

Glass Furnaces

SUMMARY

Glass furnaces are the primary source of NO_x emissions in glass manufacturing, emitting between approximately 43,000 and 76,000 tons of NO_x per year.

Although uncontrolled NO_x emissions vary widely, the following emission factors are representative: container glass, 10 lb NO_x/ton of glass produced; flat glass, 15.8 lb NO_x/ton; and pressed/blown glass, 22.0 lb NO_x/ton.

A variety of combustion processes and post combustion modifications are available to control NO_x emissions. One, oxy-firing, can achieve reductions in the range of 85 percent.

Cost effectiveness figures for NO_x reductions from glass furnaces are primarily in the range of thousands (as opposed to hundreds) of dollars.

DESCRIPTION OF SOURCE

Glass furnaces are used to melt raw materials in the manufacture of glass. The three main types of glass (apart from fiberglass) are container, flat and pressed/blown. Of the approximately 20 million tons of glass produced in

the U.S., each year, about 53 percent is container glass, 22 percent is flat glass and 25 percent is pressed/blown glass (see *Table 1*). Flue gas from glass furnaces is the major NO_x source in the glass industry.

Glass manufacturing consists of preparation of raw materials, glass furnace melting and refining and glass forming and finishing.

Raw, dry ingredients, such as sand, lime and soda ash, are first mixed in a batch. In most large furnaces, this batch is mixed and fed to one end of the melting furnace where chemical reactions occur among the batch ingredients. Natural gas burners that are fired over the glass melt usually supply the heat for these reactions.

The most common furnace is a continuous regenerative type, which has either an end-port or side-port configuration. In end-port furnaces, the flames travel in a U-shaped path over the melt. These furnaces are used in the container and pressed/blown industries. In side-port furnaces, used for flat and container glass production, the flames travel from one side of the furnace to the other.

End-port furnaces are generally smaller (less than 175 tons/day) and are used in the container and pressed/blown industries. Side-port furnaces are larger (some over 800 tons/day) and provide more even heating,

which is necessary in flat glass production, in both cases, refractory-lined flues recover energy from the hot flue gas.

The high temperature of the flue gas exiting the furnace heats the refractory "checker bricks." In both the end- and side port configurations, the cycle of air flow from one checker to the other is reversed about every 15 to 30 minutes. The combustion air preheat temperatures can reach 1500° to 2000°, and substantial NO_x can be formed in the checkers.

Both the container and flat glass industries make extensive use of broken glass called "cullet". The cullet can be internally recycled glass or come from external recycling operations. Because the chemical reactions necessary to form glass have already occurred in the cullet, melting cullet requires only about half the energy of virgin batch ingredients.

Processes for container, flat and pressed/blown glass do not differ greatly through the melting step, except that pressed/blown glass furnaces do not usually use regenerators to recover heat from the flue gas and, thus, have higher energy use.

Figure 1 illustrates the process of container glass production.

The batch components and cullet react to form glass in the melting chamber. The melt becomes homogeneous and free of bubbles in a refining or "fining" section that is downstream of and separated from the melting section by a refractory bridge wall or throat through which the molten glass passes.

In flat glass production, molten glass coming from the fining section is pulled onto a bath of molten tin and gradually cooled to around 1950° to 1130°. It then enters an annealing section where it is further cooled.

The major difference between container and flat glass is in the forming operation. Container glass is formed by blow molding. Flat glass floats the molten glass continuously on a liquid alloy surface with simultaneous cooling to sheet glass.

Melting for both container and flat glass is generally done in a continuous reverberatory furnace fed by natural gas or fuel oil. The reverberatory matters, regenerative heat recovery and are commonly constructed of checker brick.

In addition to the melting furnaces discussed above, some glass, primarily fiberglass, is produced in electric melting furnaces. Although electric melting furnaces may produce same NO_x if sodium nitrate is added to the glass batch, NO_x emissions are generally insignificant.

EMISSIONS PER UNIT OUTPUT

Because natural gas is used as the fuel in almost all glass furnaces, most of the NO_x generated is thermal NO_x.

