Glass Furnaces

SUMMARY

Glass furnaces are the primary source of NO, emissions in glass manufacturing, emitting between approximately 43,000 and 76,000 tons of NO, per year.

Although uncontrolled NO, emissions vary widely, the following emission factors are representative: container glass, 10 In NO,/t,, of glass produced; flat glass, 15.8 to NO,/tun: and pressed/blown glass, 22.0 IF NO,/ton,

A variety of combustion processes and post combustion modifications are available to control NO, emissions. One, oxy-firing, can achieve reductions in the range of 85 percent.

Cost effectiveness figures for NO, 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, aw 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 L.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, 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 aver 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.

EndTon 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 tans/day) and provide more even heating, which is necessary in flat glass production, in both cases, , ,fractory-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 m the other is reversed about every 15 to 30 minutes. The combustion air preheat tempt atutes can reach 1500'. to 2000°., and substantial NO, can be formed in the checkers.

Both the container and flat glass industries make extensive use of broken glass called "cullet". The cutlet 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 I 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 gener ally done in a continuous reverberatory furnace feed by natural gas or fuel oil. The reverberatory matters us, 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 nicer (sodium nitrate) is added to the glass batch, NO, 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, generated is thermal NO,.

STAPPA/ALAPCO Recommendation

1 State and local agencies can achieve reductions in NO, 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,/ton of glass removed. The South Coast Air Quality Management District has set a limit of 4.0 lbs NO_R/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, emissions ranging from 2.5 to 21.6 lb NO,/ton glass for container glass, 8.8 to 25.8 In NO./ton for flat glass and 16.8 to 27.2 lb NO,/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_N/ton of glass produced; flat glass, 15.8 IF NO_N/con; and pressed/blown glass, 22.0 lb NO_N/ton *(see Table 2).* However, as shown in *Table 3,* EPA's AP-42 NO, emission factors are historically lower.

NATIONAL EMISSIONS ESTIMATE

According to EPA's *National Air Pollutant Emissions "6ends,1900-1992,* published in 1993. annual NO, emissions from glass manufacturing are 43,000 tons. EPA's *AIRS Facility Subsystem* shows NO,, emissions from glass furnaces to be 65,000 tons annually and EPA's *AIRS Executive* database documents 76,000 tons of NO, emitted annually from glass manufacturing plants. Total NO, 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, emissions by type of melting furnace.

GEOGRAPHIC DISTRIBUTION OF SOURCES AND EMISSIONS

The geographic location and annual NO, emissions of 107 glass plants, which should reflect all container, flat and pressed/blown glass plants that emit at least 100 tons of NO, 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 plant, 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, emissions from glass melting furnaces *are* combustion modifications *(low* excess air, oxy-firing and low NO, burners), process modifications (cutlet 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, emissions, in these cases by 28 percent. This same study shows that NO, reductions are possible by decreasing air and fuel velocities and reducing contact angle.

In some cases, all of the potential NO, reductions to be achieved via to, 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 sid,po,t 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, reductions. Research shows, for example, that adjusting burners to produce a long, lazy flame may yield modest NO, 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 end by carefully sizing pons. BAAQMD found that such modifications can be made at relatively minor cost during furnace rebuild and that such modifications should reduce NO, emissions by 10-15 percent.

Low NO, 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, emissions, but do not include all of the features that commonly define "low NO, bumersP

Low NO, 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, 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,.

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, efficiencies. ranging up to 80-90 percent.

Finally, converting hour gas-firing to oil-firing will reduce NO, 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,, 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, emissions. One test showed a 16-percent NO, reduction with 50-percent cullet preheated to 9009. 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, emissions, is a possible control strategy for modest NO, reductions. Many plants, however, may already be using cullet at high rates (due to rec) cling) 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 rat,. 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, emissions in half, as discussed below the approach is not cost eft ective 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, 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, reduction. These four installations have ail 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, 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 is oxidized to NO,, which is then reduced to sodium sulfate, sodium chloride, nitrogen and water vapor. The manufacturer ('fRl-MER Corporation) claims this can reduce NO, emissions by 90 percent from glass furnaces. This system has not been installed on any glass furnaces.

The typical NO, removal efficiencies of control strategies available for glass furnaces are summarized in *Table 6.*

POTENTIAL NATIONAL EMISSIONS REDUCTION

As noted, large NO, 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, controls; therefore, it is not possible to estimate precisely how much of the 43,000 to 76,000 tons of NO, these furnaces enut annually could be reduced by widespread adoption of these controls.

COSTS AND COST EFFECTIVENESS

Table 7 identifies the capital and annual costs for NO, control technologies, which will vary with plant size.

