Glass in energy

Energy efficiency in glass manufacture

MAT 498

Lehigh University

MAT 498: Glass in energy

Objectives

- **To provide an overview of the use of glass in the field of energy, starting with a general introduction to glass, followed by a review of specific domains where glass is used in energy at present, or is emerging as an alternative for the near future.**

- **Lecture 1 (1/17): Glass basics I**
- **Lecture 2 (1/19): Glass basics II**
- **Lecture 3 (1/24): Energy efficiency in glass manufacture**
- **Lecture 4 (1/26): Glasses for solar energy I – low-E and solar control glass**
- **Lecture 5 (1/31): Glasses for solar energy II – solar thermal energy**
- **Lecture 6 (2/2): Glasses for solar energy III – PV and photochemical**
- **Lecture 7 (2/7): Glass fibers for wind energy**
- **Lecture 8 (2/9): Glasses for nuclear waste vitrification**
- **Lecture 9 (2/14): Glasses for fuel cells and H_2 storage**
- **Lecture 10 (2/16): Glasses for Li batteries and super-capacitors I (Prof. S. Martin)**
- **Lecture 11 (2/21): Glasses for Li batteries and super-capacitors II (")**
- **Lecture 12 (2/23): Laser glass**
- **Lecture 13 (2/28): Glasses for white light generation**
- **Lecture 14 (3/1): Exam**

Increasing demand of *energy* due to continuing development of countries around the world, particularly more demand from developing countries (China, India, Brazil, Russia, certain countries in Africa …) has lead to a continuous depletion of traditional fossil fuel *energy* sources like oil and gas.

On the other hand, the need to lower the production of greenhouse gases, namely CO_2, requires the increasing use of renewable *energy* sources, namely solar, wind and water, but also of abundant nuclear energy (fission and fusion).

On top of that, the need to lower the amount of pollution in the environment (e.g. smog) makes the most abundant energy source on the planet – coal – an increasingly less desirable alternative, due to its abundant emissions of CO_2 and particulate matter.

The continuous search for new, renewable and clean energy sources goes in parallel with the need to reduce the use or energy by promoting energy efficiency.

All these fields represent numerous opportunities in the development of new materials for sustainable energy and, in particular, glass, whose role in energy conversion, storage and conservation is specifically addressed during this short course.

Major (U.S.) glass industry segments and typical products

Flat glass

Float glass for residential and commercial construction, automotive applications, tabletops and mirrors.

Container glass

Hollow glass for packaging of foods, beverages, household chemicals, pharmaceuticals and cosmetics.

Specialty glass

Pressed and blown glass for tableware, cookware, lighting, televisions, liquid crystal displays, laboratory equipment and optical communications.

Fiberglass

Fiberglass (glass wool) insulation for buildings, roofing and panels. Textile and plastic reinforcement fibers for composites in the construction, transportation and marine industries.

The process of **glass manufacturing** includes six basic steps:

- raw materials selection

- batch preparation (i.e. weighing and mixing raw materials)

