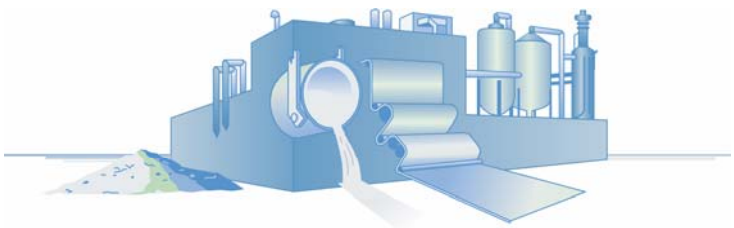

Results of the

DOE/GMIC Glass Workshop and Review

Industrial Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

In association with the Glass Manufacturing Industry Council

November 2, 2006
Columbus, Ohio

Proceedings of the

DOE and GMIC
Glass Workshop and Review

November 2, 2006
Fawcett Center
Columbus, Ohio

Coordinated by
Elliott Levine
U.S. Department of Energy
Energy Efficiency and Renewable Energy
Industrial Technologies Program

Prepared by
Energetics, Inc.
Columbia, Maryland

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***E**nergy-Efficient Glass Melting: The Next Generation Melter (Submerged Combustion Melting and Rapid Conditioning)*

***H**igh-Intensity Plasma Glass Melting*

***D**evelopment and Validation of a Coupled Combustion Space/Glass Bath Furnace Simulation*

***D**OE ITP Glass Program Accomplishments and Legacy: Serving as a Catalyst for Positive Change within the Glass Industry*

***I**ndustrial Glass Bandwidth Analysis*

3 Workshop Survey Comments

4 Attendees

Agenda

FINAL AGENDA

DOE/GMIC GLASS WORKSHOP AND REVIEW

November 2, 2006
Fawcett Center
Columbus, Ohio

Time	Activity	Speaker(s)
7:30 - 8:15 am	**REGISTRATION and CONTINENTAL BREAKFAST**	
8:15 - 8:30 am	Welcoming Remarks and Introductions	Elliott Levine Department of Energy Michael Greenman Glass Manufacturing Industry Council
8:30 - 9:15 am	*Submerged Combustion Melting and Rapid Conditioning (14231)* Questions and Answers	David Rue Gas Technology Institute
9:15 – 9:45 am	*High-Intensity Plasma Glass Melter (14232)* Questions and Answers	Ron Gonterman Plasmelt
9:45 - 10:00 am	**BREAK**	
10:00 - 10:30 am	*Coupled Combustion Space/Glass Bath Furnace Model (1025)* Questions and Answers	Steve Lottes Argonne National Laboratory
10:30 – 10:50 am	Program Accomplishments and Outlook	Elliott Levine Department of Energy
10:50 – 11:10 am	Reflection and Opportunities	Michael Greenman Glass Manufacturing Industry Council
11:10 - 11:40 am	*Glass Analysis/Bandwidth*	Warren Wolf
11:40 – 12:45 pm	**LUNCH**	
12:45 – 2:00 pm	Open Discussion: 1) Maintaining the collaborative environment and future opportunities 2) Maximizing energy efficiency impacts 3) Alternatives to natural gas	TBD
2:00 pm	**ADJOURN**	

2

Presentations

Energy-Efficient Glass Melting
The Next Generation Melter

David Rue
Gas Technology Institute

DOE Industrial Technology Program

2005 Project-Industry Review
Nov. 2, 2006

The Next Generation Melter

Goal

- demonstrate melting and homogenization stage of a low capital cost, energy efficient Next Generation Glass Melting System

Challenge

- fabricate 1 ton/h pilot melter based on submerged combustion melting and generate homogeneous glass without stones

Benefits

- Energy savings
- emissions reductions
- Capital savings using a much less expensive melter
- Flexibility in operations and glass compositions
- Simplified feed system accepting wider size range

FY 2006 Activities

- Complete 1 ton/h pilot SCM
- Parametric and long-term tests with multiple glass compositions
- Analyze product glasses
- Prepare for rapid conditioning of product glass
- Improve CFD model to accurately model SCM
- Plan first industrial SCM demo

Project Sponsors

- U.S. Department of Energy – OIT
- Gas Industry
  - **GTI Sustaining Membership Program (SMP)**
  - **Gas Research Institute FERC funds**
- New York State Energy Research and Development Authority (NYSERDA)
- Glass companies each giving cash and in-kind support
  - **Corning Incorporated**
  - **Johns Manville**
  - **Owens Corning**
  - **PPG Industries, Inc.**
  - **Schott North America**

Project Participants

- GTI
- Glass company consortium (5 glass companies)
- Fluent, Inc.
- A.C. Leadbetter and Son, Inc.
- Praxair, Inc.
- Consultants
  - **Leonard S. Pioro - SCM developer**
  - **Vladimir Olabin – Gas Institute, Ukraine**
  - **John Brown – glass technology and GMIC contact**
- GMIC - monitoring

Barriers, Pathway, Metrics, Benefits

Barriers

- Technical (meet industry needs)
- Financial (provide large cost savings)
- Organizational (affect change in melting practice)

Pathway

- Build and operate 1 ton/h pilot SCM
- Sample and analyze product glass
- Provide cold flow and CFD models
- Develop rapid conditioning stage
- Move to field demo with working SCM

Critical Metrics

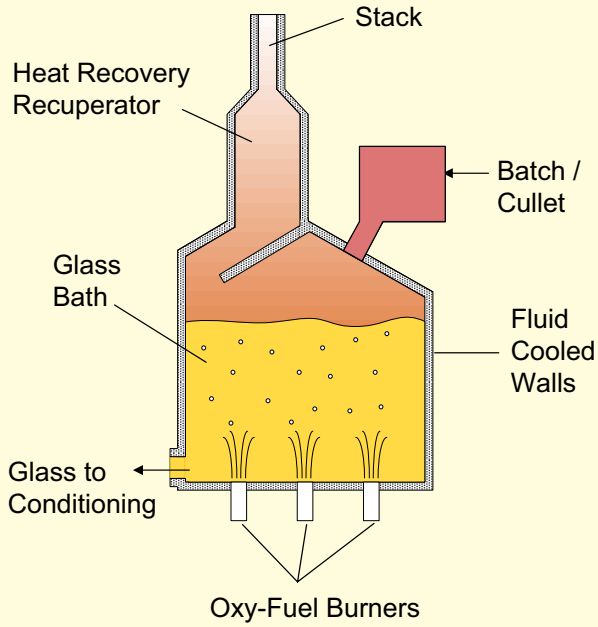
- Material / energy balances (with heat recovery)
- Glass quality analyses
- Working and validated CFD model

Benefit	
Energy Savings	18.1 TCF
Capital Savings	$94 million
Carbon Reduction	0.29 MMTCe
Refractory Reduction	80 %

Requirements for NGMS Melting Step

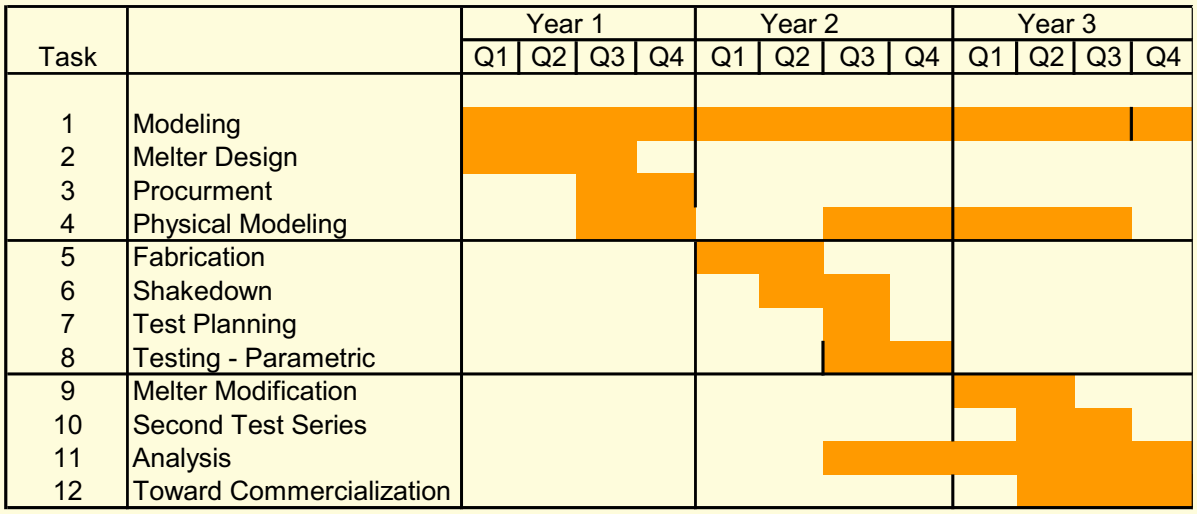
- Melt all glass compositions
- Scalable from 25 to 500+ tons/day
- Rapid melting (high heat transfer)
- Low capital cost (small size, minimal refractory)
- Long furnace life
- High thermal efficiency
- Homogeneous product (needed for rapid fining)
- Low emissions (CO, NO_x, particulates)
- Stable operation over wide range of pull rates
- Low volatilization of alkalis, borates, etc.
- Reliable, low-cost batch handling and charging
- Foam management
- Redox control
- Physically compatible with rapid fining step of NGMS

Submerged Combustion Melting

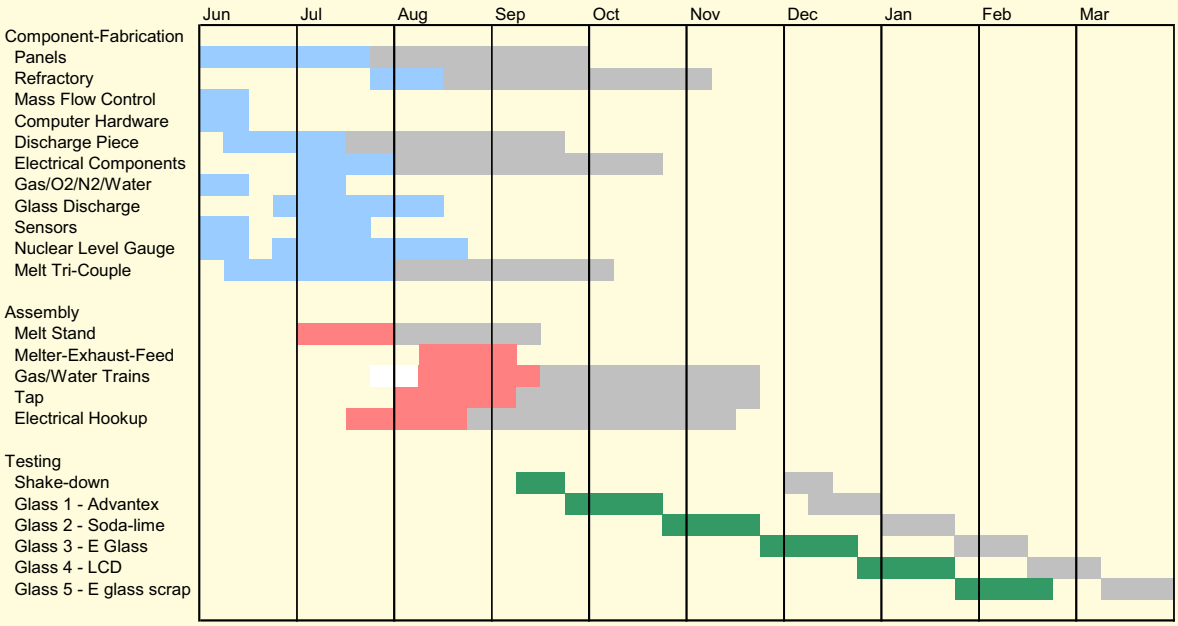


- Air-gas or oxy-gas
- Multiple feed positions
- Feed can have wide particle size range and be poorly blended
- Externally cooled walls
  - Corrosive melts possible
  - Very high temp. possible
- Reducing or oxidizing conditions
- Multiple discharges
  - Manual drain for rapid discharge
  - Heated Pt tap for glass
- Full melt flow < 4 h
- Interruptible melt flow
- Small volume allows flexibility in production

Original Project Schedule



Phase I NGMS Project Completion



NGMS Development Status

- 1 ton/h pilot SCM unit completion in Nov. 2006
- Shake-down of pilot SCM in Dec. 2006
- Testing (24-72 h. tests) in Dec. 2006 - March 2007
  - E glass – Owens Corning
  - Soda-lime glass – PPG
  - E glass (second composition) – Johns Manville
  - LCD glass – Corning
  - Scrap fiberglass
- Initiated project to develop and test rapid conditioning approaches – Sept. 2006
- First commercial license granted to IMM to make blast abrasives (plant in northwest Indiana)

FY 2006 Project Activities

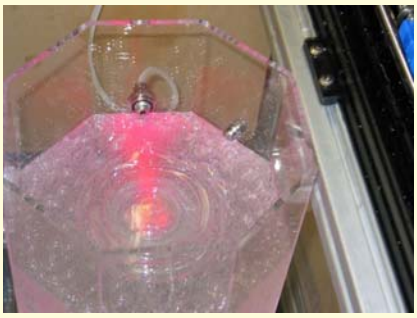
- Completion of lab-scale SCM tests
  - **Acquire data for pilot-scale SCM design**
  - **Evaluate product glass for needed conditioning**
- Pilot-scale melter
  - **Design**
  - **Fabrication**
- Working CFD Fluent model
  - **to assess parameter changes**
  - **to guide scale up decisions**
- **Preparations for pilot-scale SCM tests**
  - **Glass composition and batch selection**
  - **Test plan development**
  - **Next consortium meeting at GTI on Nov. 8, 2006**

Cold Flow Glycerin-dye Tests

Easier at Low-Temperature

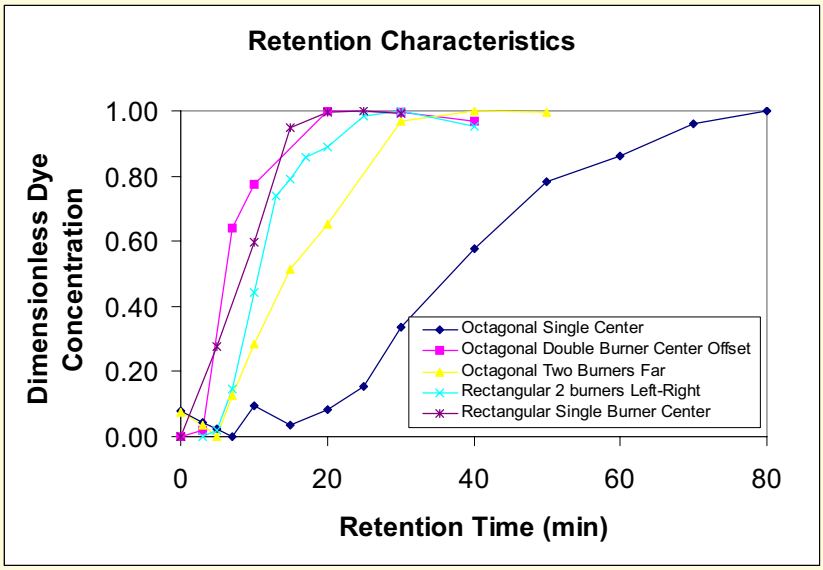
5 min.

- Easily change geometry
- Match melter through dimensionless groups
- Excellent visualization
- Flow patterns
- Number of burners
- Burner patterns
- Seeking
  - Excellent mixing
  - No feed bypassing



40 min.

