Proceedings of the

FY 2005 Glass Portfolio Review

Industrial Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

In association with the Glass Manufacturing Industry Council

September 14-16, 2005
Chicago, Illinois

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FY 2005 Glass Portfolio Review

September 14-16, 2005
Best Western Inn of Chicago
Chicago, Illinois

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

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Energetics, Inc.
Columbia, Maryland

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4 Final Project Evaluation Presentations

***M**easurement and Control of Glass Feedstocks*

***M**onitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion*

***D**evelopment/Demonstration of an Advanced Oxy-Fuel Fired Front-End System*

***I**mprovement of Performance and Yield of Continuous Glass Fiber Drawing Technology*

Appendices

A Other Presentations

***D**OE-EERE ITP Glass Portfolio Review*

***A**dvanced Thermoelectric Materials for Efficiency Waste Heat Recovery in Process Industries*

***D**istance Learning for the Glass Industry*

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***I**ndustrial Glass Bandwidth Analysis*

***I**TP Glass Program: Portfolio and Strategy*

B Sample Evaluation Forms

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Agenda

FINAL AGENDA

DOE GLASS PORTFOLIO REVIEW

September 14, 2005
Best Western Inn of Chicago
Chicago, Illinois

Time	Activity	Speaker(s)
12:30 - 1:00 pm	**REGISTRATION**	
1:00 - 1:25 pm	Welcoming Remarks and Introductions	Elliott Levine Department of Energy Michael Greenman Glass Manufacturing Industry Council
1:25 - 1:55 pm	*Coupled Combustion Space/Glass Bath Furnace Model (1025)* Questions and Answers	Mike Petrick/Steve Lottes Argonne National Laboratory
1:55 - 2:30 pm	*Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries (16947)* Questions and Answers	Moe Khaleel Pacific Northwest National Laboratory
2:30 - 3:00 pm	*Measurement and Control of Glass Feedstocks (1609)* Questions and Answers	Robert De Saro Energy Research Company
3:00 - 3:15 pm	**BREAK**	
3:15 - 3:45 pm	*Distance Learning for the Glass Industry*	Tom Seward Alfred University
3:45 – 4:25 pm	*High-Intensity Plasma Glass Melter (14232)* Questions and Answers	Ron Gonterman Plasmelt Mike Weinstein Plasment
4:25 – 4:40 pm	*GPLUS Update (1253)*	Peter Angelini Oak Ridge National Laboratory
4:40 - 5:10 pm	*Glass Analysis/Bandwidth*	David Rue Gas Technology Institute
5:10 pm	**ADJOURN**	
6:30 pm	**RECEPTION and CASH BAR**	

September 15, 2005
Best Western Inn of Chicago
Chicago, Illinois

Time	Activity	Speaker(s)
7:00 - 8:00 am	**REGISTRATION and CONTINENTAL BREAKFAST**	
8:00 - 8:30 am	*Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology* Questions and Answers	Simon Rekhson Cleveland State University
8:30 - 9:10 am	*Submerged Combustion Melting (14231)* Questions and Answers	David Rue Gas Technology Institute Lewis Collins Fluent Inc.
9:10 - 9:40 am	*Monitoring and Control of Alkali Volatilization and Batch Carryover for Minimization of Particulates and Crown Corrosion (1608)* Questions and Answers	Chris Shaddix Sandia National Laboratory
9:40 - 10:00 am	**BREAK**	
10:00 - 10:40 am	*Advanced Oxy-Fuel Fired Front-End System (14233)* Questions and Answers	Steve Mighton Owens Corning
10:55 am	**DEPART Hotel for Argonne**	
12:00 – 1:00 pm	**LUNCH at Argonne Guest House**	
1:00 – 2:30 pm	Tour at Argonne	
2:30 pm	**DEPART Argonne for Gas Technology Institute**	
3:15 – 5:00 pm	Tour at Gas Technology Institute	
5:00 pm	**DEPART Gas Technology Institute**	
6:30 pm	**DINNER at Greek Islands Restaurant**	

September 16, 2005
Best Western Inn of Chicago
Chicago, Illinois

Time	Activity	Speaker(s)
7:00 - 8:00 am	**REGISTRATION and CONTINENTAL BREAKFAST**	
8:00 - 8:45 am	*Glass Portfolio Strategy and Direction*	Elliott Levine Department of Energy
8:45 - 9:15 am	*Question and Answer Session*	Elliott Levine Department of Energy
9:15 - 9:55 am	*Facilitated Discussion*	Elliott Levine Department of Energy
9:55 - 10:00 am	Closing Comments	Elliott Levine Department of Energy Michael Greenman Glass Manufacturing Industry Council
10:00 am	**ADJOURN Review Meeting**	

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List of Reviewers

Reviewers

Portfolio Reviewers

Ed Boulos
John Brown
Chris Jian
John Plodinec
Fred Quan
Tom Seward
Jim Shell

Glass Manufacturing Industry Council Reviewers

CORE MEMBERS

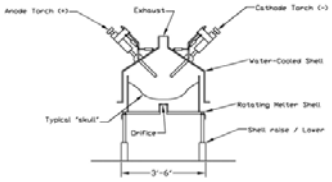
Terry Berg (CertainTeed)
Doug Boessneck (AGY)
Charlie Brossia (Metal Container Corporation/Longhorn Glass)
Manoj Choudhary (Owens Corning)
John Connors (PPG Industries)
Madonna Cornelissen (Corning Incorporated)
Aaron Huber (Johns Manville)
James Jones (Visteon)
Susan Jones (Longhorn Glass)
Steve Mighton (Owens Corning)
Bruno Purnode (Owens Corning)
Mohan Rajaram (Evanite Fiber)
Sheila Sweval (Holophane)
Rajiv Tiwary (PPG Industries)

ASSOCIATE MEMBERS

Kevin Cook (Eclipse/Combustion Tec)
Doug Davis (Toledo Engineering Company)
Mike Druckenmiller (Synsil Products)
Simon Rekhson (Cleveland State University)
James Marra (Westinghouse Savannah River Company)
David Rue (Gas Technology Institute)
Ronald Palmer (Diagnostic Instrumentation and Analysis Laboratory)
George Sakoske (Ferro Corporation)
Bill Von Drasek (American Air Liquide)

3

Ongoing Project Evaluation Presentations

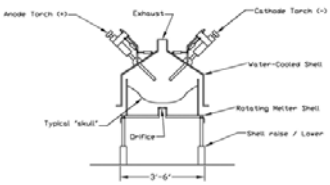


High Intensity Plasma Glass Melter

DOE Review—Chicago
Sept. 14-16, 2005

Ron Gonterman & Mike Weinstein

High Intensity Glass Plasma Melter—GO13093



Goal: Develop a 500 lb/hr transferred-arc plasma melting process that can produce high quality glass suitable for processing into a commercial article.

Challenge: Plasma melting of glass potentially provides high intensity, highly flexible, efficient glass melting but is hampered by short torch lives and unstable process operating conditions.

Benefits: Ability to turn off production glass furnaces when business dictates; rapid startup / shutdown capabilities saves energy; skull melting eliminates refractories/minimizes heat losses; high temperature capabilities can be applied to new materials.

Potential End-User Applications: Specialty glasses; Frit manufacturers; Fiberglass; Labware etc.

FY06 Activities: (With funding) Melt numerous glass compositions of broad interest to glass industry; improve glass homogeneity for broader acceptance; perfect an automated controls system to improve process stability.

Participants:
Plasmelt Glass Tech
AGY
Johns Manville

High Intensity Glass Plasma Melter—GO13093

Barrier-Pathway Approach

Barriers

- Torch Life previously shown by JM to be minutes only.
- Process Instability is necessarily high with small high-intensity melters.
- Quality of very short dwell time glass is a well-known challenge.

Pathways

- Development of proprietary torch design and critical tolerances
- Process development of automatic sensors and controls systems
- Melting process setup and operation plus mixed batch quality

Critical Metrics

- Torch Life ≥ 100 hours
- Energy Usage per ton of Glass-Goal=4.1 MM BTU/ton
- Fiberizing perf. ≤ 0.5 B/BH

Benefits (est.)	2020
Energy Savings	6.1 trillion Btu
Cost Savings	$9 million
Carbon Reduction	0.01 MMTCe

ACKNOWLEDGMENTS

- Sincere thanks to DOE for selecting and sponsoring this project
- Thanks to JM and AGY—Our Partners
  - For making the project possible
  - For lending technical support and contributing materials / equipment
- Thanks to our many sub-contractors:
  - Jim Hayward
  - Dr. Oleg Prokhorenko
  - Integrex Analytical Labs
  - Robert Kirkland
  - Zybek Advanced Products, Inc.
  - Tooley Design Services
  - West Monarch Analytical Labs
  - Dr. Scott Parker

AGENDA

- Results, Results, Results
  - Glass Quality
  - Plasma Melter:
    - Glasses Melted
    - Energy Efficiency / Operating Costs
    - Torch life
    - Temperatures of plasma / System model
    - Marketing Study
- Industrial Applications
  - Attributes
  - Best Applications
- Plasmelt's Path Forward

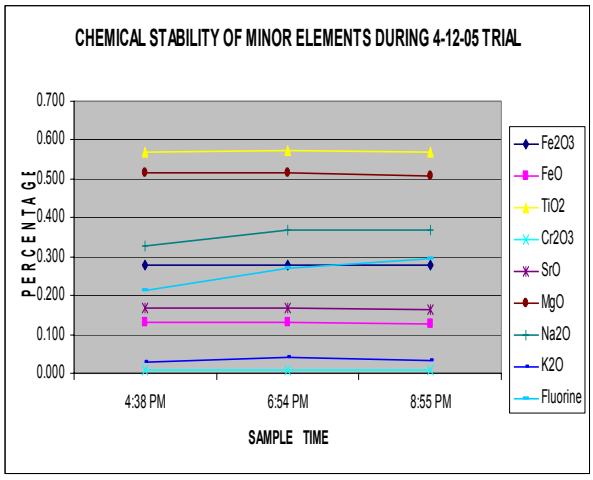
RESULTS: Glass Quality

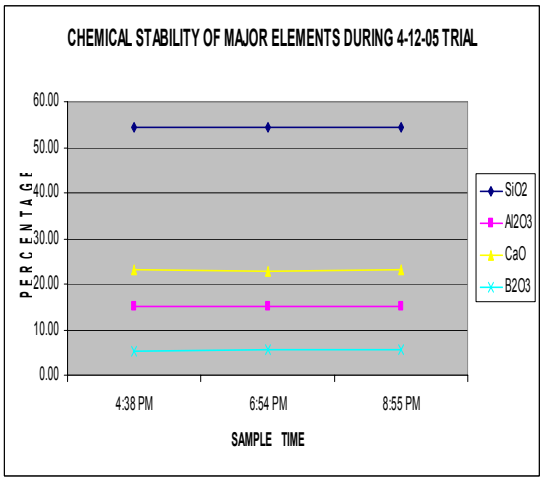
- Metrics
  - Glass Chemistry
  - Seeds/stones/cords
  - Contamination from spurious materials
  - Volatilization
  - REDOX
  - Fiberization performance
  - Fiber quality

RESULTS: Glass Quality

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

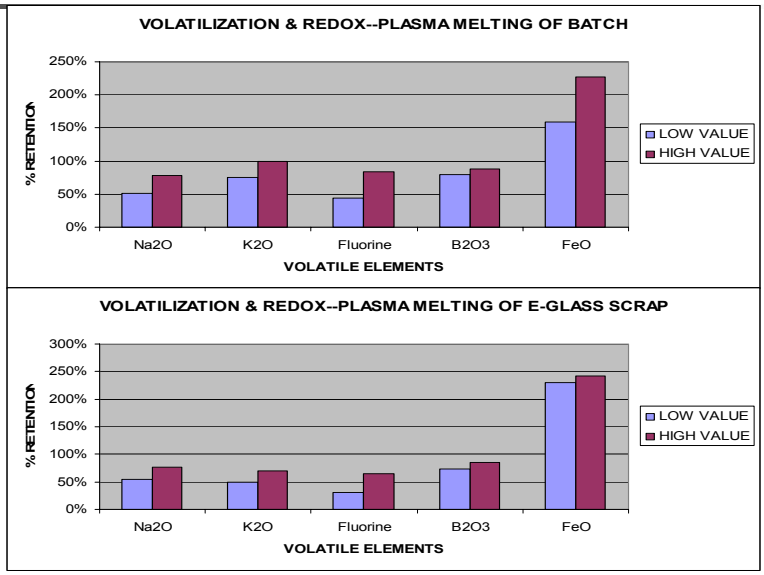
RESULTS: Chemical Stability During 4-12-05 Trial





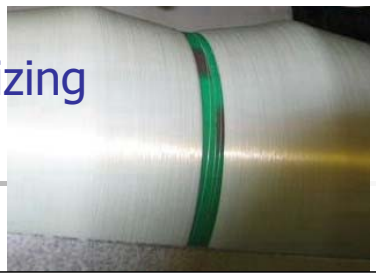
CONCLUSION: Overall chemistries were reasonably stable during this 6-hour "hands-off" production run.

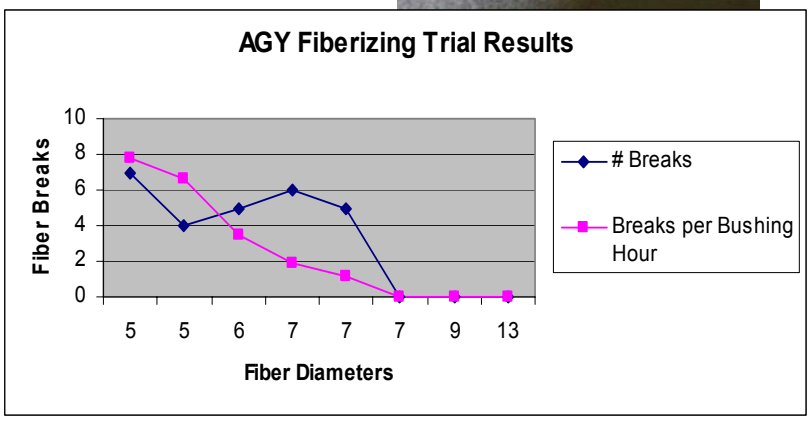
RESULTS: Influence of Plasma Melting on Volatilization and REDOX of E-Glass



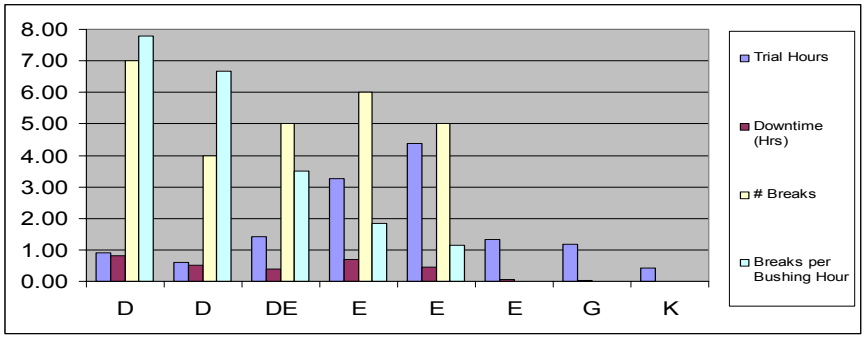
CONCLUSION: Plasma melter process settings influence much control of volatilization. Process optimization will pay dividends.

RESULTS: AGY Fiberizing Trial Data





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

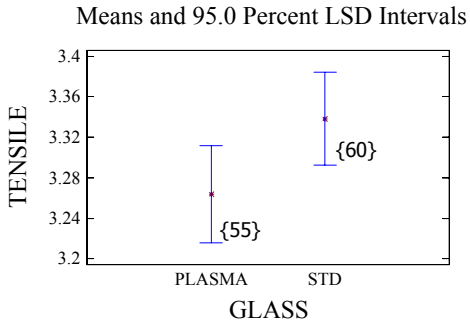
< Preliminary Conclusion >

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

85-90% of all commercial fiberglass is produced in diameters of 9 to 24 microns!

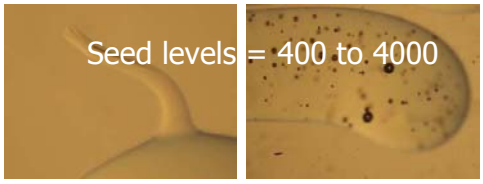
RESULTS: Glass Quality

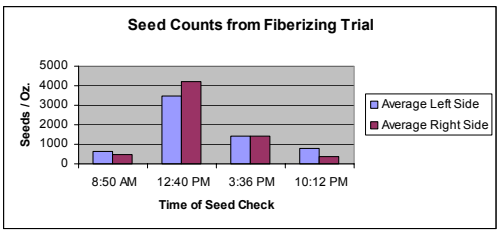
- Fiber Quality

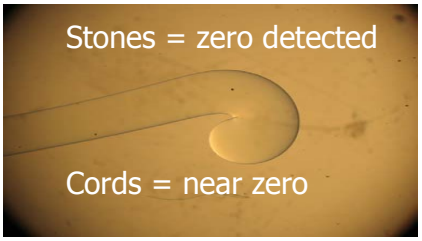


Conclusion: No statistically significant difference in the plasma-melted and standard glass.

RESULTS: Glass Quality—Seeds/Stones/Cord





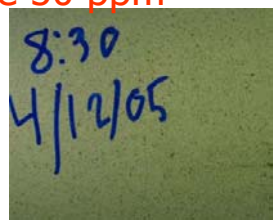


Time	Left	Right
8:50 AM	623	469
12:40 PM	3500	4200
3:36 PM	1400	1400
10:12 PM	791	364

RESULTS: Glass Quality

- Contamination by metals
  - Copper electrode and water jacket materials contribute 60 ppm CuO on average
  - Molybdenum orifice materials contribute 50 ppm on average

High MoO3 E-Glass



Normal E-Glass with MoO3 ~ 50 ppm

RESULTS: Plasma Melting of E-glass

Trial Conclusions

1. INITIAL TRIAL = plasma-melted glass (with an extremely short dwell time) produced an acceptable quality 7 - 13 micron continuous fiber!!!
2. Very high seed levels
3. No stones and only minor cords
4. Volatilization slightly higher than a standard oxy-fuel fired system—WITH OUR INITIAL DESIGN
5. Metals contamination is a function of the INITIAL DESIGN and is likely to be lower in the "industrial" version
6. First global demonstration of successful fiberization of glass from a plasma melter
7. Further trials are needed to relate melter throughput to glass quality and energy efficiency

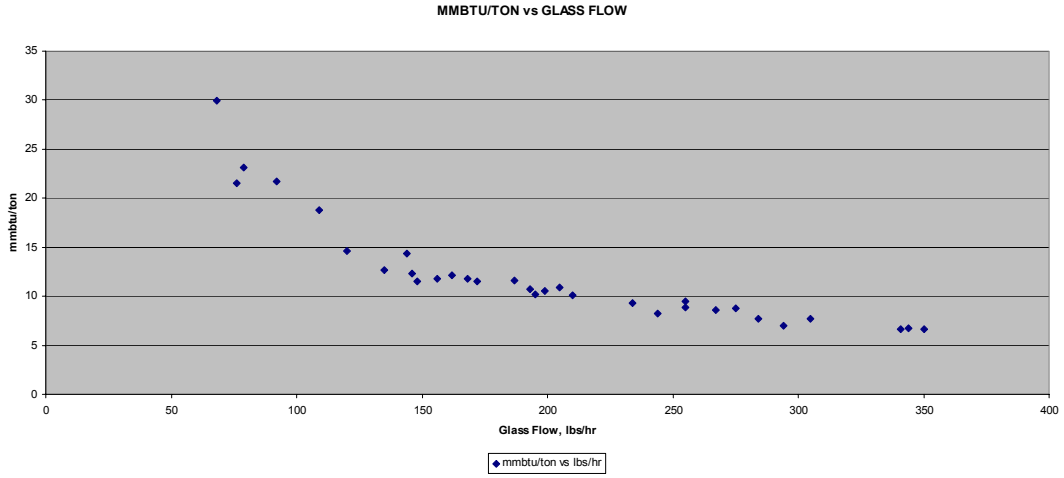
Results: Plasma Melter

RESULTS: Plasma Melter

- Summary of Glasses Melted
  - E Glass
  - S Glass
  - Frit Glass
  - Lighting Tube Glass
  - Scrap E-Glass
  - Quartz Sand (SiO2)

RESULTS: Plasma Melting

- Energy Efficiency – E Glass



RESULTS: Energy Efficiency

- Efficiency Conclusions:
  - The energy efficiency of plasma melting will vary widely based on the type of glass composition that is melted.
  - Energy efficiency is strongly related to the glass throughput.
  - For E-glass, we have already demonstrated 350 #/hr ~ 6MM BTU/Ton vs actual commercial furnaces using 4 to 12 MM BTU/Ton.
  - More work is needed to achieve even higher throughputs and higher efficiencies.
  - "Glass on Demand"

RESULTS: Plasma Melting

- Estimated operating costs (current)

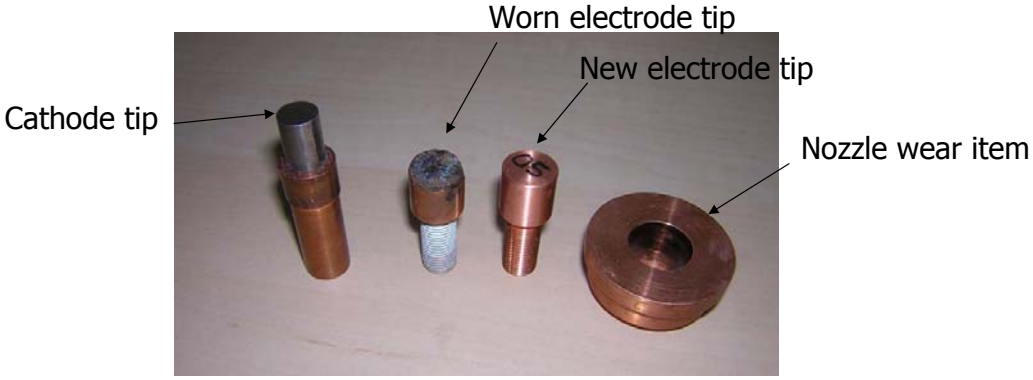
Operating Cost	350	lbs/hr							
Direct					Hour			Day	
Electricity	300	kw	0.06	$/kwh	$ 18.00		$/hr	$ 432.00	$/day
Argon	200	scfh	0.04787	$/scf	$ 9.57		$/hr	$ 229.78	$/day
Nitrogen	100	scfh	0.018067	$/scf	$ 1.81		$/hr	$ 43.36	$/day
Torch service	100	hour / service	100	$/service		1	$/hr	$ 24.00	$/day
Total					$ 30.38		$/hr	$ 729.14	

RESULTS: Plasma Melting

- Torch Life
  - From 30 seconds to 30 hours (+)
    - 30 hrs failed because of "operator error"
  - Drastically improved fixed and maintenance cost
  - Torch replacement ~5 minutes

RESULTS: Plasma Melting

- Torch Life
  - Low-cost maintenance parts
  - Easy to replace



RESULTS: Plasma Melting

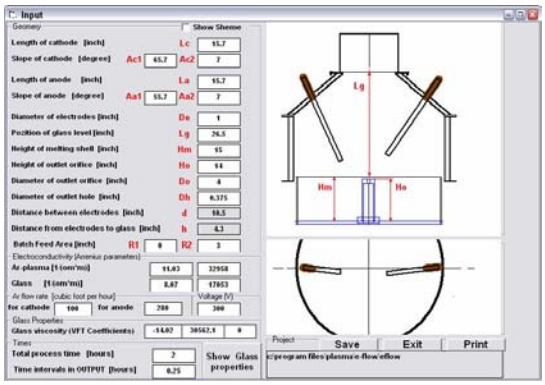
- Plasma Analysis
  In partnership with Dr. Scott Parker, CU Dept of Plasma Physics
  - Used Spectrometer to measure atomic / molecular line emission
  - Temperature measurements made using ratio of line intensities with Ar gas
  - Plasma temperatures at ~350 amps range from 13,000˚K to 21,000˚K
  - Results are preliminary but verified by published research.