- melting and refining

- conditioning

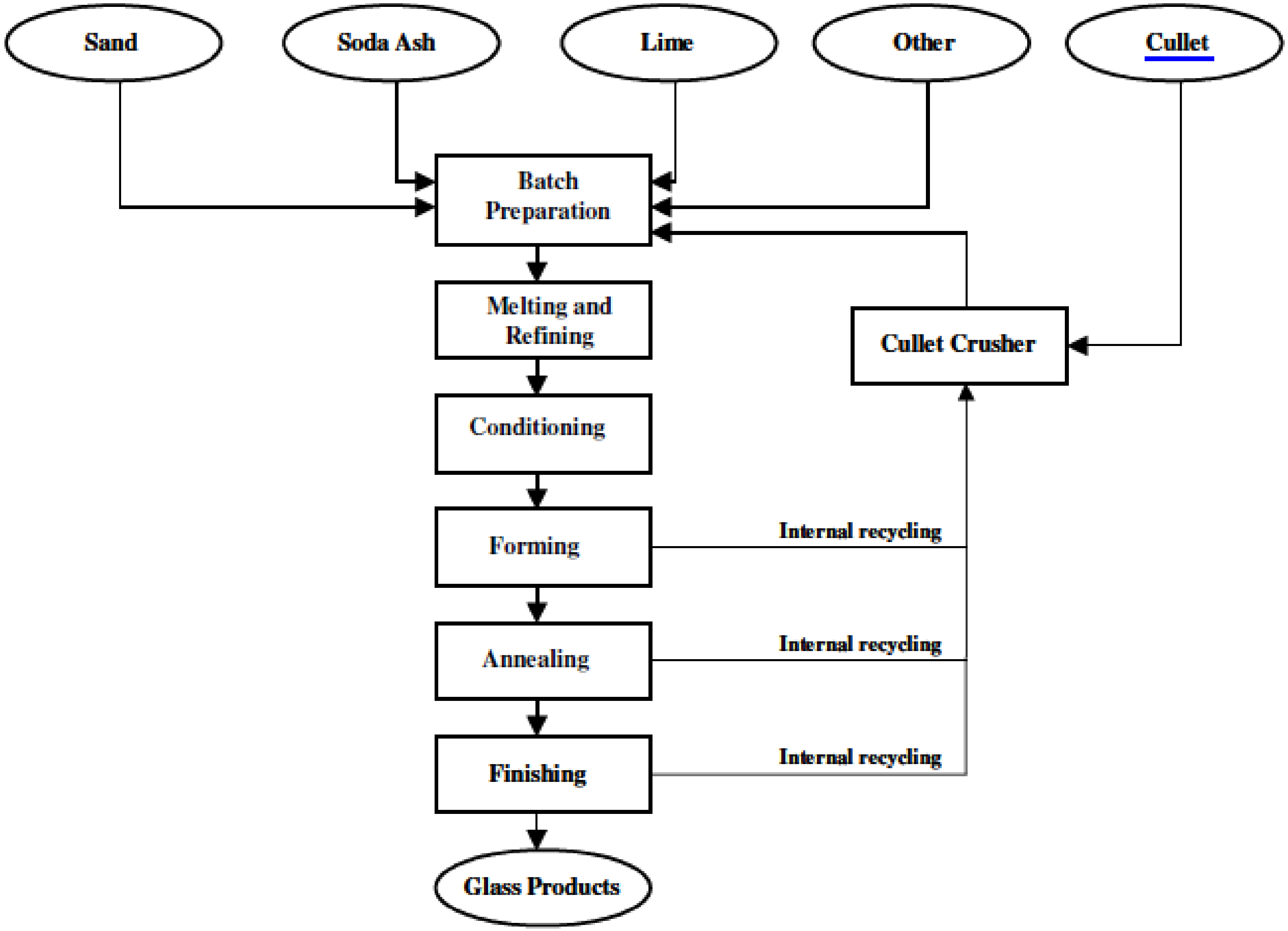
- forming

- post-processing (i.e. annealing, tempering, polishing or coating).

The technologies employed in each step depend on the glass product manufactured.

Simplified process schematic of glass manufacture
(typical of container glass making).

Raw materials

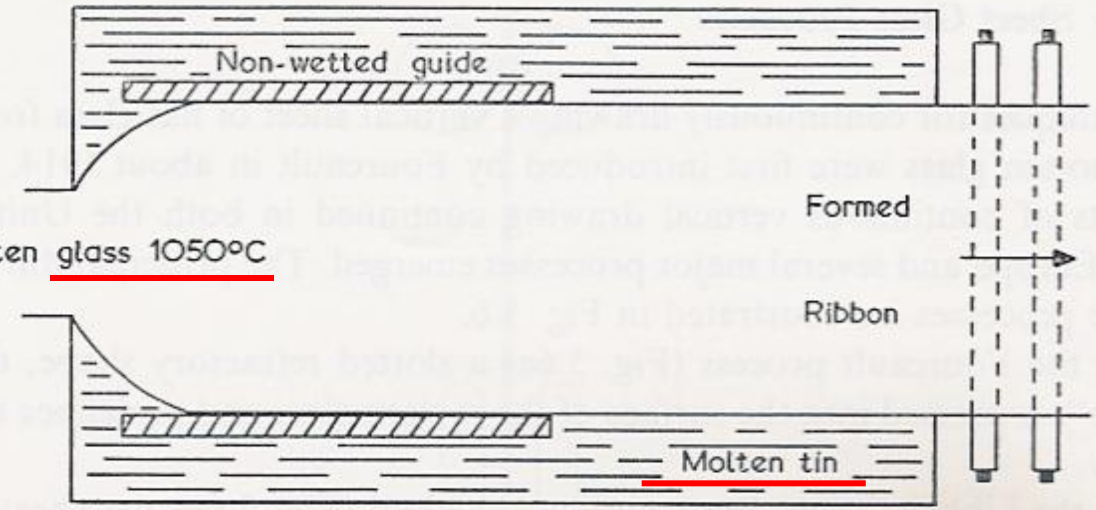


Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).