STAPPA/ALAPCO Recommendation

1 State and local agencies can achieve reductions in NO_x emissions from glass furnaces by requiring combustion modifications, process changes and post-combustion controls (particularly selective noncatalytic reduction). Several states have already adopted RACT limits in the range of 5.3-5.5 lbs NO_x/ton of glass removed. The South Coast Air Quality Management District has set a limit of 4.0 lbs NO_x/ton of glass removed. Costs can be reduced by coordinating the installation of controls with routine furnace rebuilds.

Emission factors for this Industry vary widely. Data from various facilities reported to EPA's ACT document, show uncontrolled NO_x emissions ranging from 2.5 to 21.6 lb NO_x/ton glass for container glass, 8.8 to 25.8 lb NO_x/ton for flat glass and 16.8 to 27.2 lb NO_x/ton for pressed/blown glass.

For purposes of analysis, however, the draft EPA ACT document uses the following emission factors as representative: container glass, 10 lb NO_x/ton of glass produced; flat glass, 15.8 lb NO_x/ton; and pressed/blown glass, 22.0 lb NO_x/ton (see Table 2). However, as shown in Table 3, EPA's AP-42 NO_x emission factors are historically lower.

NATIONAL EMISSIONS ESTIMATE

According to EPA's *National Air Pollutant Emissions Trends, 1900-1992*, published in 1993, annual NO_x emissions from glass manufacturing are 43,000 tons. EPA's *AIRS Facility Subsystem* shows NO_x emissions from glass furnaces to be 65,000 tons annually and EPA's *AIRS Executive* database documents 76,000 tons of NO_x emitted annually from glass manufacturing plants. Total NO_x emissions from glass furnaces, thus, seems to fall between 43,000 and 76,000 tons per year. Table 4 provides a breakdown of total NO_x emissions by type of melting furnace.

GEOGRAPHIC DISTRIBUTION OF SOURCES AND EMISSIONS

The geographic location and annual NO_x emissions of 107 glass plants, which should reflect all container, flat and pressed/blown glass plants that emit at least 100 tons of NO_x per year, are identified in Table 5. As shown, there are significant concentrations of glass manufacturing plants in Illinois, Indiana, Ohio, New York, Pennsylvania, North Carolina, South Carolina, Oklahoma and Texas.

The current number of glass plants is lower than historical levels. The most recent new container glass plant was built in the U. S. in 1980.

AVAILABLE CONTROL STRATEGIES

Control strategies for reducing NO_x emissions from glass melting furnaces are combustion modifications (low excess air, oxy-firing and low NO_x burners), process modifications (cullet preheat, electric boosting/all-electric melting) and post combustion controls (SCR, SNCR and hydrocarbon injection).

Combustion Modifications. Test data from commercial-scale end-port and side-port glass furnaces and from a pilot-scale facility show that lowering excess air leads to lower NO_x emissions, in these cases by 28 percent. This same study shows that NO_x reductions are possible by decreasing air and fuel velocities and reducing contact angle.

In some cases, all of the potential NO_x reductions to be achieved via low excess air operation have already been realized because of the significant energy efficiency advantages in such operations. Achieving further reductions in a side-port furnace is considerably more difficult than in an end-port furnace because air enters a side-port through three or four ports rather than one. Also, reducing excess air may increase the opacity of stack emissions.

Glass melting burners may, however, be adjusted to achieve some NO_x reductions. Research shows, for example, that adjusting burners to produce a long, lazy flame may yield modest NO_x reductions.

The Bay Area (San Francisco) Air Quality Management District concluded that it is possible to reduce excess air in some furnaces by using exhaust gas oxygen sensors to regulate combustion air and by carefully sizing ports. BAAQMD found that such modifications can be made at relatively minor cost during furnace rebuild and that such modifications should reduce NO_x emissions by 10-15 percent.

Low NO_x burner approaches include combustion staging, which involves creating fuel-rich and air-rich

combustion zones in a single burner, and limited excess air burners, which create turbulent mixing of fuel and air, thereby reducing the need for excess air. Many available burners for glass furnaces include features to allow adjustment of air/fuel velocities, contact angle, flame shape and injection orifice. Each of these can reduce NO_x emissions, but do not include all of the features that commonly define "low NO_x burners."

Low NO_x burners cannot be directly retrofitted to glass furnaces in that the burner in these furnaces serves as a fuel injector, injecting fuel into the flow of combustion air entering the furnace. The mixing of fuel and air takes place within the furnace. There are, therefore, no off-the-shelf low NO_x burners.