SNCR cost effectiveness is $800-$2000/ton. SCR is comparatively cost effective on large furnaces (58I0,/ton), with vendor estimates significantly below EPA's for mid- and large-size furnaces.

Gullet preheat has a cost effectiveness of 5890/tmr on small furnaces, but is limited in the NO, emissions reductions that can be achieved.

Oxy-firing cost effectiveness ranges from 52200-$5300/ton, but can achieve any high NO, 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 to, Some NO, emissions will, however, be shifted to the utility that generates the electricity.

In 1991, the SCAQMD estimated the cost effectiveness of meeting a NO, limit of 4.0 Ibs of NO_x permit of glass at $18,400/ton of NO_x reduced, based on the application of a11-electric glass melting furnaces and a 95-percent control efficiency.

FEDERAL RULEMANING 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 Net ffer, U.S. Environrnenm7 Protection Agency, Emission Standards Division, Research T*riangle 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, 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, 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, reduction of about 25 percent as a result of this rule.

Connecticut and New Jersey have NO, limits (effective May 31, 1995) of 55lb/ton of glass removed. Massachusetts' NO, limit for container glass furnaces is 5.3 lb/ton of glass removed. Different limits apply in some cases for specialty glass manufacturing.

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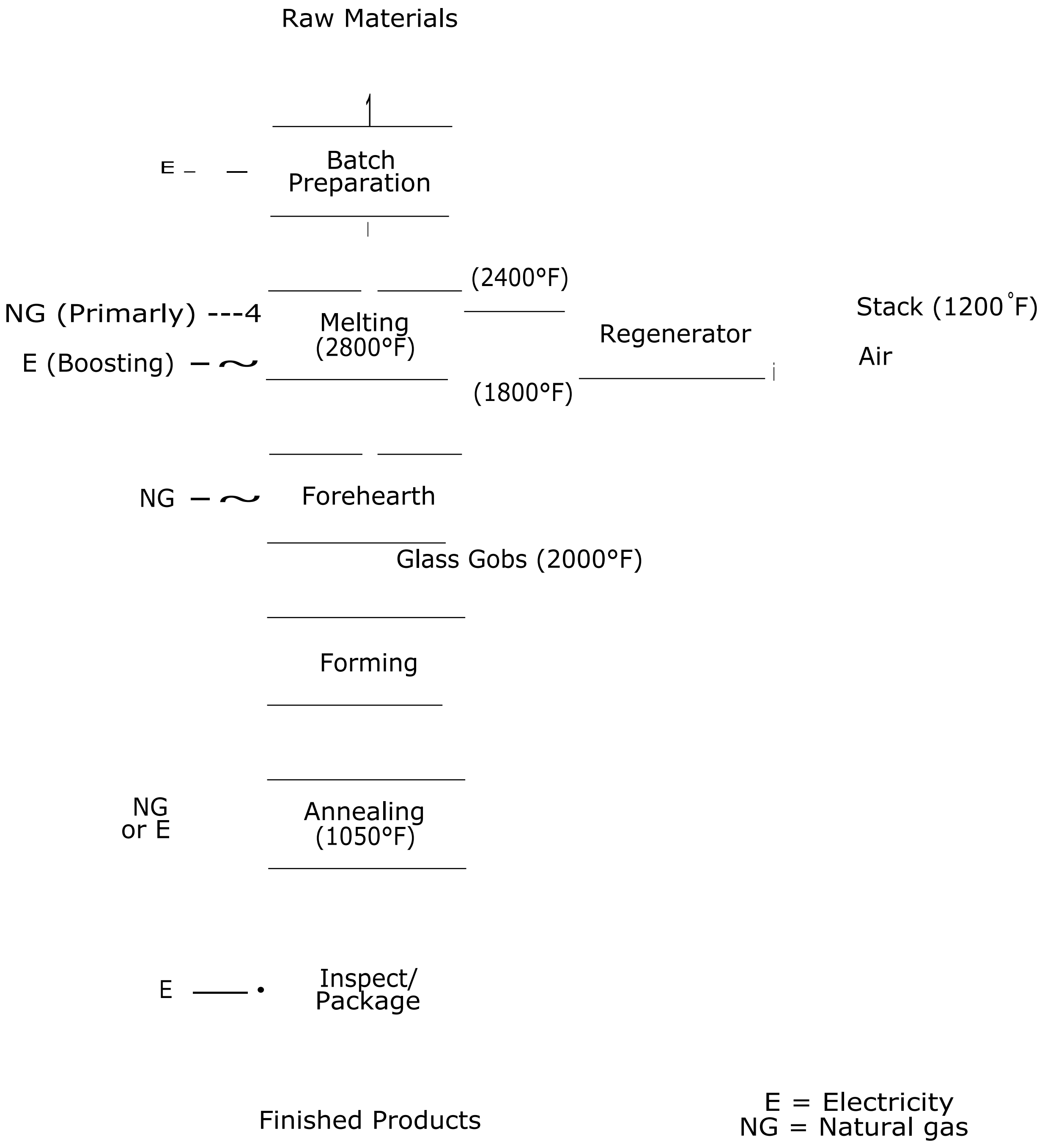
Figure 1