Approximate composition of different glass types

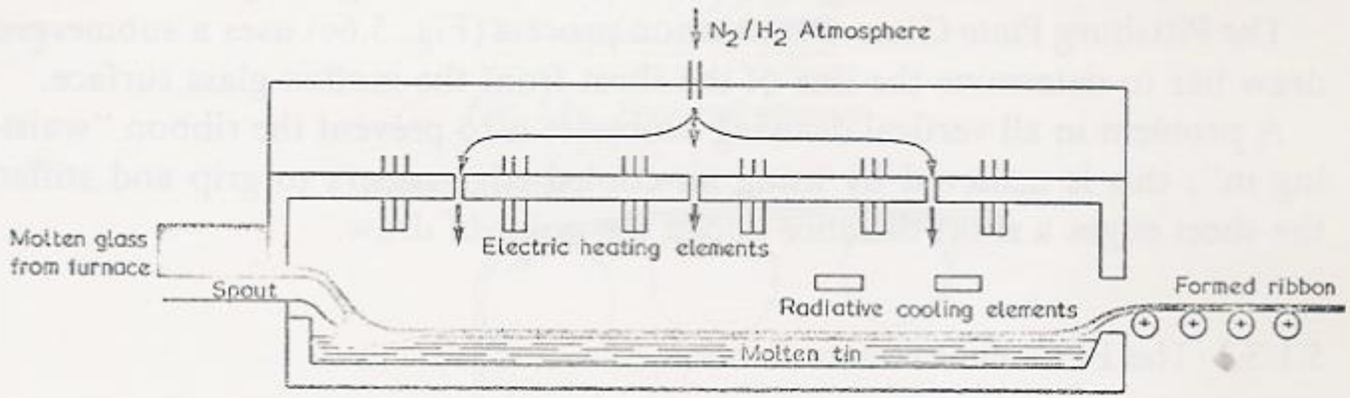
Oxide	Container Glass	Float glass	Fiberglass (E-Glass)	Laboratory Ware
SiO_2 [w%]	73	72	54	80
B_2O_3 [w%]			10	10
Al_2O_3 [w%]	1.5	0.3	14	3
CaO [w%]	10	9	17.5	1
MgO [w%]	0.1	4	4.5	1
Na_2O [w%]	14	14		5
K_2O [w%]	0.6			

Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).



4. Manufacture of thick float ribbon (~ 10 – 25 mm)

Example: float glass fabrication



5. Vertical section through float bath

Molten Sn bath in a N_2 / 10% H_2 reducing atmosphere.