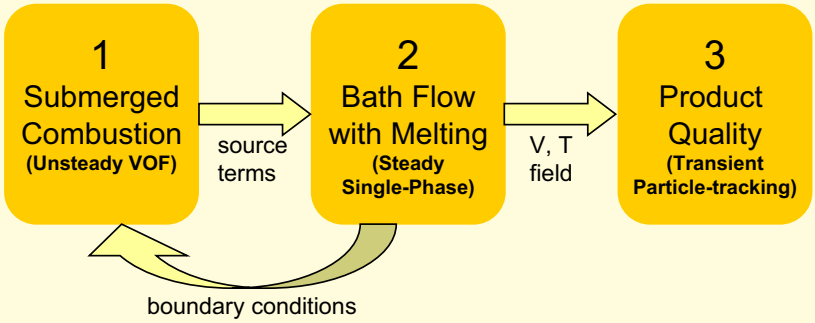
Long Retention Time → Smaller Melter & Complete Melting



- Burners create circulation patterns in the melt
- Symmetry improves retention time
- Burner positions strongly effect flow patterns
- Heat transfer, channeling not considered

CFD Methods

- Interface-resolving volume-of-fluid (VOF) method selected as best approach
  - Due to large submerged-combustion gas bubbles/jets
- Multi-stage analysis method to decouple disparate time scales
  - Flexible and computationally efficient



Advances in Modeling Technology

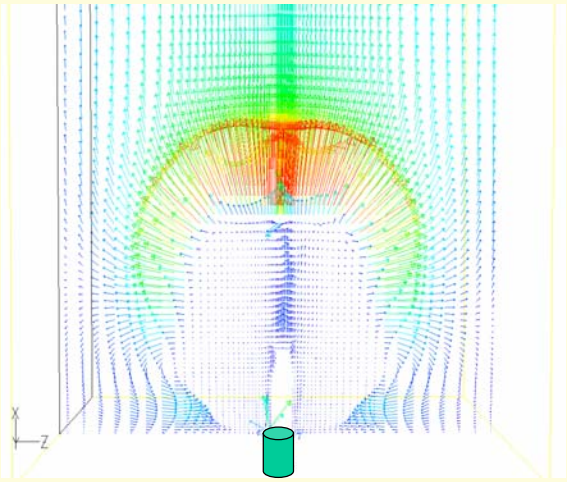
Project-Driven Enhancements to FLUENT:

- Faster time integration scheme for multiphase solver
- Radiation speedup for highly absorptive media
- VOF free-surface reconstruction method improvement for high-viscosity fluids

VOF reconstruction of a high-viscosity liquid surface in a channel:
left - FLUENT 6.2 (current release); right - FLUENT 6.3 (CICSAM method)

More Advances in Modeling Technology

- Adapted conventional-melter approach for glass batch melting (chemical species/reaction approach) for SCM conditions
- Calculation and transfer of momentum and thermal source-terms to support multi-stage approach

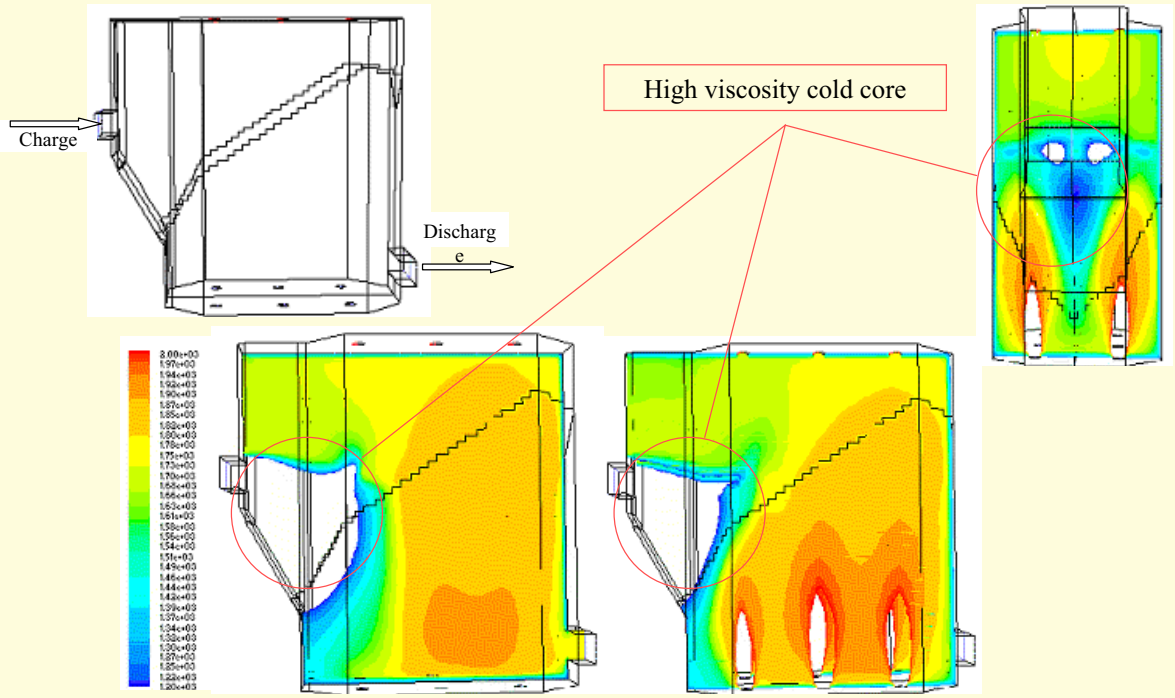


Instantaneous velocity field in near-burner region during submerged combustion bubble formation

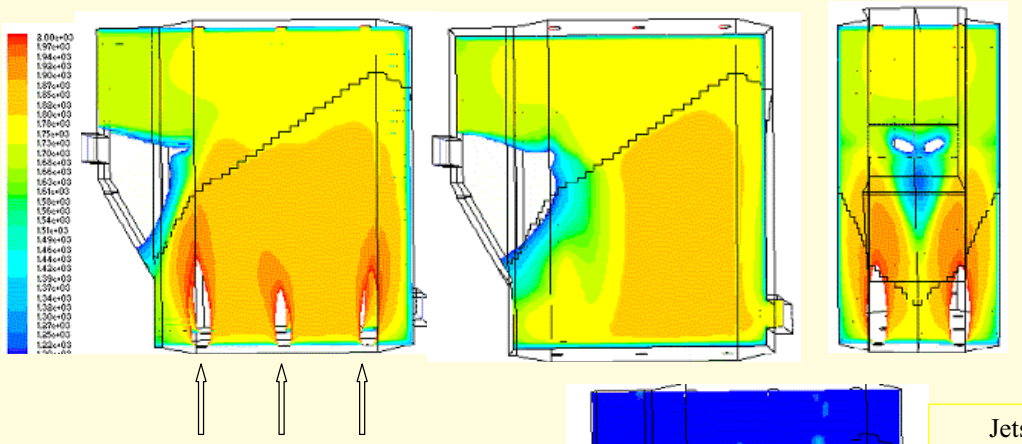
CFD Technology Transfer Plans

- FLUENT enhancements prototyped in this project are being "mainstreamed" into the commercially-released version
  - Most GMIC members already actively using FLUENT
- CFD documentation and training materials will be developed in 2007 to support the industry in further SCM process development
- Publications planned showcasing validation

Octagonal Pilot SCM shape and Burner Location Optimization

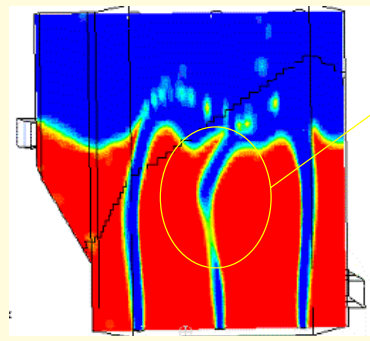


Firing Rate Distribution Optimization



Firing rates: 2 1 1.5 MMBtu/hr

45% 22% 33%

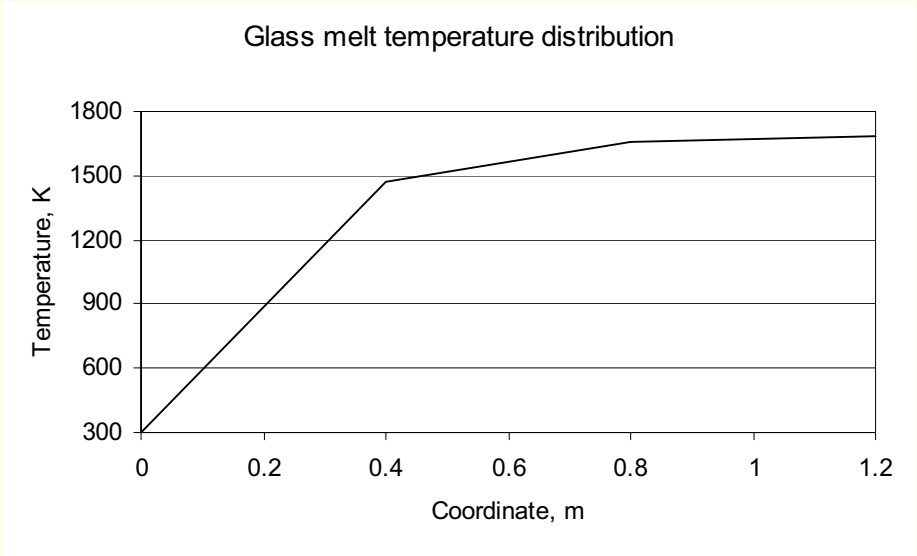


Volume fractions field (gas jets geometry)

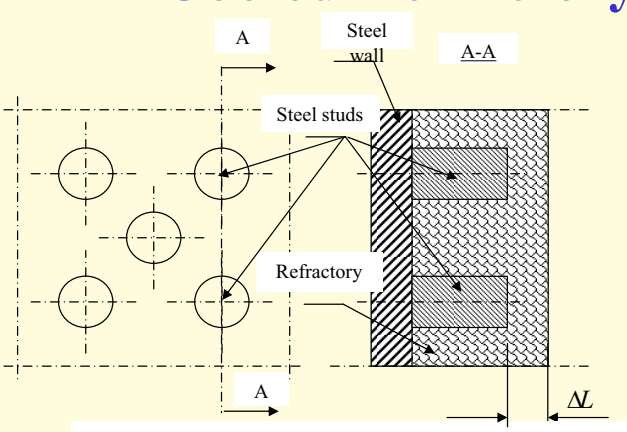
Thermal Efficiency, Heat Loss Optimization

1 ton/h Pilot SCM	1st Burner Row	2nd Burner Row	3rd Burner Row	Total 6 Burners
Each Burner, MMBtu/h	1.4	0.8	1	
% of Total Heat Input	44	25	31	32

Using optimal calculated firing pattern



Cooled Refractory Optimization



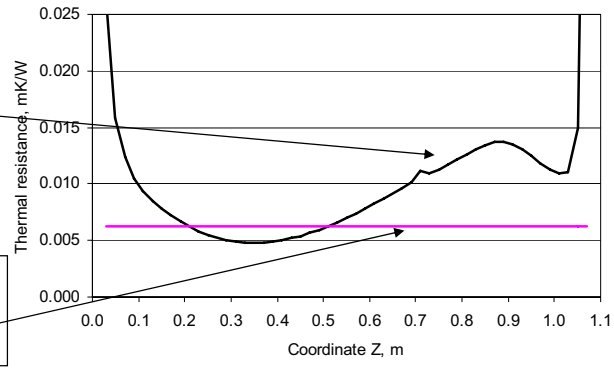
Schematic of cooled refractory

Parameters to optimize

1. overall refractory thickness
2. stud height.

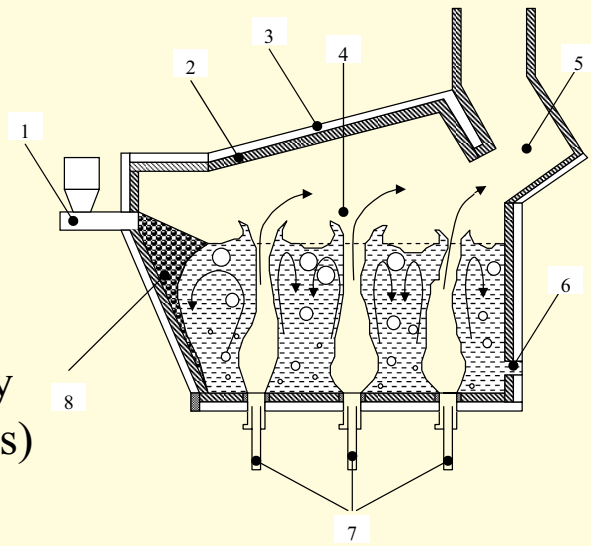
Maximum refractory equilibrium thermal resistance

Uniform refractory effective thermal resistance



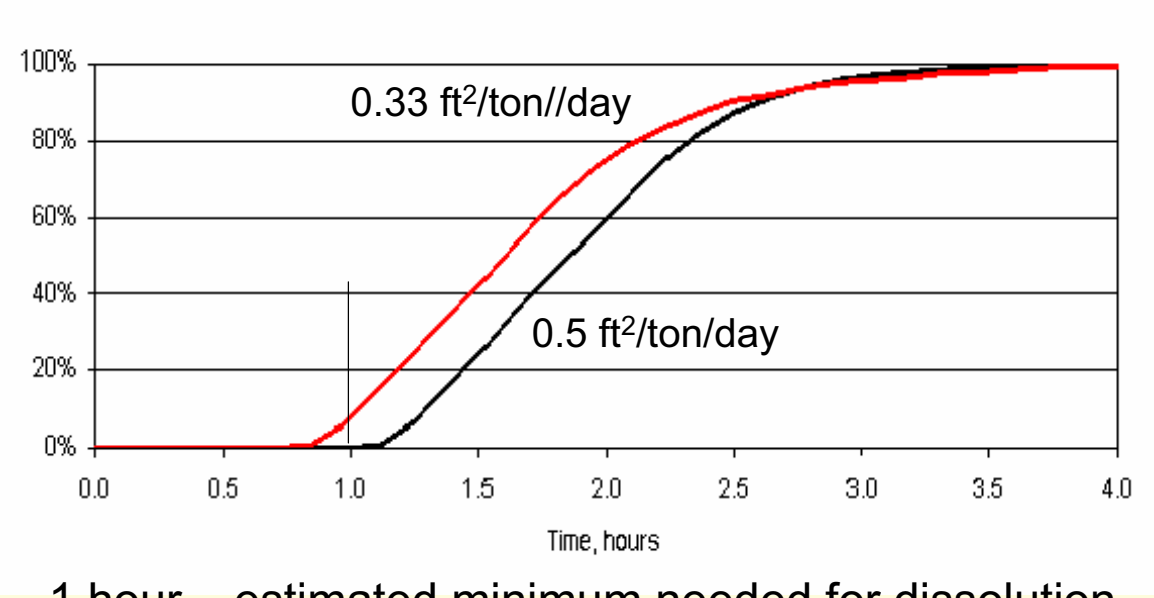
Main Pilot Melter Features Determined by CFD Modeling

- Octagonal cross section
- Sloped feed pocket
- Three rows of burners of two burners each
- Non-uniform firing rate distribution (approximately 45 – 25 –30% total by rows)
- Parameters of cooled refractory
- Estimated thermal efficiency



Schematic Sketch of Submerged Combustion Melter: 1 - Feeder, 2 – Refractory, 3 – Cooled panels, 4 – Melting bath, 5 – Separation zone, 6 – Melt removal tap, 7 – Submerged burners, 8 – Sloped feed pocket

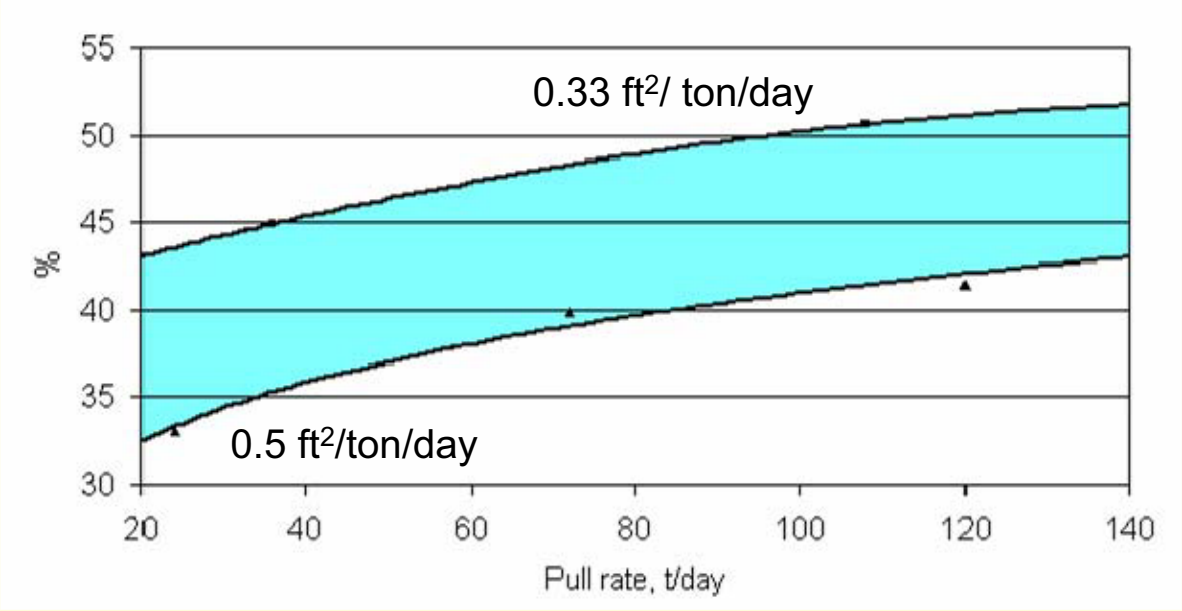
Calculated SCM Flow Element Residence Times



