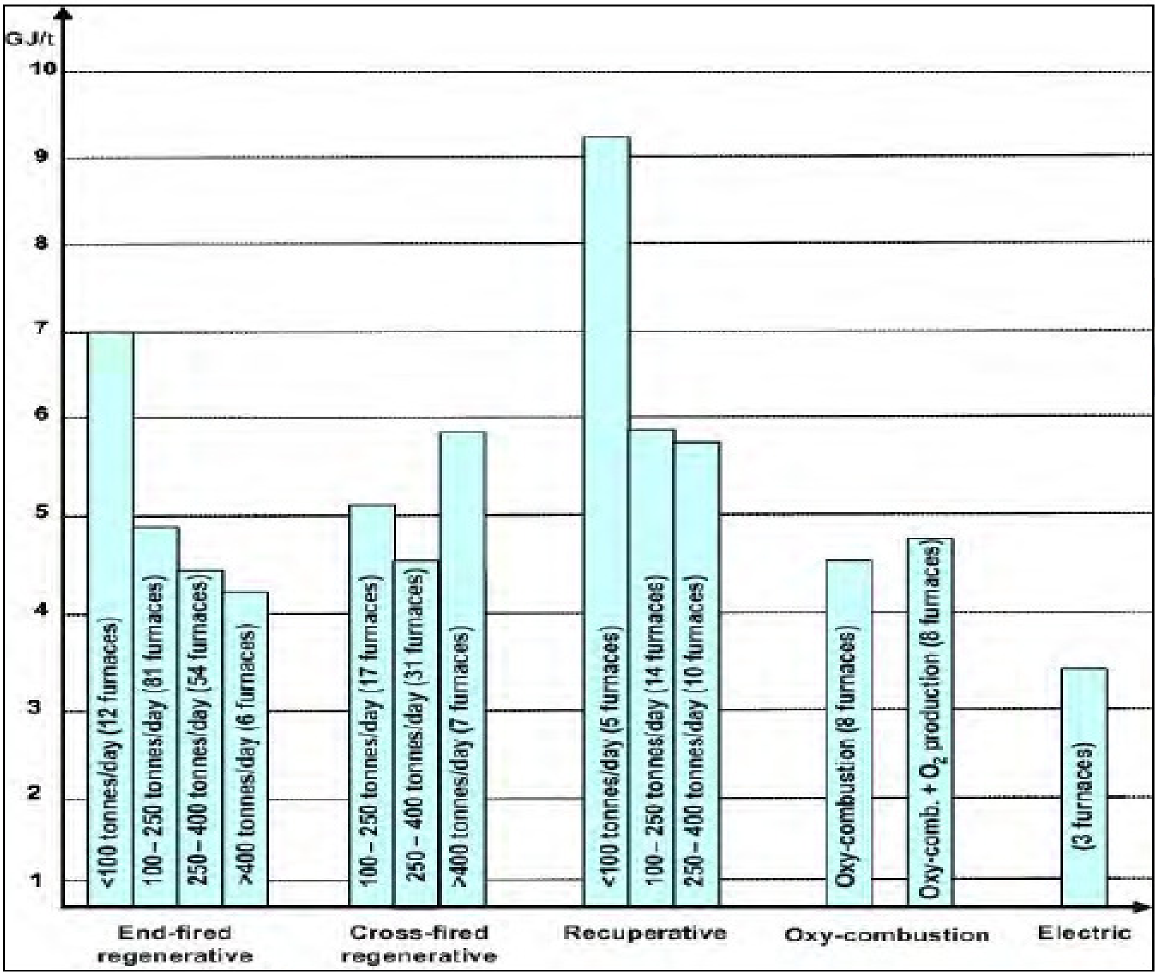

Figure 1-2: Mean energy consumption in glass container furnaces expressed in GJ/tonne melted glass and standardised to 50 % cullet [Figure 3.4, BREF GLS]

Flat Glass

The energy usage distribution for a typical float glass process is shown in Figure 1-3, but energy usage in particular processes may vary slightly. It can be seen that over three quarters of the energy used in float glass plants is spent on melting glass. Forming and annealing takes a further 5 % of the total. The remaining energy is used for services, control systems, lighting, factory heating, and post-forming processes such as inspection and packaging. The distribution presented in Figure 1-3 does not include downstream activities such as coating application, cutting, thermal toughening, ion exchange treatments, mirror production, etc. which may be carried out outside the installation.

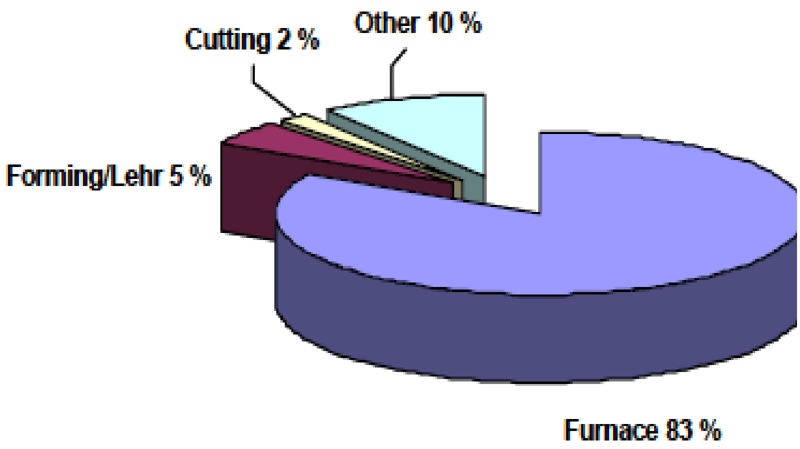

Figure 1-3: Energy usage distribution for a typical float glass process [Figure 3.5, BREF GLS]

Float glass furnaces are almost exclusively fired on heavy fuel oil or natural gas, sometimes with an electrical boost of up to 10 %. Many furnaces have the capacity to fire on either oil or gas, or potentially both at the same time on different burners. There are some examples of electrical furnaces, but these are small scale and for specialist applications. There are also three oxy-fuel fired furnaces in the US, which began operation in 1998, and a new one started operations in 2009 in France.

Forehearths (in rolled glass) and annealing lehrs are heated by gas or electricity. Electrical energy is used to drive air compressors and fans needed for the process. General services include water pumping, usually steam generation for fuel storage and trace heating, humidification/heating of the batch and sometimes heating buildings. In some cases, larger furnaces have been equipped with waste heat boilers to produce part or all of the steam required. A limited number of furnaces are equipped with turbines and generators to produce electricity from steam.