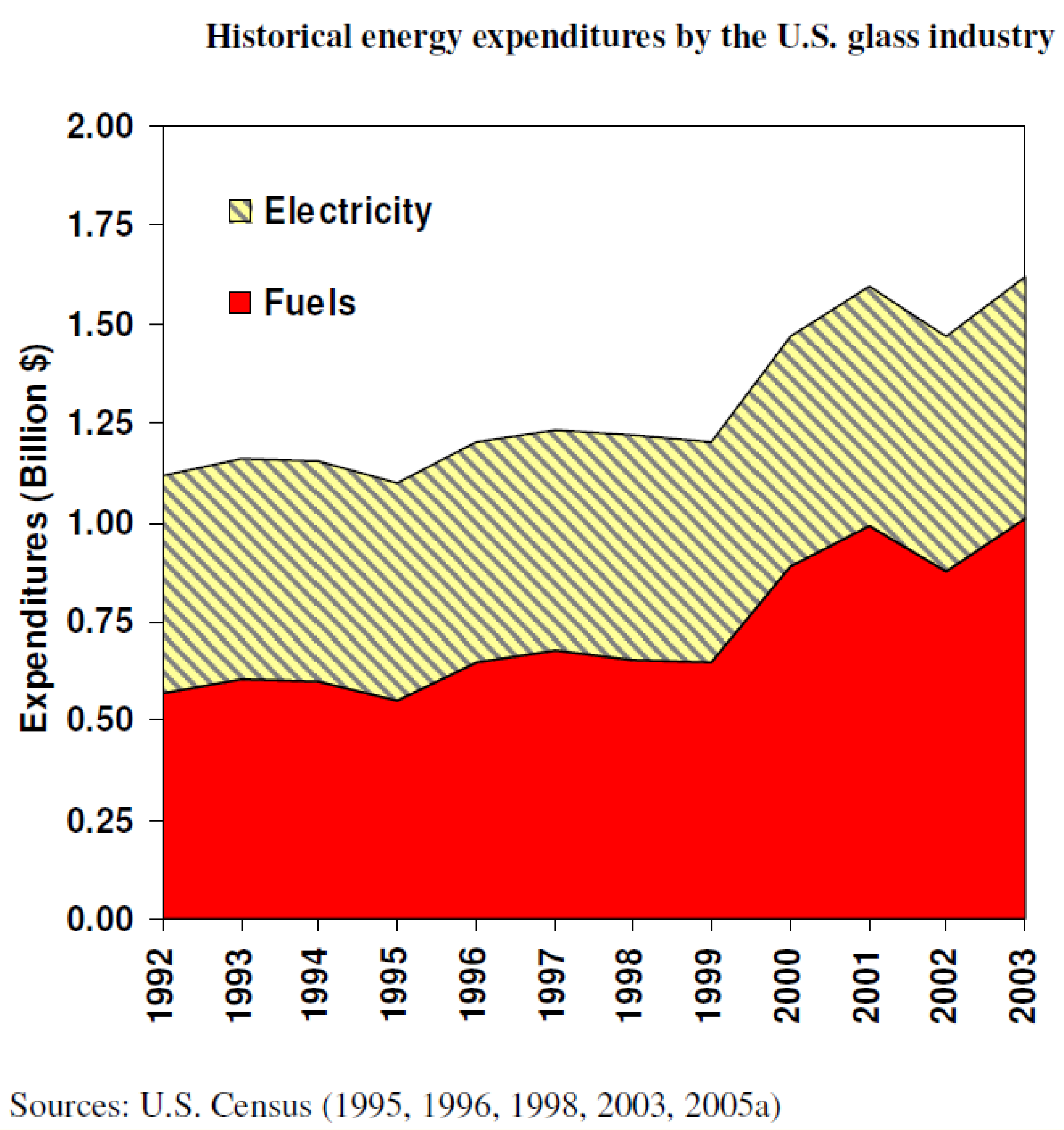
(Adapted from: Glass-making today, P.J. Doyle, Portculis Press, 1979)

ENERGY use in glass fabrication

Energy costs are significant in the glass industry and account for ~ 15 % of the US glass industry direct costs (GMIC, Glass Manufacturing Industry Council, 2002).

In the US glass industry, in 2003, the four primary segments spent ca. $1.6 billion on fuel and electricity:

~ 60% on fuels (~ all natural gas) and ~ 40% on electricity (~ all purchased). Electricity is used as booster energy in melting tanks and throughout the plant for lights, fans, pumps, compressed air systems and forming equipment.



Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).

Natural gas is normally used as the fuel in glass furnaces.

Some furnaces also use electrical boosters, usually based on molybdenum electrodes; since molten glass is an electrical conductor at high temperatures, the boosters, which supply ~ 10 – 30 % of the energy input to the furnace, help melt the glass. The melting of wool-type fiberglass is predominantly done with all electric furnaces.

Glass melting is a large source of NO_x emissions which must be reduced, while simultaneously reducing energy costs. Oxy-fuel firing (no N_2 as in air-fuel mixtures) reduces the NO_x emissions.

Next we review the main glass manufacturing steps during which energy savings have been achieved and may still be further increased in the future.

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BATCH preparation

Glass manufacture begins with weighing and mixing of the batch ingredients, which include glass formers, modifiers (*fluxes*), intermediates (*stabilizers*) and sometimes chromophores *(colorants)*.