1 hour – estimated minimum needed for dissolution of typical E glass batch

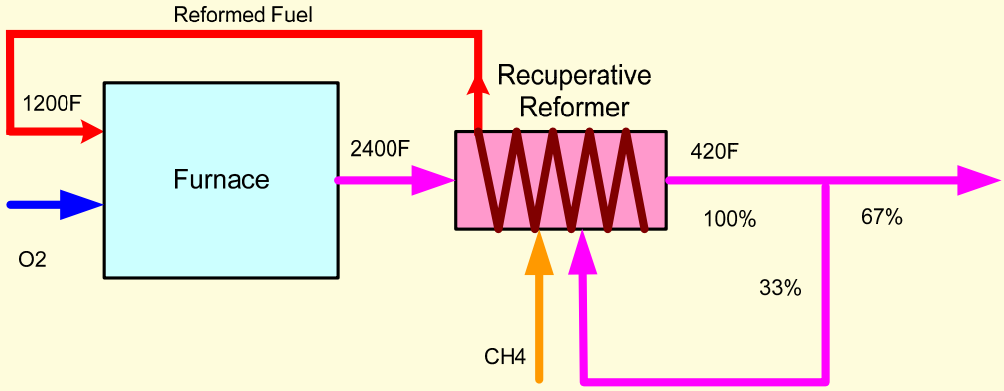
Calculated SCM Thermal Efficiency as Function of Pull Rates

E glass, 3 ft. depth, 1400 C (2550 F)



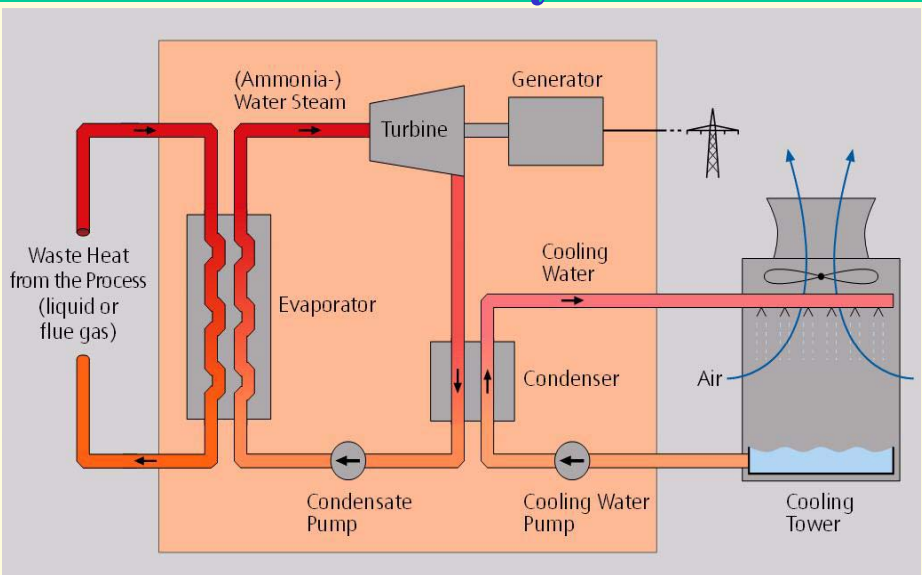
SCM With Thermo-chemical Recuperation

Lowers Fuel Per Ton by 15%



	Without TCR	With TCR
Exhaust Temp., F	2400	420
Useful Heat, %	33	39
Heat to Exhaust, %	27	13
Heat to Walls, %	40	48

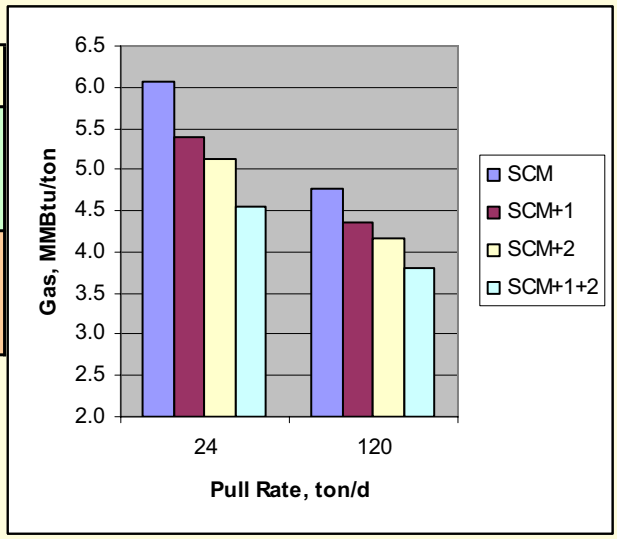
Working Principle of a Siemens Heat Recovery Plant



Improving SCM Efficiency

Sample Case – E Glass at 0.5 ft^2/ton/day

Pull Rate	System	Thermal Eff., %	Gas, MMBtu/ton	% Gas Saved
24 ton/d	SCM only	33.0	6.1	0.0
	SCM + 1	37.1	5.4	11.0
	SCM + 2	39.0	5.1	15.4
	SCM +1+2	43.8	4.6	24.7
120 ton/d	SCM only	50.0	4.0	0.0
	SCM + 1	53.4	3.7	6.3
	SCM + 2	56.0	3.6	10.7
	SCM +1+2	60.3	3.3	17.1



1- Siemens Waste Heat Recovery from wall coolant

2 – TCR from exhaust gas

Lab-Scale Melter Assembly (2005)

- Building annex
- Frames and catwalks
- Vacuum feed system
- Weight hoppers
- Calibrated screws
- Dilution air fans
- Exhaust gas baghouse
- Oxygen supply
- Burner controls
- Pt discharge pipe
- New burners

Red - Usable with pilot SCM

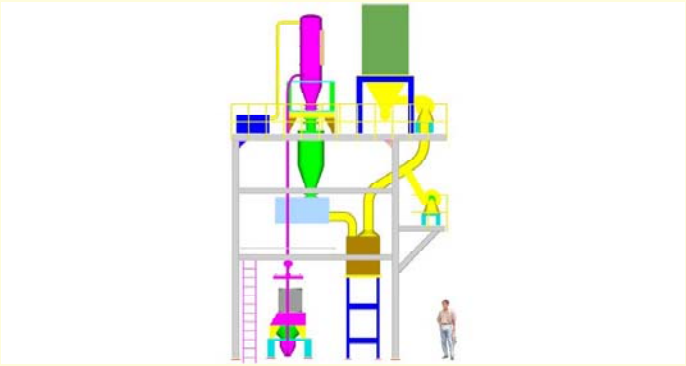
Lab-Scale SCM Tests

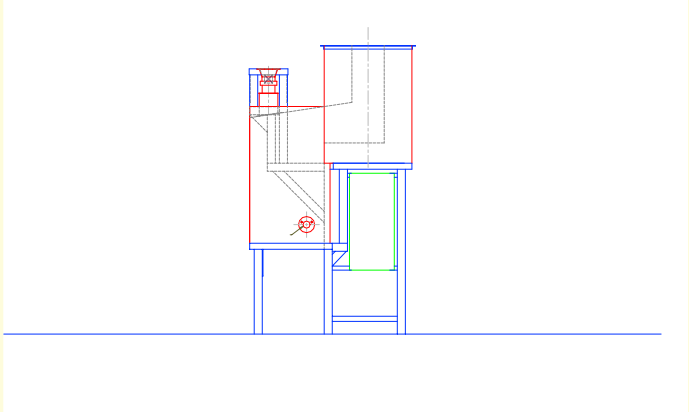
All tests in batch mode

- Soda-lime glass (CertainTeed batch)
  - Feb. 4, 2005
  - March 4, 2005
  - March 9, 2005
- LCD glass (Corning 1737 batch)
  - March 16, 2005
  - Sept. 7, 2005
- E glass (Johns Manville batch)
  - Oct. 18, 2005
- E glass (Johns Manville batch) and scrap
  - Oct. 6, 2005 (Owens Corning Advantex scrap)
  - Nov. 10, 2005 (Johns Manville wool insulation scrap)
- Soda-lime melts made to clean unit between tests

Lab-Scale SCM Melter

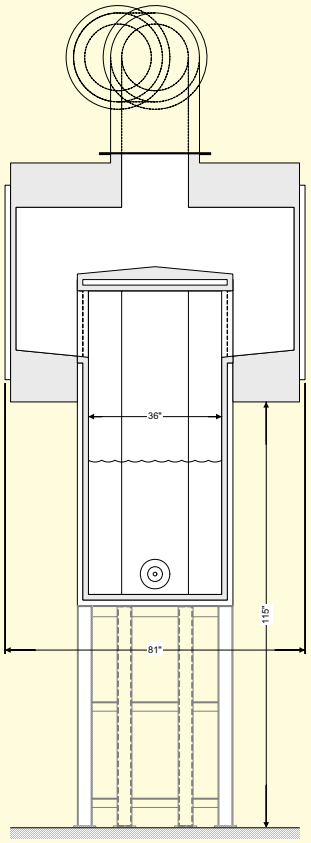
- Rectangular melt chamber
- 2 burners (up to 1.5 MMBtu/h each)
- Best for batch or semi-continuous operation
- Feed enters almost over a burner
- Limited instrumentation



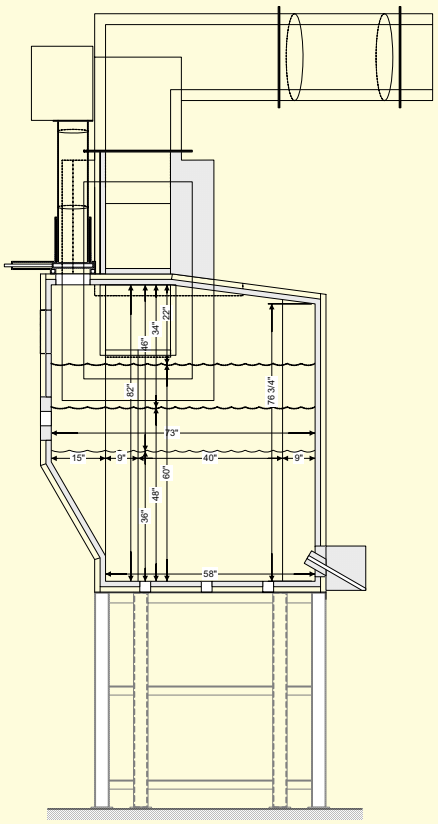


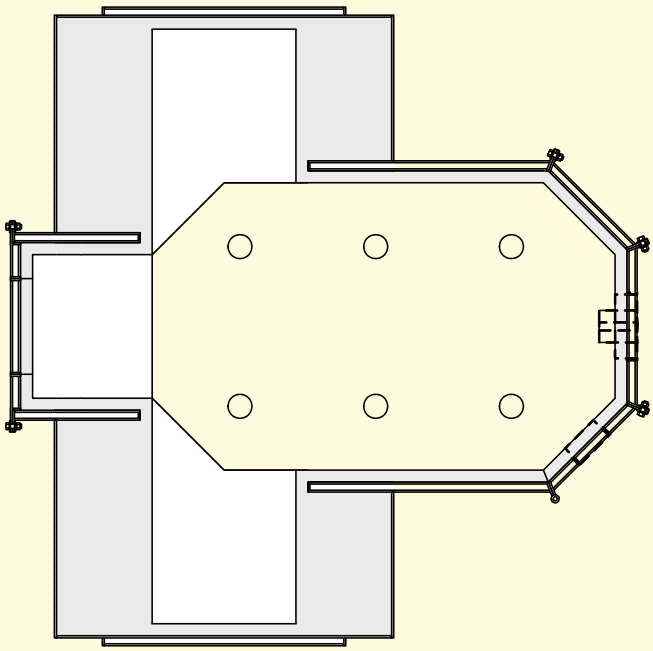
Pilot-Scale SCM

- Continuous feed and discharge
  - Larger capacity melter (0.5-1.0 ton/h)\
  - Demonstrated platinum discharge tap
- Most components are in place and tested
  - Melter, burners (6 x 1500 SCFH) needed
  - Added instrumentation into data acquisition
- Multiple burners spaced to create
  - Uniform temperature profile
  - Desired mixing / residence time distributions
  - Good mixing in corners and along walls
- Flexibility built into the unit
  - Changeable burner patterns
  - Two discharge locations
  - Provisions for two feed locations



Pilot-Scale SCM





1 ton/h SCM Chamber and Exhaust Panels

- 23 carbon steel panels with internal water channels
- 1.5 inch anchored castable refractory on all surfaces
- Feed, melt discharge, exhaust, instrument ports
- Replaceable floor panel to change burner pattern

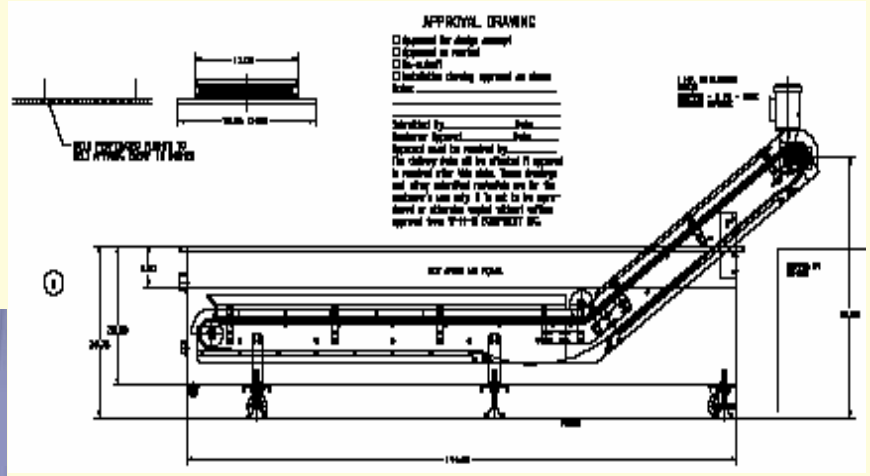
Burners and Controls

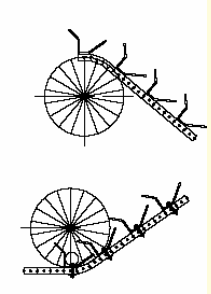
- 6 oxy-gas SCM burners
- Independently controlled at up to 1.5 MMBtu/h
- Burner tops zirconia coated for long life and to avoid metals contamination
- Mass flow meter control of oxygen and natural gas
- Automatic switch to nitrogen if flame or lost and during shutdown
- Independent exhaust gas oxygen measurement

Pilot Melter Instrumentation

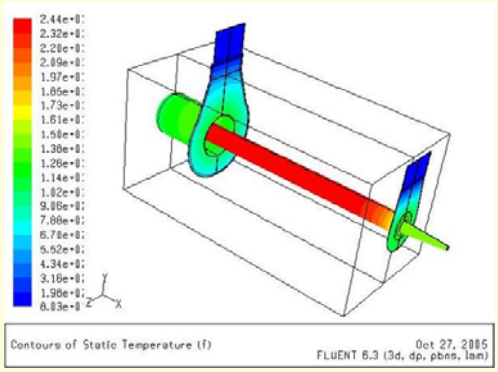
Gas and oxygen flow	Into all 6 burners
Gas and oxygen pressure	Into each burner
Water flow	Into each melter panel
Differential pressure	At melter flue exhaust
Melt temperature	Internal thermowell
Temperatures	Gas, oxygen, water, tap, exhaust gas, refractory
Nuclear level gauge	Average bed height
Digital cameras	Melt surface and tap
Voltage, amps	Tap transformer control
Weights	Batch feed rate