RESULTS: Plasma Model

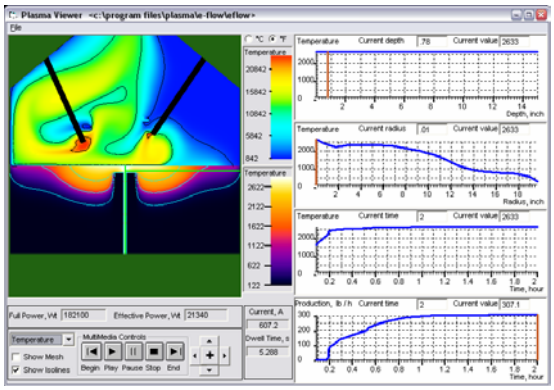
- Developed 2D mathematical model of plasma system—in partnership with Dr. Oleg Prokhorenko
- Based on Ar discharge plasma heater as coupled gas flow, and thermal sub-routines
- Measure absorption spectra of E- and S- glasses at high temperatures (1100 - 2730°F)
- Throughput depends on absorption of molten glass in near infrared range (0.7 – 2.6 μm)
- In case of low depth of the orifice, glass melts within "active" zone having radius ~3" and depth ~1"

RESULTS: 2D Plasma Model

Input Screen

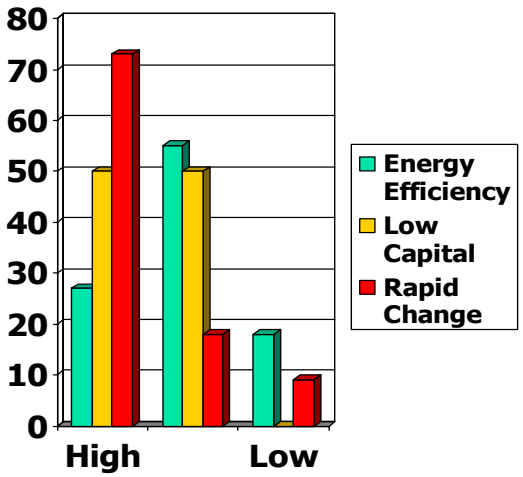


Output Screen



RESULTS: Marketing Study

- **Market Study Results**
  - Highest benefits of the Plasmelt Melter:
    - **Rapid changeover capability**
    - **Low initial capital**
    - **Low maintenance costs**
  - Energy use is important. Electric melting at 4.1 MM btu/lb is not perceived as a particularly low cost melting process.
  - Environmental benefits, (with the exception of the elimination of refractory disposal), are low in relative value to segment companies interviewed. Ability to recycle waste with a plasma melter is important.
  - **New Materials / New Products / New Lines** is a potential benefit of the high temperature capability of the plasma melter system.



INDUSTRIAL APPLICATIONS

Attributes of Plasma Melting:

- Flexible
  - Ability to melt several different formulations per week
  - Ability to melt on shifts / adjust for market demands
- Higher temperature capabilities
- Uses electricity
- No / minimal refractories
- Low capital cost
- Rapid startup / shutdown
- Can be used for scrap glass melting
- Can be used for melter-boosting of commercial melters

INDUSTRIAL APPLICATONS

Best-Fit Applications:

- Fiberglass (both continuous and insulation)
- Specialty glasses
  - e.g. S-glass, frit glass, etc.
  - New, test market products
- Low volume operations
- Flexible production operational schedules
- Multiple glass compositions in one factory
- Melter boost for commercial melters
- Scrap re-melt

PLASMELT'S PATH FORWARD

- Parallel Activities:
  - Seek out glass company clients to continue to melt broad range of glass compositions and materials to broadly match US industry needs
  - Build industrial pilot melter for specific application
  - Seek partners to develop a Portable Plasma Melter for broad industry applications
- Conduct refining work to lower the seed content
- Develop more robust glass-contact materials
- Continued system refinement / improvements aimed at improved glass quality and energy efficiency

PLASMELT'S PATH FORWARD

- Business Plans
  - Continue to support our cost share partners
    - With plasma melting and other ancillary development
  - Pursue already-identified business applications for plasma melting / identify new business opportunities to realize return on everyone's investment
  - Options:
    - Work with individual companies to find fastest means to get the technology implemented
    - Seek marketing or end user partners who can assist with commercial implementation
    - Seek equity partners

CONCLUSIONS

- Plasmelt has run a low-overhead, cost-efficient, rapid development cycle time program.
  - 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 of quality that can fiberize
  - Flexible system that melts E glass, scrap, and others
  - Capable of melting high temperature materials
  - Dramatic torch life improvements
  - Controlled process stability
- Plasmelt is now soliciting GMIC to help locate companies who can realize the benefits of plasma-melting technology.

RESULTS: Glass Quality—Chemistries

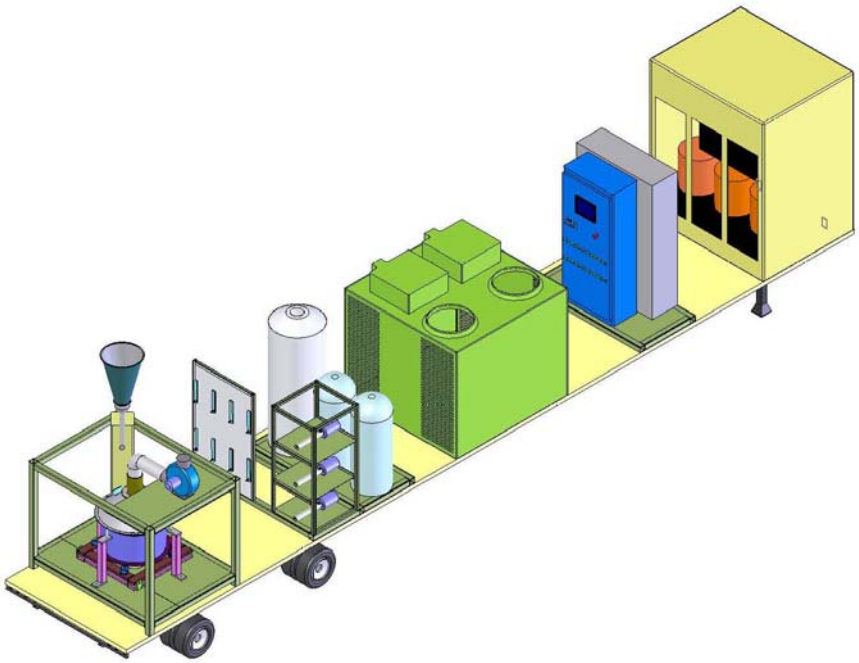
Plasma-Melted E-glass Produced on 4-12-05 in Boulder, CO Lab for AGY Fiberizing Trials						
Time of Production	4:38 - 4:52 PM	5:54 - 6:09 PM	6:54 - 7:05 PM	7:51 - 8:00 PM	8:55 - 9:09 PM	"STD" E-glass
SiO2	54.39	--	54.32	--	54.27	53.6
Fe2O3	0.279	--	0.279	--	0.278	0.3
FeO	0.133	--	0.133	--	0.127	0.1
TiO2	0.57	--	0.57	--	0.57	0.6
Al2O3	15.06	--	15.01	--	15	14.8
Cr2O3	0.01	--	0.01	--	0.01	
CaO	23.05	--	22.91	--	23.07	22.4
SrO	0.167	--	0.166	--	0.165	
MgO	0.52	--	0.52	--	0.51	0.5
Na2O	0.33	--	0.37	--	0.37	0.6
K2O	0.03	--	0.04	--	0.03	
Fluorine	0.21	0.25	0.27	0.29	0.3	0.45
B2O3	5.42	5.56	5.57	5.66	5.67	6.9
MoO3	0.0054	0.0079	0.0049	0.0043	0.0082	
CuO	0.004	0.005	0.005	0.004	0.004	
SO3	<0.01	--	<0.01	--	<0.01	

NOTE: All values are expressed as weight %.

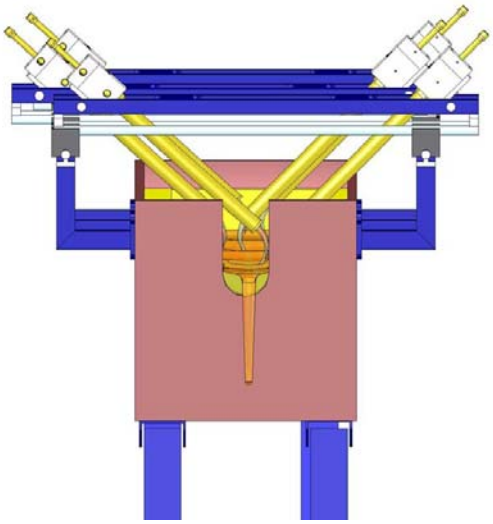
MILESTONES FROM ORIGINAL PLASMELT PROPOSAL

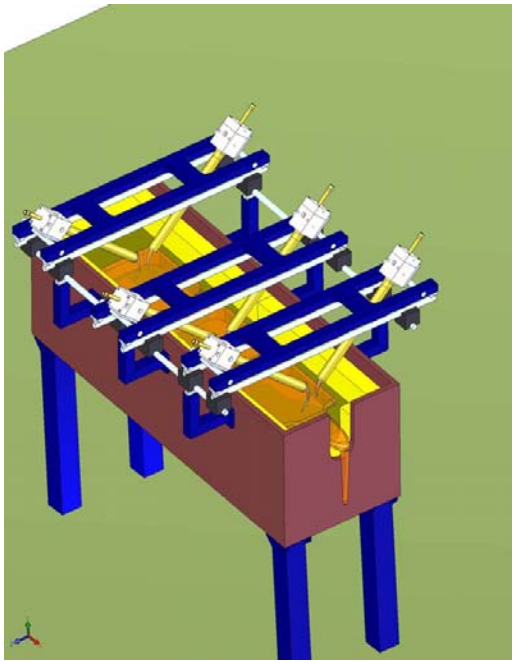
ID Number	Task / Milestone Description	Planned Completion	Actual Completion	Comments
M 1	Project Startup: Establish WBS and Schedule, operating agreements, IP Terms, subcontract agreements	10/31/03	10/31/03	Complete
M 2.1	Melter Design: Develop Project Request Documents, specifications, materials lists, engineering packages	10/31/03	10/31/03	Complete
M.2.2	Laboratory Preparation: Identify candidate facilities, sign lease agreements, establish environmental permits	12/31/03	10/31/03	Complete. Notification of environmental Exemption Letter received from Colorado DPHE
M.2.3	Construct Melter: Subcontract fabrication and construction, install melter at site	12/31/03	2/29/04	Most of the delay due to major change in the building electrical system upgrade by Xcel Energy. Melter construction and fabrication are now complete.
M 3	Market Survey	5/31/04	5/31/04	Work is complete.
M 4	Melter/Process Test Program: Startup and operation at 500 #/hr rate [GO/NO GO DECISION], preliminary energy balance, preliminary report	7/27/04	In progress	Although 500#/hr has not yet been achieved on a routine basis, this work is ongoing. Long stable runs have been achieved at 300 #/hr but not at 500 #/hr. A report was issued to our team-members documenting our "GO" decision.
M 5	Assess Glass Quality: Patty Making Installation, Patty Production, and Fiberizing Testing [GO/NO GO DECISION]	1/31/05	4/30/05	Fiberization and fiber product testing completed. Good fiber forming performance for 10 micron and larger fibers. Good tensile testing results of plasma-melted glass.
M 6.1	Optimization: Process refinement, energy balance updates [GO/NO GO DECISION]	6/30/05	In progress	
M 6.2	Final Reporting to DOE	Before end of project on 7/27/06		

Portable Melter



Plasma Refiner Concept





Energy-Efficient Glass Melting
The Next Generation Melter

David Rue
Gas Technology Institute

DOE Industrial Technology Program

2005 Project-Industry Review
Sept. 15, 2005

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 (6 glass companies)
- Fluent, Inc.
- A.C. Leadbetter and Son, Inc.
- Praxair, Inc.
- Combustion Tec / Eclipse
- 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 supporting SCM
- Develop rapid conditioning stage
- Move to field demo with working SCM

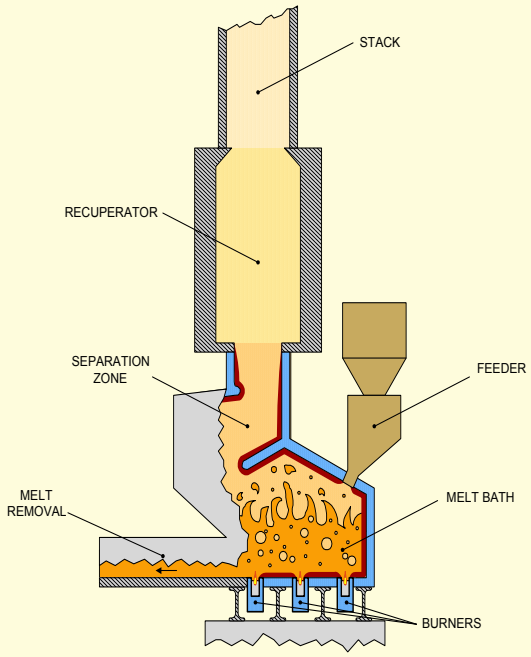
Critical Metrics
- Material / energy balances (with OTM)
- Glass quality analyses
- Working and validated CFD model

Benefit	
Energy Savings	18.1 TCF
Cost 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

SCM Technology



- Oxy-gas firing into the melt bath
  - Intense combustion
  - Direct contact heat transfer - products of combustion bubble through the melt
    - reduced NO_x formation
    - reduced CO and unburned HCs
  - High heat transfer, rapid mass transfer
    - High thermal efficiency
    - Reduced melter size
- Melter is reliable and robust
  - Low capital cost
  - Externally cooled walls
  - Can be stopped and started easily
- Melting and mixing in one step
- Compatible with NGMS operations
  - Charging
  - Rapid conditioning
  - heat recovery

SCM Saves Energy

Melter		Tank	SCM	SCM
Wall Heat Rec., %		0	0	20
Res. Time, h	Melter	--	4.5	4.5
	Fining	--	3.25	3.25
	Total	30	7.75	7.75
Pull Rate, ft2/ton/day	Melter	--	0.63	0.63
	Fining	--	0.47	0.47
	Total	4.2	1.1	1.1
Surface Area,	Melter	--	15	15
% of tank melter	Fining	--	11	11
	Total	100	--	--
Wall Loss,	Melter	--	0.48	0.39
MMBtu/ton	Fining	--	0.07	0.07
	Total	0.73	0.55	0.46
Total Energy, MMBtu/ton		3.64	3.46	3.37
Energy Savings, %		0	5	7.5

Assume SCM wall loss of 3 times tank wall heat flux in Btu/ft^2.h

Project Schedule

Task		Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Modeling												
2	Melter Design												
3	Procurment												
4	Physical Modeling												
5	Fabrication												
6	Shakedown												
7	Test Planning												
8	Testing - Parametric												
9	Melter Modification												
10	Second Test Series												
11	Analysis												
12	Toward Commercialization												

FY 2005 Project Activities

- Lab-scale SCM tests
  - **Acquire data for pilot-scale SCM design**
  - **Evaluate product glass for needed conditioning**
- Pilot-scale melter
  - **Design**
  - **Fabrication**
  - **First melts and glass analyses**
- Cold flow model tests to optimize melter flow patterns
- Working CFD model
  - **to assess parameter changes**
  - **to guide scale up decisions**

Physical Modeling – Why?

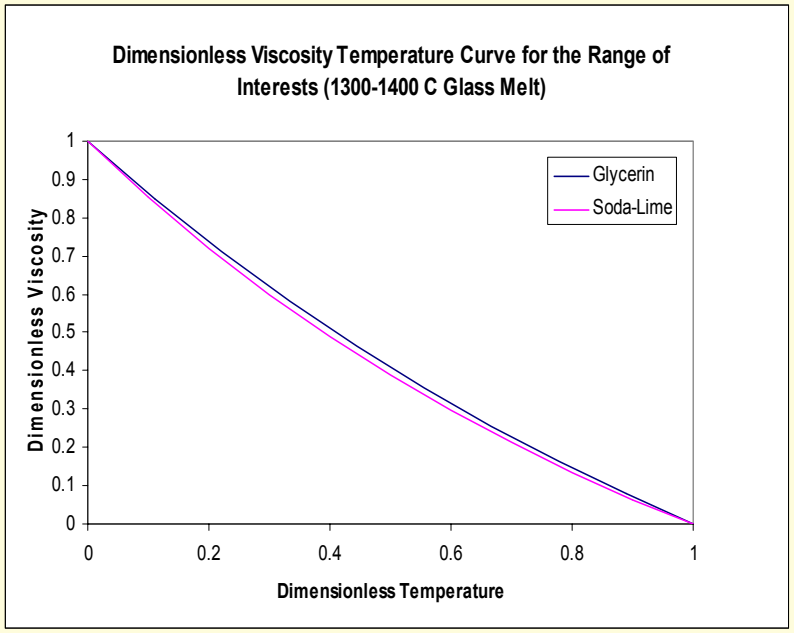
- Provides insights to full scale unit
  - Fast turn around
    - Reduce scale (physical dimension, temperature, velocity, viscosity..etc.)
  - Low initial and running cost
  - Easily accessible for quantitative data
  - Flexible evaluation of design concepts and parameters
  - Validation of numerical models
- Model molten glass flow patterns
- Investigate design parameter effects on the response time/curve
- Temperature mapping and heat transfer characteristics

Dimensionless Groups

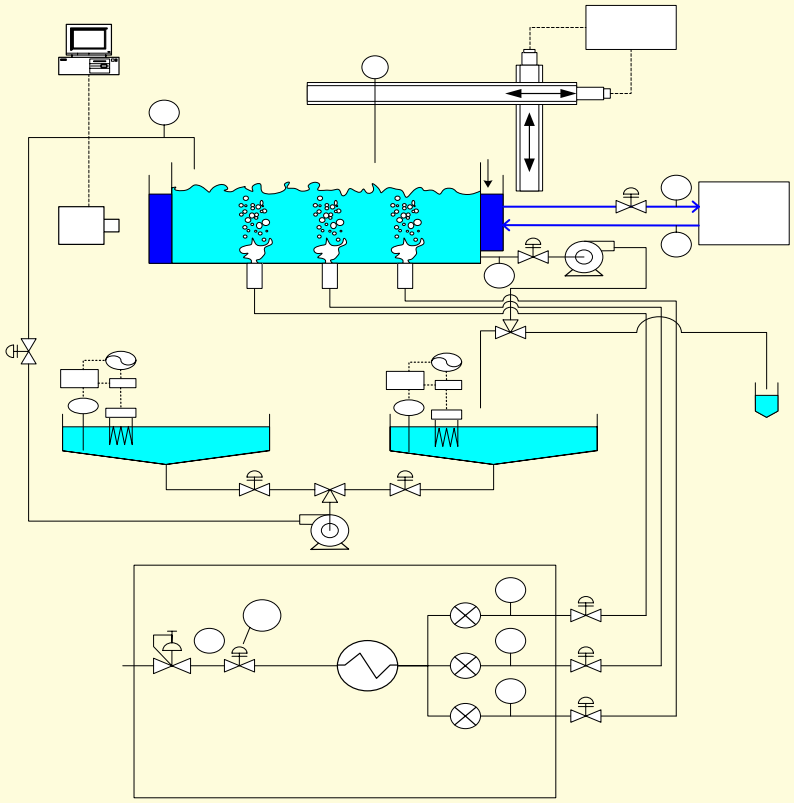
- Grashof and Reynolds numbers
  - Grashof # $\equiv \frac{l^3}{\nu^2}\beta\Delta T\frac{(inertia)(buoyant)}{(viscous)}$
  - Reynolds # $\equiv \frac{Vl}{\nu}\frac{(inertia)}{(viscous)}$
- Advantage:
  - Match viscosity-temperature curve.
  - Model flow patterns well in traditional glass melter
- Disadvantage:
  - Does not take heat transfer into consideration.

Selecting the Model Liquid

- Glycerin was selected.
  - Easy to clean up.
  - Viscosity-temperature characteristics.
- Yielded
  - 10:1 model size
  - 58 viscosity scale, 3 velocity scale.
  - 28-37°C operation temperature for soda lime glass

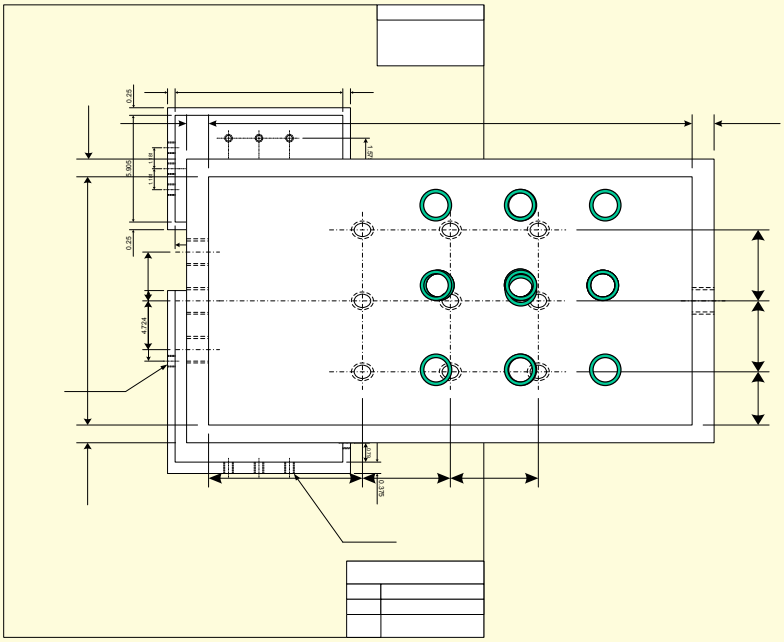


Physical Modeling Apparatus

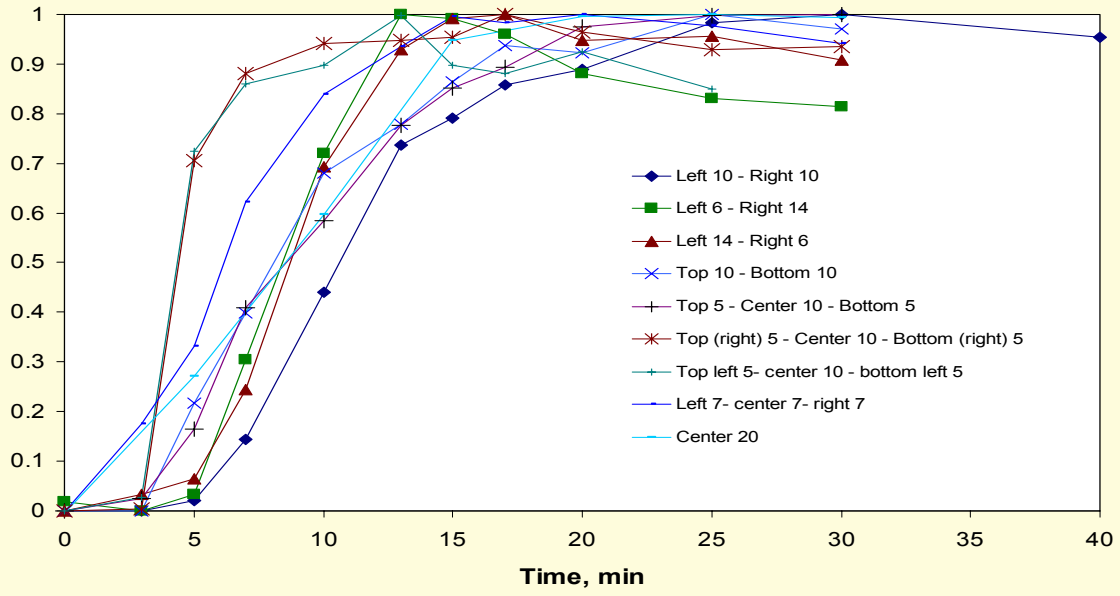


Physical Modeling Apparatus

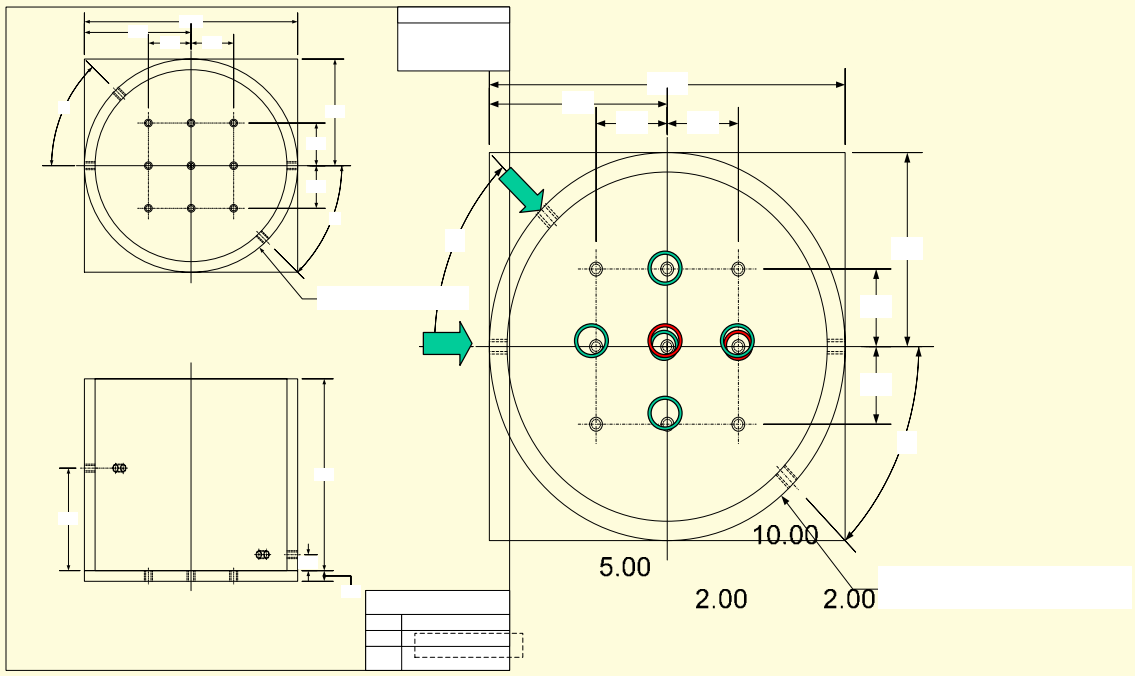
Model- Rectangular (8:5)