Grinding of the raw materials increases their ability to mix and their reactivity during melting, but excessive grinding to very fine particle sizes may consume too much energy (lost as heat). A balance is necessary.

It is very important that the raw materials are well blended, which is the case in large plants with computer controlled weighing equipment, where the materials are weighed directly onto a conveyor belt, which feeds them into a solids mixer.

Main raw materials

used in the glass industry

The use of Li compounds as fluxes (e.g. **Li_2CO_3**) has been increasing, since the melting temperatures are somewhat lowered.

But there is also increased demand of Li compounds for other ends (Li batteries, etc.)

(Adapted from: Glass-making today, P.J. Doyle, Portcullis Press,1979)

Name	Formula	Molecular weight	oxide
Boric acid	H_3BO_3	61·84	B_2O_3
Borax	$Na_2B_4O_7 . 10H_2O$	381·43	B_2O_3, Na_2O
Anhydrous borax	$Na_2B_4O_7$	201·27	B_2O_3, Na_2O
Limestone	$CaCO_3$	100·09	CaO
Dolomite, pearlspar	$MgCO_3 . CaCO_3$	184·42	CaO, MgO
Hydrated lime	$Ca(OH)_2$	74·10	CaO
Magnesite	$MgCO_3$	84·33	MgO
Barium carbonate, witherite	$BaCO_3$	197·37	BaO
Barium sulphate, barytes	$BaSO_4$	233·43	BaO, SO_3
Red lead, minium	Pb_3O_4	685·43	PbO
Litharge	PbO	223·19	PbO
Soda ash	Na_2CO_3	106·00	Na_2O
Sodium sulphate, saltcake	Na_2SO_4	142·06	Na_2O, SO_3
Sodium nitrate, chili-saltpetre	$NaNO_3$	85·01	Na_2O
Potash, pearl ash	K_2CO_3	138·21	K_2O
Glassmakers' potash	$K_2CO_3 . 1\frac{1}{2}H_2O$	165·24	K_2O
Potassium nitrate, saltpetre	KNO_3	101·10	K_2O
Lithium carbonate	Li_2CO_3	73·89	Li_2O
Fluorspar	CaF_2	78·08	CaO

Melting and **refining**

Continuously operated **tank furnaces** are normally used for glass melting. These include a batch charging area (*doghouse*) attached to a refractory basin covered by a refractory roof *(crown).*

Heating normally uses oxy-fuel or air-fuel burners, or direct electrical (Joule) heating, or a combination of both (electrical boosting).

The fuel is normally natural gas. The use of oxygen to replace combustion air helps to reduce NO_x emissions.

To keep the glass level constant, the mixture of batch and *cullet* (recycled glass) is continuously charged into the melting furnace to compensate for the glass withdrawn.

The process of refining, during which the molten glass is freed from (air and CO_2) bubbles, homogenized and heat conditioned before the glass is introduced into the forehearth, takes place in the melting chamber. Na_2SO_4 is normally used as a *fining agent*.

Each campaign life may vary from ~ 2 to 10 years, depending on the glass furnace construction.

Cullet use

Cullet is recycled glass that is added to the raw material batch. Because no chemical reactions take place in melting the cullet (it is simply dissolved in the molten batch which it simultaneously helps melting), the energy savings may be quite significant.