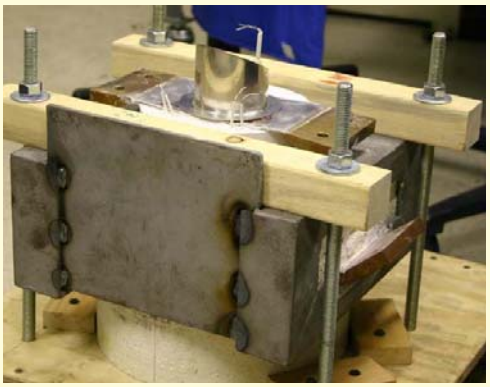
Melt Discharge





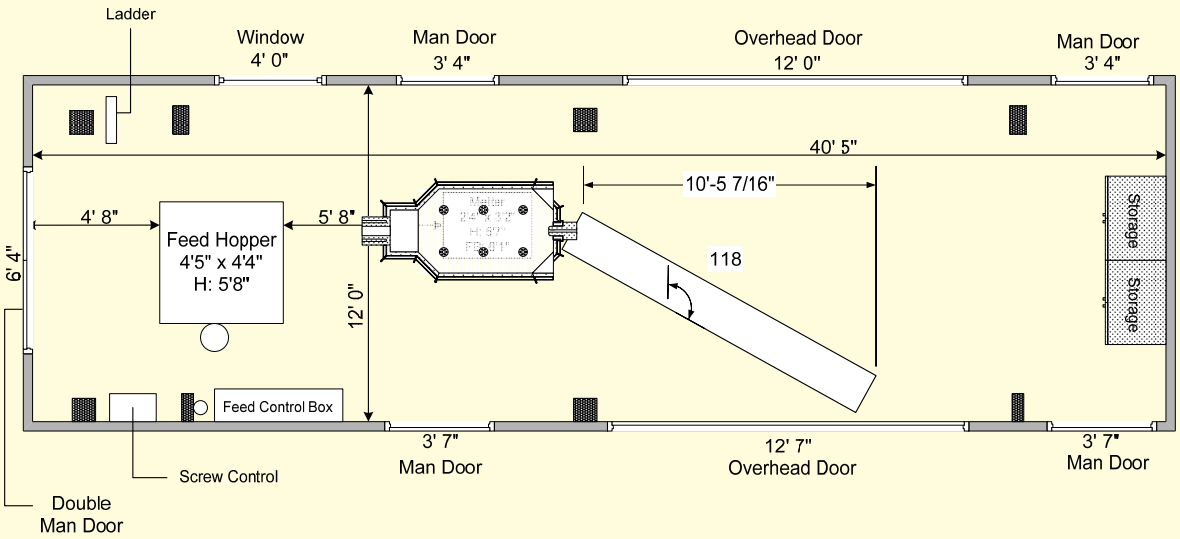
New Melt Tap for Pilot SCM





- Electrically heated Pt/Rh pipe
  - Continuous melt discharge
  - Helps control melt flow rate
  - Removes melt from inside wall boundary layer
- New design eliminates hot spots
- Strong consortium assistance
  - Designed by Carsten Weinhold of Schott N.A.
  - Electrical components supplied by Owens Corning
  - Fabricated by Corning Metal Shop

Pilot SCM Test Cell Layout



SCM Facility Components

All Pilot SCM components now tested

Component	SCM Version	Status
Calibrated vacuum feed system	Lab / Pilot	Fully Tested
Gas/O_2/N_2 control/safety trains	Lab/Pilot	Fully Tested
Exhaust gas system	Lab/Pilot	Fully Tested
Baghouse	Lab/Pilot	Fully Tested
Data acquisition system	Lab/Pilot	Installed – more sensors for Pilot SCM
Cooling Chiller	Pilot	Not needed
Tap Piece	Pilot	New tap built for Pilot SCM
Building and steel framing	Lab/Pilot	New frame built for Pilot SCM
Oxy/Gas burners	Lab/Pilot	New burners for Pilot SCM
Pilot SCM 0.5-1.0 ton/h	Pilot	Finishing refractory – Nov.10

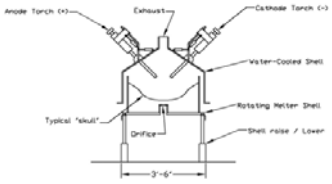
Phase II – NGMS Rapid Conditioning

- Objectives
  - Investigate most promising rapid conditioning approaches
  - Improved melter operations
  - Melt diagnostics (molten and cold glass)
- Rapid conditioning techniques
  - Ultrasonic refining
  - Short retention time
  - Steam refining
- Design 1-3 ton/h NGMS for scrap fiberglass recycle

Rapid Conditioning

- 2-year effort divided into 3 Tasks
  - Test and analysis preparation
  - Testing in pilot SCM focusing testing and glass analysis wtih improved melter operations and ultrasonic conditioning
  - Design of 1-3 ton/h fiberglass recycle NGMS
- Testing with E glass in the pilot-scale SCM
- Funding from DOE, NYSERDA, gas industry
- Partners include GTI, Owens Corning, Johns Manville, potentially PPG and Schott

High-Intensity Plasma Glass-Melting



DOE Project Summary

GMIC WORKSHOP
Glass Problems Conf—Columbus, OH
Nov. 2, 2006

PLASMELT GLASS TECHNOLOGIES, LLC
Boulder, Colorado, USA

Ron Gonterman & Mike Weinstein

ACKNOWLEDGMENTS

- Thanks
  - US Dept of Energy for financial support & Elliott Levine for moral support
  - Johns Manville and AGY—Our Partners
  - Sub-contractors
    - Jim Hayward
    - Dr. Oleg Prokhorenko
    - Integrex Analytical Labs
    - Zybek Advanced Products, Inc.
    - Tooley Design Services
    - West Monarch Analytical Labs
    - Dr. Scott Parker

Agenda for Talk

I. Summary Results of DOE Project
II. The Melting Platform
III. Applications
IV. Next Phase for Plasmelt

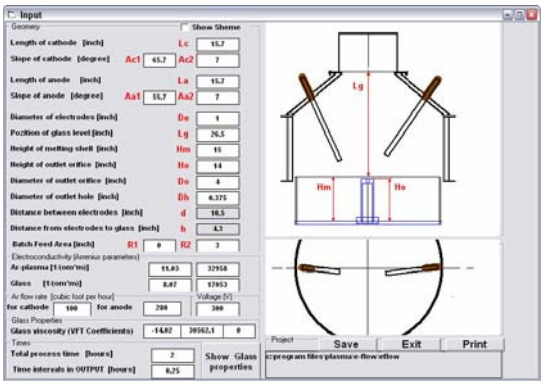
Summary Results
Demonstrated During DOE Project

- **Highly-Flexible Low-Cost Furnace Design**
- **Generic Design** Capable of melting **many different glass compositions**
- World's first **glass fibers** from plasma-melted glass
- **Torch designs** with significant life improvements and low cost
- **Furnace throughputs** up to 350 #/hr
- **Un-optimized energy efficiency** from ~1 kwh/# (~6.8 MM BTU/Ton)
- **Processes developed** for routinely melting various glasses
- **Scrap re-melt** process

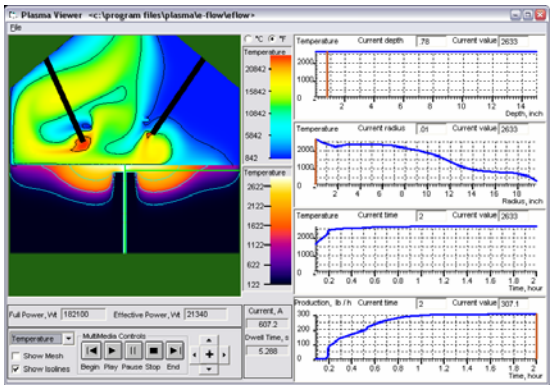
*Strongly dependent on glass composition

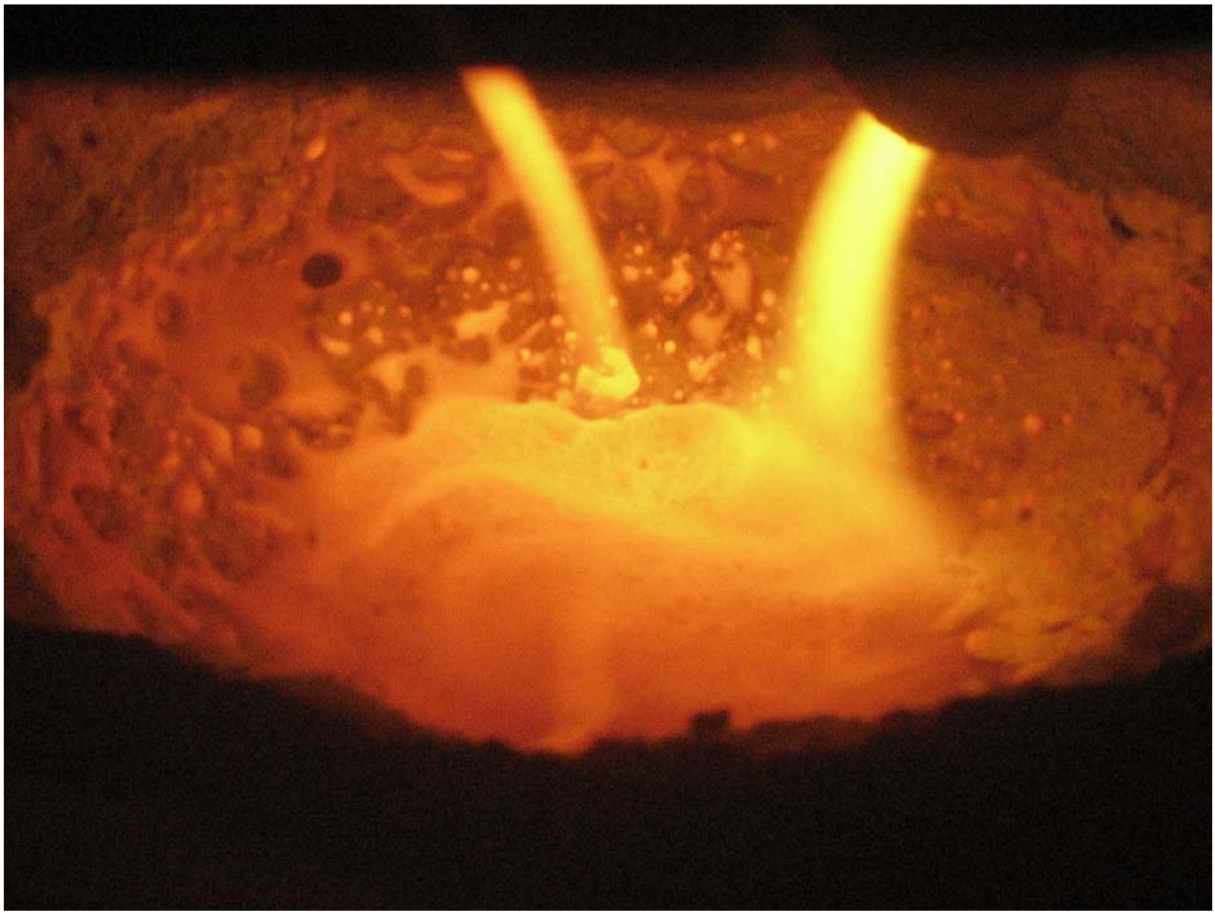
RESULTS: 2D Plasma Model

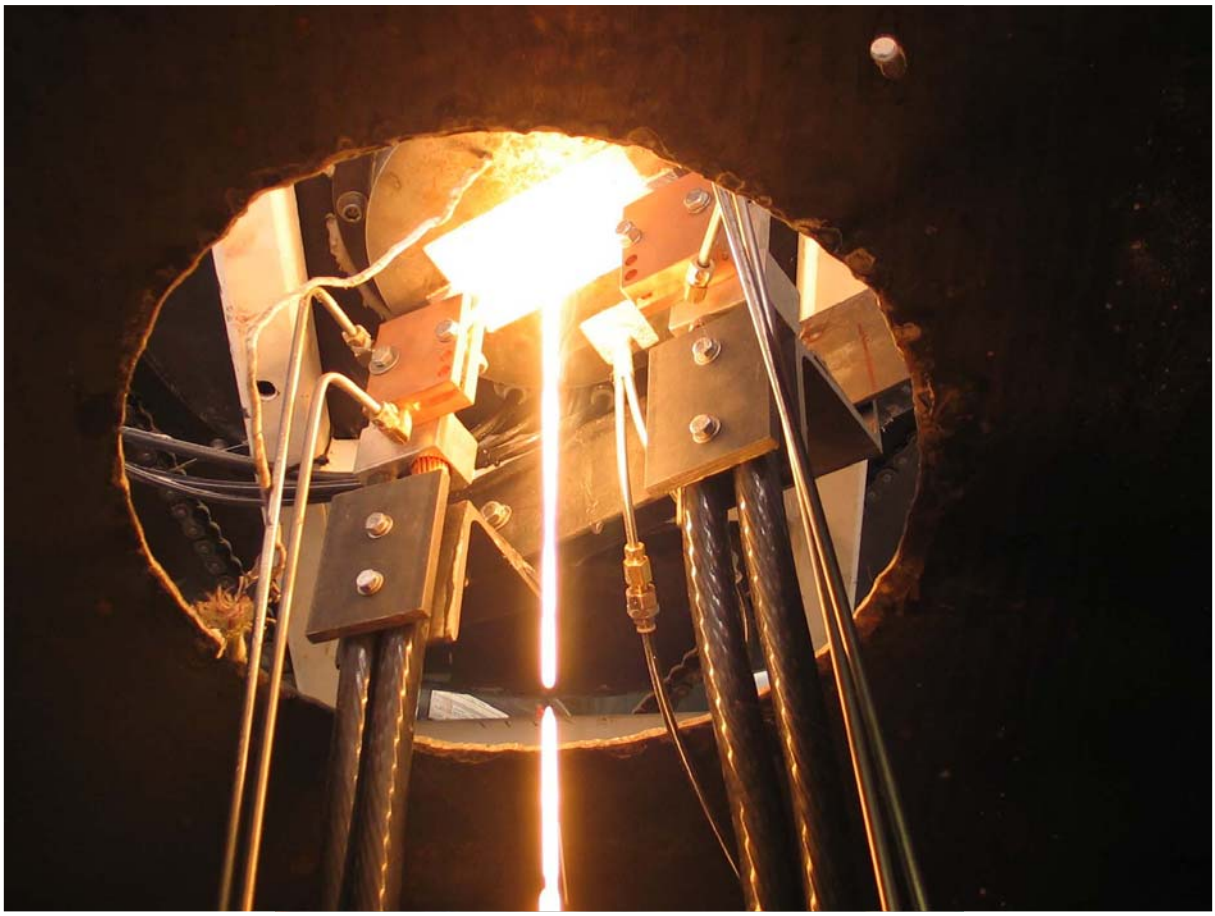
Input Screen



Output Screen







Plasma Melting Platform

- Glass on Demand
- Small-footprint rapid High-Intensity Melter
- High Energy Density
- DC Transferred Arc Electrodes
- Robotic-controlled Torches
- Rotating Skull Melter
- Customized Melting Process for each Composition

PLATFORM
Plasma Melting Glass-on-Demand

- High-temperature melting capability
- Modular design
- Low capital cost
- No glass contact refractory or electrodes
- *Yields fully melted and partially-refined glass*

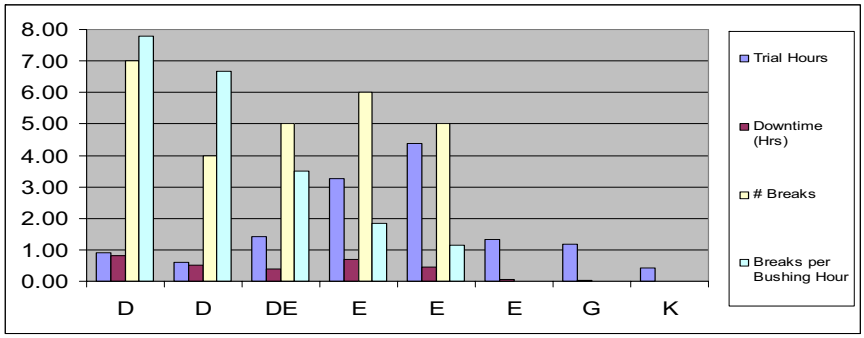
RESULTS: Plasma Melter

- **Glasses Melted**
  - E Glass – with and without boron
  - AR Glass -- Alkali Resistant for concrete reinforcement
  - S - T - R Glass Family – High strength fiberglass
  - Frit Glass – High: boron - fluorine - alkali
  - Lighting Tube Glass
  - Scrap Fiber E-Glass
  - C-Glass – Acid Resistant
  - High Boron Low Dielectric Glass
- **Minerals Melted**
  - Wollastonite
  - Feldspars
  - Alumino-silicate compositions ~ kaolinite
  - Zircon
  - Enstatite
  - Cordierite

RESULTS: Fiberizable Glass Quality

- Trials of fine filaments at AGY's Huntingdon, PA facility
  - Marble re-melt process
  - Using plasma-produced glass "marbles"

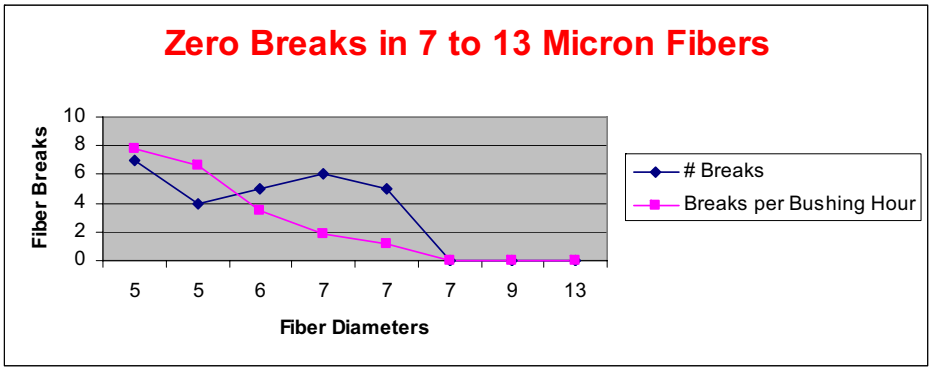
RESULTS: AGY Fiberizing Trial Data



Filament Diameter (microns)	Trial Hours	Downtime (Hrs)	# Breaks	Breaks per Bushing Hour
D (5)	0.90	0.82	7	7.78
D (5)	0.60	0.52	4	6.67
DE (6)	1.43	0.38	5	3.49
E (7)	3.25	0.70	6	1.85
E (7)	4.38	0.45	5	1.14
E (7)	1.32	0.07	0	0.00
G (9)	1.18	0.03	0	0.00
K (13)	0.43	0.00	0	0.00

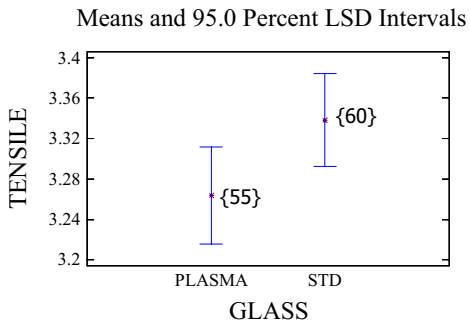
Zero breaks were demonstrated on fibers diameters of 7 to 13 µm.