Another combustion modification technique is called oxygen enrichment, which refers to the substitution of oxygen for nitrogen in the combustion air; oxygen enrichment above 90 percent is called "oxy-firing." The result is that there is little nitrogen available to form NO_x.

Oxy-firing differs from the other combustion modification techniques noted above in three basic ways. First, it improves combustion efficiency. Second, retrofitting a conventional side-port regenerative melter with oxy-fuel technology is relatively complex since it requires new burners, heat recovery equipment, an air separation unit, piping, controls, modifications to the flue gas system and removal of the regenerators (because the flue heat is no longer used to pre-heat incoming combustion air). Third, it can achieve high NO_x efficiencies, ranging up to 80-90 percent.

Finally, converting from gas-firing to oil-firing will reduce NO_x emissions, but the reasons why this occurs are not well understood. It is hypothesized that switching to alternative fuels (e.g., methanol or propane) may also reduce NO_x, but quantitative data are unavailable.

Process Modifications. Several types of cullet preheat systems are in use in container glass production. Their purpose is to recover energy, thus requiring less fuel and reducing NO_x emissions. One test showed a 16-percent NO_x reduction with 50-percent cullet preheated to 900°F. A disadvantage, however, is that cullet preheat requires complex and expensive mechanical systems, leading many authorities to conclude that the energy savings from cullet preheat systems do not offset the increased maintenance costs. EPA, for example, finds cullet preheat extremely limited as a NO_x emissions control strategy.

In addition, simply using more cullet, which lowers energy requirements, and thus NO_x emissions, is a possible control strategy for modest NO_x reductions. Many plants, however, may already be using cullet at high rates (due to recycling) and cullet costs are now significantly higher than raw material costs.

Electric boosting, used in many glass furnaces, involves an electrical current passing between electrodes submerged in the glass melt to heat the batch materials and boost the furnace's maximum production rate. The heat generated via the "boost" can supplant heat that would otherwise be generated by fuel combustion. Although electrical boosting at high rates (20 percent of total energy input) can cut NO_x emissions in half, as discussed below the approach is not cost effective due to the high cost of electricity, although it can be used with other measures to obtain some reduction.

Post-Combustion Controls. There are no SCR systems operating in the U.S. on glass furnaces, but SCRs have been installed on glass plants in Europe. One reported issue, however, has been the accumulation of fine dust on the catalyst, which decreases conversion efficiency, even where the SCR is located downstream of a particulate control device. To address this problem, pulsing blowers and steel facings have reportedly been installed in front of the catalyst and there are recent developments in soot blower technology for removing dust from the SCR catalyst surface. NO_x removal efficiencies of 70 to 80 percent have been reported.

Ammonia-based SNCR is currently installed on at least four glass furnaces worldwide, including a furnace in California, installed in 1991, which is achieving a 59-percent NO_x reduction. These four installations have all been on flat glass furnaces. With respect to container glass furnaces, however, one potential issue may be finding a location in the furnace that provides the proper temperature window for injection.

Another noncatalytic process is injection of hydrocarbon fuel into the flue gas, which has been tested in Japan. Although there appears to be little recent research, some California glass manufacturers believe this is a very promising technology that may be available in the late 1990s to achieve significant NO_x reductions at a lower cost than oxy-fuel technology.

Finally, the SCAQMD has evaluated a wet process known as "TRI-NO," that uses multi-stage scrubbing. Flue gas NO_x is oxidized to NO₂, which is then reduced to sodium sulfate, sodium chloride, nitrogen and water vapor. The manufacturer (TRI-MER Corporation) claims this can reduce NO_x emissions by 90 percent from glass furnaces. This system has not been installed on any glass furnaces.

The typical NO_x removal efficiencies of control strategies available for glass furnaces are summarized in *Table 6*.

POTENTIAL NATIONAL EMISSIONS REDUCTION

As noted, large NO_x emissions reductions can be achieved via retrofit of available control strategies. Data

is unavailable, however, on how many existing glass furnaces are already using NO_x controls; therefore, it is not possible to estimate precisely how much of the 43,000 to 76,000 tons of NO_x these furnaces emit annually could be reduced by widespread adoption of these controls.

COSTS AND COST EFFECTIVENESS

Table 7 identifies the capital and annual costs for NO_x control technologies, which will vary with plant size.