The energy consumption of the process will depend on many factors, the main ones being those outlined in Section 3.2.3 of the BREF GLS. **The range of energy consumption encountered within the sector is quite narrow, if compared with other sectors, because there is relatively little variation in the type of furnace used. Specific energy consumption depends strongly on the size of the furnace; a furnace with more than 800 tonnes/day of melted glass requires about 10 - 12 % less energy compared with a furnace producing about 500 tonnes/day. The ageing of the furnace leads to an increase of energy consumption equivalent to 1 - 1.3 % per year, on average**. **Within the EU-27 installations, energy levels for melting are typically between 5.2 and 8.7 GJ/tonne of melted glass, mainly depending on the size and age of the installation, with an average value of 7.5 GJ/tonne of glass.** Values as low as 5.0 GJ/tonne of melted glass can be achieved at the beginning of the furnace campaign for very high capacity furnaces. **The specific energy requirements for the process as a whole are generally less than 8.0 GJ/tonne** [75, Germany-HVG Glass Industry report 2007].

Continuous Filament Glass Fibre

The direct energy usage distribution for a typical continuous filament glass fibre process is shown in Figure 1-4. Energy usage in particular processes may vary depending on the size of the melter and the type of downstream processes. Generally over three quarters of the energy is used for melting.

Forming, including bushing heating and product conversion account for around 15 % of energy use, and the remaining energy is used for services, control systems, lighting, and factory heating.

In 2005, most furnaces in this sector were gas-fired recuperative-type furnaces, some with an electric boost (up to 20 % of melting energy). In the same year, oxy-fuel melters were representing about 46 % of the total number of furnaces, while in 2007 the share of this type of furnaces was between 50 and 55 %. There are also examples of oil-fired furnaces and oxygen enriched firing furnaces. **The air preheat temperature of recuperative furnaces is lower than that of regenerative furnaces and the energy requirements are consequently higher per tonne of glass.** In this sector, the electrical conductivity of the glass is very low, and currently 100 % electric melting is not considered economically or technically practicable.

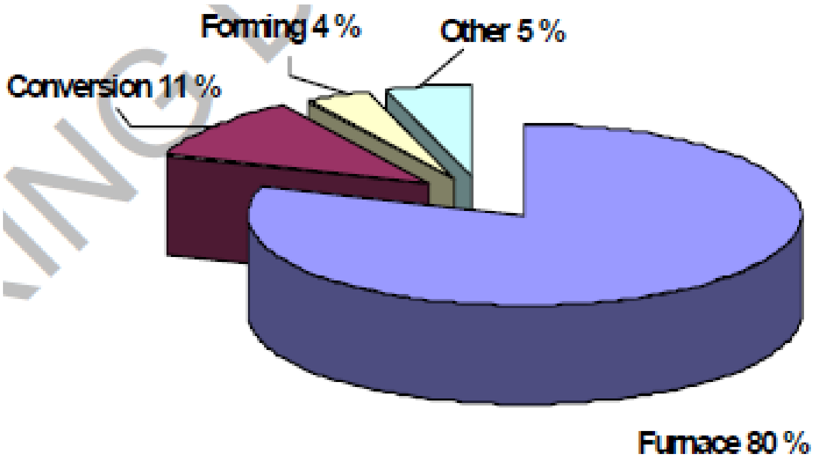

Figure 1-4: Direct energy usage in atypical continuous filament glass fibre production process [Figure 3.7, BREF GLS]

The energy consumption of the process will depend on many factors, the main ones being outlined in Section 3.2.3 of the BREF GLS. **Energy consumption for melting is typically 7 to 18 GJ/tonne of melt, although for some small furnaces producing specialised compositions, this can be up to 30 GJ/tonne. Overall energy consumption is usually in the range of 10 to 25 GJ/tonne of product, the lower end of the range being associated with large oxy-fired furnaces.** The indirect energy consumption related to the production of oxygen and/or the generation of electricity is not included in the data presented above. **Overall, the average energy usage per tonne of glass, based on 2007 data (APFE members production), is equivalent to 16.5 GJ/tonne of finished product, of which 12.4 GJ/tonne are from fossil fuel (mainly natural gas) and 4.1 GJ/tonne are from electricity.** This translates into CO_2 direct emissions of about 770 kg CO_2/tonne product (fossil fuel + process emissions).

Maximum crown temperatures in continuous filament glass fibre furnaces are typically around 1650 ºC, which is up to 50 ºC higher than for container glass furnaces and up to 250 ºC higher than for glass wool furnaces. **The higher melting temperatures contribute to the relatively high specific energy consumption in this sector**.

Domestic Glass

The consideration of energy consumption in this sector is quite difficult due to its diversity and the wide range of melting techniques employed. High-volume production of soda-lime tableware has much in common with container glass production (see Section 3.3.5 of the BREF GLS) and shows comparable energy usage distribution. However, a higher proportion of energy use is associated with downstream operations (e.g. fire-polishing and finishing). Specific energy consumption for melting is higher in this sector than for container glass. This is because furnaces tend to be smaller, melting temperatures are slightly higher, and residence time in the furnace is up to 50 % longer.

The energy values normally refer only to the primary process and do not include downstream activities such as engraving, cutting, polishing, welding, etc. **Typical energy values for these downstream activities can reach 5 to 10 GJ/tonne of glass produced.** The energy usage distribution for a typical soda-lime-silica glass tableware production is shown in Figure 1-5 and examples of specific energy consumption are presented in Section 3.2.3 of the BREF GLS. **When electric melting is applied the typical energy consumption for melting is in the range of 4 to 7 GJ/tonne glass, with values as low as 3.4 GJ/t. For conventional furnaces the energy consumption for melting is in general in the range of 4.8 to 10 GJ/tonne of melted glass.** For the production of high-quality tableware in rather small volumes, the energy requirements are higher (similar to flaconnage compared to bottles for the packaging sector).

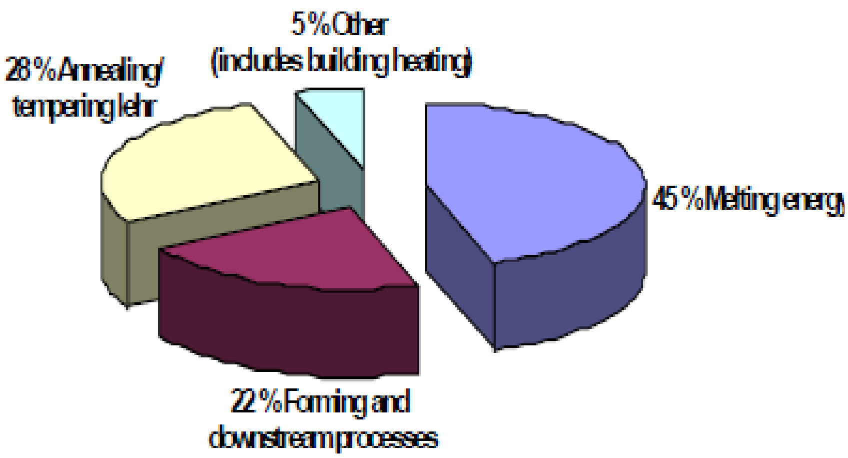

Figure 1-5: Energy usage in soda-lime-silica glass tableware production [Figure 3.8, BREF GLS]

The overall energy consumption for lead crystal manufacture can be even higher (up to 28 GJ/tonne of finished product), when the calculated theoretical energy requirement for melting from normal raw materials is only around 2.5 GJ/tonne. The difference can be due to many factors, but the main ones are given below.