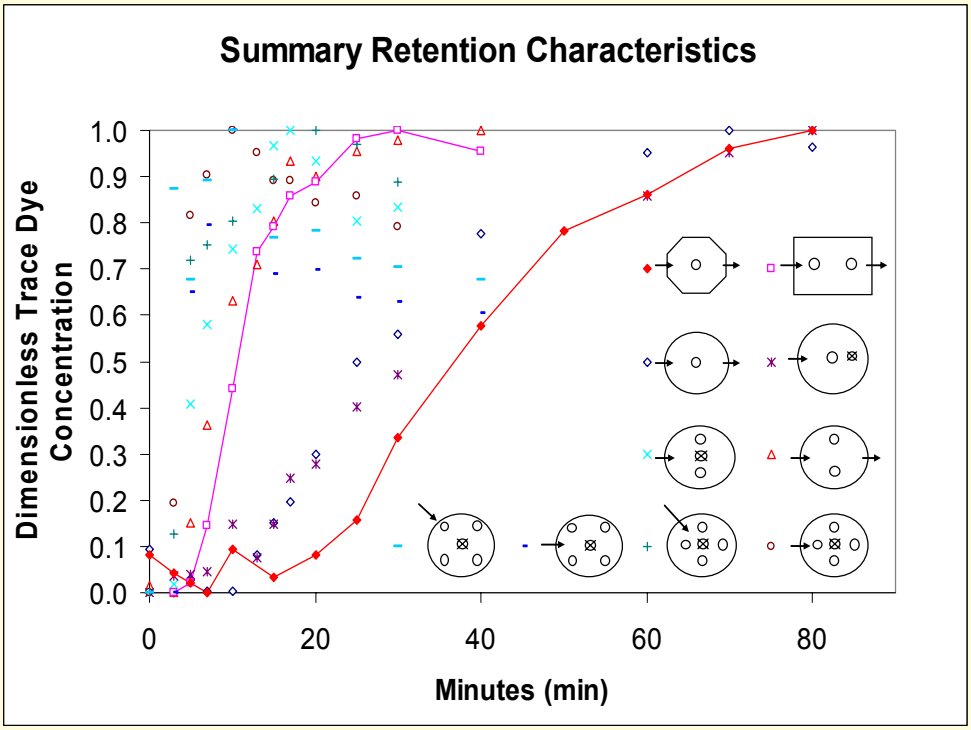
Retention Curve – Rectangular Model (8:5)



Round SCM Model



Round/Octagonal Models



Physical Modeling Conclusion

- Jets create vertically oriented convective flow paths
- Rectangular model tests showed
  - Symmetric jet positions prevent flow particle bypassing
  - Flow particles leave convective flow loops at the liquid-gas interface
- Round model confirmed importance of melter-jet symmetry by giving 2.5 times longer retention time
- Octagonal model performed similarly to round model in retention characteristics
- Results do not apply DIRECTLY to SCM because –
  - A single SCM burner would create too much turbulence
  - SCM burners should be within certain firing ranges
  - Melt bath temperature uniformity is important in SCM
  - Glass temperature-viscosity relationships have a large impact on SCM flow patterns

Lab-Scale SCM Tests

- Industry batch melted to product glass
- Batch feed
- Continuous discharge
- Evaluation of all components before pilot SCM fabrication
- All components scaled for the 0.5-1.0 ton/h pilot SCM unit

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	Needed
Tap Piece	Pilot	Tested – rebuild needed for use on Pilot SCM
Building and steel framing	Lab/Pilot	Modify frame for Pilot SCM
Oxy/Gas burners	Lab/Pilot	Tested – new burners for Pilot SCM
Pilot SCM 0.5-1.0 ton/h	Pilot	Starting fabrication

Glass Batch Analyses

Selected to cover range of difficulty and volatility of major industrial glasses

Glass	Soda-Lime	E glass	LCD (1737)
Source	CertainTeed	Johns Manville	Corning
Si, wt%	39.4	26.4	31.0
Alkali (Na+K), wt%	6.5	<0.4	0.0
Ca, wt%	4.6	12.5	2.2
Description	Typical container glass	Borosilicate glass – low alkali	Non-alkali 'hard' glass
Melting Point	Low	Medium	High

Lab-Scale SCM Tests

- Tests without new tap piece
  - >6 soda-lime glass tests
    - Easily removed from melter
  - 2 LCD glass tests
    - Not practical to remove from melter
- Tests with new tap piece
  - 1 soda-lime glass test
    - Easily removed with tap piece
  - 1 LCD glass test
    - Practical with new tap, tap needs modification
- E glass scheduled next before installing pilot SCM

SCM Product Glass Analyses

Tests without new tap piece

Glass	Soda-lime	LCD
Silica, wt%	35.2	29.9
Alkali (Na+K), wt%	12.2	1.9
Ca, wt%	7.9	4.9
Hg (bulk) density, g/cc	2.10	2.19
He (true) density, g/cc	2.53	2.63

- High alkali measured in soda-lime glass
- Alkali in LCD glass show contamination from soda-lime glass
- Void fraction – 17%

Producing Glass

- Batch to molten glass (~1000 lb) in < 60 min.
- Samples were collected for analysis
- Glass product contained components from earlier melt tests

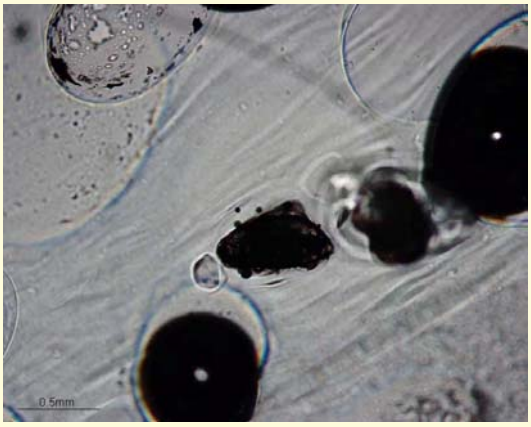
Soda-lime

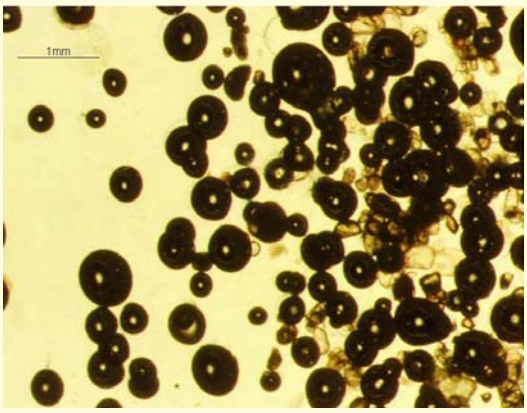
Graphite mold sampling

LCD

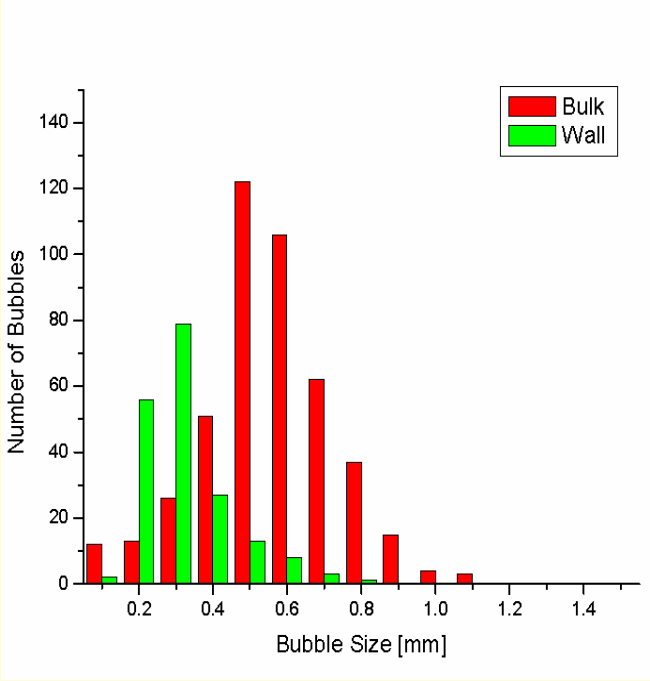
SCM Soda-lime Glass

Sample for Micro-Analysis





Soda-Lime Glass Bubble Count

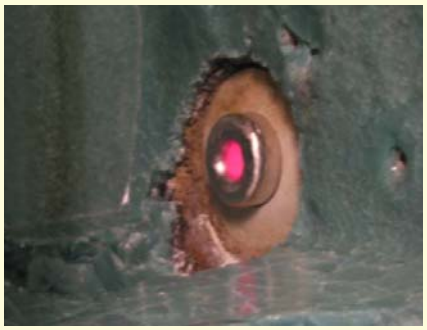


- Average bubble size
  - 0.3 mm. near the wall
  - >0.5 mm. away from wall
- Away from the wall
  - >90% of bubbles are >0.3 mm.
  - Larger bubbles are more easily removed

New SCM Discharge Tap

- Electrically heated platinum pipe
  - Allows continuous melt discharge
  - Serves to control melt flow rate
  - Removes melt from inside wall boundary layer
- Tested successfully with LCD and soda-lime batch
- Will be modified and installed on pilot SCM unit
- Strong consortium assistance
  - Designed by Carsten Weinhold of Schott N.A.
  - Electrical components supplied by Owens Corning
  - Fabrication by Corning Metal Shop (build and re-build)
- Achieves project milestone of continuous flow of stone-free product over full industrial glass range

Tap Operation and Evaluation



Soda-Lime Glass

Pilot-Scale SCM Unit

- Objective – continuous feed and discharge – made easier with
  - Larger capacity melter (0.5-1.0 ton/h)\
  - Demonstrated platinum discharge tap
- Most components are in place and tested
  - Melter, burners, cooling water chiller needed
  - Added instrumentation into data acquisition system
- Rectangular SCM with cut corners eliminates poor melting zones
- Multiple burners spaced far enough apart to create
  - Uniform temperature profile
  - Desired mixing and residence time distribuitions
- Flexibility built into the unit
  - Changeable burner patterns
  - Provisions for two or more discharge locations
  - Provisions for two feed locations

Plans for FY 2006 - Milestones

Year	Milestone	Description	Completion
1	1	Initial working FLUENT CFD model	Sept. 04
1	2	Design pilot-scale SCM unit	June 05
1	3	Procure pilot SCM major equipment	Sept. 04 – Oct. 05
2	4	Fabricate pilot-scale SCM unit	Oct. 05
2	5	Prepare test plan	Mar. 05
2	6	Complete pilot-scale melting tests	Mar. 06
2	7	Finish all sample analyses	Apr. 06
3	8	Modify pilot-scale SCM as needed	May 06
3	9	Parametric and long-term pilot SCM tests	July 06
3	10	Finalize physical and CFD modeling	Aug. 06
3	11	Complete OTM analysis	June 06
3	12	Prepare SCM development plan	Sept. 06

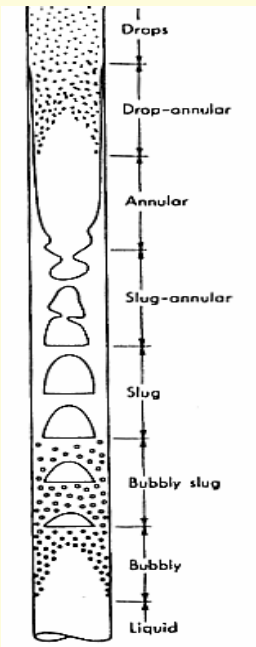
CFD Simulation Objectives

- Support pilot melter design and concept evaluation
  - Including energy efficiency assessment
- Advance modeling technology
  - "Associated underlying knowledge in … glass furnace models"*
  - "Development and validation of sub-models to be used with currently available CFD based models for glass furnaces"*
- Validated SCM melter model available to industry
  - accelerate technology transfer and process commercialization

*(2002 Glass Industry Technology Roadmap, Energy Efficiency priority area. Quoted in DOE Solicitation No. DE-PS07-02ID14308, "Glass Industry of the Future", Topical Areas of Interest.)

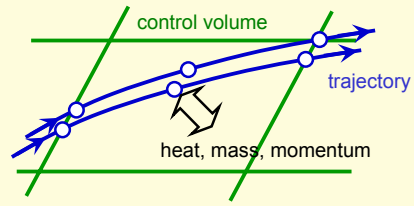
Simulation Challenges

- Highly uncertain multiphase flow regime
  - Not well suited to traditional glass codes/methods
  - Need *a priori* knowledge to select best method
- Disparate time scales introduced by
  - submerged combustion chemistry and gas plumes
  - water-cooled walls (ultra-slow "frozen layer")
- Wide range of bubble sizes - all important!
- SCM batch melting unlike conventional "batch blanket"
- Complex, participating-media radiation



Vertical liquid/gas flow regimes

Multiphase CFD Methods in FLUENT



- Lagrangian Dispersed Phase Model (DPM)

➢Solve for each particle
➢Can overlay with others below

- Single-fluid drift flux method (Mixture Model)
- Interface-capturing volume-of-fluid method (VOF)
- Eulerian *N*-fluid method (interpenetrating continua)

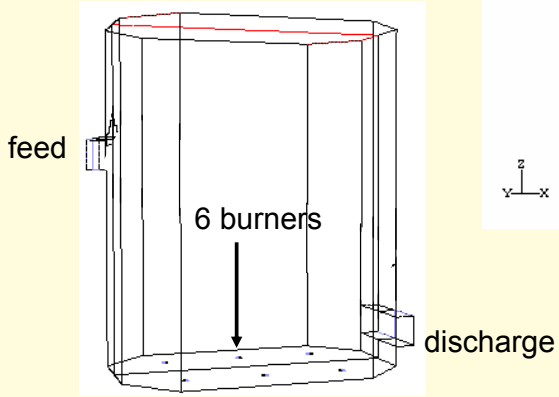
➢Solve for volume fractions
➢Must select only one

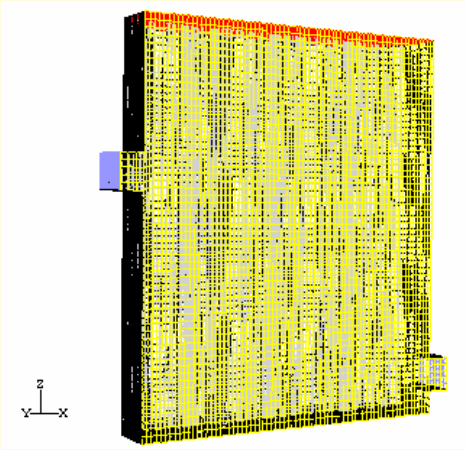
Progress and Solutions

- Initial research and experimentation established the best CFD methodology
  - VOF to model large burner gas jets/slugs
  - DPM to model small entrained bubbles
  - DPM to model transport and dissolution of solid batch
  - All compatible with FLUENT's suite of combustion and radiation models
  - Explicit glass $\mu(T)$ to simulate the frozen layer
- FLUENT is being extended to address identified physico-chemical modeling gaps
  - General versatility for rapid solution "tailored" for SCM

Pilot Melter CFD Model

- Footprint 55” x 35” stretched octagon
- Bath depth 39” nominal
  - Detailed surface found dynamically by the VOF simulation
- 160,000 finite volume cells





Sectional view of mesh (symmetry plane)

SCM Model Status and FY06 Plans

• Two-phase hydrodynamics	Complete
• Heat transfer - basic version	Complete
• Temperature-dependent viscosity	Complete
• Refined water-cooled walls	Oct-05
• Third phase: batch transport & dissolution	Nov-05
• Combustion and emissions	Dec-05
• Small bubble nucleation & entrainment	Feb-06
• Refined radiation model	Apr-06
• Scale-up plant geometry	Jul-06
• Melt chemistry	Not planned

CFD Goal: Predict Key SCM Metrics

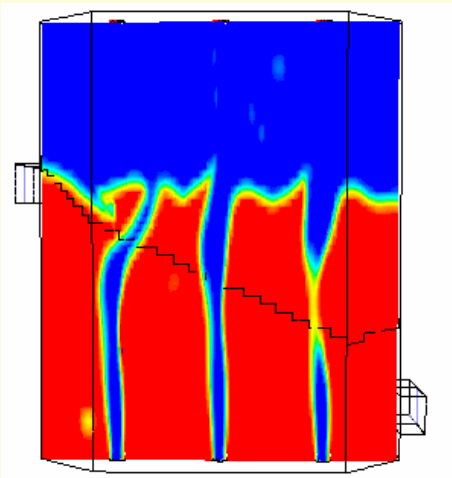
- ✓ Melting intensity: energy use per ton melted output
- ✓ Minimum and average residence time
- ✓ Homogenization index
- ✓ Maximum allowable batch/cullet particle size
- ✓ Bubble content at discharge
- ✓ CO & NO_x emissions per ton melted output

... for both pilot melter and production-scale SCM

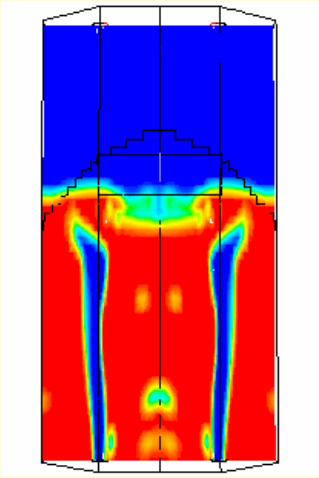
Preliminary Results - Volume Fractions

All cases run by Dr. Grigory Aronchik (GTI)

- 6 burners, 9 MMBth/h total firing rate, uniformly distributed
- (red = glass; blue = combustion gases)



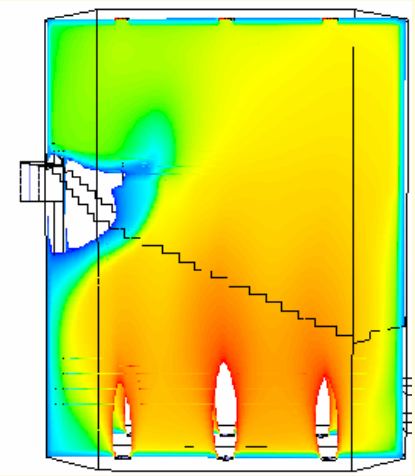
In plane of right column of burners



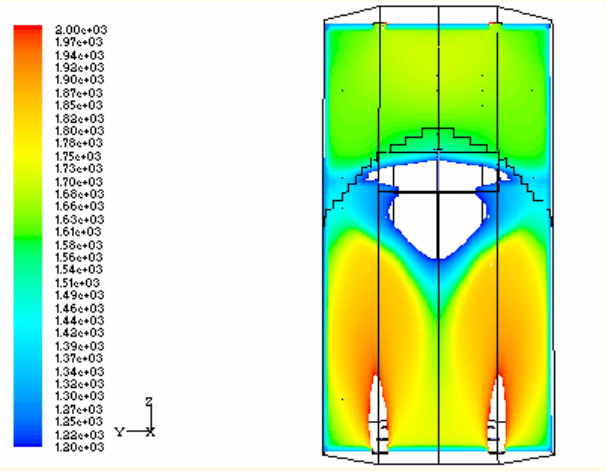
In plane of first row of burners

Preliminary Results - Temperatures

- 6 burners, 9 MMBth/h total firing rate, uniformly distributed
- (white regions are outside selected 1200-2000 K contour band)



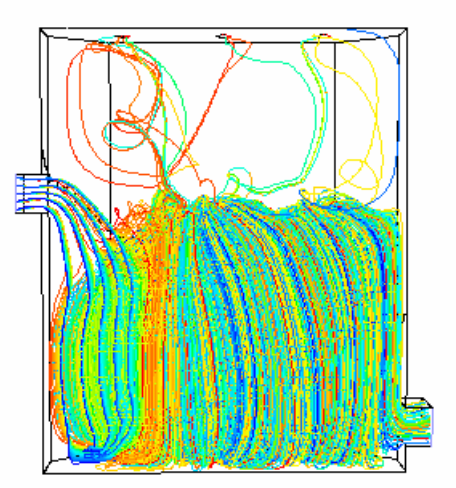
In plane of right column of burners



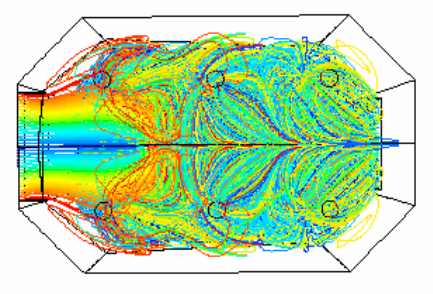
In plane of first row of burners

Preliminary Results - Fluid Pathlines

- 6 burners, 9 MMBth/h total firing rate, uniformly distributed
- (combined liquid and gas paths; color has no significance)



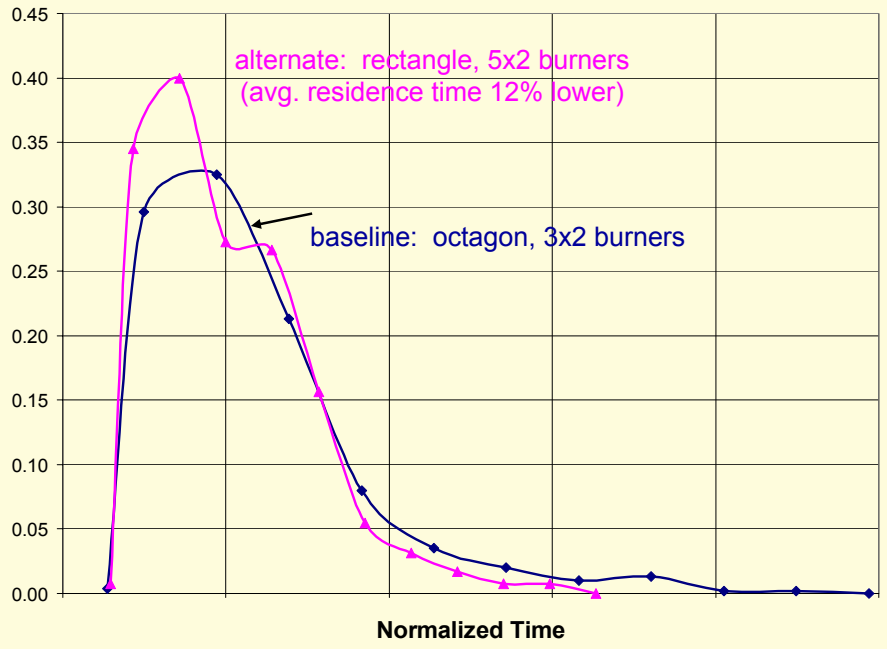
In plane of symmetry



From above

Preliminary Results - Residence Time

- 6 burners, 9 MMBtu/h total firing rate, uniformly distributed

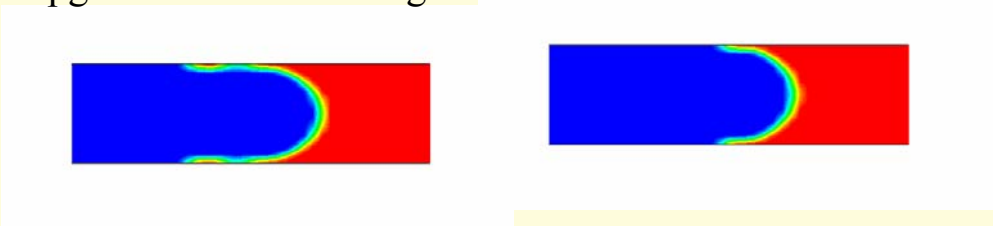


Pilot SCM Design Guidance from CFD

- Stretched octagon helps minimize cold/stagnant zones
- Multiple burners (particularly 3 rows of 2) provide good heat distribution
  - can be operated as 3 pairs slaved together
  - non-uniform firing rate front-to-back may be beneficial
- Physical symmetry appears to improve mixing control
- Minimum separation guidelines to maintain best flow:
- Tap piece should penetrate several inches inside wall to collect well-mixed glass
- Batch preheating and introduction details may have significant effects - further investigation needed

CFD Code Enhancements

- Faster time integration scheme for multiphase solver
- VOF method improvement for high μ (CICSAM scheme)
- Radiation speedup for highly absorptive media (novel coupling between radiation and energy equations)
- Framework combining radiation models with Eulerian multiphase
- Compressible formulation of dispersed phase (e.g., effect of hydrostatic head on bubbles for deep baths)
- Upgraded conventional glass batch UDF to FLUENT Version 6



VOF reconstruction of a high-viscosity free surface at a wall:
left - FLUENT 6.2 (current release); right - CICSAM prototype

CFD Technology Transfer Plans

- All FLUENT enhancements prototyped in this project will be subsequently "mainstreamed" for a future commercially-released version
  - Most GMIC members already actively using FLUENT
- Publications planned showcasing validation
- Documentation and training materials will be developed in FY06 to support the industry in further SCM development

4

Final Project Evaluation Presentations

Measurement and Control of Glass Feedstocks

Arel Weisberg, Ph.D.
Robert De Saro
Joseph Craparo, Ph.D.
James Simpson, Ph.D.