SNCR cost effectiveness is \$800-\$2000/ton. SCR is comparatively cost effective on large furnaces (5810\$/ton), with vendor estimates significantly below EPA's for mid- and large-size furnaces.

Gullet preheat has a cost effectiveness of 5890/ton on small furnaces, but is limited in the NO_x emissions reductions that can be achieved.

Oxy-firing cost effectiveness ranges from 52200-\$5300/ton, but can achieve any high NO_x efficiencies. If oxy-firing is installed during a major rebuild, however, the costs saved by not rebuilding the regenerator may be sufficient to pay for installation of the oxy-firing technology. Operating costs may be significantly higher for an oxy-fuel furnace, since oxygen separation relies on electricity. This operation cost premium may range from \$5-SIB a ton. Some NO_x emissions will, however, be shifted to the utility that generates the electricity.

In 1991, the SCAQMD estimated the cost effectiveness of meeting a NO_x limit of 4.0 lbs of NO_x per ton of glass at \$18,400/ton of NO_x reduced, based on the application of all-electric glass melting furnaces and a 95-percent control efficiency.

FEDERAL RULEMAKING AND/OR GUIDANCE DOCUMENTS

EPA has developed an ACT document on glass furnaces. A second draft dated February 1993 is available, and the main chapters have been updated as of March 1994, with a final document scheduled for release in June 1994.

For farther information on the ACT, contact Bill Netter, U.S. Environmental Protection Agency, Emission Standards Division, Research Triangle Park, NC 27711 (telephone: 9191541-5435).

STATE AND LOCAL CONTROL EFFORTS

The South Coast (Los Angeles) Air Quality Management District's Rule 1117 (adopted in 1983) sets a limit of 4.0 lbs NO_x per ton of glass produced, effective January 1, 1993. *Table S* identifies the SCAQMD PACT guidelines for glass melting furnaces.

The Bay Area (San Francisco) Air Quality Management District's Regulation 9. Rule 12 (adopted in January 1994) sets a limit of 5j lbs NO_x per ton of glass pulled (i.e. removed from the furnace), with a 3-hour average and interim reduction requirements. The rule sought to minimize costs by allowing affected sources to coordinate installation of controls with normal furnace rebuild schedules. BAAQMD expects an overall NO_x reduction of about 25 percent as a result of this rule.

Connecticut and New Jersey have NO_x limits (effective May 31, 1995) of 55lb/ton of glass removed. Massachusetts' NO_x limit for container glass furnaces is 5.3 lb/ton of glass removed. Different limits apply in some cases for specialty glass manufacturing.

REFERENCES

1. Connecticut Department of Environmental Protection. February 9, 1994. Rule 22a-174-22, *Control of NO_x Emissions and Hearing Report*.
2. Bay Area Air Quality Management District. October 8, 1993. *Staff Report Proposed Regulation 9, Rule 12: Nitrogen Oxides from Glass Melting Furnaces*.
3. U. S. Environmental Protection Agency. October 1991 *National Air Pollutant Emission Trends, 1900-1992*. EPA-454/R-93-032.
4. U.S. Environmental Protection Agency. February 1993 with March 1994 updates, *Alternative Control Techniques Document-Control of NO_x Emissions from, Glass Manufacturing (Second Draft)*.
5. California Air Resources Board. August 7, 1992. *Sources and Control of Oxides of Nitrogen Emissions*.
6. U.S. Environmental Protection Agency. February 1992. *Summary of NO_x Control Technologies and their Availability and Extent of Application*.
7. Air & Waste Management Association. 1992, *A6' Pollution Engineering Manual*.
8. South Coast Air Quality Management District. July 1991. *Final Air Quality Management Plan, 1991 Revision*.
9. U.S. Environmental Protection Agency. March 1990. *AIRS Facility Subsystem Emission Factor Listing for Criteria Air Pollutants*.
10. U.S. Environmental Protection Agency. July 1993. *AIRS Facility Subsystem*.
11. U.S. Environmental Protection Agency. January 28, 1994. *AIRS Executive*.