- High-quality requirements may lead to high reject levels. The pot is slowly dissolved by the glass, leading to cords and stones in the product.
- The glass is frequently hand worked and the yield from forming may be below 50 %, and the articles may need reheating during forming.
- The pots have to be 'founded' or fired up to a high temperature before use, and they have a very limited lifetime compared to continuous furnaces.

Electric melting of lead crystal allows for the use of high-quality refractories, which give a much higher glass quality and therefore lower reject rate and better yield. The continuous nature of electric melting and the fact that there are not hot flue-gases from combustion often result in a more efficient automated forming. **However, the overall energy demand including the downstream activities can lead to energy consumption close to the figure of 25 GJ/tonne of product.**

Special Glass

For such a diverse sector, it is very difficult to give general information on energy consumption. **In Table 3.34 of the BREF GLS specific energy consumption data for the melting furnaces are indicated for three different types of products, ranging from a minimum of 5 GJ/tonne up to 17 GJ/tonne of melted glass,** depending on the type of product, furnace size and melting technique. A wide variation of energy consumption data may be observed depending on the batch formulation, the melting technique, and how the plant is designed and operated. **Data in the range of 12 – 16 GJ/tonne of finished product have been reported in particular for soda-lime silica glasses** [tm29 Infomil][30, Infomil 1998]. [75, Germany-HVG Glass Industry report 2007] [111, Austrian Special glass plant 2006].

The general description in Section 3.2.3 of the BREF GLS is applicable to this sector and the discussion of energy efficient techniques in Chapter 4 provides further information. Considerations specific to special glass are that the melting temperatures for special glasses are generally higher than those for mass produced glasses, and that special glass furnaces are, in general, smaller than in other sectors of the glass industry. Both of these factors result in higher CO_2 emissions and higher specific energy consumption.

Mineral Wool

The predominant energy sources for glass wool melting are natural gas and electricity. Stone wool is predominantly produced in cupola furnaces which are fuelled by coke and there are some examples of gas-fired and electrically-heated furnaces. Natural gas is also used in substantial quantities for fiberising and curing. Electricity is used for general services and light fuel oil, propane and butane are sometimes used as backup fuels. There are a number of oxygas- fired furnaces applied to the sector.

The three main areas of energy consumption are melting, fiberising and curing. The split can vary greatly between processes and is very commercially sensitive. Table 1-8 shows the total energy consumption in mineral wool production, with a breakdown into the main process areas. The values for fiberising, curing and other consumption are estimates.

Energy distribution	**Glass wool**	**Stone/slag wool**
	GJ/tonne finished product	**GJ/tonne finished product**
Total energy consumption	**9 - 20**	**7 - 14**
	% of total energy	**% of total energy**
Melting	20 - 45	60 - 80
Fiberising	25 - 35	2 - 10
Curing	25 - 35	15 - 30
Other	6 - 10	5 - 10
Source:[89, EURIMA Suggestions 2007]		

Table 1-8: Energy use in mineral wool production [Table 3.4.7, BREF GLS]

High Temperature Insulation Wools

There is little information available on energy use within the ASW/RCF and AES sector. Melting is exclusively electrically heated with very low volatile losses. Therefore, the direct melting efficiency (excluding off-site issues) is quite high, although the composition has a high melting energy requirement and the furnaces are relatively small. **The energy consumption ranges from 6.5 - 16.5 GJ/tonne of melted product. The energy consumption for the other activities ranges from 3.5 - 9.5 GJ/tonne product (based on 75 % conversion of raw materials to finished product).**

Frits

Frits furnaces are normally very small compared to other furnaces used in the glass industry. Only a few individual furnaces have a capacity exceeding 20 tonnes per day. All existing furnaces are natural gas-fired, and there are no known examples of electrical melting on a commercial scale. There are usually several furnaces in an installation, each producing different frits formulations. **Energy use per tonne of melted frits is comparable to other sectors (above 13 GJ/tonne, corresponding to 300 Nm3 of gas per tonne of frits). Oxy-fuel fired furnaces show lower values in the range of 9 - 13 GJ/tonne of frits.** The energy consumed in other processes is usually low, given that there are few downstream activities and products are not usually dried. A significant number of furnaces use oxygen as the oxidising agent which can result in energy savings and reduced emissions. However, the energy required for oxygen production should be taken into account in the estimation of the total energy consumption per tonne of frits. Moreover, the indirect emissions associated with the production of oxygen, together with additional cross-media effects (i.e. wear of refractory materials) should be considered.

1.3.3 Techniques to consider in the determination of BAT

Glass making is a very energy-intensive process and the choices of energy source, heating technique and heat recovery method are central to the design of the furnace and to the economic performance of the process. The same choices are also necessary for some of the most important factors affecting the environmental performance and energy efficiency of the melting operation. In general, the energy necessary for melting glass may account for over 75 % of the total energy requirements of glass manufacture, with an average of about 65 % of the total energy input when considering all the sectors of the glass industry. The percentages indicated above refer to energy at the point of use and are not corrected to primary energy (see Section 3.2.3 of the BREF GLS).

A summary of the typical values achieved by applying the available techniques/measures for the minimisation of specific energy consumption is given in Table 1-9 where data presented for the different glass sectors are derived on the basis of the aggregated statistical data reported in Chapter 3 of the BREF GLS (e.g. for container glass the lower 50th percentile of the aggregated data has been used) and example installation values.

Sector	Furnace type/capacity	GJ/tonne melted glass ([1])	GJ/tonne finished product ([2])
Container glass			
Bottles and jars	<100 t/d	**5.5 - 7**	**<7.7**
	>100 t/d	**3.3 – 4.6**	

	Electric furnaces	**2.9 – 3.6**	
Flaconnage	<100 t/d	**7 – 9**	**<16**
	>100 t/d	**4.8 – 6**	
Flat Glass			
	All capacities	**5 – 7**	**<8**
Continuous filament glass fibre			
	All capacities	**7 – 14**	**<20**
Domestic glass			
	Conventional furnaces		**<24 for capacities <100 t/d (3)** **<18 for capacities >100 t/d**
	<100 t/d (3)	**6.7 – 9.5**	
	>100 t/d	**5 – 6**	
	Electric furnaces (4)	**3.4 – 4.3**	
Special glass			
All products	Electric furnaces (4)	**3.9 – 4.5**	**<20**
Soda-lime glass	Conventional furnaces	**5 – 10**	
Borosilicate glass		**10 – 15**	
Mineral wool			
Glass wool	All capacities	**2.7 – 5.5**	**<14**
Stone wool	All capacities	**4.2 – 10**	**<12**
High Temperature Insulation Wool			
	All capacities	**6.5 – 16.5**	**<20**
Frits			
	Oxy-fired furnaces	**≤ 9**	
	Air/fuel and enriched air/fuel fired furnaces	**≤ 13**	

(1) Data refer to the furnace energy consumption.
(2) Data refer to the overall energy consumption of the installation.
(3) Values do not include installations equipped with pot furnaces or day tanks which energy consumption for the melting process may be in the range of 10 – 30 GJ/tonne melted glass.
(4) Data reported refer to energy at the point of use and are not corrected to primary energy.