Energy Research Company

2005 OIT Glass Project Review

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Participants in Glass Project

- DOE Industrial Technologies Program – Industries of the Future: Glass
- Energy Research Company
- PPG Industries (Fiber Glass)
- Fenton Art Glass
- Oak Ridge National Laboratory

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

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PPG

FENTON
Handcrafted American Glass Artistry

OAK RIDGE NATIONAL LABORATORY

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PPG at Ohio Showcase

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Batch Measurements at PPG

PPG Product Manager Kevin Streicher Operating ERCo LIBS Batch Sensor

Chester Fiber Glass Plant

Test Sample (blind)	Boron Concentration Difference
A	0.00 %
A	0.03 %
B	0.24 %
B	0.30 %

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Project Summary

- Goal: Develop a plant instrument for rapidly measuring oxides in batch materials
- Challenge: Bringing LIBS technology from the lab to the plant with the accompanying issues of accuracy, robustness, ease of use, and low maintenance
- Benefits: Reduction in product defects. Energy savings of 2.1 trillion Btu per year worth $10 million. Carbon Reduction of 0.03 MMTCe
- FY05 Activities: Long term testing of instrument at PPG fiber glass plant while continuing to upgrade the instrument's capabilities

Barrier-Pathway Approach

- Barriers
  - Using LIBS to measure many elements rapidly and simultaneously with widely varying concentrations (fractions of % to tens of %)
  - Ruggedizing LIBS for plant environment
    - Ease of use, low maintenance
- Pathway
  - State-of-the-art LIBS hardware components
  - Innovative software algorithms
  - Complete automation
- Critical Metrics
  - 5% relative error or 0.05% absolute error in concentration measurements

Use of LIBS

- Measure Individual Batch Components for Elemental Consistency
- Measure Batch Segregation
- On-Line, Off-Line

Glass Segments

- Container (SIC 3221, NAICS 327213) – Food, beverage, and pharmaceutical applications.
- Flat (SIC 3211, NAICS 327211) – Sheet, plate, and various forms of rolled glass, mostly for vehicle and building applications.
- Fiberglass (SIC 3296) – Fiberglass for insulation, textiles, and optics.
- Pressed and Blown (SIC 3229, NAICS 327212) – Lamp enclosures, bulbs, tubing, flat displays, etc.
- Mineral Wool (SIC 3296, NAICS 327993) – Insulation

- In 2001, the American glass industry's shipments were $28 billion,
- Purchased energy cost of $1.8 billion.
- Fiber production 17% of that, or $4.76 billion
- Glass manufacturing facilities are concentrated in Ohio, Pennsylvania, California and North Carolina,

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Market Potential

Glass Manufacturing Market

USA &Canada Fiberglass Shipmnts (Annual in $ Mil.)	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
USA &Canada Annual Production (Thousands Tons)	4,994	5,094	5,298	5,456	5,620	5,789	5,962	6,141
USA & Canada	1,960	2,000	2,080	2,142	2,207	2,273	2,341	2,411
Number of Plants:								
USA	37	37	38	39	40	42	43	44
Canada	N/A	6	6	6	6	7	7	7
Total		43	44	45	46	49	50	51
Number of Furnaces:								
USA & Canada	58	64	67	69	71	73	75	77

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C-LESS™ LIBS Software

- ERCo has Proprietary Software Using First Principles that Translates LIBS Spectra into Concentration Measurements
- Calibration Not Required
- Method is Automatic – no user assistance necessary
- Method Applies to both Molten and Solid Data
- Method is Independent of Experimental Parameters that Can Fluctuate such as Laser Power

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Accomplishments

- Built Full Scale Sensor
  - Automated & Robust LIBS Hardware
  - Developed "1-click" LIBS Software
- Installation and Testing at PPG
  - Extensive ulexite testing
  - Limestone residue testing
  - Commercial Installation August 2004
  - Upgrades for clay, colemanite, silica, and Baghouse Dust

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Accomplishments

- Applied Advanced Calibration-less (C-LESS™) LIBS Analysis to Batch Materials
- Demonstrated LIBS Utility for Cullet Sorting
- Measured Molten Glass Composition
- Related Funded Work in:
  - Coal
  - Aluminum
  - Steel
  - Alloy sorting

Problem Statement

- The Glass Industry Technology Roadmap emphasizes this need for accurate process and feedstock sensors (p. 12):

  "The lack of effective in-process sensors and control systems is the most serious barrier to better production efficiency."

Problem Statement

- Lack of Effective Way to Ensure Accurate Batch Oxide Concentrations
  - An indeterminate mixture of prior deliveries to a silo exits the silo
- Oxide Fluctuations Lead to
  - Wasted Feedstock
  - Quality Problems
  - Increased Energy Use and Emissions
  - Wasted Product

Benefits for PPG

- Knowledge of batch oxides is expected to significantly improve plant efficiency leading to:
  - Energy savings
  - Material savings
  - Overall financial savings
- Result: Payback on the instrument less than 1 year

Goal

- Develop a plant instrument for rapidly measuring oxides in batch materials

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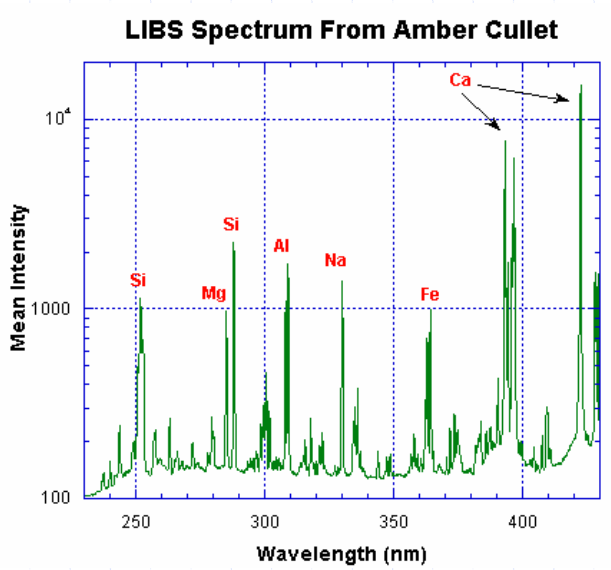
LIBS Technology



Spectrometer gathers the plasma light and spreads it, like a prism, into a spectrum where the contribution of each element can be seen

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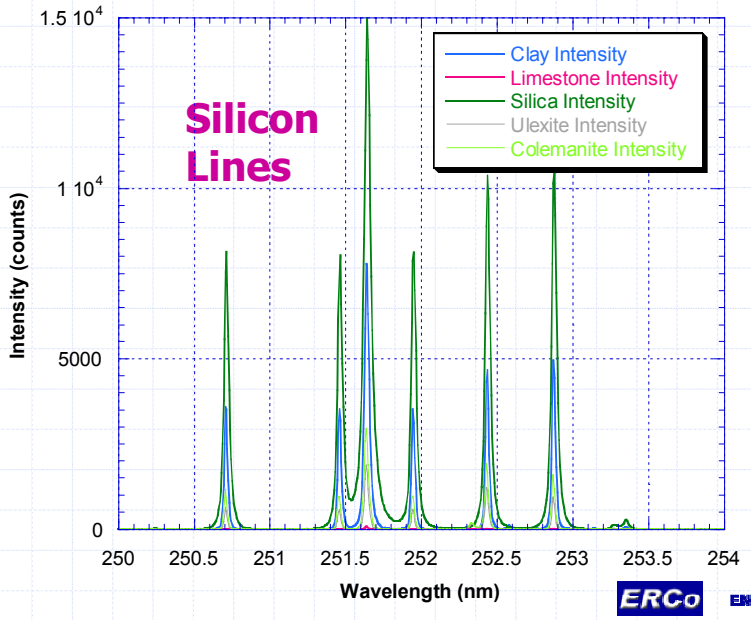
Batch Constituents

- LIBS Spectra Collected from Each Sample



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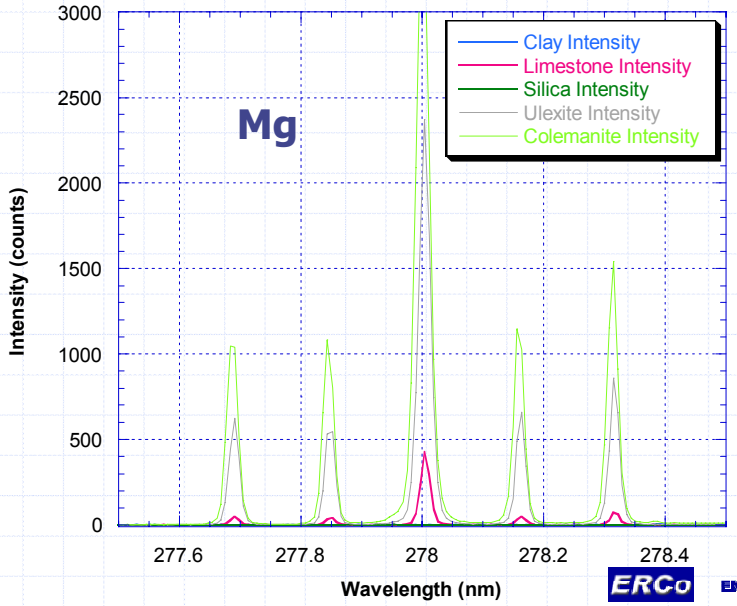
Batch Constituents

- LIBS Spectra Collected from Each Sample



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LIBS Advantages

- Fast
  - A few minutes to perform a complete elemental analysis
- Accurate
  - Fractions of a percent to ppm
- Applicable to a wide range of materials
  - Glass, Batch
  - Metals, other solids, liquids, gases
- Proven
  - Extensive literature on use of the process in lab environments
  - **ERCo's** LIBS installation in aluminum plant production line

Experimental Results

- Apparatus and method
- Concentration measurements from PPG on-site test

Apparatus

- PPG requested an off-line analyzer
  - Ability to measure more than one material more important than continuous operation
    - Batch minerals such as ulexite, clay, limestone, silica
    - Limestone residue from scrubber system
  - Batch materials likely not varying within any one 24 hour period
  - Potential for analysis of glass "buttons" in same instrument

ERCo LIBS Batch Analyzer at PPG's Chester Plant

- Laser
  - Big Sky Laser ULTRA-CFR, 1064nm
  - Up to 20 Hz , 50 mJ
  - Industrial Design
  - Low Maintenance
- Spectrometer
  - LLA ESA 3000
  - 200-850nm Echelle
  - $\lambda/\delta\lambda$=40,000

ERCo LIBS Batch Analyzer

- Sample Chamber
  - Contains laser head, motorized stages, and detection optics
  - Samples consist of a few grams on custom holder and placed inside the chamber door
- Completely Computer Controlled
- Laser light is contained – Eye Safe
- Low Maintenance

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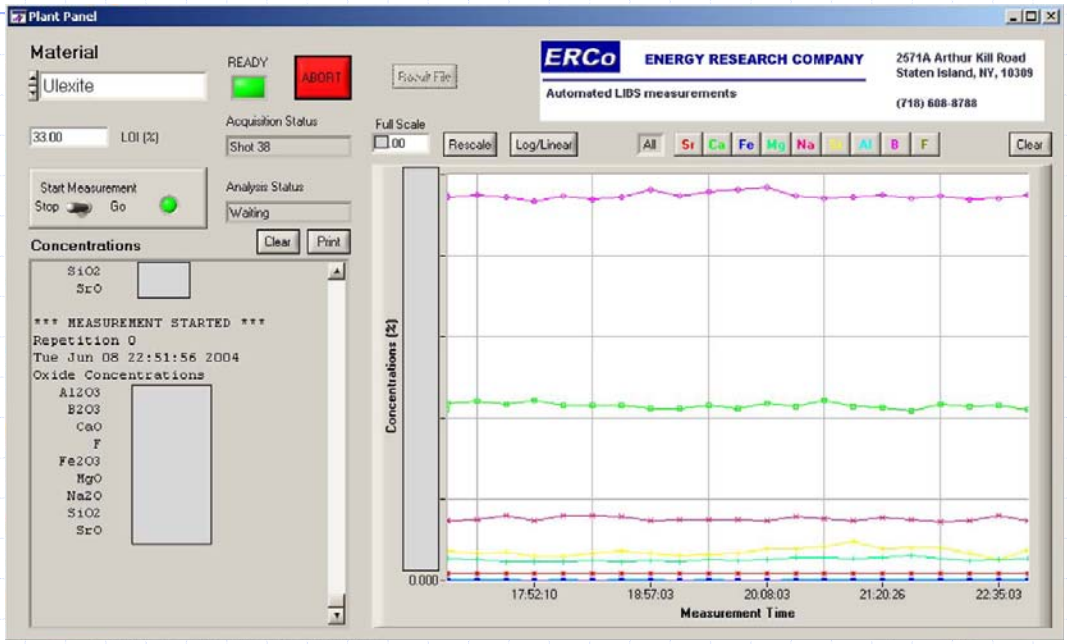
ERCo LIBS Batch Analyzer



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Materials

- Materials choice determined by PPG
  - Single batch ingredient analysis more useful than mixed batch analysis
  - Ulexite is the top priority material
  - Limestone used in scrubber system is next most important

» Sensor will analyze all of PPG's materials of interest

PPG Testing Program

- Ulexite samples provided by PPG together with compositional analyses prior to testing
  - 3 different mine locations
  - Samples from same mine location illustrative of variability in shipments
  - Each delivery to PPG sampled only once by mining company

PPG Chester Test Results

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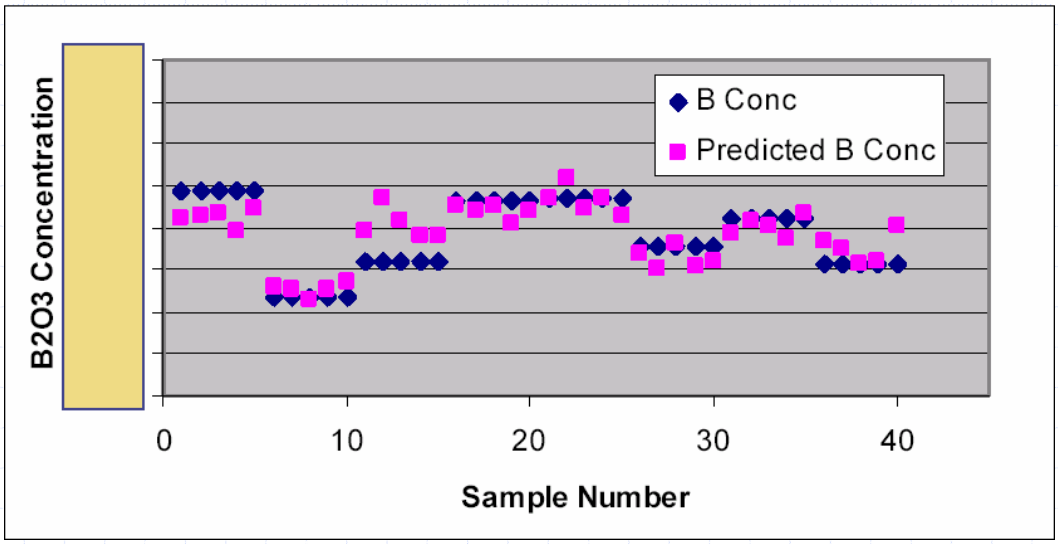
Boron



Average difference: 0.54% ± 0.43%

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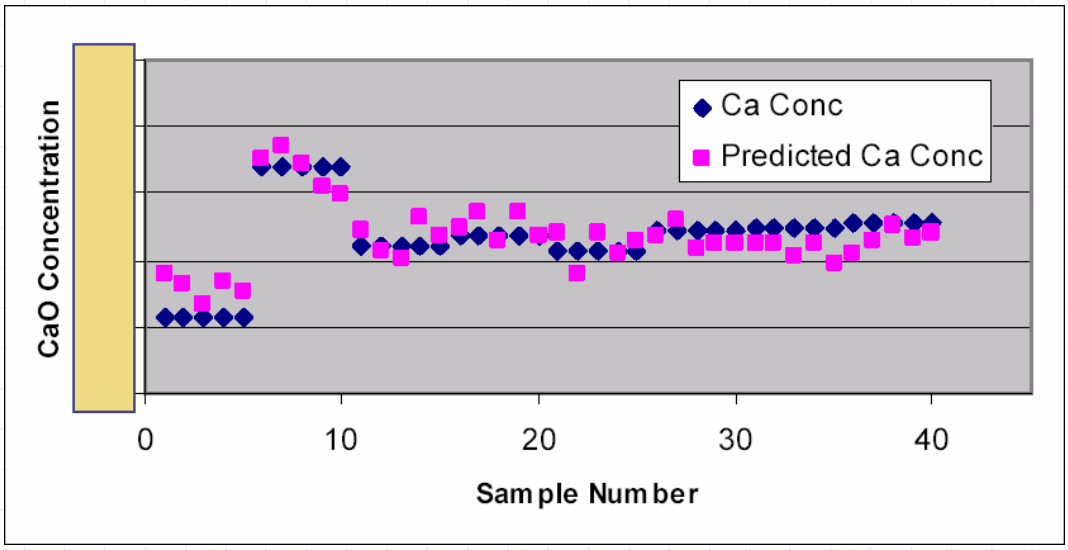
Calcium



Average difference: 1.51% ± 0.94%

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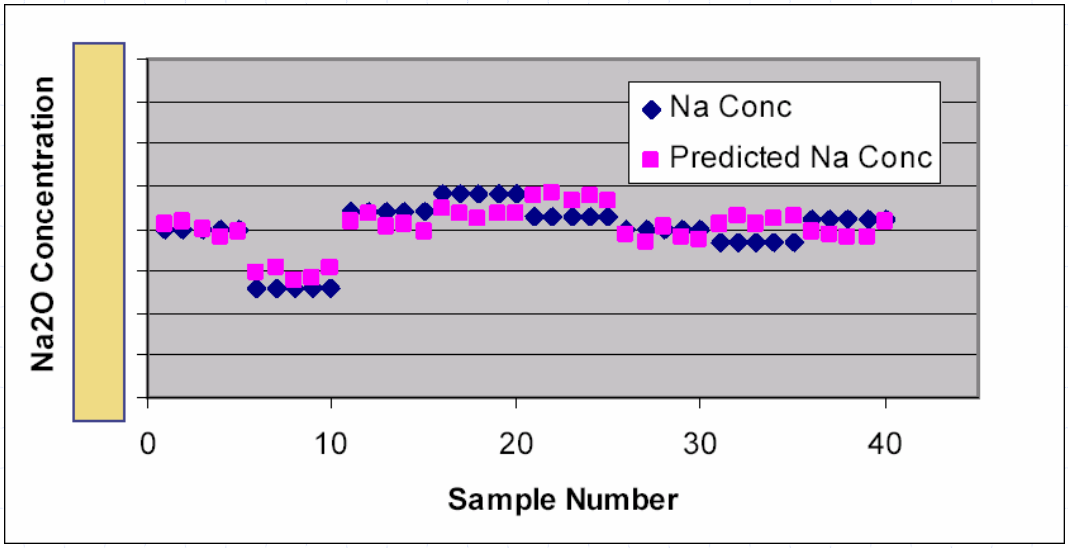
Sodium



Average difference: 2.75% ± 1.34%

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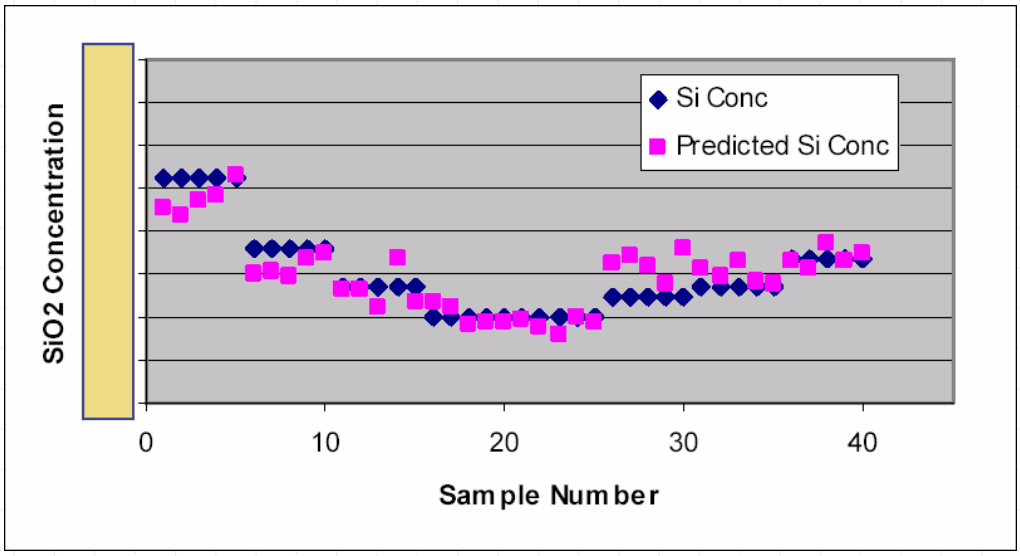
Silicon



Average difference: 4.98% ± 4.02%

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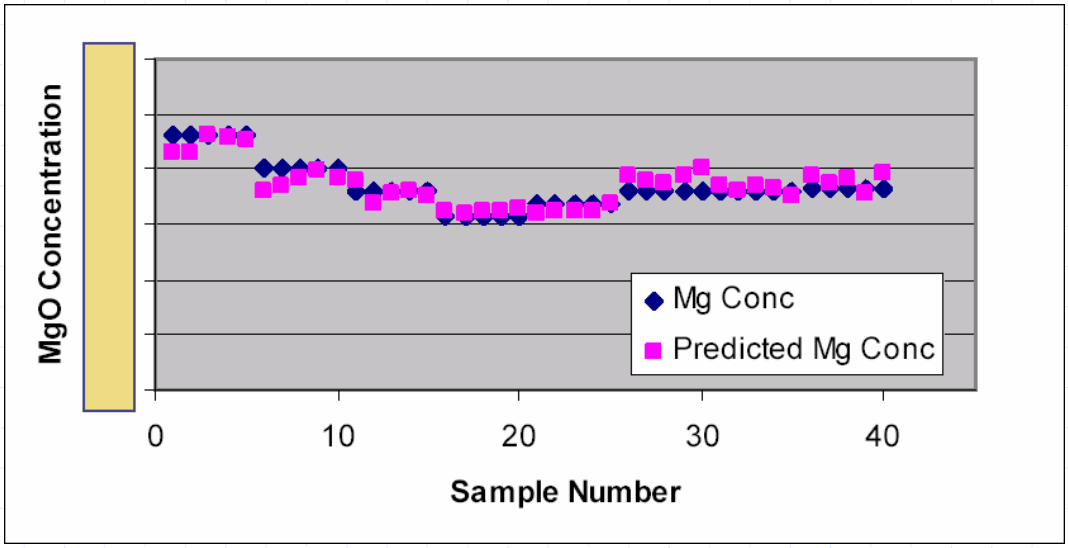
Magnesium