Figure 1

Container Glass Production

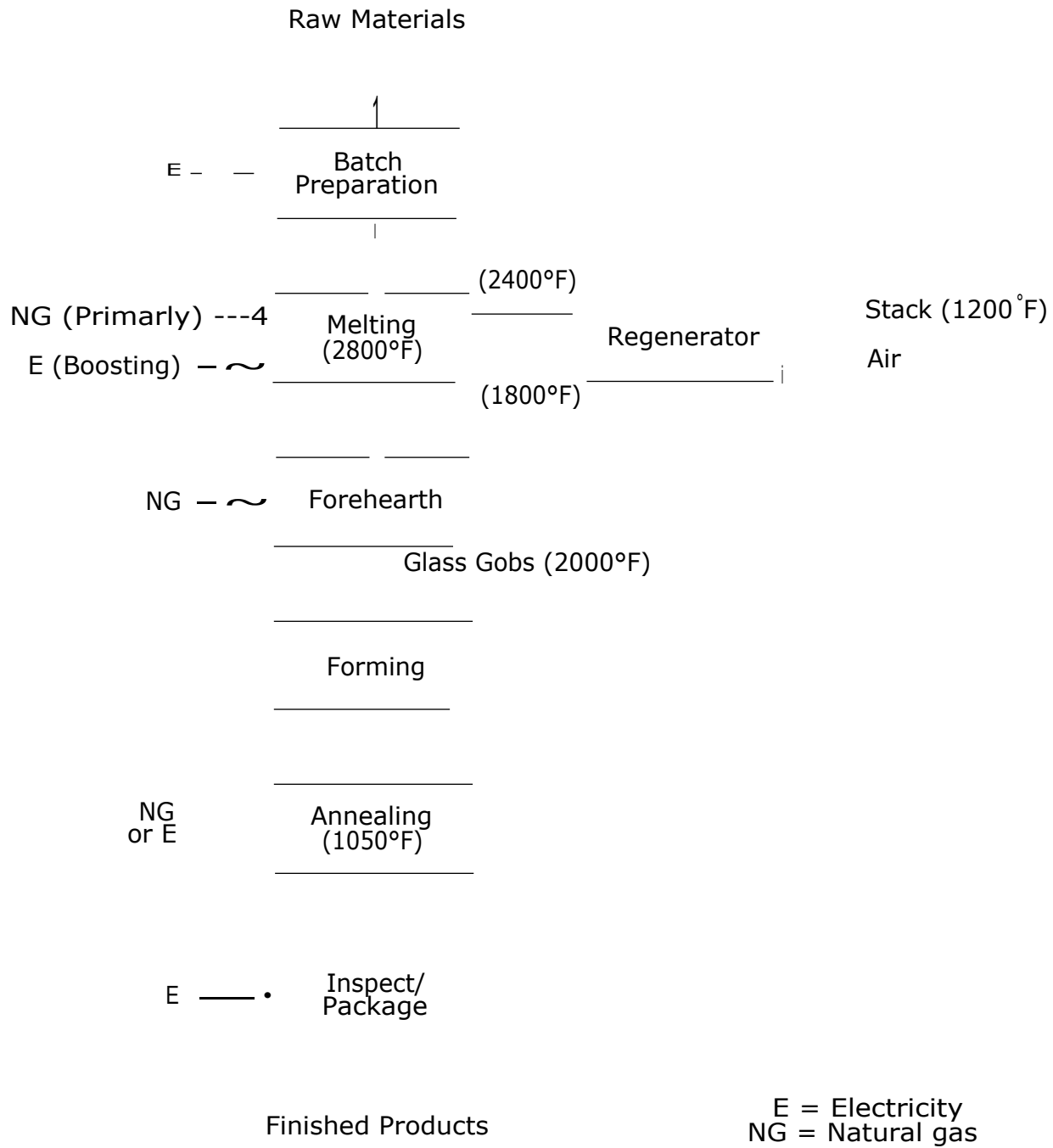


Table 4

Glass Production in 1988

Total NO_x Emissions

Industry	Glass Production 10 tons	Percent of Production	Melting Furnace	Annual Emissions (tons/year)
Container	10.1	53	Container Glass	30,500
Fat	4.1	22	Fat Glass	23,700
Pressed/Blown	4.7	25	Pressed and Blown Glass	11,200
Total	18.9	100	Ground Gullet Beading Furnace	8
			Total	65,000

Source: EPA, draft ACT February 1993.

Source: EPA, AIRS Far, laySubsystem July 1993.