Table 1-9: Typical specific energy consumption values achieved by applying available techniques/measures for minimising the use of energy [Table 4.43, BREF GLS]

Values reported in Table 1-9 represent indicative figures for the specific sectors; however they might not cover the whole range of operating conditions of the melting furnace and all the downstream activities associated with a specific glass product. In fact, the cullet rate used in the batch formulation, the quality requirements for the glass melt and the pack-to-melt ratio may vary significantly within each sector with a consequent influence on the specific energy consumption. The correction to primary energy of the values presented (i.e. for electric melting, electric boosting, oxy-fuel firing) may also have a significant influence on the specific energy consumption levels.

The cost of energy for melting is one of the largest factors in operational costs for glass installations and there is a significant incentive for operators to reduce energy use. **Economic savings have traditionally been the motivation for implementing energy saving techniques, but recently the environmental aspects of energy use have increased in importance.** In fossil fuel fired furnaces, the energy use also affects the direct and indirect emissions per tonne of glass of those substances which relate directly to the amount of fossil fuel burned, particularly CO_2, SO_2 and NO_X, but also particulate matter. These issues are discussed in the substance-specific sections of this chapter.

Energy use and the main factors affecting energy efficiency are discussed in Chapter 3 of the BREF GLS, where specific energy consumption data are presented for each sector of the glass industry. This section discusses techniques for improving furnace efficiency.

Melting techniques and furnace design

The selection of the melting technique can have a great effect on energy efficiency. The choice is largely determined by a range of economic considerations. The main factor is the desired production rate and the associated capital and operating costs over the life of the furnace. An important aspect of the operating costs is the energy usage, and in general, the operator will choose the most energy-efficient design possible.

In conventional fossil fuel-fired furnaces, the main difference in furnace design is whether the heat recovery system is based on regenerators or a recuperator. The differences in the design and operation are discussed in Chapter 2 of the BREF GLS. One of the main factors in the choice is the furnace size, which is discussed further in Section 4.2 of the BREF GLS.

Regenerative furnaces achieve a higher combustion air preheat temperature for the combustion gases; up to 1300 - 1400 °C, compared with a maximum of 750 - 800 °C for recuperative furnaces, resulting in better melting efficiencies. The generally larger size of the regenerative furnaces also makes them more energy efficient than the smaller recuperative furnaces. This is because specific structural losses are inversely proportional to the furnace size, the main reason being the change in surface area to volume ratio. **A modern regenerative container furnace will have an overall thermal efficiency of around 50 %, with waste gas losses of around 25 - 35 % (about 14 - 20 % when batch and cullet preheating is used), and structural losses making up the vast majority of the remainder. The thermal efficiency of a recuperative furnace without additional heat recovery will be closer to 20 – 30 %.**

Regenerative furnaces can be end-fired or cross-fired. The end-fired furnaces are theoretically more thermally efficient (up to 10 % higher), but temperature control is more limited and there is an upper limit to the furnace size (currently around 150 m^2 for container glass). **Overall, the furnace operation plays a more important role in the energy efficiency than the type of furnace (end-fired or cross-fired)**. **Float glass, tableware and flaconnage (perfume and luxury cosmetics) furnaces are less efficient than container glass furnaces, because the specific pulls are much lower due to quality requirements and/or refining chemistry.**

The energy recovered by regenerators may be maximised by increasing the quantity of refractory bricks employed. In practice, these may be organised in enlarged regenerator chambers or in separate but connected structures, given the term multi-pass regenerators. The law of diminishing returns applies as the regenerator efficiency is approaching asymptotically its maximum limit. The principle limitations are the cost of the extra refractory bricks, and in the case of existing furnaces, the limitations are of available space and the additional costs of modifying the furnace infrastructures. This principle is more commonly applied to end-fired furnaces due to their simple regenerator geometry, although some applications on cross-fired furnaces have been made. Modification of regenerator structures on existing furnaces (if this is technically and economically feasible given the plant layout) can only be made during furnace reconstruction. At the beginning of the regenerators campaign, energy consumption may be reduced by up to 15 %, with respect to the equivalent furnace with typical single pass regenerators, depending on the size of the original single pass regenerator. On the other hand, the use of multi-pass regenerators may be associated with potential condensation problems with the consequent need for cleaning of the checkers and a subsequent decrease in energy efficiency. **Modern furnaces equipped with single pass regenerators show heat recovery efficiency close to 65 %. In these cases, the use of multi-pass regenerators would not achieve significant improvements of the energy efficiency of the furnace.**

The only negative impact is the increased volume of refractory materials to be handled at the end of the furnace life. This negative impact is limited, as a significant proportion of the extra refractory bricks withstand two or more furnace campaigns, and solutions exist, and will continue to be developed, for recycling these materials. Although the increased air preheat temperatures of furnaces equipped with multiple pass regenerators is potentially a factor to increase flame temperature and hence NOX formation, these furnaces do not, in practice, demonstrate high NO_X levels when appropriate measures of reduction at the source are taken.

There are a variety of materials available for use as heat storage media and packing in regenerators. The simplest solution is to use refractory bricks stacked in an open or 'basketweave' pattern and this will generally give a regenerator efficiency of 50 % or more (heat recovered by air compared to heat contained in the waste gas). However, heat transfer can be improved by using specially shaped packing materials. For example, fusion cast corrugated cruciforms will enhance the heat exchange efficiency compared to standard brick packing. **The effect of this type of refractory bricks on energy consumption depends on the starting situation and size of the regenerator; fuel savings of about 7 % are quoted.** In addition, these materials are very resistant to chemical attack from volatiles in the waste gas stream and show very much reduced deterioration in performance (compared to bricks) throughout the campaign. So far (2010), the use of corrugated shapes has been generalised when cruciform pieces are installed in a regenerator.

The maximum theoretical efficiency of a regenerator is about 77 % because the mass of waste gases from a furnace exceeds that of the incoming combustion air and the heat capacity of exhaust gases exceeds that of the combustion air. **In practical terms, the efficiency will be limited by the cost and the structural losses become more significant as the size of the regenerators increases. In practice, it is difficult to conceive a cost-effective regenerator design with an efficiency of greater than 70 %.**

Furnace geometry is constantly undergoing refinements to optimise thermal currents and heat transfer, both to improve glass quality and to save energy. The developments are often combined with developments in combustion systems to reduce emissions and save energy. Furnace geometry changes are only possible for new furnaces or complete rebuilds and even then, what is actually possible may be limited by the steelwork and existing infrastructure.