RESULTS: AGY Fiberizing Trial Data



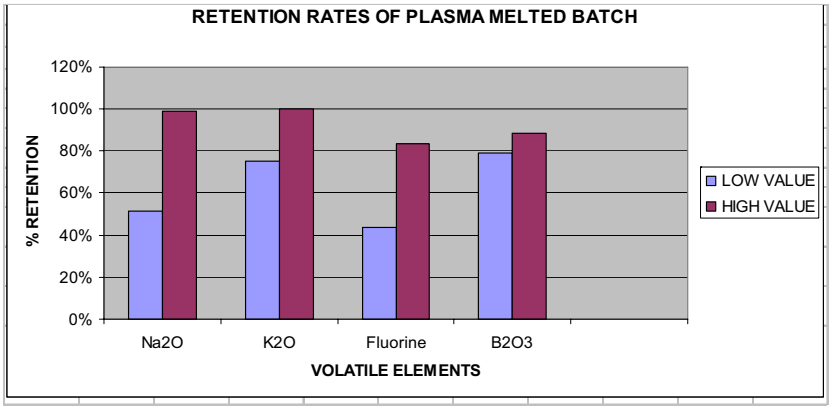
RESULTS: Glass Quality

- Fiber Quality



CONCLUSION: No statistically significant difference in the plasma-melted and standard glass.

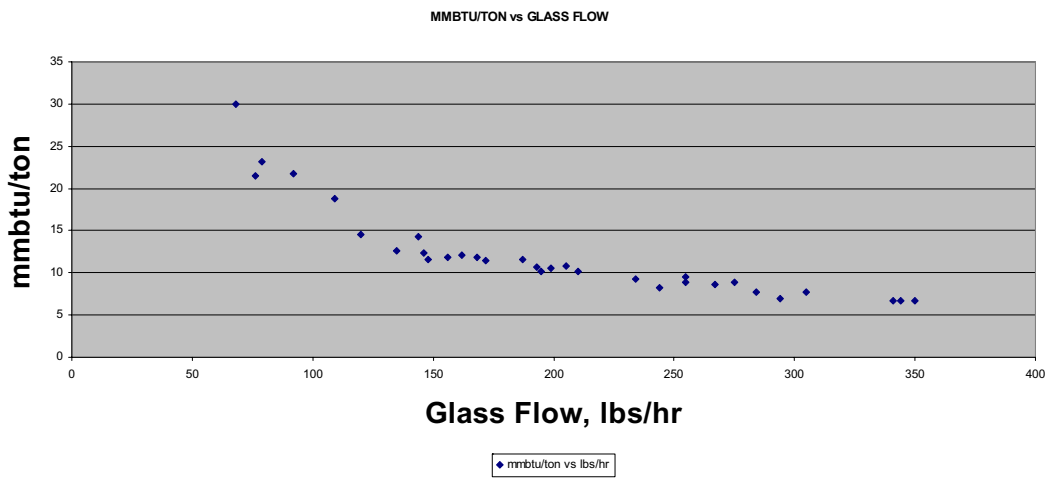
RESULTS: Influence of Plasma Melting Process on Retention of Volatiles



CONCLUSION: Volatilization can be controlled through process setup.

RESULTS: Plasma Melting

- Energy Efficiency – E Glass



Best-Fit Applications

- Fiberglass (both continuous and insulation)
- Specialty glasses
  - e.g. S-glass, frit glass, etc.
  - New, test market products
- Minerals melting that cannot be done otherwise
- Low volume operations
- Unpredictable production operational schedules
- Multiple glass compositions in one factory
- Melter boost for commercial melters
- Scrap re-melt
- Low capital cost operations

Next Phase of Plasmelt

1. Industrial Melter Contract with AGY
2. R&D Contract for Process Development
   - Demonstrate ultimate throughput
   - Demonstrate minimal seed levels
   - Demonstrate robotically controlled automated furnace process
   - Demonstrate module suitable for incremental capacity on commercial melter
3. Applications development for melting mineral, ceramic fiber, frits, refractories, and glasses
4. Solicit commercial problems to solve via plasma technology platform

CONCLUSIONS

- Plasmelt has run a low-overhead, cost-efficient, rapid development cycle time program for DOE.
  - We have demonstrated RESULTS from our efforts.
  - We are now THE LEADERS in plasma melting of glass.
- We have demonstrated
  - 15 minute startups
  - E glass quality that can fiberize
  - Flexible system that melts E glass, scrap, and many other glasses and materials
  - Capability of melting high temperature materials
  - Dramatic torch life improvements
  - Controlled process stability
  - Low capital platform
- Plasmelt is now soliciting glass melting problems to solve!

Argonne NATIONAL LABORATORY

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U.S. Department of Energy

UChicago Argonne LLC

Office of Science

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

Glass Furnace Model (GFM) Version 4

Steven A. Lottes

GFM 4.0: A New, Extensively Enhanced Upgrade of GFM 2

- GFM 4.0 includes major upgrades to all of the software components of GFM including:
  - installation procedure
  - user interface
  - combustion computation
  - radiation computation
  - melt computation
  - coupling between the components
  - automated cycling procedure
  - automated soot model calibration procedure
  - progress monitoring program & progress data gathering

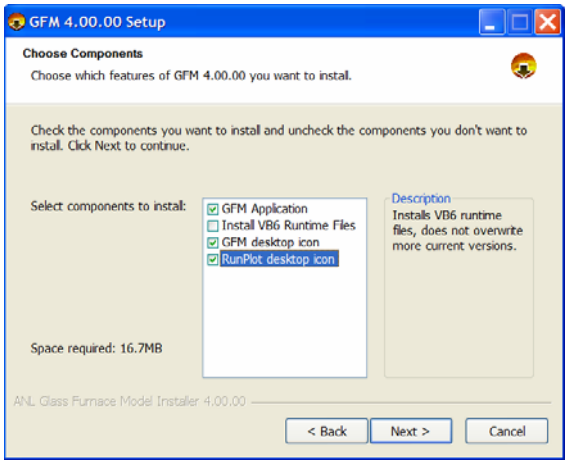
GFM 4 Incorporates a Large Number of Improvements in the Models, Algorithms, and Features

Code	March 2005	End June 2006	Growth
Combustion	10956	21728	10772
Melt	11103	16565	5462
GUI	8905	17203	8298
Installer		608	608
RunPlot		303	303
Totals	30964	56407	25443

Modern Installer Written for GFM

New install uses a standard installer with option to install VB runtime files.

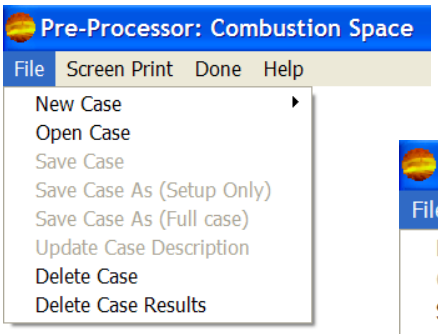
Provides start menu item, desktop icon, populated directory structure, uninstall program, etc.



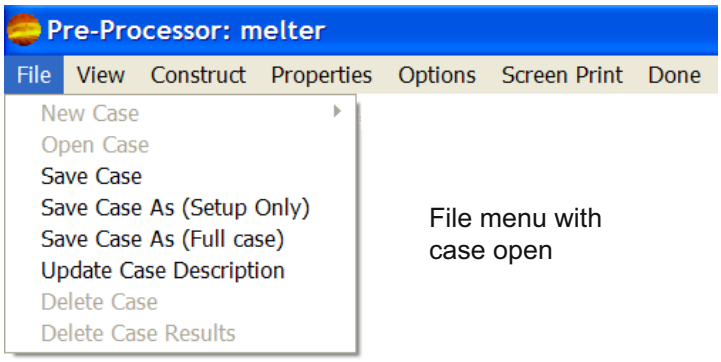
Old install procedure was manual and did not provide VB runtime files needed on some systems.

Simplified User Interface with Automated File Handling

- Much easier furnace definition, simulation setup, and control
- Simulations are now set up as cases, and the user no longer needs any knowledge about file types or file contents for furnace geometry and operating parameter definition.

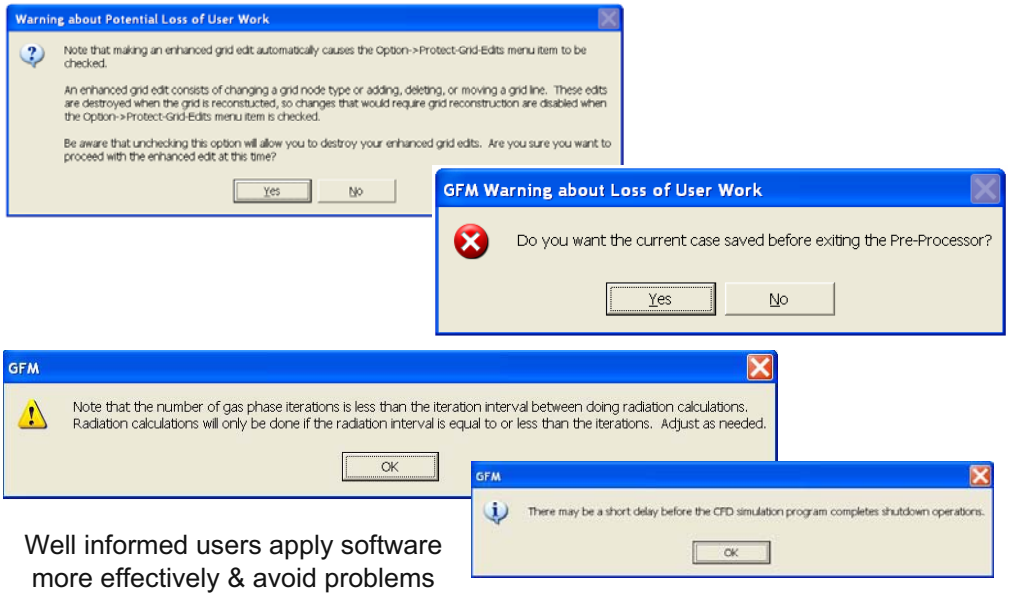


File menu with no case open



File menu with case open

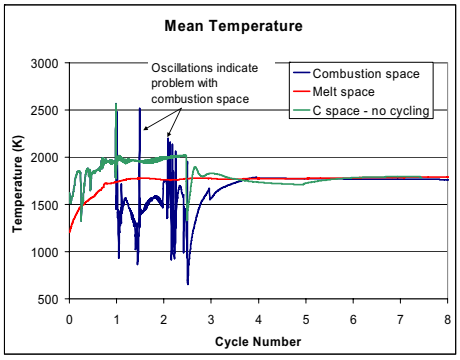
Warning Messages Improve Usability by Helping the User Avoid Mistakes



Well informed users apply software more effectively & avoid problems that cost time.

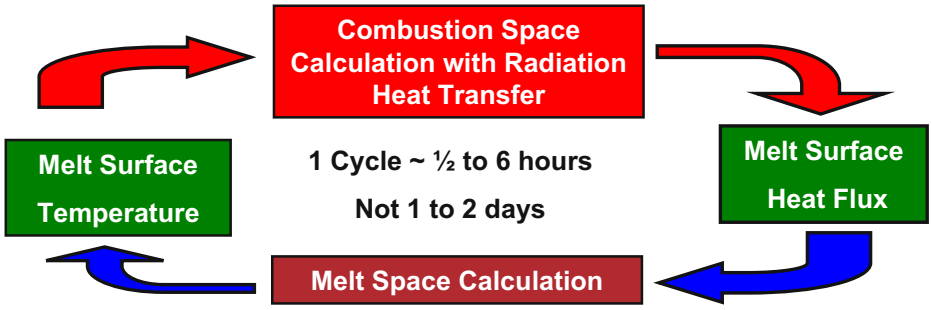
RunPlot: New Status Monitoring Program

- Plots convergence measures, average temperatures, and global heat distribution on screen during the course of a simulation
- Makes it easy to see how a simulation is progressing and when temperatures and heat transfer rates have stabilized indicating that the simulation is done
- Makes it easy to spot problems in a simulation and take steps to correct them
- Added legend and right click display options menu