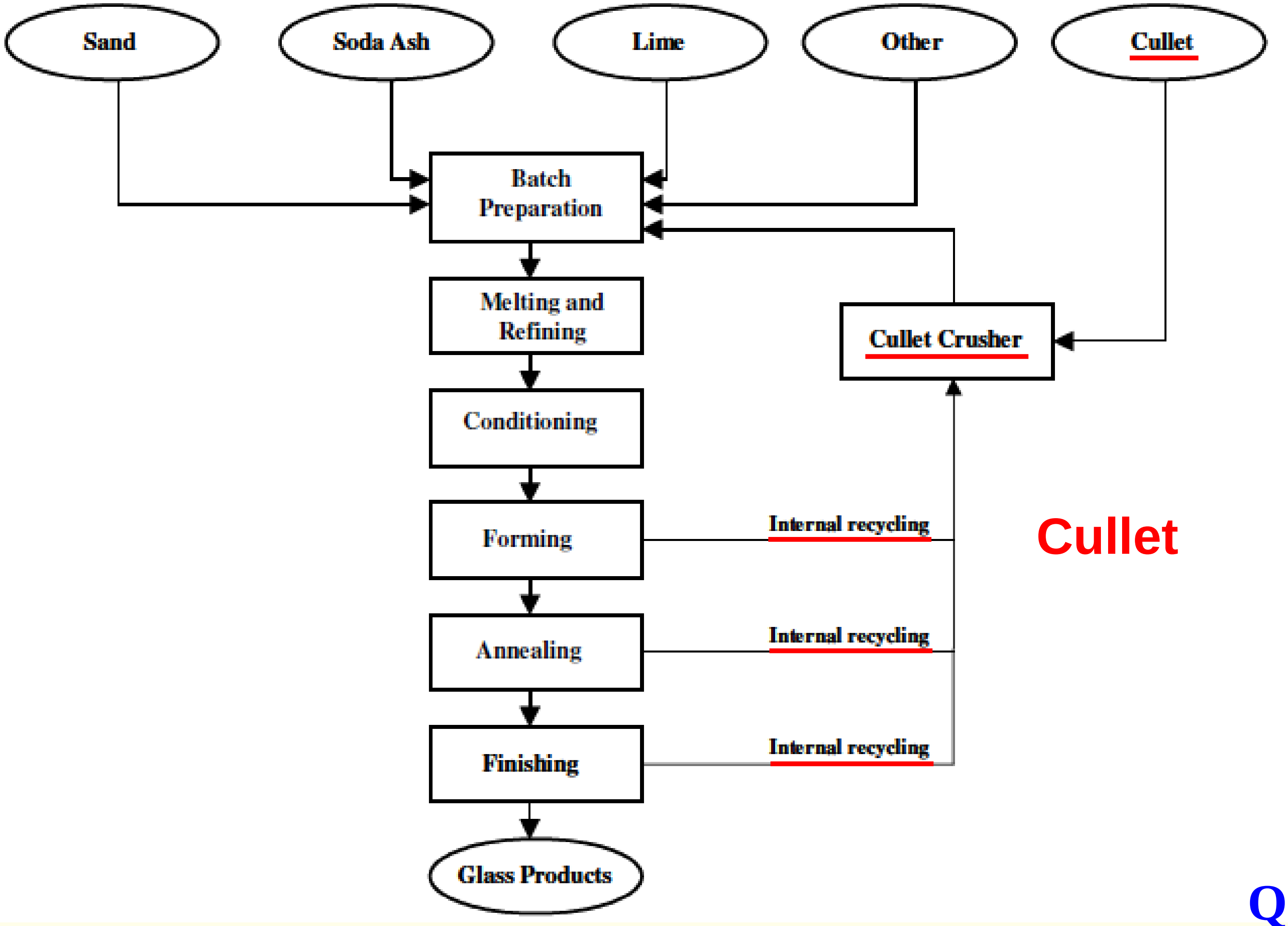
But the supply of quality cullet also requires crushing, cleaning, sorting and transportation. In particular, the color separation of cullet is essential to optimize its use for each type of glass product, so companies often prefer in-house cullet. In the end, an increase in the cullet share by 10 % (weight) reduces the net energy consumption by ~ 3 %.

Cullet can be used in all sectors of glass manufacturing. Container glass can incorporate from ~ 10 % up to 90 % or more. The US uses ~ 30 % cullet in container glass manufacture, vs. an average of 60 % in the EU (~ 95 % in Belgium, but only ~ 30 % in Greece, 2003 figures). These numbers are closely related to rate of glass container recycling in each country. Correct, large scale recycling is fundamental.

For flat glass production, the incorporated cullet normally does not exceed ~ 40 %. Also float glass furnaces are intrinsically less efficient than the container glass ones due to greater refining requirements in the former.

Simplified process schematic of glass manufacture (typical of container glass making).

Raw materials



Cullet

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Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).

Additional energy savings

Cullet pre-heating

Here the waste heat of the fuel-fired furnace is used to pre-heat the incoming cullet batch. The cullet is either in direct contact with the flue gas and is heated to ~ 400 ^{o}C, or it moves through a heat exchanger and is heated to ~ 300 ^{o}C.

Cullet pre-heaters are currently found only in glass container furnaces. But that may change in the future. Batch pre-heating is more difficult than cullet pre-heating.