Electrical melting, either partial or 100 % improves energy efficiency when considered at the site level, but when power generation efficiency and distribution losses are taken into consideration, the situation is less clear. These techniques are described in more detail in Section 4.2. Oxy-fuel melting can also result in lower energy consumption, but this is a complex subject that is discussed in more detail in Section 4.4.2.5 of the BREF GLS.

The advances in refractory materials over the past decades have allowed furnaces to operate with longer campaigns and with higher levels of insulation. The limitation of temperature to which the furnace superstructure could be subjected was, in the past, a limiting factor for high insulation. Today, the insulation must be carefully designed according to the part of the furnace and the operating conditions (temperature, type of glass, etc.). Not all parts of the furnace can be insulated. The flux line and the throat must be left uninsulated and they will have to be cooled to extend furnace life. Most glass contact and superstructure refractories are made with fusion cast or sintered chromium oxide materials that are very dense with low porosity and can resist liquid glass and volatile compounds in the superstructure. They have high thermal conductivity and need, in general, a good insulation level leading to substantial energy savings. In soda-lime glass, the crown is normally in silica and heavily insulated. For oxy-fuel-fired furnaces, other materials may be applied (fused cast alumina or AZS) in order to withstand possible attacks from alkali vapours. Silica limits the temperature of the crown of the furnace to 1600 – 1620 °C, while other crown refractory materials, such as fused cast AZS, mullite or fused cast alumina can withstand temperatures higher than 1620 °C. Any increase in furnace temperature may also adversely affect emissions of NOX and any emissions derived from volatile components of the batch.

Additional insulation can be applied to certain areas of the furnace with little risk of structural damage. Sprayed fibre insulation can significantly reduce heat losses when applied to the regenerator structure. This simple, cost-effective technique can reduce regenerator structural heat losses by up to 50 % and give energy savings in the region of 5 %. There is also the additional benefit that the material will effectively seal any cracks in the regenerator structure, thus reducing the ingress of cold air and the escape of hot air.

Combustion control and fuel choice

In recent decades the predominant fuel for glass making has been fuel oil, although the popularity of natural gas has been constantly increasing. At present, the use of both fuels is comparable. Natural gas firing results in lower SO_X emissions but generally gives rise to higher NOX emissions. This is because the natural gas flame is less radiant and the heat capacity of the flue-gases from gas-firing (per GJ combustion) is different than that from oil-firing. **This results in different heat losses even at the same flue-gas temperature, and in general, in higher energy consumption which is approximately 7 – 8 % higher for natural gas than for fuel oil. However, as experience of gas firing increases, performance levels progressively approaching those associated with oil firing can be achieved; although, in general, oil-fired furnaces still show higher energy efficiency**. Natural gas has a higher ratio of hydrogen to carbon and its use reduces overall emissions of CO_2 by up to 25 % for a given pull rate.

The developments in low-NO_X burner systems have also resulted in energy savings. By reducing the amount of combustion air to close to stoichiometric levels, less energy is lost in the waste gas.

The improvements made to the combustion system, the heat transfer systems and general process control during developments intended for NOx reduction have, in many cases, also led to improvements in furnace operation and efficiency.

A technique frequently used in the past to improve energy efficiency and pull rate was oxygen enrichment of the combustion air. The reduced gas volumes and higher flame temperatures improve energy efficiency, but unless the technique forms part of a carefully controlled overall low-NOX combustion system, NOX levels can be substantially increased. The use of this technique in isolation is becoming less common due to these environmental concerns. However, oxygen enrichment is often applied where nitrogen is separated from air (for tin bath chamber in float glass production) and oxygen-enriched air is therefore available.

Cullet Usage

The use of cullet in a glass furnace can significantly reduce the energy consumption and its use is generally applicable to all types of furnaces, i.e. fossil fuel-fired, oxy-fuel-fired and electrically heated furnaces. Most sectors of the glass industry routinely recycle all internal cullet. The main exceptions are continuous filament glass fibre, where it is not considered possible due to quality constraints and frits production (where cullet as such is not produced). In the stone wool sector, shot and bypass melt are recycled only if a briquetting process is in use (see Section 3.8.4 of the BREF GLS). The base internal cullet level in the batch will usually be in the range of 10 - 25 %.

Cullet has a lower melting energy requirement than the constituent raw materials because endothermic chemical reactions associated with glass formation have been completed and its mass is approximately 20 % lower than the equivalent batch materials. **Therefore, increasing the cullet level in the batch has the potential to save energy and, as a general rule, every 10 % of extra cullet results in a 2.5 - 3.0 % reduction in furnace energy consumption. The use of cullet generally results in significant cost savings as a result of the reduction in both energy and raw material requirements.** However, the price of cullet has been increasing significantly and its availability is becoming more difficult; therefore, the use of cullet is not always economically beneficial.

A distinction should be made between internal cullet (rejected glass from the production line) and external cullet (post-consumer glass from consumer or external industrial sources). The composition of external cullet is not as well defined and this limits its application. Quality issues often limit the use of cullet in the batch formulation due to contamination in the cullet which is difficult to detect and remove. This is particularly the case for luxury container glass (extra-flint bottles or flaconnage for perfume and cosmetics), tableware, special glass and flat glass productions where high quality requirements of the final product restrict the use of external cullet. However, the container glass sector is uniquely placed to take advantage of using significant quantities of foreign cullet from bottle recycling schemes. The recycling of glass cullet is regulated by European legislation, in particular Directive 94/62/EC which sets targets for the recycling of packaging waste. **At the time of writing (2010), except where special schemes are established, the significant use of external cullet is restricted to the container glass sector and some areas of the mineral wool sector, particularly glass wool.** Although the container glass sector is the main user of external cullet, the high-quality requirements for some final glass product (extra-flint bottles, flaconnage for perfume and cosmetics) demanded by the customers is not always compatible with the quality of the cullet available, because of its content of impurities which results in a consequent reduction of its usage in the batch formulation. Post-consumer cullet requires expensive treatment in order to render it suitable for the use as a raw material for glass production. Glass sectors with higher quality demands or low availability of external cullet (e.g. flat glass) may try to contract large consumers to recycle the waste glass they generate.

External cullet use in container glass production varies from <20 to >90 %, with an EU average in the region of 50 %.

Recycling rates vary widely between Member States depending on the material schemes for post-consumer glass collection.