Average difference: 4.06% ± 2.72%

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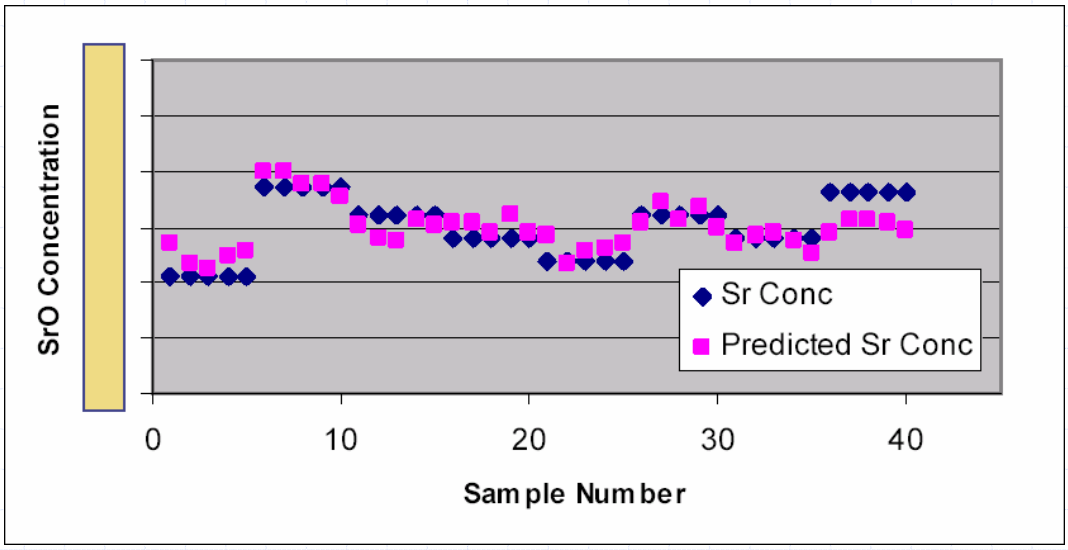
Strontium



Average difference: 0.026% ± 0.018%

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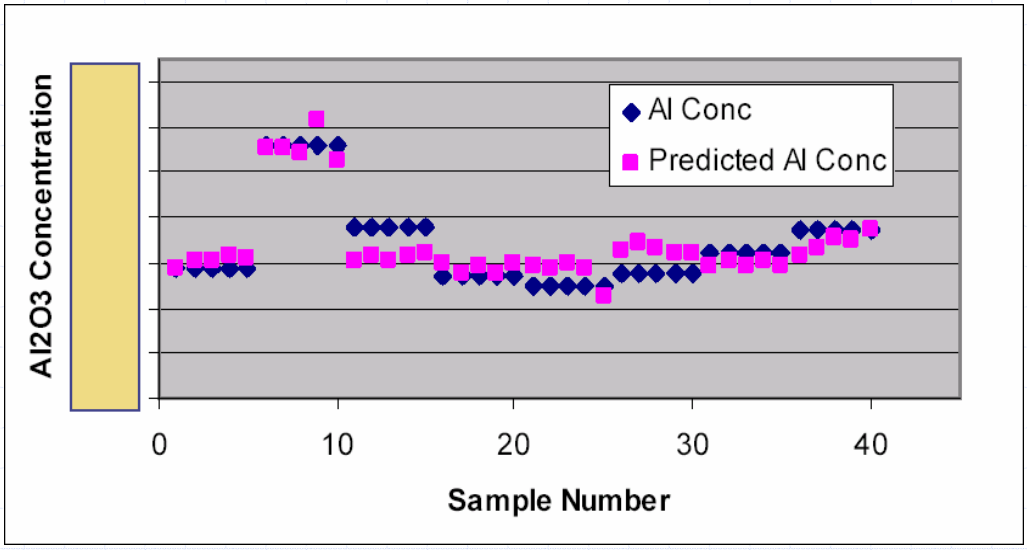
Aluminum



Average difference: 0.007% ± 0.004%

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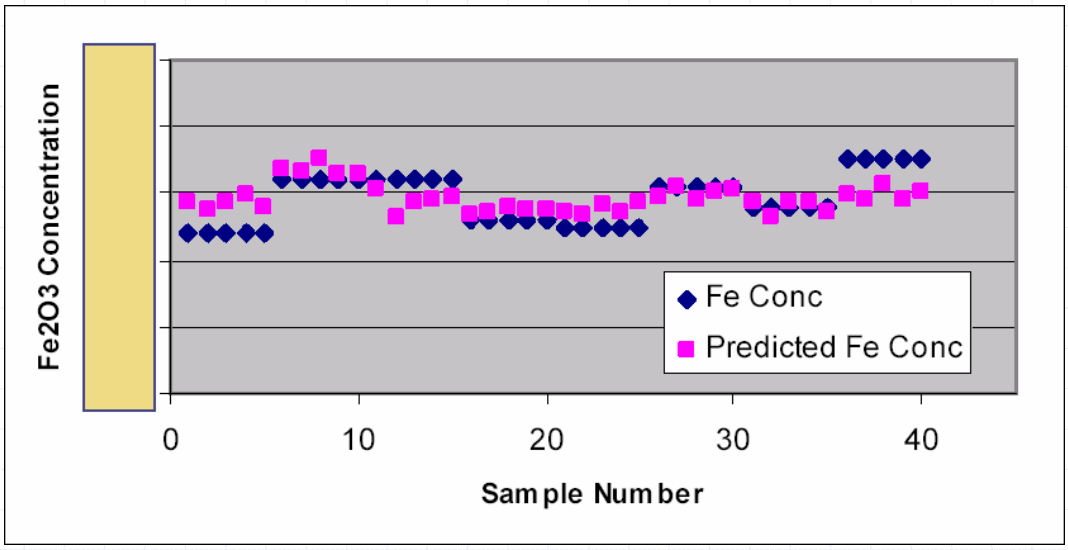
Iron



Average difference: 0.003% ± 0.002%

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"Blind" Ulexite Samples

- Samples A & B analyzed twice
- 0.3% change or variability in boron measurement not significant

Test Sample (blind)	Boron Concentration Difference
A	0.00 %
A	0.03 %
B	0.24 %
B	0.30 %

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PPG Test Summary

- Equipment successfully transported and installed
- Sensor operation is reliable
  - Operating for Over One Year
- PPG personnel satisfied with accuracy, repeatability, ease of use
- "Blind" tests successful

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Clay Results (% difference)

El.	A	B	C	D	E	Avg.
Si	0.21	2.64	2.64	2.16	2.37	**2.00**
Al	0.10	1.38	0.65	1.42	1.93	**1.10**
Ti	0.13	0.04	0.04	0.37	0.23	**0.16**
Fe	0.08	0.01	0.09	0.09	0.06	**0.07**
Na	0.03	0.03	0.03	0.03	0.03	**0.03**

Major Minor

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Silica Results (% difference)

El.	A	B	C	D	E	Avg.
Si	0.10	0.20	0.23	0.18	0.18	**0.18**
Al	0.05	0.02	0.04	0.01	0.01	**0.03**
Ti	0.01	0.01	0.01	0.00	0.00	**0.03**
Fe	0.01	0.02	0.02	0.00	0.00	**0.01**

Major Minor

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Limestone Results (% difference)

El.	A	B	C	D	E	Avg
C	1.28	0.62	1.54	1.59	0.09	**1.02**
Ca	0.26	0.09	0.57	0.41	0.18	**0.30**
Mg	0.00	0.00	0.01	0.01	0.00	**0.00**
Al	0.01	0.01	0.00	0.01	0.01	**0.01**
Si	0.08	0.07	0.10	0.10	0.13	**0.10**
Fe	0.00	0.00	0.01	0.04	0.02	**0.01**

Major Minor

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Future Interest

- Measure Concentrations of Molten Glass in Tank in Real-Time, In-Situ
- NYSERDA seed money received towards a furnace suitable for extensive molten glass LIBS work
- I&I Money Received for Laboratory Molten Glass Testing

Molten Glass Data

Element	Range Reported	Of Values	Measured by LIBS	Result	% Outside Range
Si	62.96	61.51	61.01	Good	0.81
Na	29.67	20.72	24.9	Good	
Ca	5.36	3.46	4.8	Good	
Mg	2.71	2.42	2.85	Out	5.2
Ba	4.66	0.00	4.79	Out	2.8
Fe	0.04	0.020	0.02	Good	
Sr	0.04	0.00	0.03	Good	
Mn	0.1	0.00	0.08	Good	

Industrial Installation

- Molten Aluminum LIBS Probe Installation at Commonwealth Aluminum Newport Rolling Mill

LIBS Sensor for Molten Aluminum

Commercial Installation

- Industrial Cabinet

- Sealed, Air Conditioned, EMI Shielded

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Molten Aluminum Concentrations

Aluminum Alloy 3105

	Al	Cu	Fe	Mg	Mn	Si	Cr
LIBS Average	97.87	0.17	0.65	0.47	0.52	0.28	0.04
Commonwealth Average	97.56	0.18	0.65	0.49	0.56	0.30	0.05
% Difference	0.32	5.6	0.0	4.1	7.1	6.7	20.0
LIBS RSD	0.09	5.0	4.87	11.61	4.54	6.29	5.52
Commonwealth RSD	0.03	3.51	3.65	1.53	3.57	2.25	2.17

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Discussion and Conclusions

- ERCo's LIBS Batch Analyzer proven in role as rapid glass batch analysis
- Follow on testing and upgrades to continue in FY05
- Oxide concentrations in PPG batch and other materials measured using ERCo's C-LESS™ method
- Molten glass preliminary concentration measurements successful

Commercialization Plans

- Intellectual Property Consisting of Issued Patent and Trade Secrets
- Business Plan Completed
- ERCo will Spin Off New Company for Marketing and Selling LIBS Instruments to the Aluminum, Glass, and Coal-Fired Power Plant Industries

Monitoring of Alkali Volatilization and Batch Carryover in Glass-Melting Furnaces

Chris Shaddix, Linda Blevins†, Alejandro Molina, and Shane Sickafoose

Sandia National Labs
Livermore, CA

Peter Walsh
University of Alabama Birmingham
Birmingham, AL

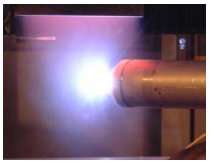
John Neufeld
Gallo Glass Company
Modesto, CA

† on assignment to National Science Foundation

Alkali Volatilization and Batch Carryover: Project Summary

Goal

- use LIBS to monitor volatilized alkali and batch carryover in oxy-fuel furnace
- determine optimum conditions for minimizing alkali volatilization and batch carryover and maximizing furnace efficiency



Challenges

- LIBS never previously used in high-temperature, fume-laden gases
- LIBS never previously used to measure carryover particles in fume
- complex chemistry and heat and mass transfer in furnace clouds cause/effect relationships

Benefits

- reduced crown corrosion rates
- reduced batch losses and flue particle loading
- increased furnace efficiency

Participants

- Sandia National Labs
- Gallo Glass Co.
- UAB

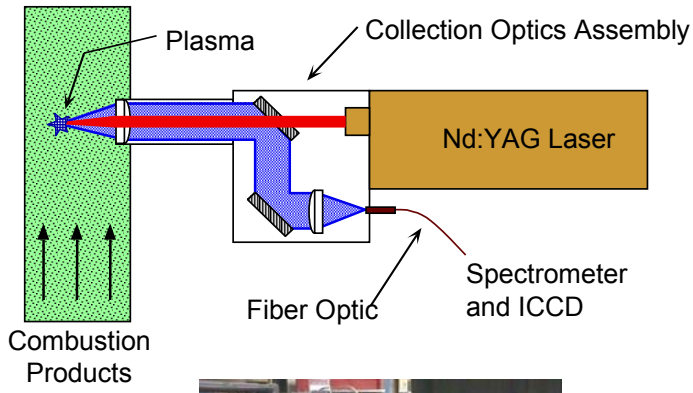
FY05 Activities

- determine effects of gas temperature and composition on LIBS signals
- complete analysis of June 2004 measurement campaign
- write final project report(s)

Sandia National Laboratories

CRF

Measurement Approach: LIBS



- use high-power, pulsed laser to create spark (microplasma) in flue gas (Nd:YAG laser: 1.06 μm, 5 Hz, 400 mJ/pulse)
- detect ionic or elemental emission intensity as spark collapses (τ = 1-80 μs)
- quantify elemental concentration based on emission intensity

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Supplementary Measurement: μ-GC

- compact on-line gas analysis system that can measure O_2, N_2, and CO_2
- requires calibration bottles, extractive gas sampling, ice bath, particle filter, and DAQ system

Sandia National Laboratories

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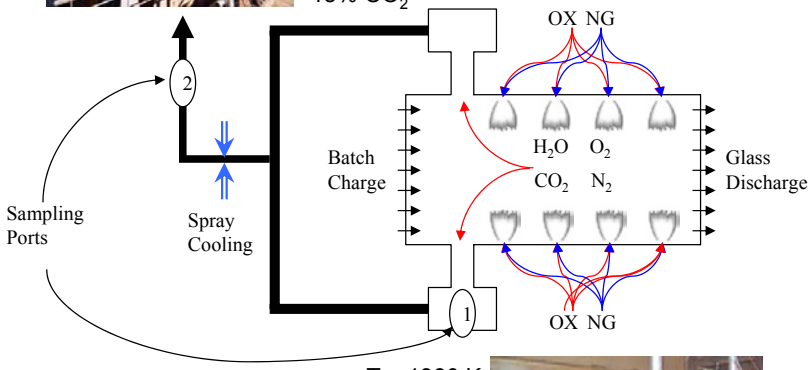
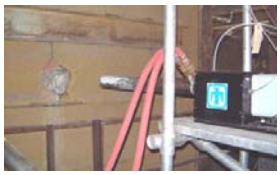
Measurement Campaigns: Gallo Tank #1

T = 720 K
v = 31 m/s
39% H_2O
6% O_2
39% N_2
15% CO_2



T = 1380 K
v = 0.8 m/s
40% H_2O
3% O_2
24% N_2
32% CO_2



- sampling performed near bottom of vertical flue and in downstream exhaust
- downstream position has cooler gas, but is diluted from spray cooling and has some metals added from water spray

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Measurement Campaigns: Gallo Tank #1

Date	Pull Rate (t/day)	O/G (indicated)	Heat Release Rate (MW)	% Boost
Dec 2001	430	2.16	15.2	14.6
June 2002	336, 435	2.12	12.0, 14.9	13.2
May 2003	322, 405	1.98-2.18	11.3-13.9	13.7-15.6
June 2004	325, 270,375	2.00-2.13	13.1-14.8	12.6-14.6

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Technical Findings of Project: LIBS

- Probe design
  - External water jacket and internal water cooling required for sampling in high-T flue
  - well-positioned purge jets required to keep lens clean at small enough flow to avoid disturbance of probe volume
- Alkali atom interference
  - under high-temperature, even slightly fuel-rich conditions, enough Na and K atoms are present in furnace exhaust to absorb LIBS line emission
  - avoid this interference by measuring at lower temperatures or assuring oxidative conditions
- LIBS of sodium fume
  - high Na concentrations produce some self-absorption in the LIBS spark
  - calibration plot needs to be generated at high Na loading to measure the falloff in response

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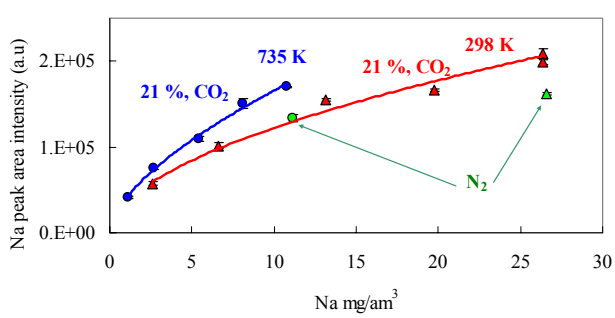
Technical Findings of Project: LIBS

- Effect of gas T and gas composition on alkali LIBS
  - traditionally gas T and gas composition thought to be inconsequential to metal LIBS signals
  - alkali metals, with low ionization potential, are detected at long delay times from the spark initiation (typ. τ_{delay} = 10 µs)
  - lab measurements show that alkali LIBS signals are dependent on initial gas density (i.e., temperature) and CO_2 content (because of CO_2's ability to form low-ionization potential fragments)



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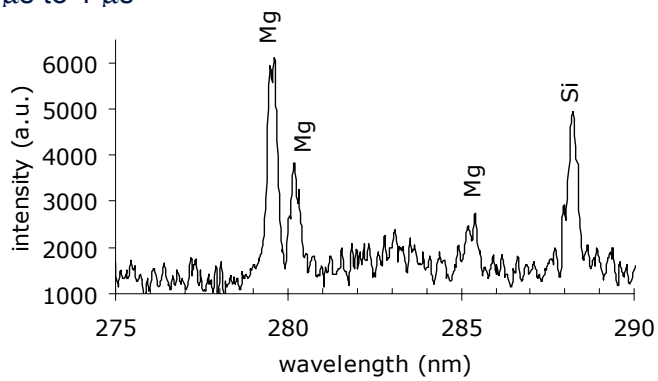
Technical Findings of Project: LIBS

- Carryover Detection
  - single-shot LIBS analysis shows carryover particles contain Ca (limestone), Si (sand), Mg (dolomite), or Al (contaminant)
  - Mg and Si are good indicator elements for carryover and occur in same LIBS spectral region
  - detectability of particles is improved by reducing the detector gate delay from 10 μs to 1 μs



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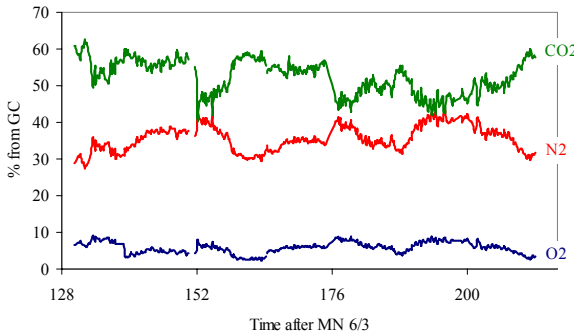
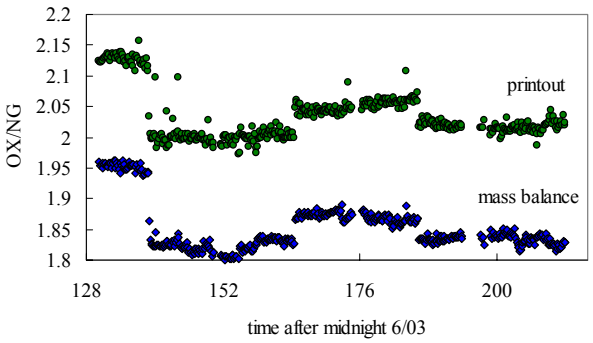
Technical Findings of Project: μ-GC Gas Analysis

- with measurements of O_2, N_2, and CO_2, can use furnace mass balancing to calculate actual O_2/NG firing ratio and amount of air infiltration (in real-time)
- useful for optimizing furnace efficiency and minimizing crown refractory corrosion





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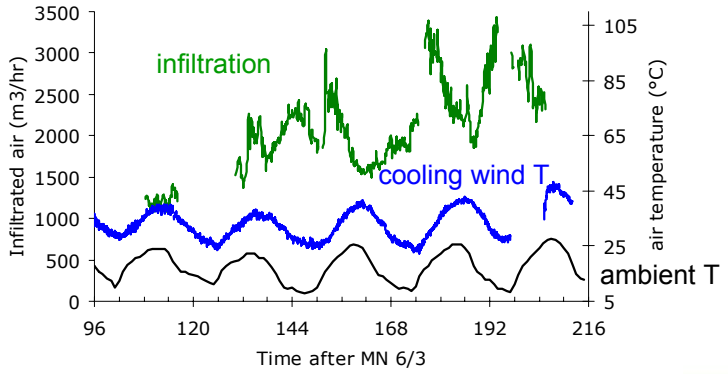
Technical Findings of Project: Air Infiltration

- Air infiltration complicates interpretation of measurements
  - difficult to know how much of the infiltration occurs in flue duct, downstream of furnace
  - apparent exhaust stoichiometry is not the as-fired stoichiometry, nor the effective in-furnace stoichiometry
  - what are local effects of air infiltration in the furnace?
- Amount of air infiltration varies strongly with ambient temperature



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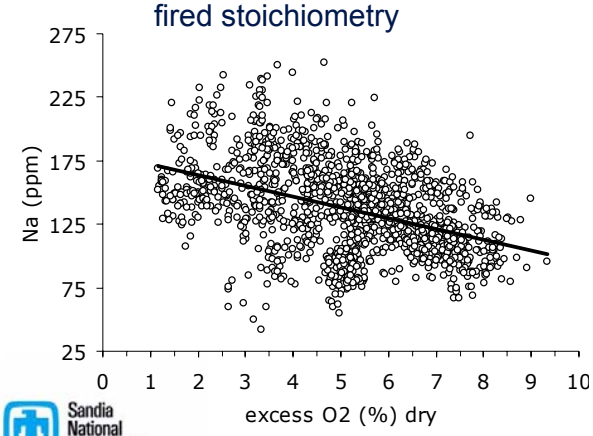
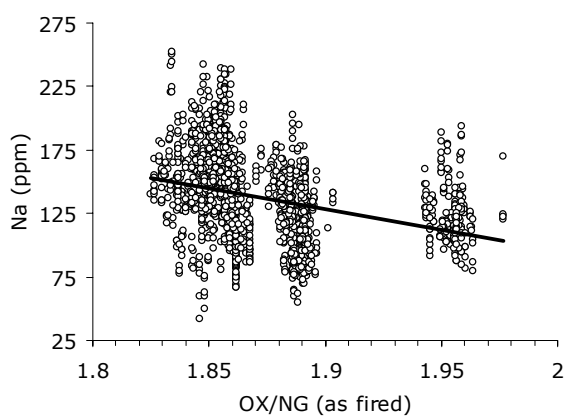
Major Results: Alkali Concentrations and Stoichiometry

- mean Na concentration of ~ 150 ppm
- Na and K concentrations, after correction for air infiltration, correlates with gas composition (80-hour measurement period)
  - higher oxygen concentration decreases Na concentration
  - correlates for both effective stoichiometry (with air infiltration) and for as-fired stoichiometry





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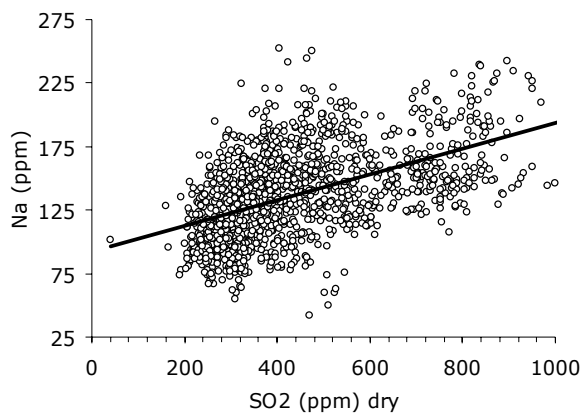
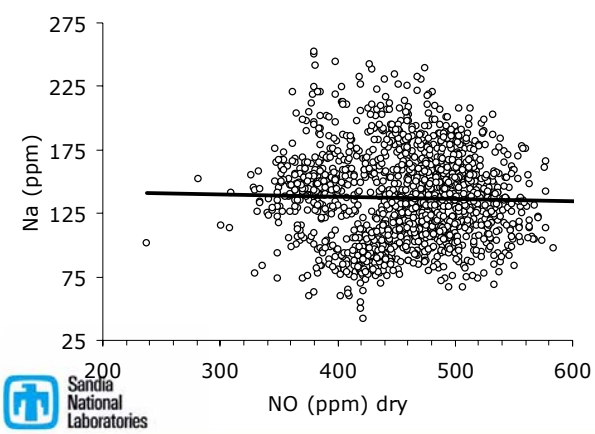
Major Results: Alkali Concentrations and SO2