Additional energy savings

Melting tank

Considerable efforts have been placed on the optimization of the melting tank, where the most energy-consuming steps of glass making take place. Improvements can be made at the end of the campaign life of an existing furnace, or when constructing a new furnace.

One important change for existing furnaces is the introduction of computer-based process control systems (also called expert systems), although process control for energy efficiency of a glass melting tank is still difficult.

Control systems are either based on mathematical models derived from a detailed understanding of the process, or are neural networks/fuzzy logic models that simulate the best operators and which "learn by doing", using information obtained from the process.

All systems lead to energy savings directly, due to improved temperature control and reduced residence time in the furnace, or indirectly, due to reduced rejection rates.

Overview of commercially available control systems for glass melting (not exhaustive)

Control System	Developer/Supplier
Expert System II	Glass Service, Czech Republic
GlassMax	Universal Dynamics, Canada
MeltingExpert	IPCOS, The Netherlands/Belgium
SIGLAS- Expert	Siemens, Germany

Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).

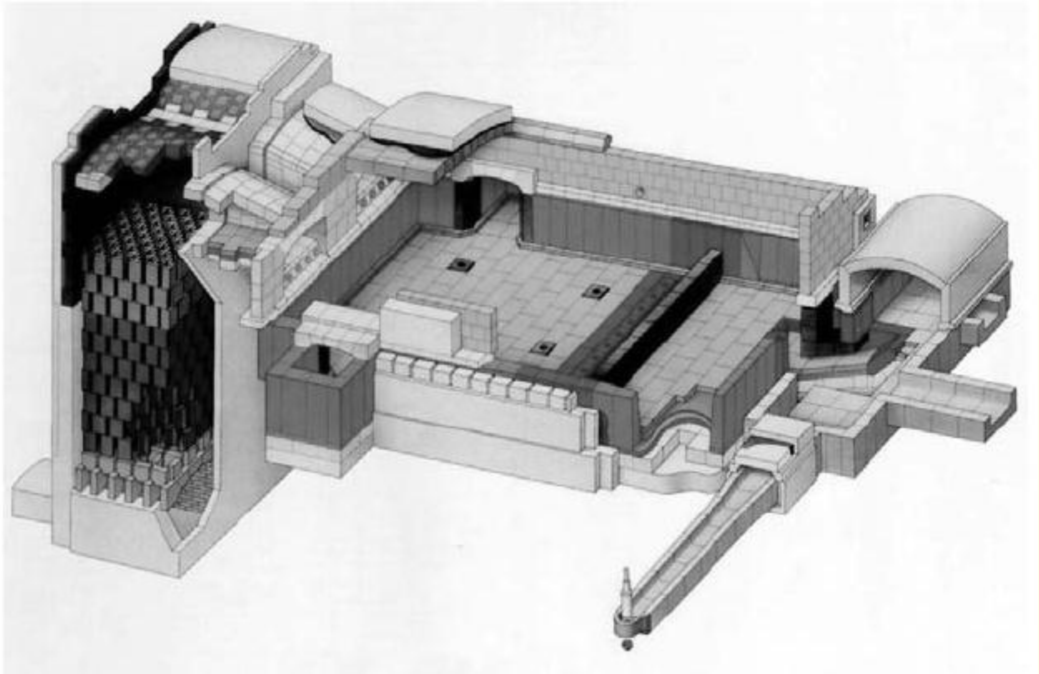
Recuperation / regeneration

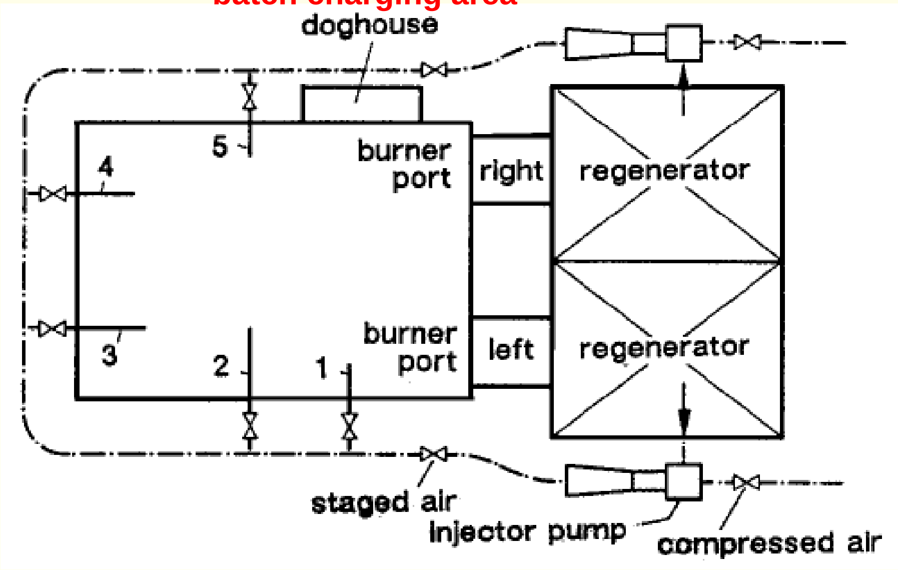
A very important aspect related to energy efficiency is the recover of heat from the exhaust (flue) gases with recuperative or regenerative systems in order to pre-heat the air/oxygen used in the fuel combustion. While recuperative systems use heat exchangers, regenerative systems use chambers with refractory bricks forming open conduits. Both schemes can increase the overall efficiency of the glass furnace to 50–65 %.

Ninety percent of all glass is melted nowadays in regenerative furnaces, which operate in two cycles. First the combustion gases pass through large chambers packed with refractory bricks and heat them. About every 20 minutes, the flow is reversed and the new cold combustion air is heated by the hot brickwork and then mixed with the fuel (natural gas) in a combustion chamber. The cycle time is automatically adjusted by a control system, to achieve the highest efficiency possible. Sometimes there are two regenerator chambers: one chamber is heated by waste gas from the combustion process, while the other preheats incoming combustion air. The furnace is fired on only one of two sets of burners at any given time and the flow alternates from one side to the other every 20 minutes.