In the domestic glass sector, quality considerations generally prevent the use of external cullet in the process. Internal cullet usage is limited by the availability of cullet at the correct quality and composition. **In general, the average amounts of internal cullet used are around 25 % for soda-lime products, although amounts as high as 50 % are possible depending on the type of article produced; for lead crystal, average amounts of 35 % are normally applied.**

For the manufacture of flint (colourless glass) only very low levels of coloured cullet can be tolerated since coloured glass cannot be decolourised. Therefore, recycling schemes with either separate collection between the main glass colours, or alternatively colour sorting of cullet from mixed collection are necessary to maximise recycling. In general, throughout the EU, there are ample supplies of mixed coloured, green and brown cullet. However, flint cullet tends to be less common and because of this situation, furnaces melting coloured glass operate at higher cullet levels, particularly for the production of green glass where a mixture of different colours can be used. The situation varies significantly between Member States due to regional differences, for example, it is a problem in the UK since the bulk of production is flint glass, yet a substantial proportion of cullet is coloured, from imported wine bottles. Consequently, furnace cullet levels in the UK are lower, on average.

In terms of furnace operation, high cullet levels can also give other benefits such as lower particulate emissions. Cullet is easier than batch to preheat. The output of the furnace can also be greatly increased, but there are a number of drawbacks to the manufacturer when operating at high cullet levels such as those listed below.

- Metallic impurities such as bottle caps or foils from wine bottles can cause serious refractory damage and shorten the furnace life. The metallics sink to the bottom where a phenomenon known as ‘downward drilling’ takes place. Metals, or metal droplets (particularly lead) accumulating at the refractory bottom of the melting furnace, will drill into the bottom material, due to dissolution of refractory material enhanced by surface tension gradients which occur in the direct vicinity of the metal droplets. Metal contamination, the presence of lead crystal glass and reducing components in the cullet may cause defects in the glass.
- Ceramic inclusions, such as earthenware or pottery and glass ceramics that have a very low dissolution rate in the glass melt will appear as ‘stones’ or knots, often with an opaque colour, in the final product and lead to rejects.

- At high cullet levels, the control of composition and therefore the physical characteristics of the glass melt can be reduced, possibly leading to final product quality problems. The variable content of organic matter (food residues, paper labels, plastics) in particular can cause problems in the oxidation-reduction state, leading to colour and refining difficulties.
- Aluminium caps and foils act as strong local reducing agents causing the silica of the glass to reduce to silicon metal (Si). The silicon forms inclusions in the glass products (small beads), which significantly reduce the mechanical strength of the glass, due to stresses resulting from the high difference of thermal expansion coefficient between the glass and silicon.
- • Impurities from cullet can lead to air emissions (lead, fluorine and boron compounds, etc.).

In addition to the substantial energy savings possible with cullet usage, there are a number of other important associated environmental benefits. Emissions of CO_2, SO_X, NO_X and dust are greatly reduced due to reduced fuel usage and lower furnace temperatures. Emissions of other volatile substances may also be lower due to the reduced temperatures. However, impurities in the cullet may lead to higher emissions of HCl, HF and metals and SO_X (when glasses with low sulphur content are produced). This is particularly relevant in areas with high recycling rates where impurities can build up in the recycled material. Many raw materials in glass making are carbonates and sulphates, which release CO_2 and SO_X upon melting.

The increased cullet usage reduces these raw material derived emissions and reduces the consumption of virgin raw materials.

Waste heat boiler

The principle of this technique is to pass waste gases directly through an appropriate tube boiler to generate steam. The steam may be used for heating purposes (space heating and heating of fuel oil storage and piping) or, via a suitable steam motor or turbine to drive electricity generation equipment or plant items such as air compressors or Individual Section (IS) machine ventilator fans.

Incoming gases from regenerators/recuperators are usually in the temperature range from 600 to 300 °C. The outlet temperature determines the available recoverable heat which is limited to approximately 200 °C due to the risk of condensation in the boiler and to ensure correct stack operation. Boiler tubes exposed to furnace waste gases can become coated with condensed materials (e.g. sodium sulphate, depending on the composition) and sticky and corrosive compounds (e.g. sodium bisulphate) could form, depending on the temperature and composition of the flue-gases which may react with the metal structure of the pipes. **Therefore, boiler tubes must be periodically cleaned to maintain recovery efficiency (this is not as important for boilers operating downstream of dust removal devices). In situ cleaning may be carried out automatically by steam, by mechanical means, or by periodic maintenance.**

The applicability and economic feasibility of the technique is dictated by the overall efficiency that may be obtained (including effective use of the steam generated). In practice, waste heat boilers have only been considered to recover residual heat downstream from regenerator or recuperator systems and there is thought to be at least two examples with oxy-fuel-fired furnaces (see Table 4.18 in the BREF GLS). **In many cases, the quantity of recoverable energy is low for efficient power**

generation and supplementary firing may be needed to generate superheated steam to drive turbines. Recuperative furnaces with higher waste gas temperatures or installations where it is possible to group the waste gases from several furnaces offer more opportunities for power generation. Waste heat boilers are in industrial use on some container glass facilities but most applications are with float glass furnaces. All float furnaces in Germany and many in other Member States have waste heat boilers.

Investment costs can exceed EUR 1 million with variable payback periods, depending on performance and prevailing energy prices. The ongoing improvements in primary energy efficiency are eroding the cost-effectiveness of waste heat boilers. In some applications, there may not be an attractive payback period, but this will vary from case to case. The 3R process can help to make existing waste heat boiler systems more effective and would likely improve the economic performance of any new system proposed for installation. However, if for whatever reason the installation of a waste heat boiler is considered inappropriate or economically unattractive, the installation of the 3R process will not necessarily change this situation.

In Table 4.44 of the BREF GLS data are reported concerning example installations where waste heat boilers (heat exchangers) are applied in different sectors of the glass industry.

Batch cullet preheating

Batch and cullet is normally introduced cold into the furnace, but by using the residual heat of the waste gases to preheat the batch and cullet, significant energy savings can be possible. This only applies to fossil fuel-fired glass furnaces. In the stone wool industry, predominantly cupola furnaces are used, which have a design that preheats the raw materials intrinsically. Preheating temperatures should preferably not be lower than 270 °C but should not exceed 500 – 550 °C. In practice, most batch and cullet preheaters operate at batch preheat temperatures between 275 and 325 °C.

Batch/cullet preheaters have been developed and installed by Nienburg/Interprojekt (direct preheating), Zippe (indirect preheating) and Sorg (direct preheating). A combined direct cullet preheater and electrostatic precipitator was developed and installed by Edmeston, now Praxair EGB. A new type is under development in the US for high temperature flue-gases of about 1300 °C, which should allow preheating the batch and cullet up to about 500 °C.

The available systems are described below.

- Direct preheating – this type of preheating involves direct contact between the flue-gas and the raw material (cullet and batch) in a cross-counter flow. The waste gases are supplied to the preheater from the waste gas duct behind the regenerator. They pass through the cavities in the preheater, thereby coming into direct contact with the raw material. The outlet temperature of the cullet and batch is about 300 ºC and could go up to 400 ºC. The system incorporates a bypass that allows furnace operations to continue when preheater use is either inappropriate or impossible. Direct preheaters are developed and installed by Nienburg/Interprojekt and by Sorg. An example installation for the application of direct cullet preheating is reported in Table 4.45 of the BREF GLS.