Glass Industry: Representative Emission Factors

Table 5

Glass Manufacturing Plants

Glass Type	Emission Factor (lb NO _x /ton)	Slate	Plans	Tons/year	Percent of Total Stationary Source Emissions
Container	10.0	California	1	179	0.4%
Flat	15.8	Colorado	1	267	0.2%
Pressed/Blown	22.0	Florida	2	1,176	0.3%

Source: EPA, draft ACT February 1994. The emission factors shown are representative; actual uncontrolled NO_x emissions vary widely.

Glass Industry: EPA AP-42 Emission Factors

Container Glass:	6.2 lb/ton	Massachusetts	2	1,975	1.8%
Melting Furnace		Minnesota	1	682	0.5%
Flat Glass:	3.0 lb/ton	Missouri		603	0.2%
Melting Furnace		New Jersey		1,308	0.9%
Pressed and Blown Glass:	8.5 lbs/ton	New York		6,393	2.5%
Melting Furnace		North Carolina	7	7,926	2.7%
Ground Gullet Beading Furnace	8.5 lb/ton	Ohio	1	5,987	0.8%
		Oklahoma	7	4,135	2.2%
		Oregon		389	3.3%
		Pennsylvania		9,222	1.5%
		Rhode Island		291	0.9%
		South Carolina		6,583	4.7%
		Tennessee		2,346	0.7%
		Texas	7	8,260	0.8%
		Virginia	2	825	0.5%
		Washington	2	1,590	2.9%
		West Virginia	5	2,300	0.5%
		Wisconsin	1	581	0.4%
		National	107	74,307	

Source: EPA, AIRS Executive, January 28, 1994.

Typical NO_x Removal Efficiencies of Controls for Glass Furnaces

Technology	NO _x removal (%)
Combustion Modifications	
Modified Burner;	40
Oxy-Firing	85
Process Modification	
Chiller Preheat	25
Electric Boost	10
PostCombustion Modifications	
SCR	75
SNCR	40

Source EPA, draft ACT, February 1994,

Summary of Costs and Cost Effectiveness for NO_x Control Technologies for Glass Furnaces

Technology	Cost Effectiveness (\$/ton NO _x removed)			Capital Cost (\$1ea)			Annual Cost (\$10a/yr)		
	50	250	750	50	250	750	50	250	750
Retrofit Low NO _x Burners	1680	1920	790	265	695	1340	123	320	621
Oxy-Fringe	4400	5306	2150	1930	5070	9810	706	1860	3590
Gullet Preheat	890	1040	—	188	492	—	42	110	—
Electric Boost ¹	9900	8060	2600	—	N/A ²	—	178	339	525
SCR	2950	2460	810	528	1390	2690	404	769	1200
Sore	—	—	—	536	856	1496	—	—	—
SNCR	1770	2000	830	310	810	1560	135	345	660

Source: EPA, draft ACT, May 1994, Costs in 1994 dollars The 50-ton plants are pressed/bmwn. the 250-ton plants are container, the 750-ton plants are flat. Cost effectiveness is the same for both the 5-percent and 15-percent electric boost cases.

²F., electric boost, separate capital costs are not available, therefore, Initialized costs are presented.

³ vendor quote (1992 \$) for a glass furnace which includes the following equipment catalyst, catalyst modules, hot wall reactor housing inlet and outlet transition ducts, ammonia injection grid, ammonia dilution and flow control skid, ammonia storage tank, engineering specifications and continuous emissions monitoring systems. The catalyst costs shown in the table include installation and interconnecting piping and wiring, estimated at 60 percent of tire equipment cost.

SCAQMD Top-Down BACT Guidelines for Glass Melting Furnaces

Container Glass	Flat Glass	Pressed or Bill', Glass
Electric heat	Electric heat	Electric heat
Natural gas w/SCR	Natural gas a./SCR	Natural gas 1/SCR
Natural act I/SNCR	Natural gas %VSNCR	Natural gas w/SNCR
Natural gas wdh heating modifications	Natural gas with heating modifications	Natural gas with heating moditlcat ons:
• Electric boost > 15% of total heal input		
• Air to fuel ratio at <111	Excess O2 , r corts at <5%	• Air to fuel ratio at 12:1
• Gullet in raw matt charged at >2g'/=	• Culletin raw madd charged at , 15%	• Cullet in raw marld charged at> 50°e

Source: SCAOMD, July 1991.