Container Glass Production



Glass Production in 1988

Industry	Glass Production 1o tonsl	Percent or Production
Container	10.1	53
Fat	4.1	22
Pressed/Blown	4.7	25
Total	18.9	100

Source' EPA, draft ACT February 1993.

Glass Industry: Representative Emission Factors

Glass Type	[mission Factor (lb ND,llon)
Container	10 0
Flat	!5.8
Pressed/Blown	22.0

Souma: EPA, built ACT February 1994. The emission factors *shown are repraseotabve; actual uncontrolled* NO_x emissions *vary widely*

Glass Industry: EPA AP-42 Emission Factors

Container Glass: Melting Furnace	6.2 coltish
Flat Glass: Melting Furnace	3.0croon
Pressed and Brown Glass. Melting Furnace	8.5 lbs/ton
Ground Gullet Beadirg Furnace	8.5 Ido/on

Source: EPA.

Table 4

Total NO, Emissions

Melting Furnace	AnnualEmissions Itanaiyear)
Container Glass	30,500
Fat Glass	23,700
Pressed and Blown Glass	11.200
Ground Gullet Beading Furnace	8
Total	65AOB

trounce: EPS, AIRS Far, IaySubsystem . July 1993.

Table 5

Glass Manufacturing Plants

Slate	Plans	Tons year	Percent ol Total Stationary Source [missions
California	1	179	04%
Colorado	1	267	0.2%
Florida	2	1,176	0.3%
Georgia	1	1,130	04%
Illinois	`0	4,344	0.8%
Indiana	6	2,848	0.5%
Kansas	1	852	0.4%
Kentucky	2	733	02%
Louisiana	3	1,362	0.2%
Massachusetts	2	1,975	1.8%
Minnesota	1	682	0.5%
Missouri		603	0.2%
New Jersey		1,308	0.9%
New York		6,393	2.5%
North Carolina	7	7,926	2.7%
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^{0}%
Tennessee		2,346	0.7%
Texas	7	8,260	0.8%
Virginia	2	825	0.5^{0}0
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, Removal Efficiencies of Controls for Glass Furnaces

Technology	NO, ne0udmn ok)
Combustion Modificatons	
Modified Bu^new;	40
Oxy-Firing	85
Process Moditcat	
CTllet Preheat	25
Eectric Boost	1 0
PostCo~rnoustion Modifications	
SCR	75
SNCR	40

Source EPA, draft ACT, February 1994,

Summary of Costs and Cost Effectiveness for NO, Control Technologies for Glass Furnaces

	Cast Elleclivenes. (S/ton NO, removed)			Capital Us! (51ea)			Annual Cost (S10a/yr)		
	Plate Site (nitrate			plant size (tons/day)			Plant Size (tons/day)		
Technology	50	250	750	50	250	750	50	250	750
Retrofit Low NO, Burners	1680	1920	790	265	695	1340	1 23	320	621
Oxy-Fringe	4400	5306	2150	1 930	5070	9810	706	1860	3590
Gullet Preheat	890	1040	——	'. 88	492	——	42	110	
Elect ho Bocst1	9900	8060	2600	——	N/A[2]	——	1 78	339	525
SCR	2950	2460	810	528	1390	2690	404	769	1200
Sore	—		—	536	856	'. 496			—
SNCR	' 770	2000	830	310	810	1560	135	345	660

Source: *EPA, draftACT, May 1994, Costs in 1994 dollars The 50-ton plants are pressed/bmwn.* the 250-ton *plants are conrainer, the 750-ton plants are flat.*

!cost effectiveness is the same *for both the 5- percent and 15-percent* electric boost cases.

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

[3] *vendorquote (1992 S) for a* glass *furnace which includes the following equipment catalyst, catalyst modules, hot wall reactor housing inlet aid* 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 ano 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 luel ratio at <111	Excess 02 , , 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> So°e

Source: *SCAOMD, July 1991.*