- Indirect preheating – the indirect preheater is, in principle, a cross-counter flow, plate heat exchanger, in which the material is heated indirectly. It is designed in a modular form and consists of individual heat exchanger blocks situated above each other. These blocks are again divided into horizontal waste gas and vertical material funnels. In the material funnels, the material flows from the top to the bottom by gravity. Depending on the throughput, the material reaches a speed of 1 – 3 m/h and will normally be heated from ambient temperature up to approximately 300 °C. The flue-gases will be let into the bottom of the preheater and flow into the upper part by means of special detour funnels. The waste gases flow horizontally through the individual modules. Typically the flue gases will be cooled down by approximately 270 - 300 °C. The indirect cullet preheater has been developed by Zippe.
- Praxair EGB filter – the Edmeston electrified granulate bed (EGB) filter system is a hybrid system between an electrostatic precipitator for dust removal and a direct cullet preheater. The application consists of two different stages using external and internal cullet. Both cullet streams are preheated, but in a different way. Only the section operating with internal cullet plus external cullet after being treated in a pyrolysis unit (first preheater stage) is used in the electrostatic field to capture dust from the flue-gases. At the time of writing (2010) the Praxair EGB cullet preheater is not applied within the glass industry in Europe. An application, including an integrated cullet filter bed section, is running at Leone Glass in the US in connection with an oxy-gas-fired furnace producing flint container glass. Flue-gases from the oxy-fuel-fired container glass furnace using recycled cullet (internal and external) are conveyed to a cullet preheating section with external cullet (stage 1). The organic fumes released from the external cullet in the preheating stage 1 are pyrolised and combined with a second flue-gas flow from the furnace. The combined gas flow enters an ioniser chamber where the dust particles present in the flue-gases are charged. The hot flue-gases containing the charged dust particles enter a cullet preheater equipped with electrode plates (stage 2). The preheater is continuously charged with internal (clean) cullet and external cullet from the first preheating stage. The electrostatic fields bring the charged dust particles to the cullet surface to be captured. The preheated cullet materials (up to 400 °C) and adhering dust particles are charged into the glass melting furnace.

Achieved environmental benefits

These techniques have a number of environmental effects, which can vary from case to case. **In general, the benefits given below have been experienced.**

- **Specific energy savings of between 10 and 20 %** with a consequent reduction of CO_2 emissions.
- Reduction in NO_X emissions (due to lower fuel requirements and lower furnace temperatures). However, in most cases the energy savings are used to increase the pull of the furnace.
- In the case of direct preheating, reduction of acidic compounds in the flue-gases SO_2, HF and HCl, of 60 %, 50 % and 90 % respectively have been found (difference before and after the batch bed).

- An increase of pull rate of up to 10 – 15 %, is possible for applications to existing glass furnaces, with preheating of the batch to 300 °C.
- A reduction or elimination of the need for a dry-scrubbing agent.

Applicability

Cullet/batch preheating systems can theoretically be installed at any existing glass melting furnace with greater than 50 % cullet in the batch, although, under specific conditions and for a limited duration, one installation has been operating with a percentage of cullet as low as 30 %. Preheating of only the batch has been problematic and is not considered proven technology. The preheating of a batch and cullet mixture is more complicated than the preheating of cullet only. **Due to these limitations, the application of batch and cullet preheating is almost exclusively done in the container glass sector.**

An example installation for the application of direct batch and cullet preheating to a container glass furnace producing flint glass is presented in Table 4.45 of the BREF GLS.

Driving force for implementation

The main driving force for implementation would be to reduce energy consumption, with a consequent CO_2 emission reduction. An increase in the melting capacity of the furnace (up to 10 % or more) may also represent a driving force.

Example plants

All the applications of batch and cullet preheating are in the container glass sector:

- direct preheating:
  - Ardagh Glass, Nienburg, Germany (three furnaces)
  - Ardagh Glass, Neuenhagen, Germany
  - Wiegand Glas, Steinbach am Wald, Germany
  - Leone Industries, Bridgeton, New Jersey, US (oxy-fuel-fired furnace).
- indirect preheating:
  - Ardagh Glass, Dongen, Netherlands.

1.3.4 Emerging techniques

In general, the emerging techniques for the glass industry focus on the reduction of the high investment costs for the melting furnace (i.e. new melting techniques), **on energy savings (e.g. batch and cullet preheaters, new furnace design, innovative burners)** and on the improvement of the environmental performance of the production process (e.g. new product formulations, waste recovery, reduced emissions and improved removal efficiencies for the main pollutants).

Some of the emerging techniques reported in the original GLS BREF did not prove successful, while others have been completely developed and implemented within the different sectors of the glass industry.

Improved combustion techniques are among the main objectives, with the aim of reducing energy consumption and, at the same time, minimising NO_X emissions by primary measures. Combustion control systems, different types of burners and new furnace designs are always investigated and substantial innovations and developments are achieved even though they are not reported specifically in this section as emerging techniques.

In particular, low-NOX burners, in combination with combustion control systems, are still undergoing constant development to optimise performance in terms of energy efficiency and pollution reduction.

Glas Flox® high-temperature combustion system

Glas Flox® burners represent an advanced technique for glass melting. The functioning principle is based on internal recirculation of combustion gases, which are sucked in the flames by the low pressure at the burner outlet (due to high gas injection velocities through the burners). The recirculation gas will cool the root of the flames and will reduce the oxygen content in the hottest part of the flames. Compared to the standard gas burners, Glas Flox® burners operate at higher combustion speed and lead to an improved covering of the flame over the glass melt bath due to the reaction intensity as well as an expanded burning zone. These characteristics lead to a better energy transfer into the glass bath. The complete combustion operates in infrared and runs evenly without significant temperature and heat transfer gradients.

Achieved environmental benefits

The reported benefits are a reduction of about 50 % in NO_X emissions and lower specific energy consumption with a consequent reduction of CO_2 emissions.

Applicability

The burners are applicable only on recuperative glass furnaces.

Driving force for implementation

A reduction of NOX emissions together with a lower energy consumption compared to the standard burners are the main driving forces for applying the Glas Flox® burners.

Example plants

An application of the Glas Flox® high-temperature combustion system is currently (2010) running in Germany for the production of glass for light bulbs.

Advanced cullet and batch preheaters

The main examples of batch and cullet preheaters in use within the glass manufacturing industry are described in Section 4.8.5 of the BREF GLS and, therefore are not considered emerging techniques. **However, significant developments are underway, in particular for the application of cullet and batch preheating to oxy-fuel-fired furnaces. In general, the conversion of traditional furnaces to oxyfuel firing results in higher glass productivity and quality, lower emissions of NO_X and particulate, lower energy consumption and lower rebuild costs.** However, the additional cost of oxygen still represents a significant economic barrier for the application of oxy-fuel firing to many glass furnaces. The economics of oxy-fuel conversion would be much more attractive if the energy content of the flue-gases (which are released at very high temperatures of up to 1400 °C) could be recovered. The existing cullet and batch preheaters operate at temperatures in the range of 500 - 600 °C; thus, the flue-gases are cooled down with dilution air, with a consequent increase in volume.