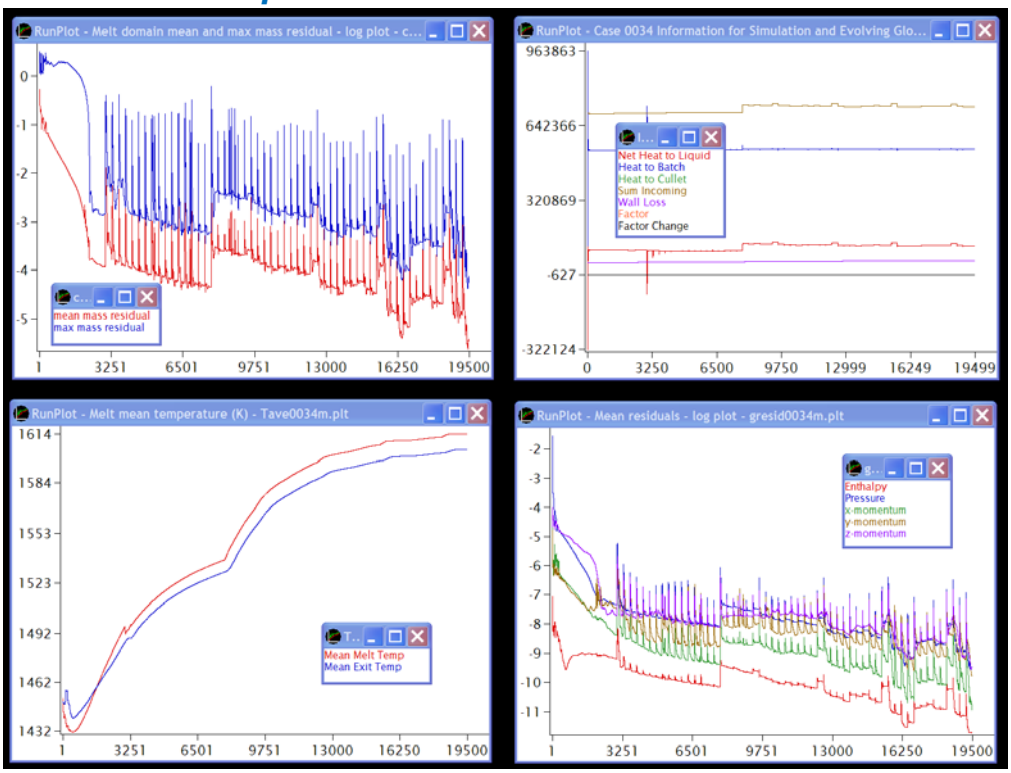


Major New Capability: Automatic Cycling Between Spaces

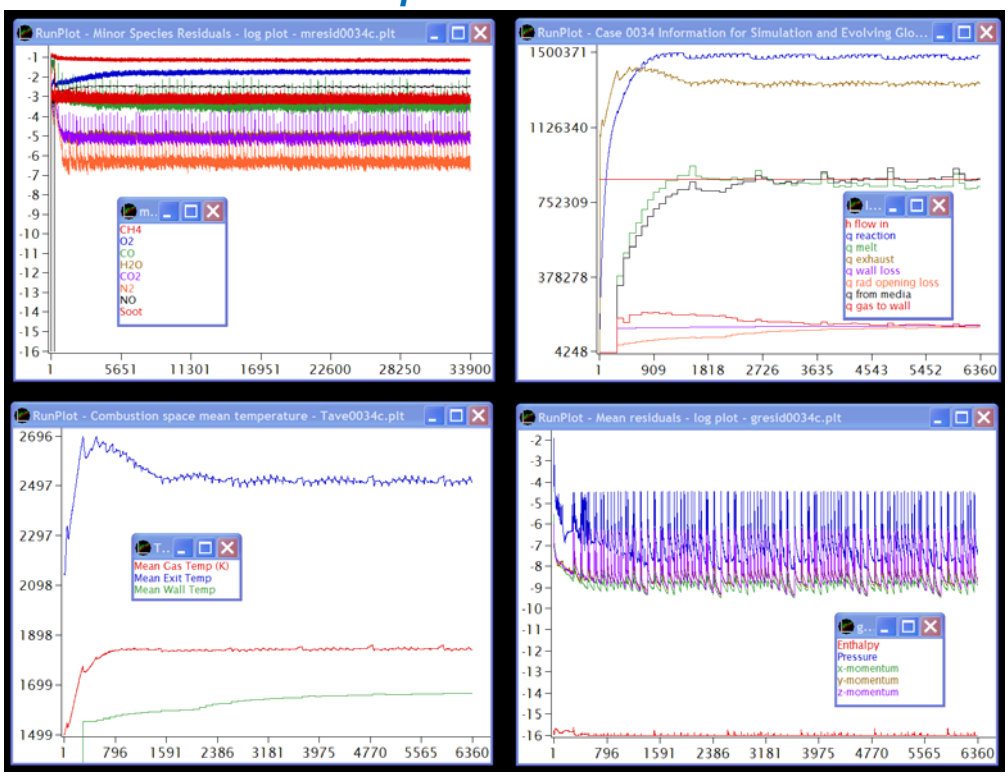
- Automatic cycling between combustion and melt spaces for both plain and regenerative furnaces
- 20 or more cycles are needed – very difficult to do manually
- Auto cycling reduces time for simulation from *~2 weeks to ~2 days*
- Auto cycling tightly couples combustion and melt spaces
  - *Radiation heat flux is cycled into the melt computation as soon as it is computed*



Melt Domain Sample RunPlots



Combustion Domain Sample RunPlots

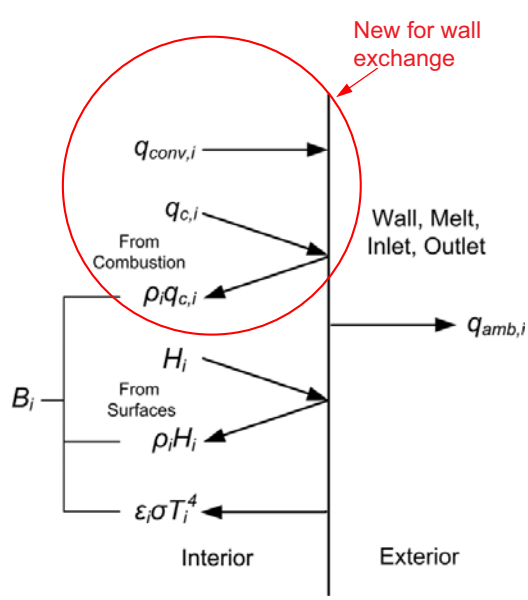


Melt Surface Boundary Condition Relaxation Scheme Applied During Cycling

- Applied to the coupling conditions between the melt and combustion spaces to damp numerical instabilities in cycling the computation between the combustion and melt

New Hybrid Radiation Computation Splits into Participating Media Volume Computation and Wall Exchange Computation

- Greatly improves the accuracy of the wall temperature computation
- Works well for furnaces
  - Emission >> Absorption
  - Solving RTE for walls is very expensive & accumulates discretion error in the volume
  - Walls treated as opaque and gray
- Volume participating media radiation solve yields:
  - incident radiation on walls direct from volume
  - local gas energy sink from radiation
- Wall exchange solve yields:
  - Very fast solve near machine precision
  - Radiation to melt surface from walls



Automated Soot Model Calibration Procedure

- In air-fuel furnaces soot is a dominate radiating species
- GFM uses a simple soot model
- The automated calibration procedure finds the soot formation pre-exponential constant, A_{sf}, that matches a "known" set of furnace operating conditions
  - *Fuel & air flow*
  - *Batch flow & material properties*
  - *Furnace geometry*
- Values for other soot kinetic parameters are needed, but heat transfer to the melt is much less sensitive to these
- The calibrated soot formation kinetic constant implicitly accounts for other model uncertainties or un-modeled phenomenon
  - *air infiltration, for example*

$$\frac{\partial}{\partial x_i}\left(\rho u_i Y_s - \Gamma_s \frac{\partial Y_s}{\partial x_i}\right) = S_{sf} - S_{so}$$

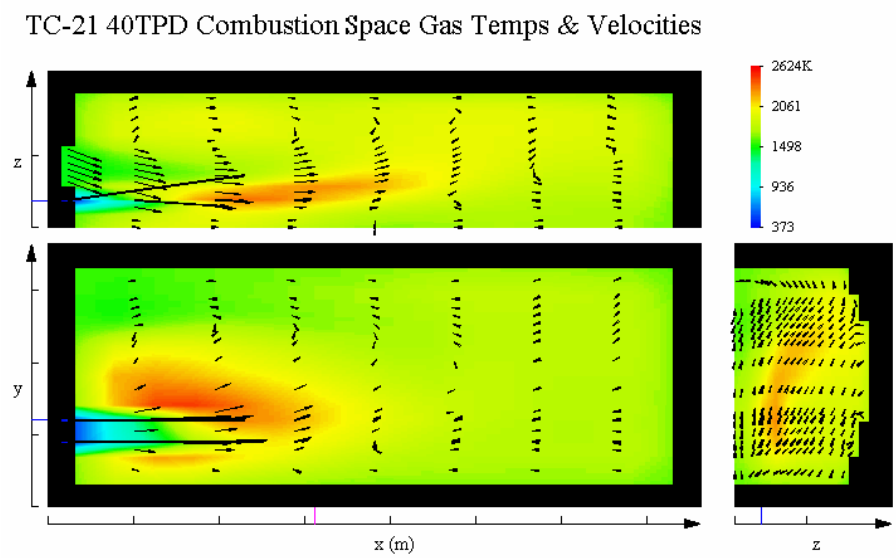
$$S_{sf} = A_{sf} Y_f \exp\left(\frac{-E_{sf}}{RT}\right)$$

$$S_{so} = A_{so} Y_s Y_o \mathrm{T}^{1/2} \exp\left(\frac{-E_{so}}{RT}\right)$$

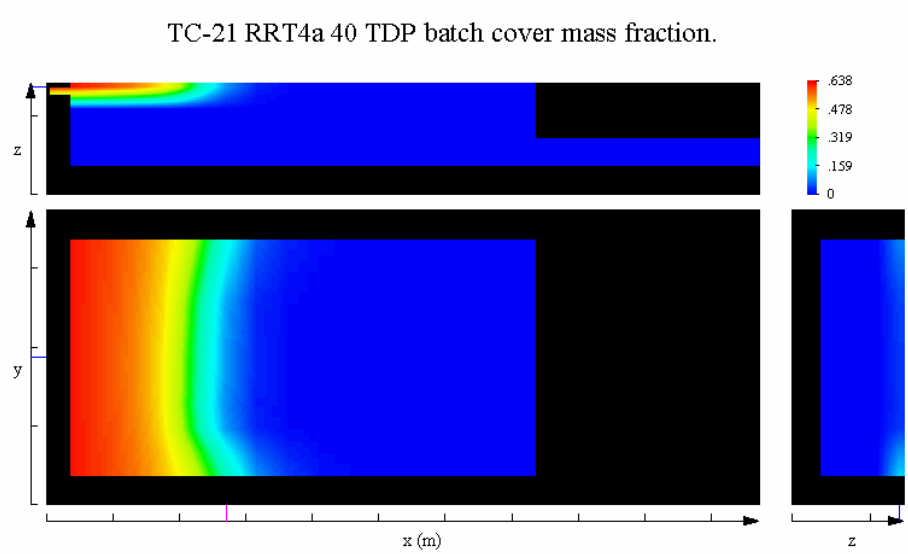
NIST Thermodynamic Property Relations

- GFM 2 used a table lookup with linear interpolation to calculate gas mixture temperature from enthalpy (accurate to 1 to 2 digits)
- GFM 4 uses NIST rational functions for the enthalpy and specific heat of gas mixture species in the combustion space
  - Mixture temperature is computed using a Newton iteration that converges to machine precision (~15 digits) in 3 to 4 iterations.
  - The temperature dependence of specific heat is very accurately represented

TC21 Problem Test Results – 40 TPD

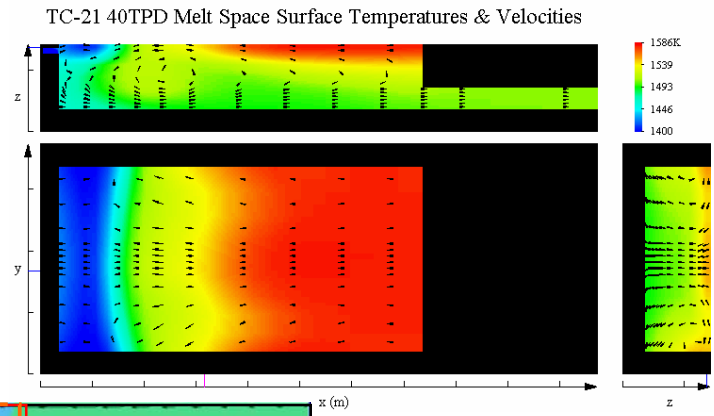


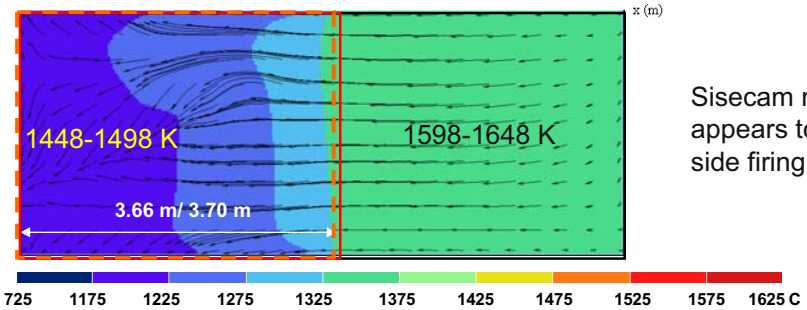
TC-21 Problem Results



Sisecam 40 TPD Surface T Compared to GFM

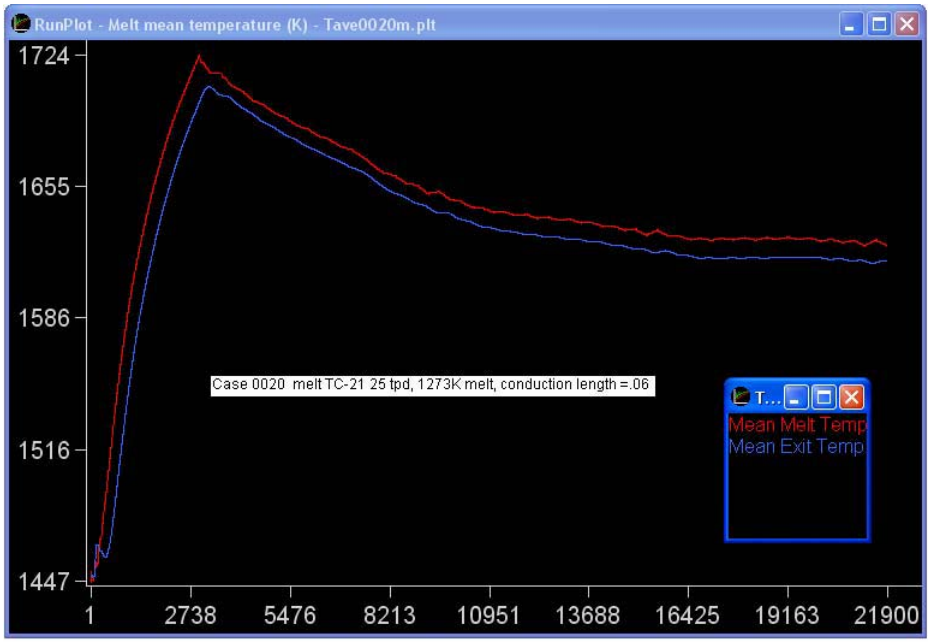
GFM averages heat fluxes from both firing patterns