When rebuilding a furnace after the campaign life ended, it may be worthwhile to expand the size of the regenerator to improve the heat recovery efficiency, by allowing increased heat recovery from the flue gases, which are in turn released at lower temperature to the environment.

Example of an end port fired **regenerative glass furnace**.





Cross sectional detail.

Adapted from: *Glass melting technology: a technical and economic assessment*, GMIC (US DoE, October 2004).

Oxy-fuel furnaces

The 100 % oxy-fuel combustion technology is possible in all segments of the glass industry. While specialty glass has the highest oxy-fuel furnace use, the flat glass industry has the least.

The energy savings when converting from air-fuel to oxy-fuel may range from ~ 20 - 45 %. Even for large efficient regenerative furnaces, savings might be between ~ 5 – 20 %. Also, the use of oxy-fuel furnaces reduces NO_x emissions by ca. 70 – 90 % and particulate emissions by 25 – 80 %, compared to traditional air-firing, combined with reduced noise and melting times.

Disadvantages may include increased refractory wear (which may affect the product quality) and decreased furnace life, in addition to the oxygen production costs.

Electric furnaces

Electric glass melting tanks are used mainly for the production of specialty products or for small batches of products like tableware.

Electric furnaces do not produce NO_x or particulate emissions, which is an enormous advantage form the environmental point of view, in particular when the electricity rates become more favorable compared to the natural gas cost. So while all-electric furnaces are typically used for smaller capacities (e.g. < 75 ton/day), larger furnaces may become economically attractive depending on the local electricity rates.

Emerging technologies

New and emerging technologies for energy savings in the glass industry are continuously being tested and developed.

The table below lists some of the main emerging technologies nowadays.

Emerging Technologies	
Oscillating combustion	Advanced glass melter
Segmented melter	Air-bottom cycle
Plasma melter	Glass fiber recycling
High speed convection	Use of waste glass in cutting
Reengineer process to spend less time in tank	Other emerging technologies
Submerged combustion melting	

Adapted from: *Energy efficiency improvement and cost saving opportunities for the glass industry*, Ernst Worrell et al., US EPA (March 2008).

References:

A.K. Varshneya, **Fundamentals of Inorganic Glasses**, 2nd Edition, Society of Glass Technology, (Sheffield, UK, 2006).

P.J. Doyle, **Glass-making today**, Portcullis Press (Redhill, UK, 1979).