The advanced cullet and batch preheaters are designed to operate with flue-gases that are not cooled or are only slightly cooled. In particular, in the advanced cullet and batch preheater system developed by Praxair (BCP system), flue-gases enter the preheater at temperatures in the range of 1200 - 1400 °C.

At the time of writing (2010), there are currently two projects, which are developed by different teams:

• PRECIOUS-project under development by Zippe Industrieanlagen GmbH in cooperation with the RWTH Aachen University, within the support programme of the Deutsche Bundesstiftung Umwelt (DBU);

The aim of the PRECIOUS-project is to reduce the CO_2 and NO_X emissions by preheating the cullet and/or the batch with the waste heat of an oxy-fuel-fired furnace. The preheating technology could theoretically be installed in any furnace with a cullet ratio of more than 50 %. Tests of this cullet and batch preheater are carried out at an oxy-fuel-fired furnace producing glass for light bulbs. An increase of energy efficiency of about 20 % is expected. The completion of the pilot project and the transfer of the technology into a large-scale project are still underway [153, Germany Precious 2007].

• PRAXAIR-BCP system under development at the Praxair Technology Center.

The PRAXAIR-BCP project’s system is suitable for batch plus cullet preheating and is dedicated to the use of the flue-gases from all oxy-fuel-fired furnaces.

Achieved environmental benefits

The reported (expected) benefits are an emission reduction of about 15 - 30 % (CO_2, NO_X and particulate matter) compared to an oxy-fuel-fired furnace without a preheater. **The reduction in energy consumption is estimated at about ± 1 GJ per tonne of melted glass, compared with an oxy-fuel-fired furnace without a preheater.**

Applicability

In principle, the advanced BCP technique is applicable for almost all normal cullet/batch ratios.

Driving force for implementation

The recovery of energy from the flue-gases and the consequent reduction of the energy consumption used in the production represent the main driving forces for applying the advanced cullet and batch preheater. A significant reduction of direct and indirect emissions would be an additional driving force for implementation.

Example plants

A pilot scale system (15 tonnes of batch per day) has been tested by Praxair in 2007, at Tonawanda, NY, US, with preheating temperatures of 480 - 535 °C. The design of a larger system to be applied to a commercial glass furnace is the next step in this project.

Submerged combustion melting technology

The submerged combustion melting (SCM) is based on a segmented melting approach in which several stages are used to optimise melting, homogenisation, refining and heat recovery. This approach is expected to reduce the average residence time of the glass melt by _80 % compared to a single large tank melter, with a consequent decrease in energy costs and emissions. The SCM melter consists of a small tank in which fuel and oxidants are fired directly into the bath of material being melted. The combustion gases bubble or flow through the glass bath, creating a high heat-transfer rate and turbulent mixing (and carryover). High shear from forced convection provides rapid particle (sand, raw materials containing alumina) dissolution and temperature uniformity. Melted material with a uniform composition, but still with many seeds and bubbles, is drained from a tap near the bottom of the bath.

Achieved environmental benefits

An overall energy savings of about 5 % over the best oxy-gas-fired tank furnace is estimated when no heat is recovered from the walls of the melter. A 20 % energy recovery of the wall losses would allow an overall energy savings of about 7.5 %.

Applicability

At the time of writing (2010), the applicability of the SCM melter is limited to the mineral wool production. The development and testing work that is underway should allow for the application of this technique to a wide range of glass compositions and colours. Most of the development work is mainly carried out in the US by the Glass Manufacturing Industry Council (GMIC) and by the Gas Technology Institute, Des Plaines, Illinois, US.

Driving force for implementation

Lower investment costs, more flexibility in the selection of raw materials, **energy savings** and lower emissions, in particular NO_X emission, represent the driving forces for a full development and application of the SCM technique.

Example plants

At the time of writing (2010), five commercial melters are in operation for the production of mineral wool, in Ukraine and Belarus.

A patent application has been filed. A project team led by the Gas Technology Institute (GTI, Chicago, US) including six glass companies is working on ‘next-generation’ melting systems, which include submerged combustion melting. For the purpose, a pilot SCM melter producing 1 tonne per hour has been built and is used to melt a range of industrial glasses under various operating conditions.

2 Proposal for the Sector Specific Supplement – Glass Sector

1. Site specific issues affecting the energy consumption of fossil fuel fired furnaces

Please indicate the furnace type, capacity, throughput and the age of the furnace. If possible indicate further site specific issues affecting the energy consumption:		
Site specific issues		**Explanations/Comments** (if required)
Furnace type (*e.g. cross-fired furnace with regenerative air preheating, recuperative furnace, oxy-fuel fired furnace, etc.*)		
Furnace capacity [t]		
Furnace throughput [t/d]		
Furnace age [years]		
Further site specific issues (*e.g. melting area, glass bath depth, length/width ratio of the tank bath, etc.*)		
...		
...		

2. Specific direct energy consumption for melted glass

Please indicate the furnace type/capacity, differentiate fuels/electricity and indicate the total specific energy consumption for melted glass.			
Sector	**Furnace type/capacity**	**Fuels/Electricity**	**GJ/tonne melted glass ([1])**
Container Glass			
Flat Glass			
Continuous Filament Glass Fibre			
Domestic Glass			
Special Glass			
Mineral Wool			

Please indicate the furnace type/capacity, differentiate fuels/electricity and indicate the total specific energy consumption for melted glass.			
Sector	Furnace type/capacity	Fuels/Electricity	GJ/tonne melted glass ([1])
High Temperature Insulation Wool			
Frits			
([1]) Data refers to the furnace energy consumption			

3. Specific direct energy consumption for finished products

Please indicate the major processes, differentiate fuels/electricity and indicate the total specific energy consumption for finished products.			
Finished products (e.g. bottles and jars, flaconnage, borosilicate glass, glass wool, stone wool, etc.	Major processes applied	Fuels/Electricity	GJ/tonne finished product ([2])
([2]) Data refers to the major processes needed to manufacture finished products			

4. Techniques to reduce specific energy consumption

Is one of the following techniques /combination of the following techniques applied in order to reduce specific energy consumption? Please also provide further explanations/justifications.		
Techniques	Yes (*provide brief explanation*):	No (*provide brief justification):*
Process optimisation through the control of the operating parameters		
Regular maintenance of the melting furnace		
Optimisation of the furnace design and the selection of the melting technique (*if applicable*)		
Application of combustion control techniques (*if applicable*)		
Use of increasing levels of cullet (*where available and economically and technically viable*)		
Use of a waste heat boiler for energy recovery (*where technically and economically viable*)		
Use of batch and cullet preheating (*where technically and economically viable*)		

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