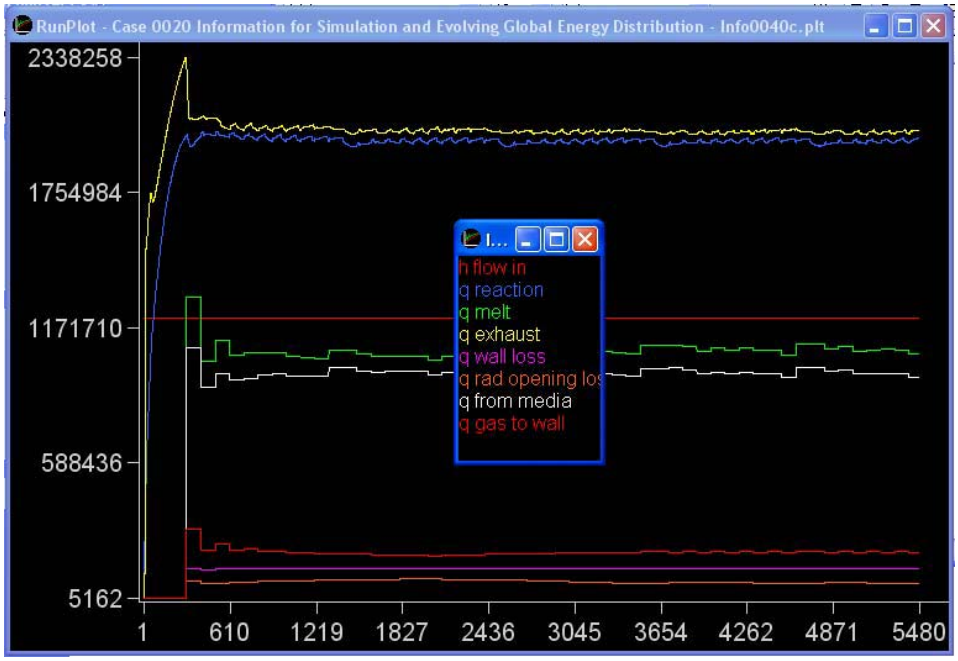


Sisecam result appears to be from one side firing

TC21 40 TPD Test Problem Results



TC21 40 TPD Test Problem Results



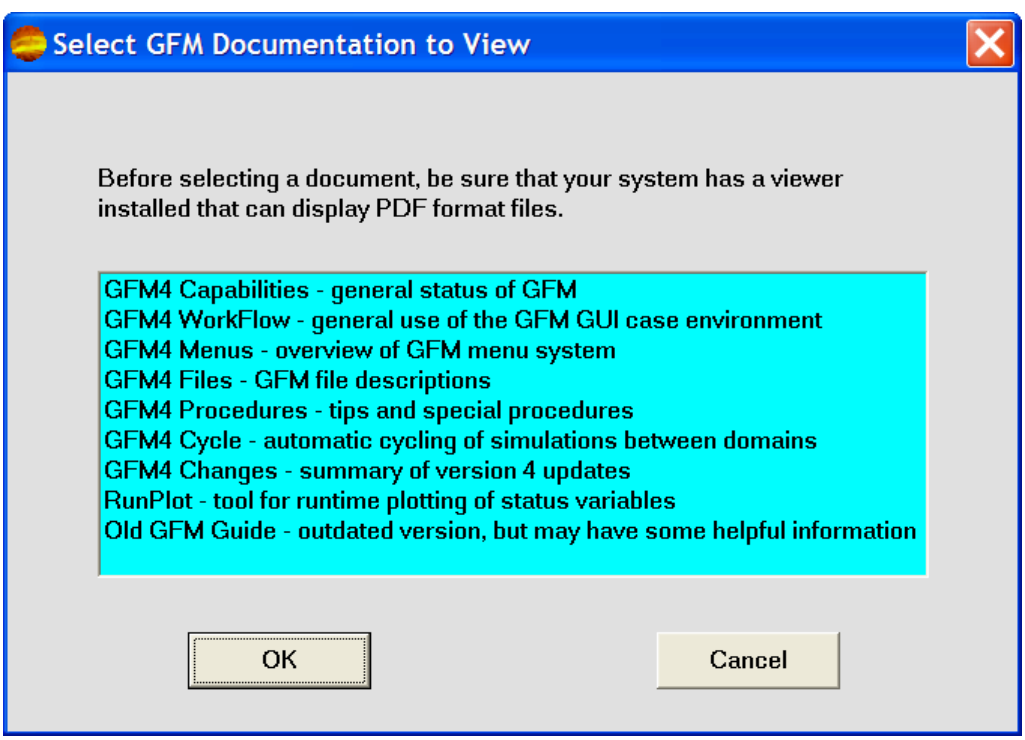
Melt Simulation Summary File (end of file)

```
#  Heat Values at Run End:

#   Radiation+Conv In:          0.72310070675753E+06 W
#   Electric Boost:             0.00000000000000E+00 W
#   Total Energy In:            0.72310070675753E+06 W

#   Batch heatup need:          0.31557353363728E+06 W
#   Batch melt need:            0.21704995672704E+06 W
#   Radiation to Batch:         0.40875249975480E+06 W
#   Conduction to Batch:        0.13073238958088E+06 W
#   Batch q needed:             0.53262349036432E+06 W
#   Batch q net:                0.53948488933568E+06 W

#   Liquid heatup need:         0.10910377824812E+06 W
#   Liquid q net:               0.12491679579722E+06 W
#   Adiabatic energy need:      0.64172726861244E+06 W
#   Wall heat loss:             0.58699021624631E+05 W
#   Net melt input energy need: 0.70042629023707E+06 W
#   Actual melt input energy:   0.72310070675753E+06 W

#   Energy need divided by input:  0.96864279579793E+00

#   Mean glass exit temperature:  0.16043246365875E+04 K
#   Batch rate in:              0.28939994230272E+00 kg/s
#   Melt rate:                  0.28939994841019E+00 kg/s
#   Glass rate out:             0.28939289006983E+00 kg/s
```

Combustion Simulation Summary File (end of file)

```
# Energy Balance on Exterior Walls      #  Total energy in:                 0.23542154827173E+07 W
# --------------------------------      #     Energy in with flow:         0.86689066296079E+06 W
                                        #     Energy in via combustion:    0.14873248197565E+07 W

                                        #  Total energy leaving furnace:   0.24384136429239E+07 W
                                        #     Energy out with flow:        0.13444618452387E+07 W
                                        #     Energy out through walls:    0.13476300555161E+06 W
                                        #     Net radiation out inlets:    0.68791297934034E+05 W
                                        #     Net radiation out outlets:   0.59097976779291E+05 W
                                        #     Energy out to melt:          0.83129951742032E+06 W
                                        #        from flame:               0.37280814443948E+05 W
                                        #        from surfaces:            0.79077172312054E+06 W
                                        #        from convection:          0.32469798558295E+04 W

# Gas Energy Balance                    #  Total energy in:                 0.23542154827173E+07 W
# --------------------------------      #     Energy in with flow:         0.86689066296079E+06 W
                                        #     Energy in via combustion:    0.14873248197565E+07 W

                                        #  Energy out with or from the gas  0.23743534266882E+07 W
                                        #     Energy out with flow          0.13444618452387E+07 W
                                        #     Convection to walls           0.14064222849204E+06 W
                                        #     Convection to melt surface    0.32469798558295E+04 W
                                        #     Radiation from flame to melt:  0.26962612327861E+06 W
                                        #     Radiation from flame to walls: 0.59740753496978E+06 W
                                        #     Radiation from flame to inlets: 0.91601634251864E+04 W
                                        #     Radiation from flame to exits: 0.98085514280762E+04 W

# --------------------------------      #  Mass in:                         0.56760373880222E+00 kg/s
                                        #  Mass out:                        0.56765171155295E+00 kg/s
                                        #  Fuel mass out:                   0.22823902801114E-03 kg/s
                                        #  Fuel energy out:                 0.11411951400557E+05 W

                                        #  Mean temperature:                0.18400522709873E+04 K
                                        #  Mean exit temperature:           0.25105402473905E+04 K
                                        #  Mean wall temperature:           0.16643211649184E+04 K
```


New User Documentation



Summary & Future Plans

- GFM 4 is a major new derivative of GFM
- Copyright for GFM 4.0 will be asserted as part of the GFM series.
- A six month trial license and installation package for GFM 4.0 will be sent to all previous trial license holders.
- A trial license will be provided to the Glass Manufacturing Industry Council (GMIC) with notification that trial licenses for GFM 4.0 are available to all GMIC members.
- A developer to continue work on GFM will be sought. Good candidates appear to be universities where student projects and thesis work could yield improvements in algorithms and new models that could be added to Argonne's version.
- GFM 4.0 will be offered for licensing on Argonne's software shop web site; a lower license fee is under consideration.
- Argonne will provide technical support as needed on a cost recovery basis.

U.S. Department of Energy
Energy Efficiency and Renewable Energy

industrial technologies program

DOE ITP Glass Program Accomplishments and Legacy:

Serving as a Catalyst for Positive Change within the Glass Industry

Elliott Levine

U.S. Department of Energy

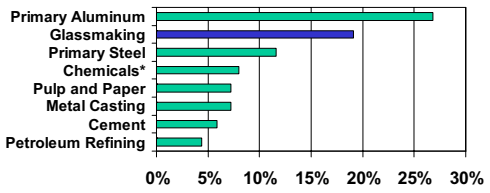
November 2, 2006

U.S. Department of Energy
Energy Efficiency and Renewable Energy

Why Focus on Glass?

High Energy Intensity

Purchased Energy for Heat and Power: Estimated Share of Direct Production Costs, 2001



Increasing Share of Energy Costs

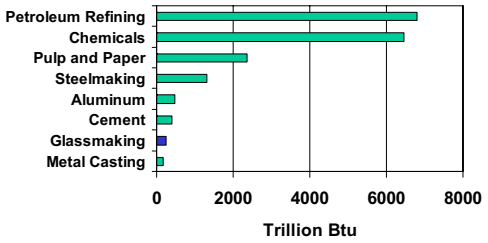
1994: 12.4% 2004: 17.9%

Preferred Method of Operation

Maximize collaboration in major energy consuming areas with broad applicability

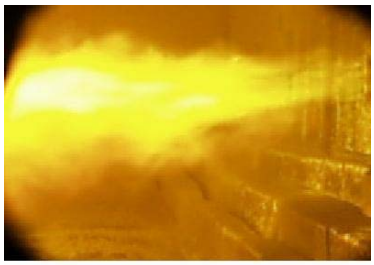
But Lower Total Consumption

Energy Consumption, 2002



Snapshot of the Glass IOF Program

- Projects
  - ~35 cost-shared core projects
  - ~35-40 GPLUS projects
  - ~10 SBIR/I&I projects
- Partners – 98 total
  - 36 glass industry
  - 28 industry vendors
  - 10 national labs
  - 13 academic
  - 11 other
- Funding
  - ~35% cost-share
- Awards
  - 2 R&D 100 Awards
- 4 commercial technologies
- >15 patents



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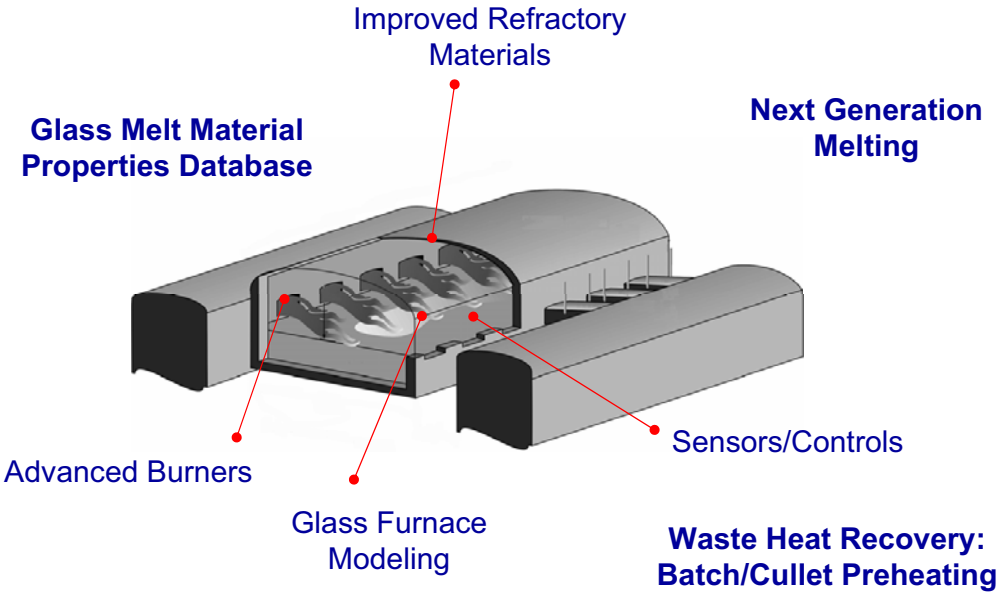
Focus on Glass Furnace Opportunities



Categories of Glass Successes

Commercial Technologies
- Oxy-Fuel Firing
- Oxygen-Enriched Air Staging
- Advanced Temperature Measurement System
- High-Luminosity, Low-NOx Burner

Knowledge/Best Practices
- CGR Glass Melt Properties Database
- Oxy-Fuel Protocol
- Distance Learning
- GPLUS

R&D 100 Awards
- Oxygen-Enriched Air Staging
- ANL Glass Furnace Model

Partnership/Collaboration
- GMIC Formation and Allied Partnership
- Next Generation Melting
- Stakeholder Engagement Forum

Analysis
- Energy and Environmental Profile
- Technical and Economic Assessment of Glass Melting
- Bandwidth study

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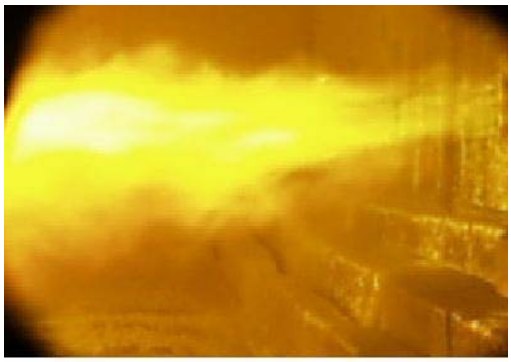
Glass Commercial Successes

- **Oxy-Fuel Firing for Glass Furnaces**
  - Commercialized in 1990
  - Increases production rates by 10-15%
  - Reduces NOx by up to 90%
  - Over 100 commercial installations in the U.S.
  - Cumulative savings of 40 TBtu through 2003

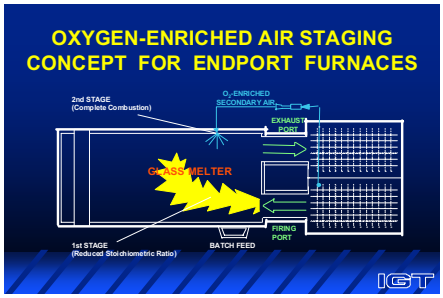
Segment	# of Oxy-Fuel Furnaces	Total # of Furnaces	Percent Oxy-Fuel
Textile Fiberglass	31	68	46%
Pressed and Blown	27	79	34%
Container	24	126	19%
Wool Fiber	12	43	28%
TV Glass	9	12	75%
Lighting	8	21	38%
Flat	2	40	5%

- **High-Luminosity, Low-NOx Burner**
  - Full-scale commercial field testing completed in two glass industry sectors
  - Impact – NOx and thermal efficiency/energy reduction
  - Commercially available, estimated savings of 0.1 TBtu/year and growing

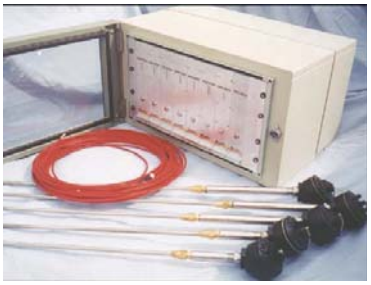


Glass Commercial Successes (Continued)

- **Oxygen-Enriched Air Staging**
  - Commercialized in 1996
  - R&D 100 Award winner
  - Demonstrated NOx reductions of 35-70%, minor improvement in energy efficiency or productivity
  - Over 15 commercial installations, estimated 0.5 TBtu cumulative savings



- **Advanced Temperature Measurement System**
  - Commercialized in 1999
  - Self-validating temperature sensor
  - Reduces rejected product, thereby increasing yield (estimated potential 1 Tbtu cumulative savings)
  - Over 40 commercial units in operation



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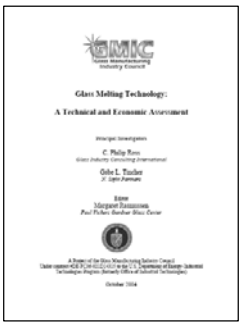
Glass Emerging Technologies

- Next Generation Melting
  - Submerged combustion melting (waste glass melt plant announced)
  - High intensity plasma melting (continuing glass testing)
- Energy Efficiency
  - ANL Glass Furnace Model (user validation)
  - Oxy-fuel front end system (in-plant demonstration)
  - On-line coatings for float glass (in-plant demonstration)
- Advanced Processing/Environmental
  - LIBS glass feedstock measurement/control system (in-plant demonstration)
  - Fiber drawing yield improvement (successful pilot-scale testing)

Analysis

- Energy and Environmental Profile
  - Energy consumption by process, overview of processes
- Technical and Economic Assessment of Melting Technology
  - Insights on previous efforts for advanced melting technologies
- Energy Bandwidth Study
  - Assessment of potential energy savings from implementing state of the art technology and potential technology improvements



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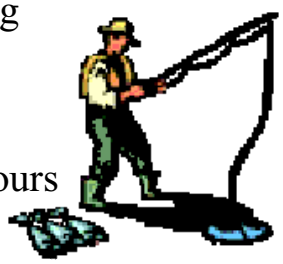
Distance Learning

- Newly developed course on energy saving opportunities in the glassmaking process
  - Developed by the Center for Glass Research in cooperation with ORNL, A. Thekdi, and D. Wishnick
  - Contains:
    - An introduction to energy concerns in glassmaking
    - An overview of glassmaking processes and associated thermal fundamentals
    - Energy savings opportunities and heat recovery
    - An introduction to on-line tools and other resources that can help save energy in glassmaking
  - Pilot class conducted on July 25-27, 2006
  - Assessing future plans: Spring 2007

Partnership and Collaboration

- Assisted GMIC formation and establishment as significant contributor for glass industry interests
- Collaboration
  - Brought together developers, end-users, and customers
  - Encouraged multi-glass company collaboration: led to consortium for submerged combustion melting
- Review meetings
  - Held annually to review project performance
  - Normally held at national labs and included tours
- Stakeholder tool
  - Opportunity to provide input on topics of interest



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Sample Partners and Participants

- Glass Manufacturers (36)
  - CertainTeed, Corning, Gallo, Johns Manville, Owens Corning, PPG Industries, Saint-Gobain
- Suppliers and vendors (28)
  - A.C. Leadbetter & Sons, BOC Gases, Eclipse, Fluent, Gas Technology Institute, Praxair, RHI Refractories
- Academia (13)
  - Alfred U., Cleveland State U., Mississippi State U., Purdue U.,
- National labs (10)
  - Argonne, Oak Ridge, Pacific Northwest, Sandia
- Other (11)
  - Glass Industry Consulting, GMIC, NYSERDA

EVERYONE HAS A ROLE TO PLAY IN DEPLOYMENT!