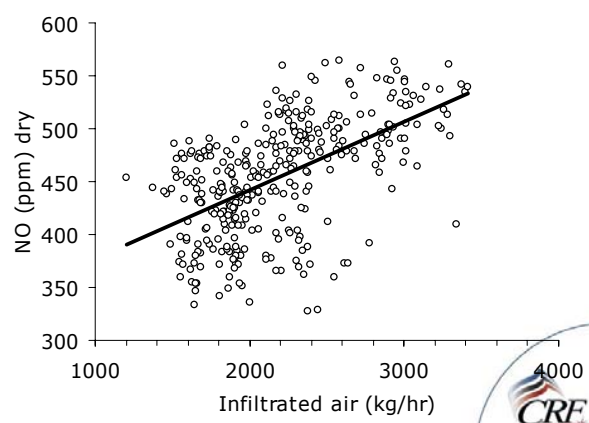
- Na concentration increases for higher SO_2 concentrations
- Similar results for potassium



Major Results: NOx

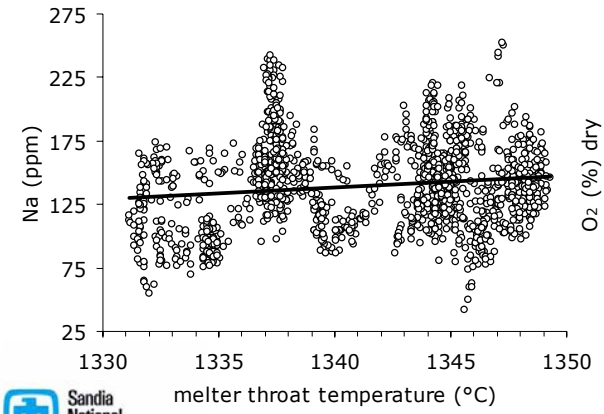
- Dilution by air infiltration does not explain variation in Na concentration with O_2 and SO_2:
  - magnitude of Na variation too high to be explained just by dilution
  - Na concentration **does not** correlate with NO concentration
- NO concentration correlates with air infiltration

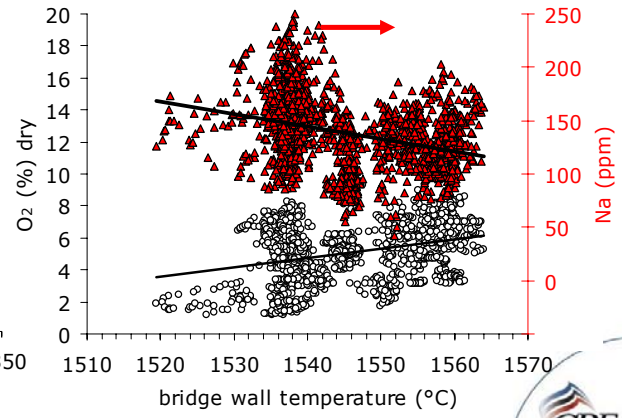




Major Results: Alkali Concentrations and Furnace Temp

- For the relatively small variation in temperature observed in the test, correlation of Na concentration with temperature seems less important than with stoichiometry:
  - melter throat temperature shows minor correlation of Na and temperature
  - bridge wall shows interaction with oxygen concentration





Major Results: Alkali Concentrations - Summary

- Na concentration increases when:
  - O_2 decreases and SO_2 increases
  - weak correlation with furnace temperature
- Results consistent with Thermal Surface Decomposition (TSD) in the batch and chemical vaporization (CV) in the glass

- TSD:

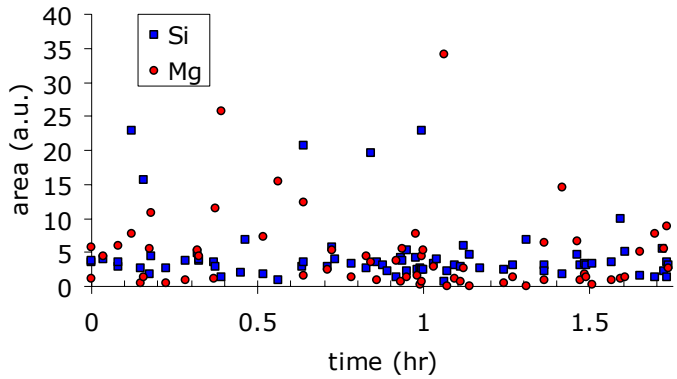
$$\begin{cases} Na_2SO_{4_{s,l}} \leftrightarrow 2Na_{(g)} + SO_{2_{(g)}} + O_2 \\ Na_2SO_{4_{s,l}} \leftrightarrow Na_2O_{(g)} + SO_{2_{(g)}} + \frac{1}{2}O_2 \\ Na_2O_{(melt)} \leftrightarrow Na_{(g)} + \frac{1}{2}O_2 \end{cases}$$

- CV:

$$\begin{cases} Na_2SO_{4_{s,l}} + H_2O \leftrightarrow 2NaOH_{(g)} + SO_{2_{(g)}} + \frac{1}{2}O_2 \\ CO + Na_2SO_{4_{s,l}} \leftrightarrow Na_2O_{(g)} + SO_{2_{(g)}} + CO_2 \\ CO + Na_2O_{(melt)} \leftrightarrow Na_{(g)} + CO_2 \end{cases}$$

Major Results: Batch Carryover

- Reductions in furnace pressure dramatically increase batch carryover
  - 0.01" water column decrease in furnace pressure increases carryover by 150%
- Magnesium- and silicon-containing particles are almost equally represented in the carryover



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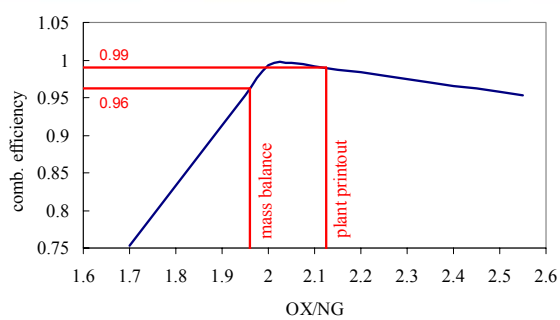
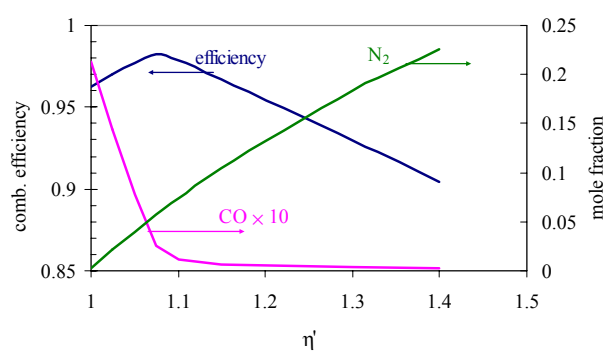
Major Results: Energy Efficiency

- Indicated O_2/NG isn't actual O_2/NG as-fired, resulting in some efficiency loss



- In general, air infiltration decreases energy efficiency, because of heating of N_2 and any excess O_2



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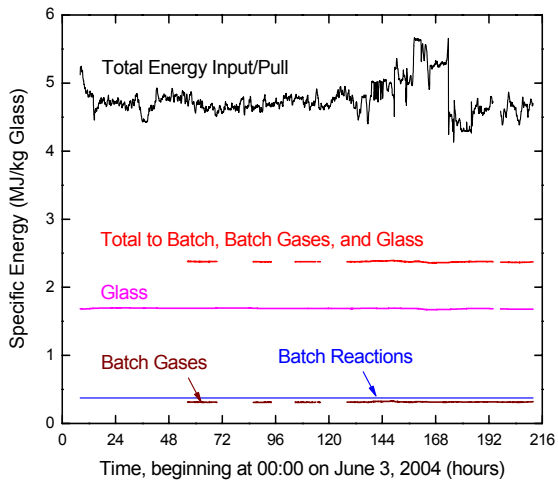
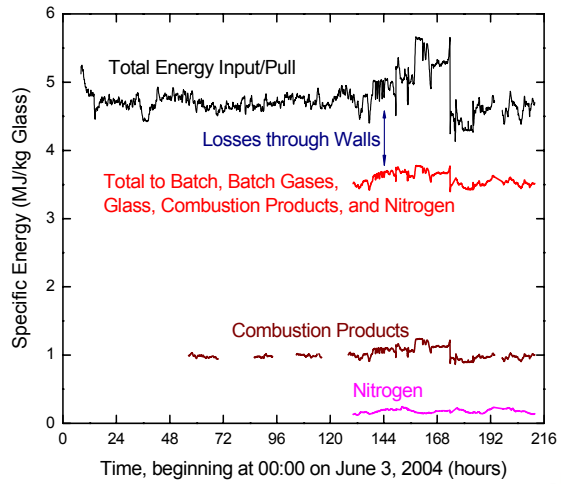
Major Results: Furnace Energy Balance, 2004 Campaign





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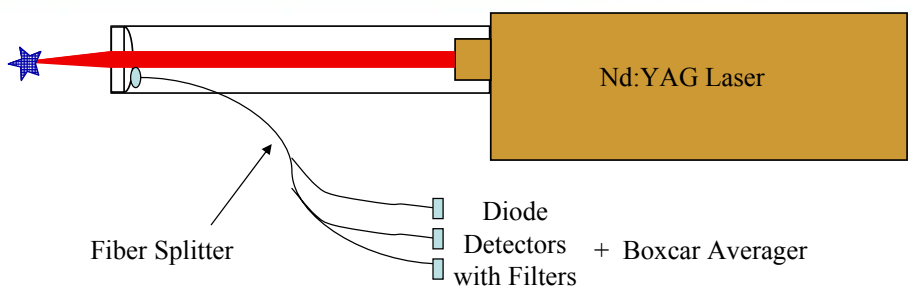
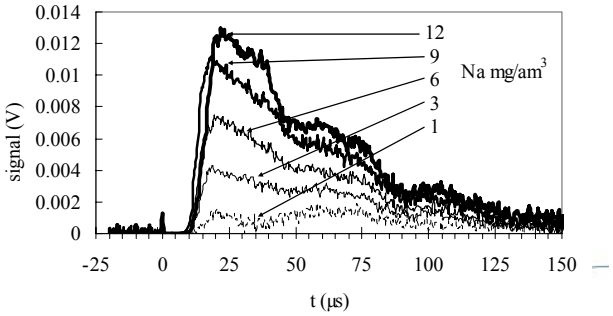
Major Results: Lower-Cost LIBS Monitor



filter

+

photo detector



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Project Outputs/Tech Transfer

- Conference Presentations
- Journal Articles
  - *Applied Optics* (2)
  - *Spectrochimica Acta Part B: Atomic Spectroscopy*
  - *J. Institute of Energy*
- Final Project Report (SAND report)
- Furnace Efficiency Report (SAND report)

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Acknowledgments

- DOE
  - *Elliott Levine*
- Gallo Glass
  - *Doug Moore*
  - *plant staff*
- Sandia National Labs
  - *Doug Scott*
  - *Gary Hubbard*
  - *Howard Johnsen*
  - *Bob Steinhaus*
  - *Bob Gallagher*
  - *Jim Wang*
  - *Jay Keller*

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

Development/Demonstration of an Advanced Oxy Fuel Front End System

Sept 15, 2005
Chicago

Steve Mighton
(740) 321-7633
steve.mighton@owenscorning.com

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

Development/Demonstration of an Advanced Oxy Fuel Front End System

Goal: Develop an oxy/fuel combustion system for a glass manufacturing front end that **reduces energy consumption by 65-70%** creating net operating savings, acceptable capital return and lowered emissions. Demonstrate the first full scale installation.

Challenge: Use fewer burners than previous schemes to reduce capital cost. Design a burner that avoids overheating problems, given that the small gas flows provide little cooling

Benefits: Lower operating costs and emissions.

End-User Applications: Front ends in certain glass manufacturing sectors.

FY06 Activities: Reduce NOx emissions, improve burner reliability, set up commercialization structure.

Participants: BOC, Eclipse, Owens Corning, Osram Sylvania

Development/Demonstration of an Advanced Oxy Fuel Front End System

Barrier-Pathway Approach

Barriers

- Low efficiency of air/gas burners for glass refining
- High cost of one for one-for-one replacement oxy-gas burners
- Low gas flows produce little cooling

Pathways

- Development of low cost burner and flow metering system
- Modeling to develop and design retrofit TE generators for implementation in waste heat stacks
- Economic analysis for implementation TE technology

Critical Metrics

- Gas consumption reduction of 65 – 70 %
- No adverse impact on production efficiency

Benefits (est.)	2020
Energy Savings	12 trillion Btu
Cost Savings	$60 million
Carbon Reduction	0.17 MMTCe

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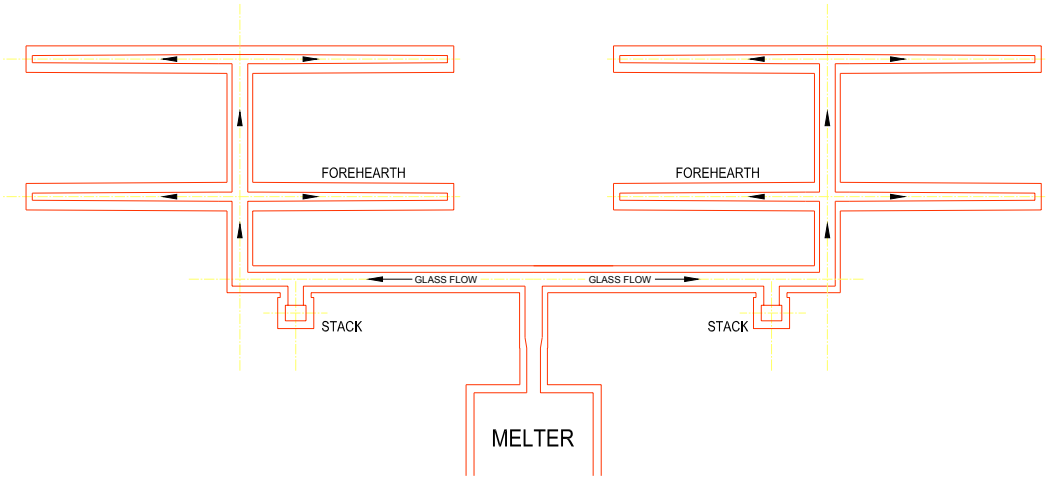
Energy Efficiency and Renewable Energy

Oxy-fuel Fired Front End System



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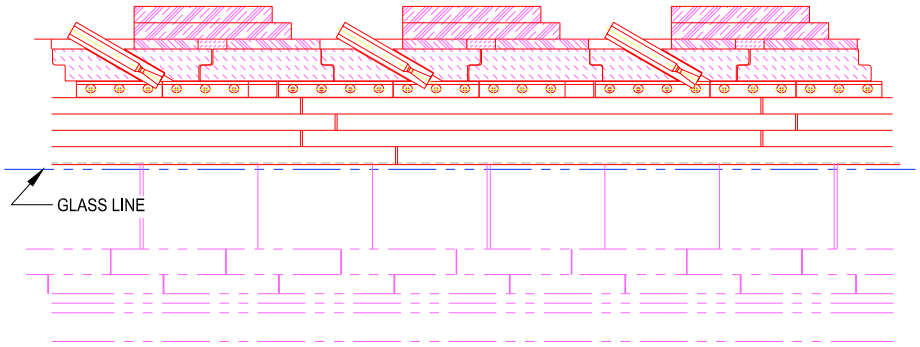
Oxy-fuel Fired Front End System



SECTION ON CENTERLINE

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Energy Efficiency and Renewable Energy

Oxy-fuel Fired Front-end System

Background:

- **Gas Energy Usage Distribution in Our Process**

Oxy-fuel Furnace	=	47%
Air-Fuel Front-end System	=	53%

- **Current Air-Fuel Technology:** Low Energy Efficiency = ~25%
  Massive Piping & Control Systems

- **Prior oxy-fuel front end conversion trials have not led to significant proliferation due to high capital cost**

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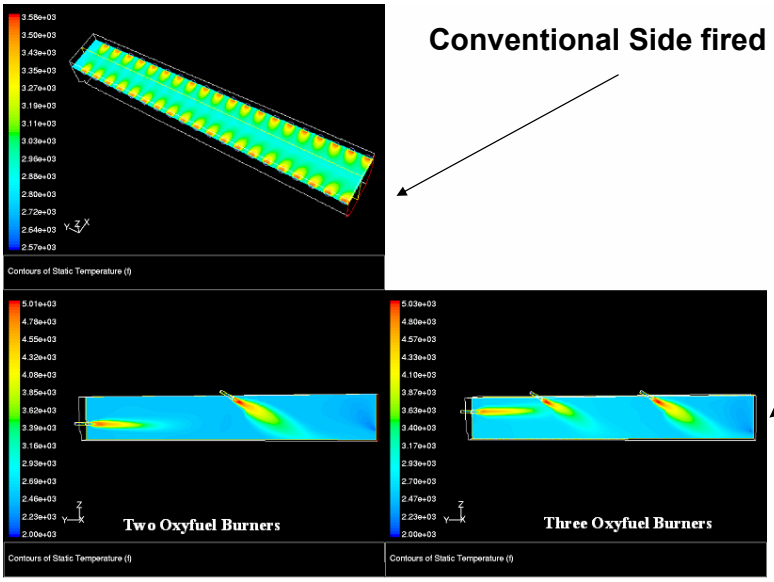
Energy Efficiency and Renewable Energy

Oxy-fuel Fired Front-end System

BOC ECLIPSE Innovative Thermal Solutions OWENS CORNING SYLVANIA



Conventional Side fired Air Gas

Top Fired Oxy-Fuel

Section through forehearth

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Oxy-fuel Fired Front-end System

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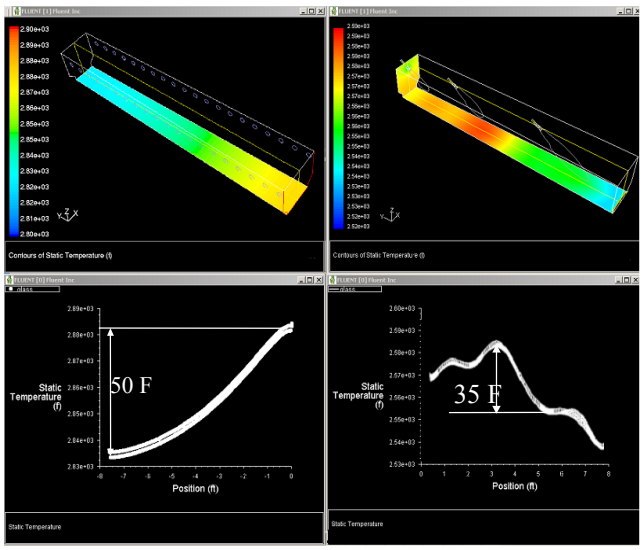
Air- Fuel Oxy Fuel

Top Fired Oxy Fuel

Fewer burners but improved distribution of energy (smaller thermal gradient)



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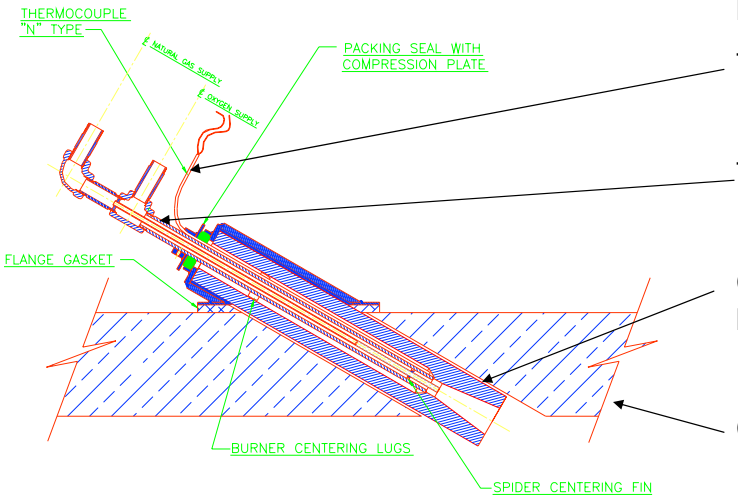
Oxy-fuel Fired Front End System



Burner and block hardware:

- Thermocouple
- Tube in tube burner
- Cylindrical burner block
- Cover tile with hole

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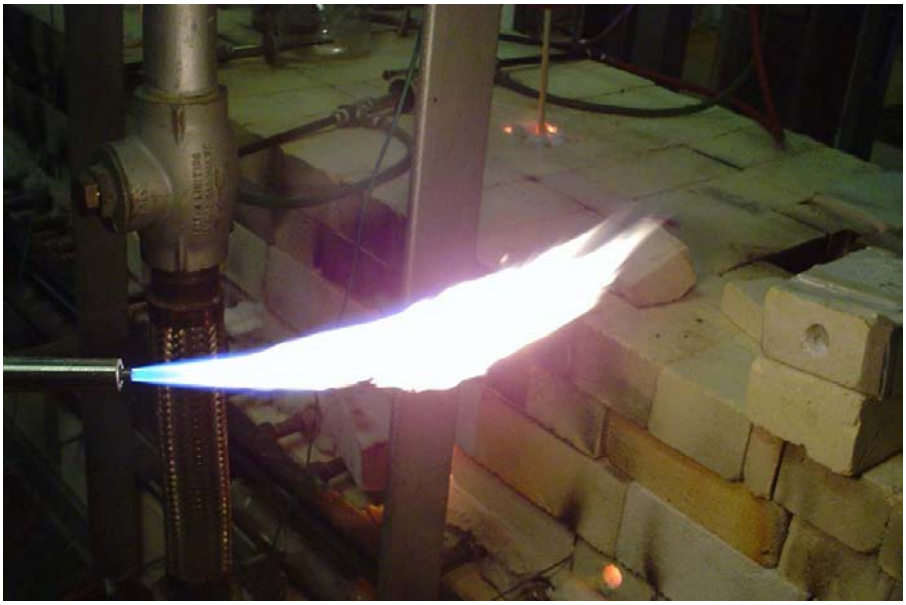
Oxy-fuel Fired Front End System



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Oxy-fuel Fired Front End System

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Top fired front end oxy/gas burners at OC Jackson plant

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Oxy-fuel Fired Front End System

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Consortium review of equipment in Jackson, Dec /04

Oxy-fuel Fired Front End System

Financial Targets @ 65% target consumption reduction

Installation Costs (no development or refractory)	**$850,000**
Gas Consumption Annual Savings	**$464,000**
based on:	**$6/DT Gas cost**
	65% reduction in gas used
	after paying for on site O2
Payback	**1.8 yr**

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Oxy-fuel Fired Front End System

Plant	Front End Nat. Gas Used	**Reduction in Nat. Gas Used**	Front End Total Energy Used *	**Reduction in Total Energy Used**	**Energy Saved**	**Cost Savings****
	[DT/hr]	**[%]**	[DT/hr]	**[%]**	**[DT/yr]**	**[$/yr]**
Target Natural Gas Energy Reduction		**65-70**				
Jackson TN Air/gas (Mar 04) Oxy/gas (Dec04)	16.5 7.3	**56**	16.6 7.9	**53**	**77,000**	**$333,000**

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Oxy-fuel Fired Front End System

Plant	Front End Nat. Gas Used	**Reduction in Nat. Gas Used**	Front End Total Energy Used *	**Reduction in Total Energy Used**	**Energy Saved**	**Cost Savings****
	[DT/hr]	**[%]**	[DT/hr]	**[%]**	**[DT/yr]**	**[$/yr]**
Target Natural Gas Energy Reduction		**65-70**				
Jackson TN						
Air/gas (Mar 04)	16.5		16.6			
Oxy/gas (Dec04)	7.3	**56**	7.9	**53**	**77,000**	**$333,000**
Guelph ON						
Air/gas (Mar 05)	24.9		25.1			
Oxy/gas (Apr 05)	9	**64**	9.8	**61**	**135,000**	**$513,000**

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Oxy-fuel Fired Front End System

Financial Results with Actual 53% consumption reduction

Installation Costs (no development or refractory) **$1,028,000**

Gas Consumption Annual Savings * **$333,000**

based on: **$7.2/DT Gas cost**

53% reduction ** in gas used

*** after paying for on site O2**

**** base consumption adjusted for different glass formulation change (hotter glass)**

Payback (probably conservative) **3.1 yr**

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Oxy-fuel Fired Front End System

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Financial Results with revised 64% consumption reduction

Installation Costs (no development or refractory)	**$1,028,000**
Gas Consumption Annual Savings *	**$458,000**

based on: **$7.2/DT Gas cost**

64% reduction ** in gas used

*** after paying for on site O2**

**** second installation achieved 64% reduction,**

no glass formulation change

Payback (estimated) **2.2 yr**

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Oxy-fuel Fired Front End System

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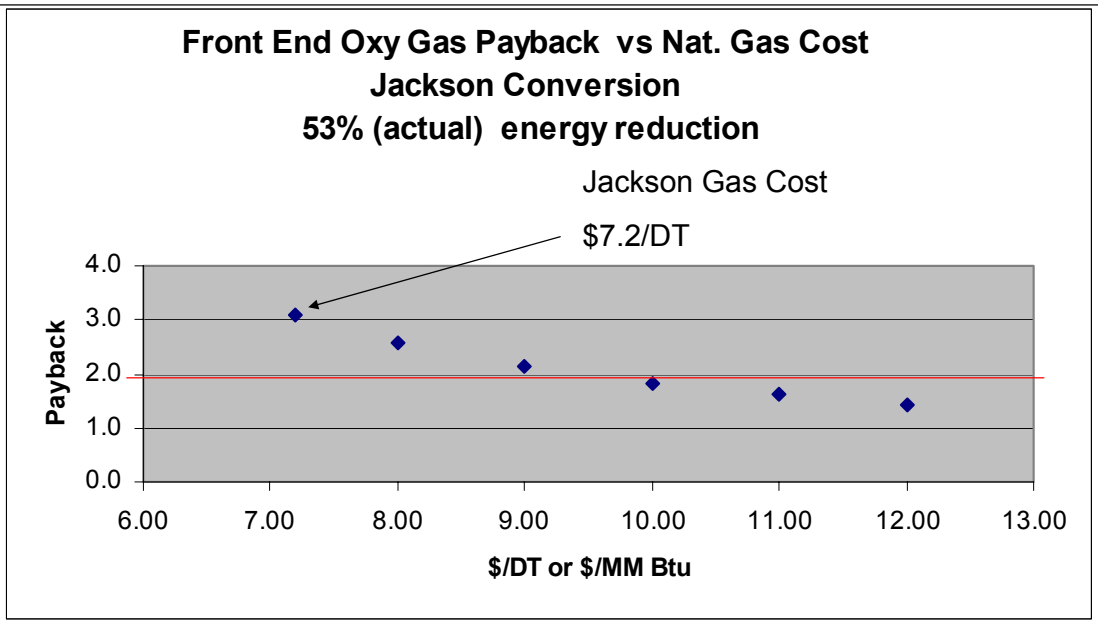

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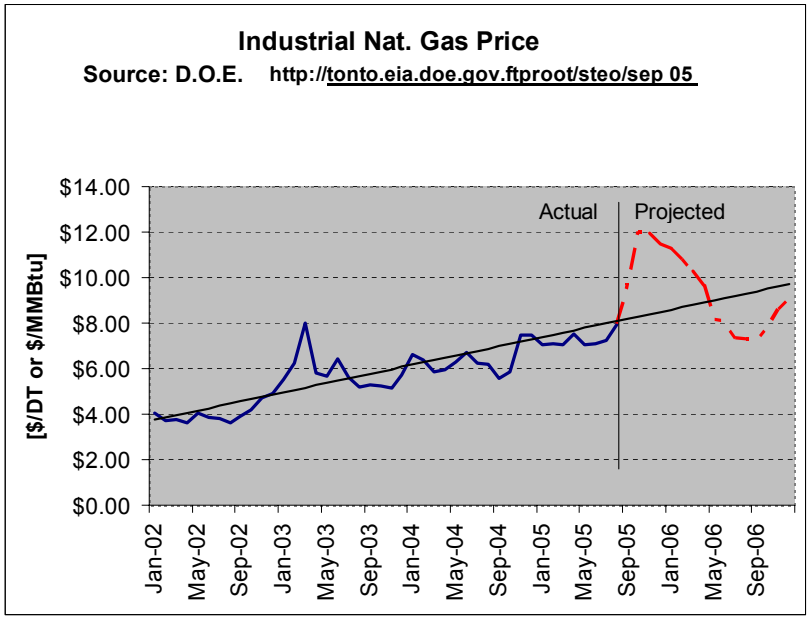
Oxy-fuel Fired Front End System



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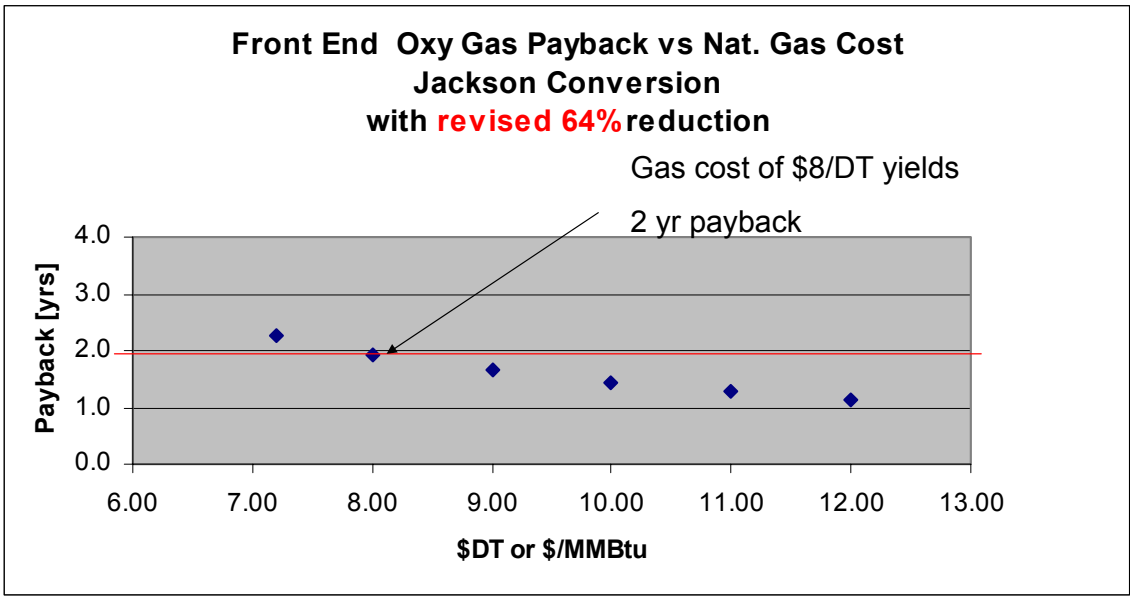
Oxy-fuel Fired Front End System



CO2 Emissions

CO2 emission reduction = gas reduction

= 53 % to 64%

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Oxy-fuel Fired Front End System

NOx Emissions

- Initially 8x to 10x increase
- Jackson melter & frontend combined had net reduction
- After sealing trial, increase dropped to 40%
- Plan to improve sealing, goal is no increase or reduction

Oxy-fuel Fired Front End System

Impact on process

- Reduced thermal gradient (top to bottom)
- No adverse impact on productivity
- Special cause upsets with burner failures

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Oxy-fuel Fired Front End System

Burner failure

- melted refractory and burner

Oxy-fuel Fired Front End System

Technical Challenges:

o Burner seating – retrofit clamp burner to block

o High temperature oxidation of some burners.

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Oxy-fuel Fired Front End System

Financial Caveates:

- O2 cost: onsite O2 cheaper than liquid O2
- Covertile replacement costs additional

Technical Caveates:

- No introduction of air for cooling – creates NOx
- Flame can't impinge on surface

Oxy-fuel Fired Front End System

Work to be done:

o Improved forehearth sealing for lower NOx

o Trial of alternate burner for elimination of high temperature degradation

o Commercialization path – licensing agreement

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Oxy-fuel Fired Front End System

Thank you!

Questions?

Improvement of Performance and Yield of Continuous Glass Fiber Drawing Technology

Simon Rekhson
Cleveland State University
Cleveland, OH

Outline

Project Overview and Summary

Barrier-Pathway-Metrics

Progress to Date

Commercialization Plans

Acknowledgements

- Our industrial partners at PPG and Johns Manville continue to work with us focusing on the transfer of the *T*-meter to the factory floor: some 50 telecons and visits over the course of the project!
- Dr. Chen, Muthoni Koromia, Akash Shah, Rick Bartel and Ugo Nwanya – our post doctorate researcher, graduate and undergraduate students are driving data collection and technology transfer
- Dr. James Leonard of GE lends a hand when we need it

Goal,Challenge,Benefits, FY05 Activities and Participants

•*An Initiative on Cooperative Programs with States for Research, Development and Demonstration*

Goal: Demonstrate a four-fold break reduction and the four-hour run time process on a CSU glass fiber drawing piloting unit

Challenge: Requires a comprehensive process design and validation effort on a better than 6 σ level

Benefits: Eliminates unrecyclable waste and saves energy - more on the next slide

FY05 Activities: Finish process design and validation; demonstrate 0.25 breaks/hour; build the *T*-meter and transfer it to our industrial partners' plants

Prime: Ohio Department of Development
Office of Energy Efficiency
Lead Organization: Cleveland State University, The Glass Forming Consortium
Participating Industrial Partners:
PPG Industries, Johns Manville

Glass Forming Technology Consortium

09/15/05 DOE review

When implemented industry-wide

Glass Forming Technology Consortium

09/15/05 DOE review

Validated process models and industrially representative platforms are key pathways

•*An Initiative on Cooperative Programs with States for Research, Development and Demonstration*

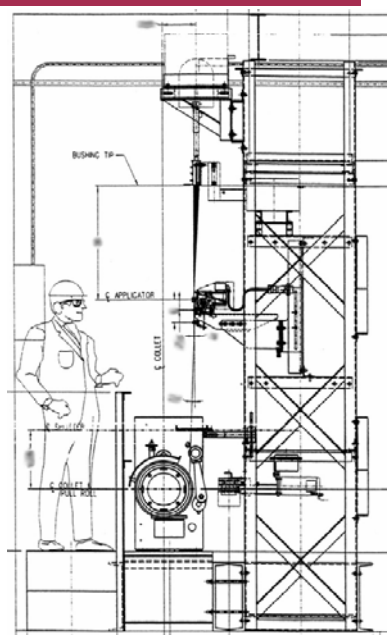
Barrier-Pathway Approach

Barriers	***Pathways***	***Critical Metrics***
• Key quantitative insights into breakage drivers	• Efficient and quantitative computer model that integrates physics and statistics into a capable process design tool	· The model is validated, its fidelity and predictive power are established using break rate data
• A single fiber drawing rig does not exhibit some of the *key* phenomena driving breakage	• Construction of an industrially representative platform for model validation and developing breakage reduction techniques	• Demonstration of reducing breakage from one break per hour to less than 0.25 breaks per hour

Glass Forming Technology Consortium

Continuous Glass Fiber Drawing Unit at CSU

- **The 200-tip = $200K Industrial Unit - continuous glass fiber drawing tower**
- **30KVA (100:1) transformer**
- **6000** amps secondary **current at 4.8 volts**
- **15-40 lb/hr throughput**
- **Winder speed up to 5000 rpm, 250 kmph**
- **Fiber sizes from 6 – 30 μm diam.**



Glass Forming Technology Consortium

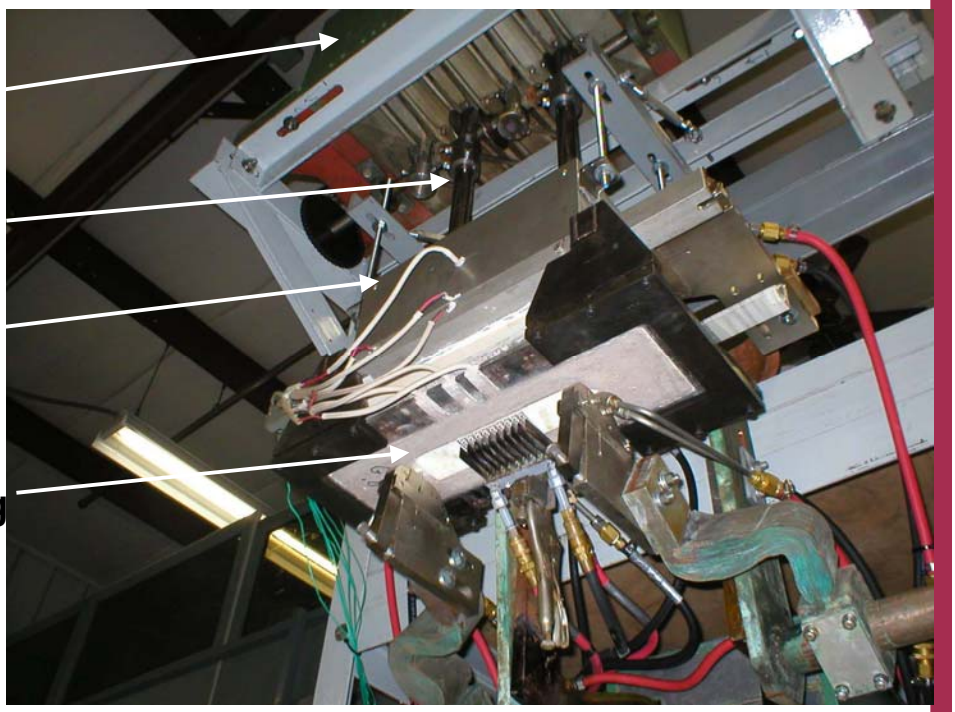
- >1200 operational hours of tests
- >15000 lbs of glass drawn

Glass Forming Technology Consortium

CSU

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

Johns Manville



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

Ohio Department of Development

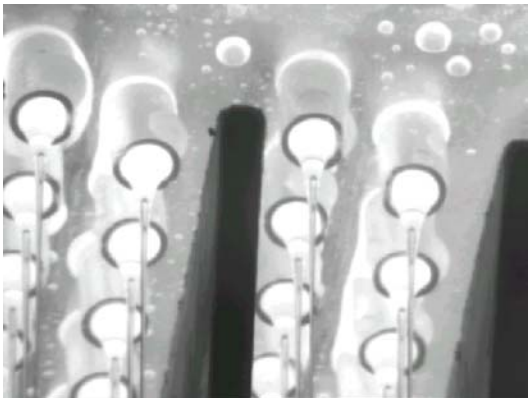
PPG

09/15/05 DOE review

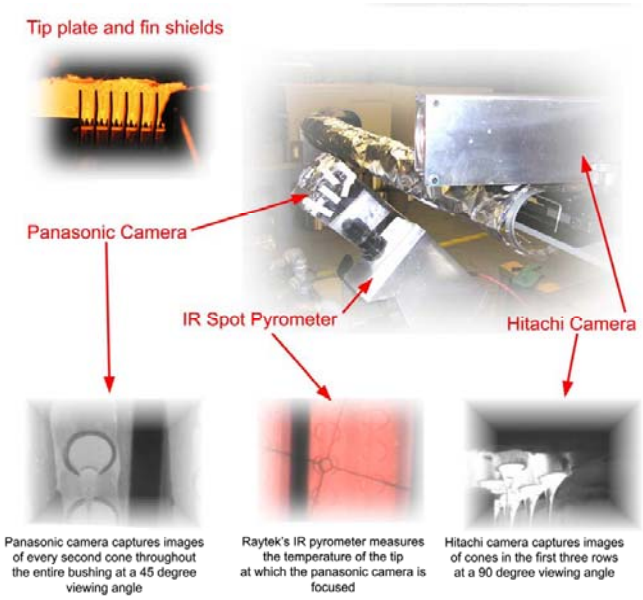
Johns Manville

Process monitoring instrumentation

- Tension – manual, three wheel
- Speed – laser doppler on the bundle continuous
- For cone image monitoring:
  - Hitachi KPM2 CCD camera – straight images in first three rows
- Simultaneous and continuous scanning over the entire bushing for cone shape and temperature
  - Panasonic BP300 and IR spot pyrometer by Raytek, both looking up at 45 degrees
- For cone image monitoring and analysis
  - Matrox for frame grabbing
  - Matlab software for image processing
- Nuclear Level Gauge – continuous feedback to melter



Process Monitoring Instrumentation, cont'd



BREAK RATE PREDICTION

Stress on each filament: $$\sigma_i = 11.3 V_L \frac{\eta_{@\text{tip}}}{L_{@500\text{mkm}}}$$

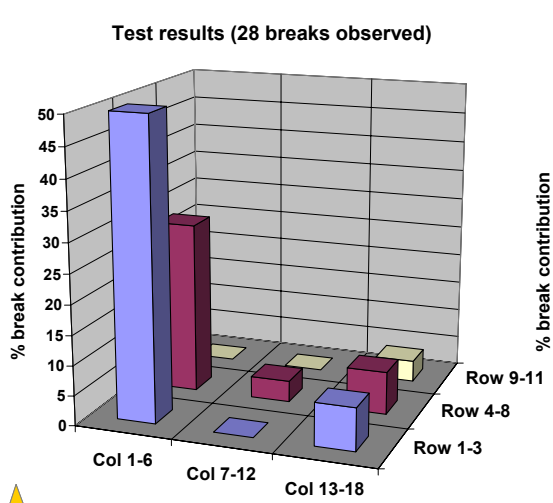
$$\text{breaks/hour} = 3600 \sum_{i=1}^{\text{number of tips}} NV \left(\frac{\sigma_i}{\sigma_0} \right)^m$$

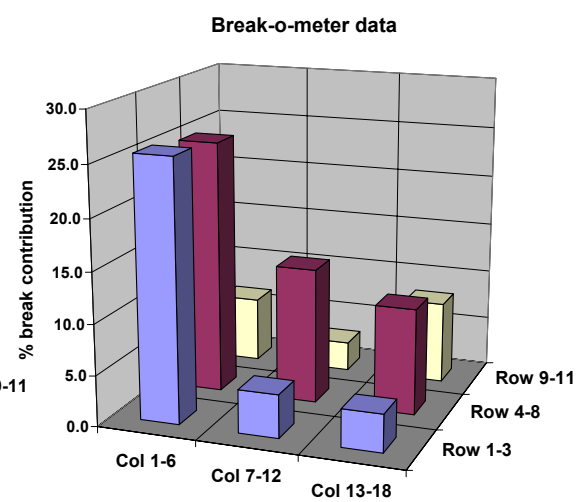
N = 0.5 parts per meter
V = 50 m/s, winder speed
σ_0, m = Weibull strength and modulus

Glass Forming Technology Consortium

09/15/05 DOE review

Is our break-o-meter capable?
(Expt#21, 2175 F, 3445 RPM, Fin 0)
(Observed break rate ≈ 10 breaks/hr)



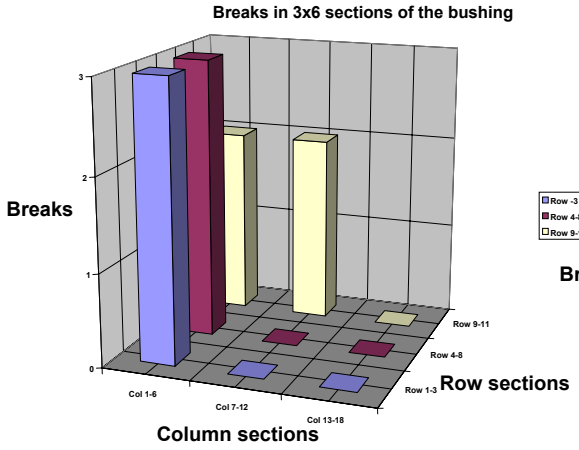


Glass Forming Technology Consortium

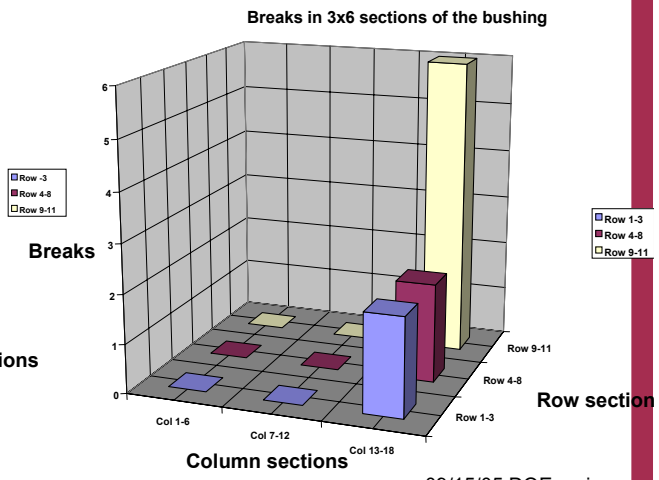
09/15/05 DOE review

Main Effects Tests: cooling fins orientation

Fins overlap tips by +1/16" on the left side of the bushing



Fins overlap tips by +1/16" on the right side of the bushing



Glass Forming Technology Consortium

09/15/05 DOE review

Key knobs to control breakage level: set point temperature and fins translation – prior work

Three level, three factor Box-Behnken design

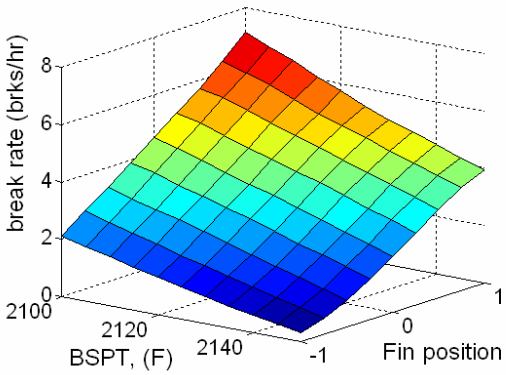
- Bushing set points = 2100 - 2150 F
- Winder speeds = 1200 - 3200 RPM
- Fin positions = 1.5 mm up, even w/ tip, 1.5 mm down

Transfer function derived and validated

Validation:

Fin position wrt tip, inches	Breaks/hr data	Breaks/hr model
+ 1/16	5.5	6.9
0	2.12	1.7
- 1/16	2.7	0.1

Transfer function calculation for 10 mkm fiber:



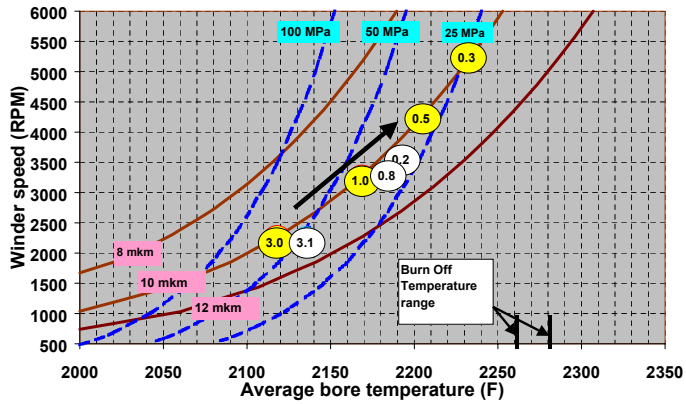
Glass Forming Technology Consortium

09/15/05 DOE review

PROCESS DESIGN AND VALIDATION

- **Computer model fully defined and used to optimize the process**
- **Extended run to validate process design**
- **Counter-intuitive solution: run faster**

Contour of diameters, max stress and break rates



That test was run continuously for 52 hr 30 min with the average break rate of 0.17 brks/hr, which is almost a six-hour run time vs committed 4 hour achieve using the 200 tip bushing vs. committed 100 tip bushing.