Glass Archiving Purpose: Provide a Legacy

- Provide summary documentation of program results
  - What was accomplished, benefits
  - High-quality print report
- Ensure other documents are completed/updated
  - Revise factsheets, complete case studies, etc.
  - CD/DVD (linked with additional on-line resources)
- Provide forum for final interaction with Glass Industry
  - Workshop and final project presentations
- Provide location to access documents
  - Website that will remain active indefinitely (OSTI maintained)

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Summary Print Document

- To include:
  - Research undertaken
  - Partners
  - Results (technical, analysis, awards, intellectual property)
  - Budget over time and cost-share
  - Partnership development and activities (vision, roadmap, etc.)
  - Peer review
  - Focus areas
  - Relevant best practice activities

- Projects
  - ~35 cost-shared core projects
  - ~35-40 GPLUS projects
  - ~10 SBIR/I&I projects

- Partners – 98 total
  - 36 glass industry
  - 28 industry vendors
  - 10 national labs
  - 13 academic
  - 11 other

- Awards
  - 2 R&D 100 Awards
- 4 commercial technologies
- >15 patents

- Funding
  - ~35% cost-share

Legacy Website

- Archiving documents at special OSTI website under development
  - http://www.osti.gov/glass
- To contain:
  - Final project reports
  - Project factsheets and case studies
  - Planning and analysis documents (vision, roadmaps, workshop reports, energy/environmental profile)
  - Program annual reports
  - Quarterly reports and portfolio review presentations
  - Best practice tools and case studies

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ITP and EERE: Opportunities Remain, Even without Formal Glass Program Area

- We encourage the glass industry to continue to implement energy efficiency practices and technologies
  - Other ITP program areas
  - Best Practices tools
  - Save Energy Now assessments
  - Fuel flexibility: gasification
  - Other EERE programs: Buildings
  - DOE Loan Guarantee program
- We encourage the glass industry to continue to collaborate on technology solutions
  - GMIC will remain the focal point for ITP interactions with the glass industry

To Be Successful, Successes Must Be Propagated

- Invent and innovate
  - Provide incentives and tools
- Invest in infrastructure
  - GMIC, Engagement tools, etc
- Invest in talent
  - CGR, Distance learning
- Promote collaborations: pool resources
- Be able to justify approach
- Listen and learn

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Government to Industry Ratio Needs to Be Less Than One

- Role of Government is to:
  - Provide jump start
  - Get industry engaged
- Industry needs to take over
  - Collaborate then compete
- Therefore G/I ratio <1

And Had a Little Fun Along the Way

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Energy Efficiency and Renewable Energy

Let's Not Be Afraid

Never be afraid to try something new…

"Remember, a lone amateur built the ark.
A large group of professionals built the Titanic."
Dave Barry, a nationally syndicated columnist

INDUSTRIAL GLASS BANDWIDTH ANALYSIS

USDOE GLASS ITP-GMIC JOINT REVIEW
NOVEMBER 2,2006
PRESENTER-WARREN WOLF

GLASS INDUSTRY ENERGY BANDWIDTH STUDY

- **SPECIAL THANKS TO**
- **GTI AND ESPECIALLY CO-AUTHORS DAVID RUE AND JAMES SERVAITES**
- **GMIC AND ESPECIALLY ITS ENERGY SUB-COMMITTEE UNDER THE CO-CHAIRSHIP OF NEIL SIMPSON AND BRUNO PURNODE AND ALSO MANOJ CHOUDHARY, MICHAEL GREENMAN AND JOHN BROWN**
- **ENERGETICS AND KEITH JAMISON**
- **ELLIOTT LEVINE**
- **ALL OF THE FOLKS IN THE GLASS INDUSTRY WHO ANSWERED SURVEYS AND/OR DISCUSSED NUMBERS BY PHONE**

GLASS INDUSTRY ENERGY BANDWIDTH ANALYSIS

- THE FINAL REPORT CAN BE DOWNLOADED

- HTTP://WWW.EERE.ENERGY.GOV/INDUSTRY/GLASS/ANALYSIS.HTML

GLASS INDUSTRY ENERGY BANDWIDTH ANALYSIS

- THERE ARE THREE PARTS TO THIS TALK:

- 1. QUICKLY REVIEW THE RESULTS AND OTHER COMMENTS FROM THE LAST REVIEW ON 9/14/2005 AND CORRECT A FEW NUMBERS.

- 2.UPDATE KEY CHANGES AS A RESULT OF REVIEW PROCESSES ESPECIALLY COMMENTS RECEIVED BY GMIC MEMBERS/ENERGY SUB-COMMITTEE.

- 3. DISCUSS AND OPEN FOR COMMENTS WHAT WE HOPE TO ACHIEVE IN A PHASE 2 OF THIS STUDY THAT IS ABOUT TO GET UNDER WAY.

SEPTEMBER 14, 2005

- GOAL OF THE STUDY WAS TO IDENTIFY WHERE IN THE GLASS INDUSTRY PROCESSES, ENERGY COULD BE SAVED; TRY TO QUANTIFY THE AMOUNT OF POTENTIAL ENERGY THAT COULD BE SAVED AND IDENTIFY HOW TO ACCOMPLISH THOSE SAVINGS.
- TO GET THE ENERGY NUMBERS WE USED :LITERATURE SURVEYS & DATA COMPILATION;SURVEYS AND PERSONAL INTERVIEWS.
- WE DID NOT COVER SPECIALTY GLASS BUT CONTAINER, FLAT AND GLASS FIBER WERE INCLUDED.
- MELTING FURNACE STILL RANKED AS #1 AREA FOR ENERGY SAVINGS WITH REFINING/CONDITIONING AND PREHEAT BATCH/CULLET BOTH EQUAL FOR #2 RANK.

SEPTEMBER 14,2005(CONTINUED)

- DEFINITIONS:
- 1.CURRENT AVERAGE-BEST ESTIMATED AVERAGE BASED ON EXISTING OPERATIONS IN THE U.S.(CA)
- 2. STATE OF THE ART-LOWEST ENERGY CONSUMING OPTION WE COULD IDENTIFY IN CURRENT OPERATION IN U.S.(SOA)
- 3.PRACTICAL MINIMUM-LOWEST VALUE THAT EXPERTS COULD IDENTIFY AS COMMERCIALLY POSSIBLE-ALSO ASSUMES ENERGY PRICES WILL STAY HIGH AND GO HIGHER.(PM)
- 4. THEORETICAL MINIMUM-ASSUMES NO ENERGY LOSS IN A GLASS MAKING PROCESS -TM

SEPTEMBER 14,2005(CONTINUED)
SUMMARY OF RESULTS

MMBTU/TON	CONTAINER	FLAT	WOOL	TEXTILE
CA	**5.8**	**6.5**	**4.5**	**6.5**
SOA	**3.4**	**4.7**	**2.8**	**3.8**
PM	**2.7**	**3.5**	**2.3**	**3.0**
TM	**2.2**	**2.8**	**2.3**	**2.3**

SEPTEMBER 14,2006(CONTINUED)
TECHNOLOGY STATUS AT EACH STAGE

	CONTAINER	FLAT	WOOL	TEXTILE
CA	AIR/GAS-SOME OXY-FUEL/EB	AIR/GAS A FEW OXY-FUEL	FEW AIR/GAS-OXY-F/ELECTRIC	SOME AIR/OXYF/EB
SOA	OXY-FUEL	OXY-FUEL	OXYF OR ELECTRIC?	OXYF/EB FRONT END-OF/ELECTRIC
PM	EXTENSIVE PREHEAT	REFINING ADVANCES& BETTER CONTROLS	INCR.CULLET/ PREHEAT	PREHEAT CULLET ONLY?
TM				

SEPTEMBER 14/2005 &NOVEMBER 2,2006
SUMMARY OF CONCLUSIONS
NUMBERS CHANGED

- ENERGY SAVINGS POTENTIAL WITHIN MELT/REFINE ONLY, IS 39 TRILLION BTU/YEAR FOR GLASS INDUSTRY FROM CA TO SOA.

- CONTAINER-22 TRILLLION BTU/YEAR
- FLAT-9.5 TRILLION BTU/YEAR
- WOOL-5.2 TRILLION BTU/TON
- TEXTILE-2.2 TRILLION BTU/TON

- THE ESTIMATE IS THAT COST WILL BE HIGHEST FOR FLAT AND IF THAT IS A 10, CONTAINER IS ABOUT AN 8, TEXTILE A 6 AND WOOL A 4.

ENERGY REQUIRED/MAKE OXYGEN TO USE WITH OX-FUEL BURNERS

PRODUCTION TYPE	PRODUCTION ENERGY (MMBTU/TON)	PRODUCTION VOLUME (TON/DAY)	PURITY (%O2)
CRYOGENIC AIR SEPARATION (CRYO)	0.84-1.36	>50	90-99
VACUUM SWING ABSORPTION (VSA)	2.08	20-90	90-93
PRESSURE SWING ABSORPTION (PSA)	2.60	20<	90-95

ENERGY SAVED THROUGH OXYGEN FIRING

- THE ENERGY SAVINGS BY FIRING OXY-GAS BURNERS IS PRIMARILY FROM SAVING NATURAL GAS
- LITERATURE GIVES OXY-FUEL FIRED MELTERS AS 25-45% HIGHER EFFICENCY THAN AIR-GAS MELTERS.
- PRODUCTION OF ELECTRICITY TO MAKE OXYGEN WAS ESTMATED AT 35 % EFFICENCY.
- THE NEXT TABLE SHOWS THAT ALTHOUGH OXYGEN PRODUCTION HAS AN ENERGY PRICE, THE USE OF OXYGEN PROVIDES AN OVERALL ENERGY SAVINGS FOR GLASS MELTING/REFINING.

EFFECT OF OXYGEN ENERGY ON SOA NUMBERS

	FLAT	CONT.	WOOL	TEXTILE
SOA/CA	4.7/6.5	3.4/5.8	2.8/4.5	3.8/6.5
CRYO	4.9	4.2	3.3	4.9
VSA	5.5	5.0	3.9	5.8
PSA	5.8	5.2	4.0	6.0

RESULTS/COMMENTS AFTER REVIEW WITH GMIC/ENERGY SUBCOMMITTEE AND OTHERS IN GLASS INDUSTRY

- GOT ESSENTIAL AGREEMENT WITH INDUSTRY ON ENERGY NUMBERS AFTER DISCOVERY OF AN ERROR ON CONTAINER GLASS (THEY REPORT IN 1,000 LBS AND TONS HAD BEEN ASSUMED)
- MANY ASKED IF THE FIRST REPORT COULD NOT NORMALIZE ENERGY TYPES SO AS TO GET A COMMON LEVEL OF COMPARISON. OUR RESPONSE IS THAT THIS IS A GOOD IDEA IN PRINCIPAL BUT WE LACK SUFFICIENT DATA. WE WOULD NEED TO KNOW THE RANGES FOR ELECTRIC BOOST;RANGE OF ELECTRIC PRODUCTION EFFICIENCIES ETC. AND FOR EACH GLASS SECTOR. IT IS A VALUABLE POINT OF VIEW BUT WE FEEL IT IS IMPRACTICAL TO IMPLEMENT WITH AVAILABLE DATA AND RESOURCES UNLESS THE GLASS INDUSTRY VOLUNTEERS TO PROVIDE A LOT OF INTERNAL DATA. WE ALSO BELIEVE THAT MANY GLASS COMPANIES MAY FEEL THE DATA WE DESIRE IS PROPRIETARY.
- THERE WERE VALID COMMENTS THAT NUMBERS FOR U.S.AIR FIRING ARE MUCH HIGHER THAN EUROPE. WE AGREE THAT IS A PROBABLE CASE BUT WE WERE ASKED TO STICK WITH U.S. BEST PRACTICES.

WHAT SHOULD AN EXTENSION OF BANDWIDTH TRY TO PURSUE?

- WE KNOW U.S.DOE/ITP IS VERY INTERESTED IN WHAT WOULD PERSUADE THE VARIOUS GLASS SECTORS TO MOVE MOST QUICKLY TO THE BEST COMMERCIAL APPROACHES TO ENERGY SAVINGS SUCH AS SOA ?
- THIS INVOLVES A COMPLEX SET OF EQUATIONS THAT INVOLVES GUESSING THE FUTURE, ESPECIALLY ON THE ENERGY COST PICTURE AND ALSO REQUIRES ANY DECISION TO MEET SOUND INVESTMENT RETURNS.
- MANOJ CHOUDHARY HAS SUGGESTED WE CARRY OUT PROJECT ENGINEERING ANALYSES OF STANDARD(USE GENERALLY ACCEPTED TONNAGES) GLASS MANUFACTURING OPERATIONS FOR DIFFERENT SECTORS USING DIFFERENT MELTING/REFININGAND CONDITIONING/FORMING OPTIONS.

WHAT SHOULD AN EXTENSION OF BANDWIDTH TRY TO PURSUE? (CONTINUED #2)

- IS OXY-FUEL A FINAL ANSWER FOR SOA OR SHOULD WE LOOK AT EUROPE'S EXTENSIVE WORK TO IMPROVE AIR/GAS
- CULLET/BATCH PREHEAT SEEMS OF IMMEDIATE INTEREST BUT HOW CAN WE QUANTIFY/IMPROVE COST OF CAPITAL,OPERATIONAL AND MAINTENANCE ISSUES? DO WE LOOK TO EUROPE WHERE MORE CURRENT WORK ON PREHEATING HAS OCCURRED?
- THE CONTAINER SECTOR IS VERY KEY –OVER 50% OF ENERGY SAVINGS GOING FROM CA TO SOA COULD HAPPEN BUT WE NEED TO UNDERSTAND ISSUES BETTER. DO WE NEED A SPECIAL MEETING WITH CONTAINER SECTOR?
- HOW MUCH ATTENTION SHOULD GO TO SYNTHETIC NG OR GASIFICATION OF COAL? ALTHOUGH IT MAY BE VALUABLE WE FEEL IT IS OUTSIDE THE BOUNDRY OF THIS PROJECT.

WHAT SHOULD AN EXTENSION OF BANDWIDTH TRY TO PURSUE (CONTINUED 3)

- WE SHOULD TRY TO PURSUE WHAT MERITS COULD ACCRUE IN FUTURE FROM SUBMERGED COMBUSTION MELTING(SCM) AS WELL AS PLASMA MELT,THE LATER ESPECIALLY FOR SPECIALTY GLASS. .
- WE SHOULD IMPROVE THE BANDWIDTH DOCUMENT BY ADDING FLOW SHEETS FOR GLASS MANUFACTURING AS WELL AS SCHEMATIC FIGURES TO SHOW THE PROCESSES.
- OTHERS?

THAT IS ALL

- THANK YOU
- QUESTIONS?

4

Attendees

Attendees

DOE and GMIC

GLASS WORKSHOP AND REVIEW

Columbus, Ohio

November 2, 2006

Olu Anjonrin-Ohu
AFG Industries

Yaser Abdesamed
Holophane

Terry Berg
CertainTeed

Don Bonk
National Energy Technology Laboratory

David Booth
Allstates Refractory Contractors, LLC

Charles Brossia
Anheuser Busch

John Brown
Glass Manufacturing Industry Council

John Chumley
LOGOTEC

John Connors
PPG Industries

Madonna Cornelissen
Corning, Incorporated

Manoj Choudhary
Owens Corning

Tom Dankert
O-I

Robert Darr
Glass Design

Doug Davis
Toledo Engineering Co.

Alain De Meringo
Saint Gobain

Scott Franklin
PPG Industries

Ron Gonterman
Plasmelt Glass Technologies

Michael Greenman
Glass Manufacturing Industry Council

Terry Hanna
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Aaron Huber
Johns Manville

Keith Jamison
Energetics, Incorporated

Christopher Jian
John Zink Co.

Jim Jones
ACH Holding, LLC

Susan Jones
Anheuser Busch

Hisashi (Sho) Kobayashi
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Ken Kubiak
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Bruno Prunode
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Evanite Fiber Corporation

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Glen Rush
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Jim Shell
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Gabe Tincher
Consultant

Rajiv Tiwary
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Yuri Vulfson
Evanite Fiber Corporation

Todd Weilacher
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Warren Wolf
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