What is the strength of 10 micron glass filament?

$$\text{breaks/hour} = 3600 \sum_{i=1}^{\text{number of tips}} NV \left(\frac{\sigma_i}{\sigma_0} \right)^m$$

N = 0.5 parts per meter

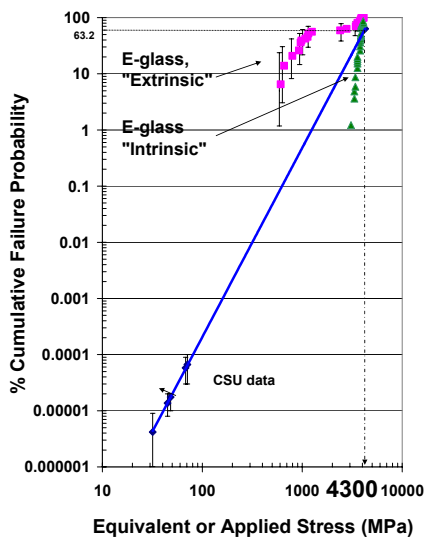
V = 50 m/s

Experiment to determine glass strength: 124 runs, 33 runtime hours

Expt# 21 data summary, BSPT 2175 F, Fin 0, Old black fins (08/12/04 - 08/26/04)

Run No.'s	Bushing setpoint (F)	Winder speed (RPM)	Measured tension (g)	No. of bushing run hours (hrs)	No. of breaks collected	Expt. Break rate (breaks/hr)
2304 - 2308, 2314-2316, 2330, 2387-2397	2175	2183	152.8	11.6	6	0.52
2291-2303, 2374-2416	2175	2869	174	7.2	16	2.23
2455-2494	2175	3266	175.5	5.2	17	3.26
2332-2353, 2495-2502	2175	3445	182.5	1.2	14	11.35
2505-2538	2175	3600	188	0.9	12	13.66

E-glass strength σ_0 = 4.3 GPa, m = 3.47



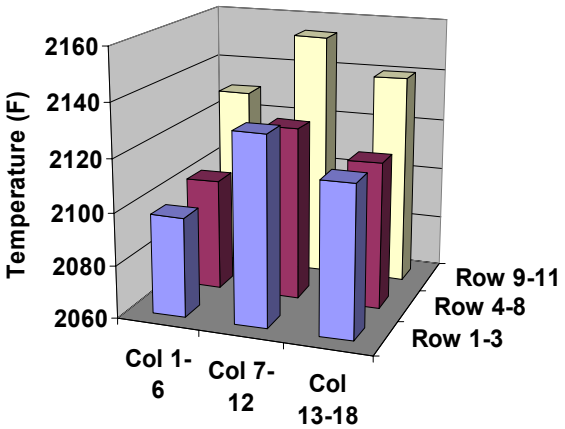
A typical experiment tests ~100 m of material; one specimen breaks - CFP = 1%

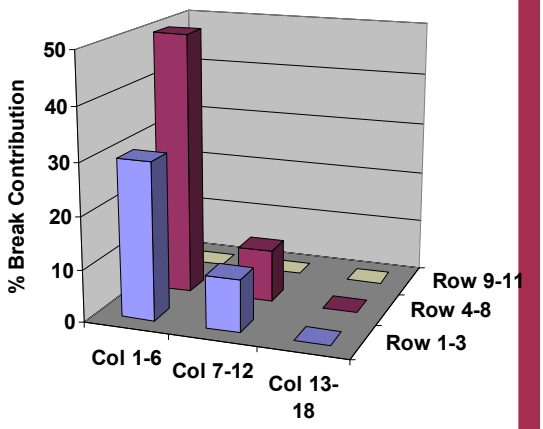
CSU run tests 40 million meters per hour; one specimen breaks – CFP = 5 10^{-6}%

Gearing up to the factory implementation/commercialization

Tip Temperature Data and Break Data
(Exp 21 BSPT 2175F, 2183 RPM, Fin 0)

6 breaks observed





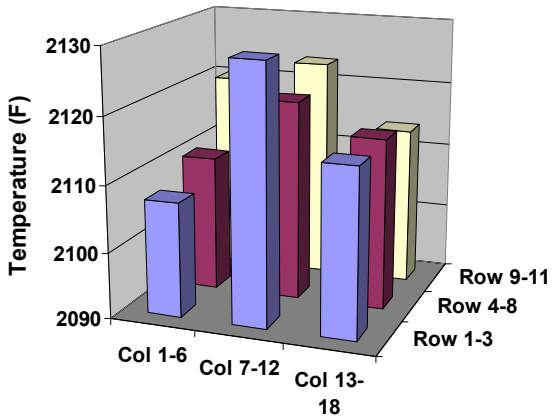
Glass Forming Technology Consortium

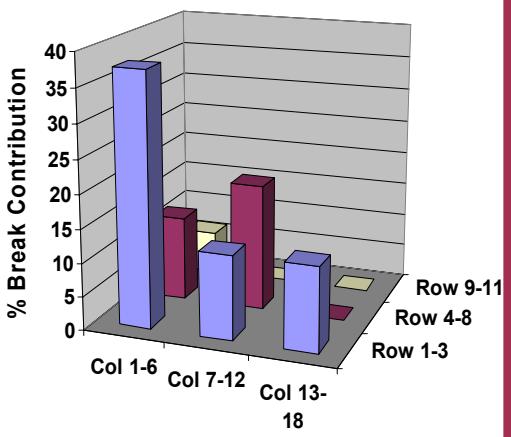
09/15/05 DOE review

Gearing up to factory…, cont'd

Tip Temperature Data and Break Data
(Exp 21- 8/04, BSPT 2175 F, 2869 RPM, Fin 0)

16 breaks observed





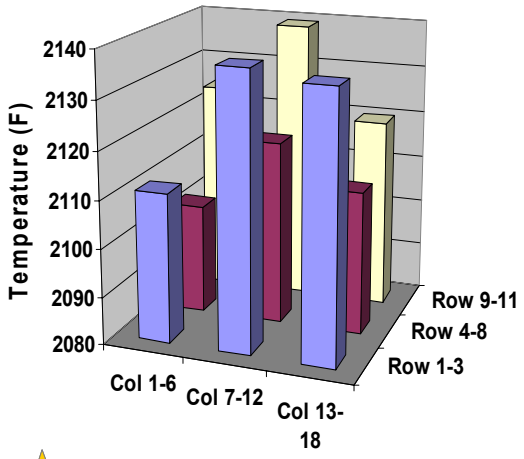
Glass Forming Technology Consortium

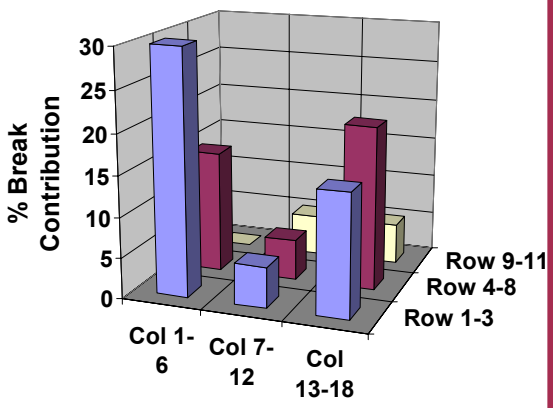
09/15/05 DOE review

Gearing up to factory…, cont'd

Tip Temperature Data and Break Data
(Exp 21 – 8/04, BSPT 2175 F, 3266 RPM, Fin 0)

20 breaks observed





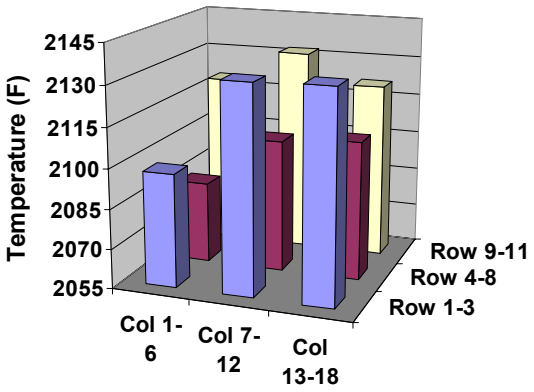
Glass Forming Technology Consortium

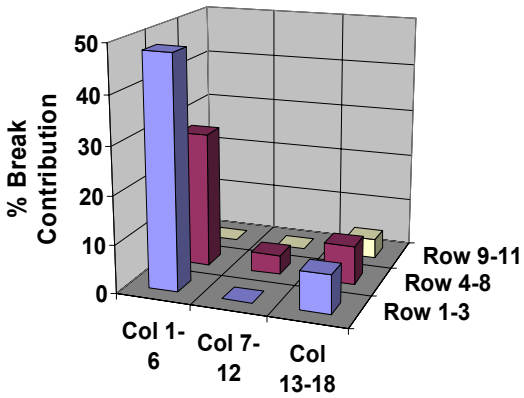
09/15/05 DOE review

Gearing up to factory…, cont'd

Tip Temperature Data and Break Data
(Exp 21- 8/04, BSPT 2175 F, 3445 RPM, Fin 0)

25 breaks observed



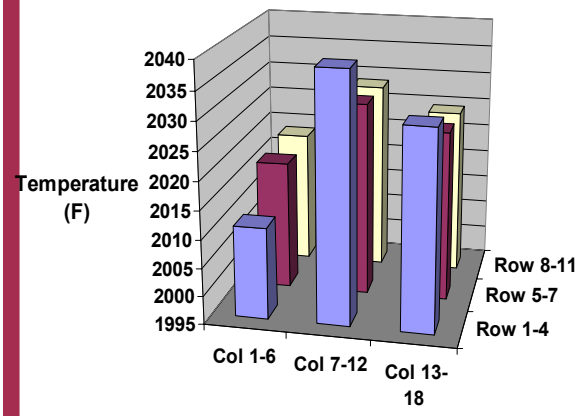


Glass Forming Technology Consortium

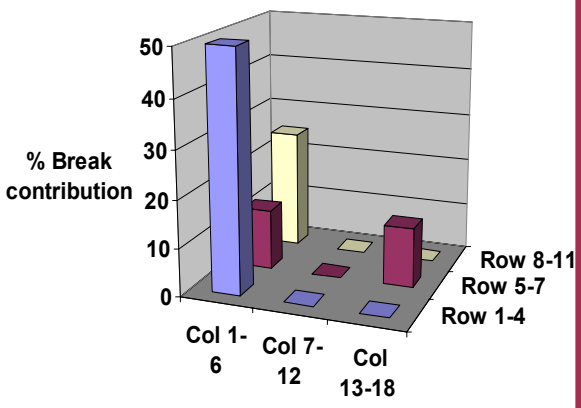
09/15/05 DOE review

Gearing up to factory…, cont'd

Tip Temperature Data and Break Data
(Exp 19 - 7/04, BSPT 2225 F, 3538 RPM, Fin 0)



9 breaks observed



Final Year Results/Plan

1. The commitment of four-hour uninterrupted performance has been exceeded and demonstrated in a 52 hr continuous test
2. Technical knowledge was disseminated in >50 telecons, a dozen conference presentations and several publications.
3. The project greatly helped to prepare students for industrial jobs as advanced technologists
4. Two weeks from now the CSU's *"Glass Fiber Drawing Pilot Plant"* will be showcased at Ohio Technology Showcase along with Alcoa, Ford, Republic and Timken companies
5. Commercialization plan: get results at the factory floor of JM and PPG within 3-4 months

A

Appendix A

Other Presentations

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

industrial technologies program

DOE-EERE ITP
Glass Portfolio Review

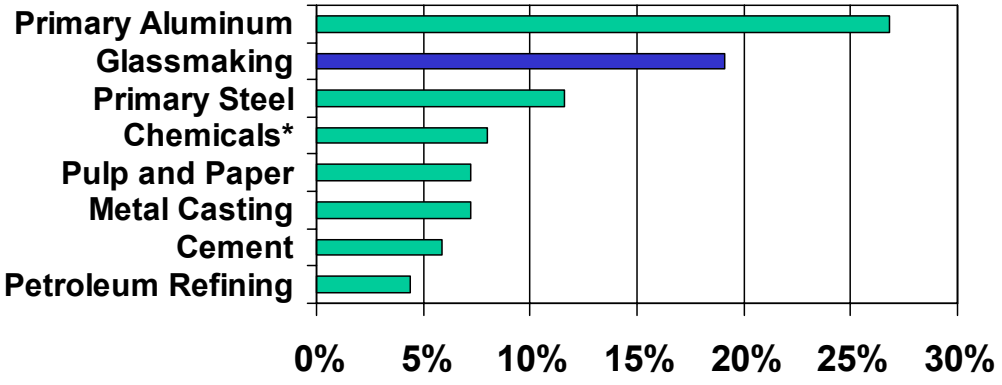
Chicago, IL
September 14, 2005

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

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

Glass: An Energy-Intensive Industry

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



* Excludes pharmaceuticals

Data derived from 2001 Annual Survey of Manufactures, Department of Commerce

Meeting Purpose

- Inform
  - Glass manufacturers about new technologies to improve glassmaking efficiency
  - Glass stakeholders on DOE-ITP activities
- Conduct Formal Review
  - Of projects and overall portfolio
  - By GMIC and outside reviewers
- Discuss
  - Distance learning
  - Bandwidth analysis

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

But First…..

Meeting Agenda

- Wednesday
  - Project Presentations
  - Reception
- Thursday
  - Additional Project Presentations
  - Tours of Argonne and Gas Technology Institute
  - Dinner at Greek Islands
- Friday
  - Portfolio Strategy
  - GMIC: additional meetings

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

DOE-ITP Glass Update

- Challenging Budget Outlook
  - FY07 Request: Under development
  - FY06 Request: $1.763 million
  - FY05 Appropriation: $2.564 million before recissions
- New DOE Management Team
  - Secretary: Samuel Bodman
  - Acting EERE Assistant Secretary: Doug Faulkner
  - ITP Program Manager: Jacques Beaudry-Losique

- Glass Technology Manager: Elliott Levine
- Golden Field Office Project Manager: Brad Ring

Glass Solicitation

- Closed April 1, 2005
- Category A Topics
  - Refining and Conditioning
  - Batch/Cullet Preheating
- Category B Topics
  - Glass Composition and Raw Materials
  - Forming and Finishing
- Status:
  - New ITP Program Manager reviewing existing program areas
  - Final determination on solicitation awards has not been made

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

Glass R&D Investment Strategy

Investment Strategy based on

- **Analysis** of energy savings opportunities

- Portfolio balance: want **transformational technologies** as well as incremental improvements

- Greater emphasis on **high risk, high potential impact** R&D

Summary of Glass R&D Focus Areas

Focus Areas	Goal	Timeframe and Risk
1. Next Generation Melting Systems	Dramatically reduce melting energy intensity through new technology	Long-Term High-Risk
2. Energy Efficiency Performance Improvement (model validation, glass compositions, materials, preheating, combustion optimization)	Maximize energy efficiency utilizing existing plant structure	Mid-Term Medium-Risk
3. Advanced Processing and Environmental R&D (robust sensors, predictive control systems and emission tools and abatement techniques)	Improve production efficiency/yield and reduce environmental impact	Mid-Term Medium-Risk

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

Meeting Changes

- Formalized review process using standardized forms
  - New project evaluation forms
    - Added benefits analysis (GPRA)
    - Shorter; less but different questions
  - Broader portfolio review
  - "Outside" reviewers in addition to GMIC reviewers
  - Attendee questionnaire
    - Please complete and hand in before leaving
- Discussion
  - Tapping into your collective interests

Benefits Analysis

- Conducted annually to assess projected benefits in future as a result of commercial introduction of funded projects
- Required by the Government Performance and Results Act (GPRA)
- Benefits dependent on user assumptions
  - Energy savings per unit
  - Market inputs (size, growth, introduction, adoption)
  - Handout provides more insight

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

Special Thanks

- Principal Investigators
- GMIC and Outside Reviewers
- Co-Sponsors
  - Eclipse, Inc.
  - Gas Technology Institute
  - Linde Gas LLC
- Host
  - Argonne National Laboratory

Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries

U.S. Department of Energy
Glass Portfolio Review

September 14, 2005

Project Summary

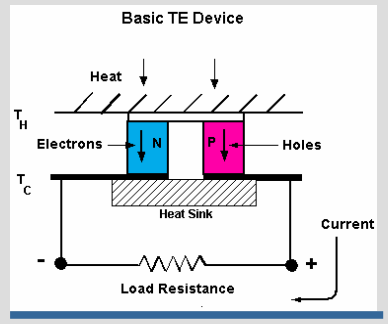
Goal: Integrate advanced thermoelectric materials into thermoelectric power generation device with efficiency >20% for waste heat recovery in industrial processes.

Challenge: Multi-layered, thin-film materials show promise for thermoelectric performance but economical scalability is required

Benefits: Recovery of energy from industrial waste heat stacks; conversion of waste heat into electrical power; energy savings of 1.6 trillion Btu/year in 2020.

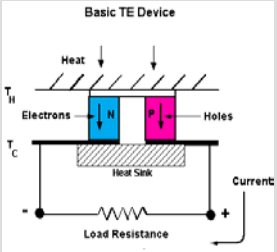
FY05 Activities: Evaluate new materials and multilayer concepts; incorporate materials into prototype power generating device; fabricate and demonstrate 1 kW device.

Hot side ("Waste Heat")



Cold side

Thermoelectric Energy Conversion



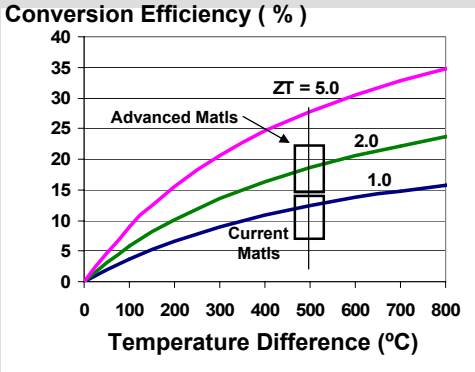
TE Material Parameters

- Electrical Conductivity (σ)
- Seebeck Coefficient (S)
- Thermal Conductivity (K)

Ideal Conversion Efficiency

- Can be Written as a Function of ZT
- ZT is Dimensionless and

  $= [S^2 \sigma / K] T$



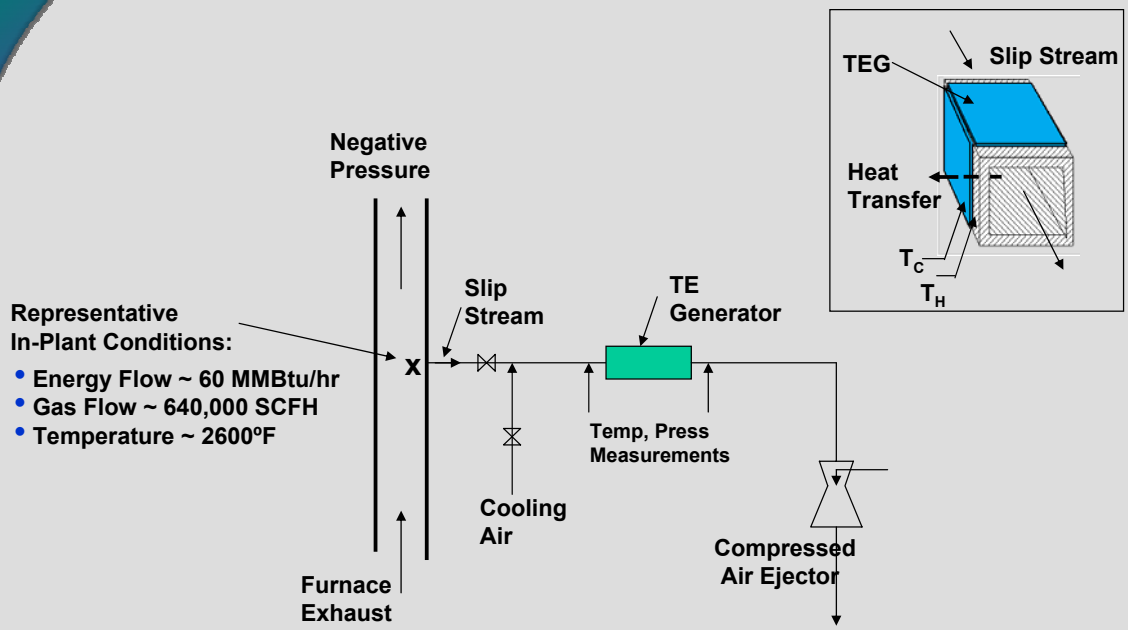
Current and Advanced Materials

- Current Materials: PbTe, Bi_2Te_3, and Others in Bulk Form
- Advanced Materials: Nanostructure Materials

3 Year Program Plan

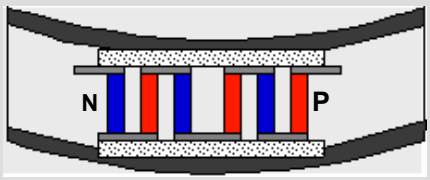
Tasks	FY04	FY05	FY06	FY07
1. Energy Conversion System Design	PbTe TEG	Adv Materials & Heat Exchange		
	Economic Analysis		Update Economic Analysis	
2. TE Generator Testing & In-Plant Demonstration	TEG Test Bed (PNNL)			
	In-Plant Demo At PPG		6 % 10 %	20 %
3. Combustion Emission Optimization		Condensate Characterization		
4. Advanced TE Materials Development	Advanced TE Films		ZT = 2, T < 1000ºF	Approach for T > 1000ºF
			Scale-Up	

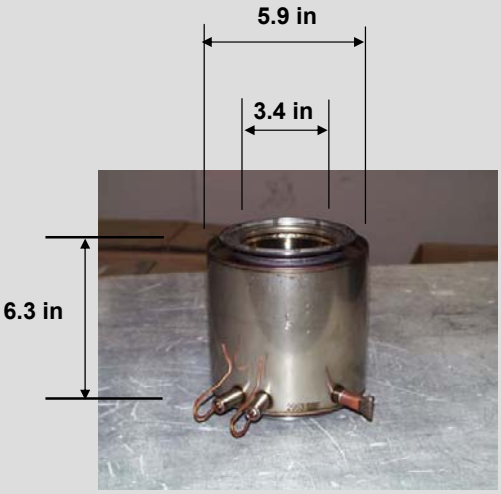
General Schematic of In-Plant Demonstration



Current Technology Generator for Initial Studies

- Utilizes PbTe Thermoelements
- 350 Watts With T_H = 1000°F (535°C)
  T_C = 100°F (38°C)





Thermoelements In Radial Configuration Placed Around the Circumference

Energy Balance Across Converter

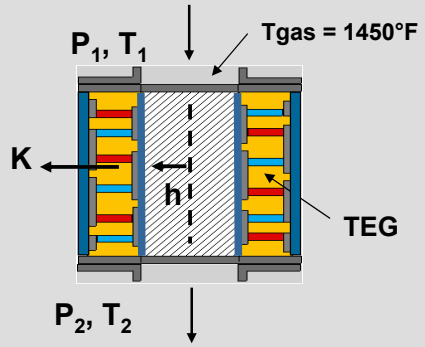
Modeling Approach

Known Information:

- TEG dimensions
- P_1 and T_1
- Assumed gas is air
- % Furnace Exhaust

Objectives of Modeling:

- h values that give radial heat transfer that match calculated values of enthalpy extracted from gas stream
- Tolerable ΔP



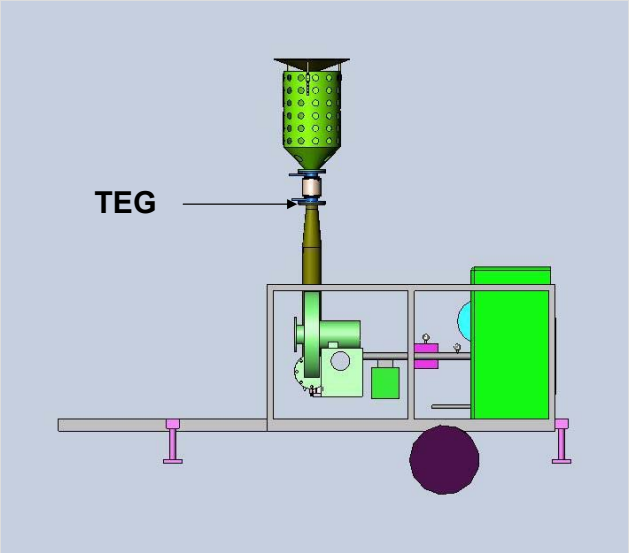
PNNL Test Bed Configuration

Design Objectives

- Provide a Test Bed for Acquiring Required Information for In-Plant Testing
- Allow Simulation of Slip Stream Available in PPG Meadville Plant
- Allow Testing of TEGs Based on Advanced Materials

PNNL Test Bed

- Utilizes Eclipse Combustion System
- Fired By Natural Gas Combustion
- Can Deliver Up To 2 Million BTU/hr (585 kW)
- Flow Rate Up To 1000 SCFM



Comparison of PNNL Test Bed and Meadville PPG In-Plant Test

PPG In-Plant Study	PNNL Test Bed
1. Aspirated Flow	Pressurized Flow with Blower
2. Off Gas with High H2O Content and Other Components	Air and Natural Gas Combustion
3. 1450°F at Entrance of TEG	Same
4. Need to Manage Condensates	None
5. Measured Quantities: - Current vs Voltage - Temperature at Entrance and Exit - Pressure at Entrance & Exit - Temperature at Cold Surface - Temperature difference and Mass Flow Rate of Coolant	Same

Test Bed Results

- ❑ TEG produced 260 W_E with 323 °C hot junction temperature
  - -- Artifact of water calorimeter that held device below design range
  - -- Indicates TEG will achieve design output without water jacket
- ❑ Heat energy intercepted by TEG was 4.7kW_T
- ❑ Estimated value of heat transfer from gas to hot junction 212 W/m^2-°C
  - -- Agrees with theoretical range 200 to 400 W/m^2-°C between gas and interior of duct only
- ❑ Overall heat-to-electricity conversion efficiency 5.5%
  - -- representing ~ 10% above expected, benefit of water jacket
- ❑ Average gas temperature in TEG section 936 °C (1717 °F)
  - -- Exceeded theoretical design point of 1450 °F (subject to further review)
- ❑ Axial pressure differential in TEG - 8 inches H_2O
  - -- Four times theoretical value attributable to mantle design

Advanced TE Materials

Boron / Boron Carbide Multilayers

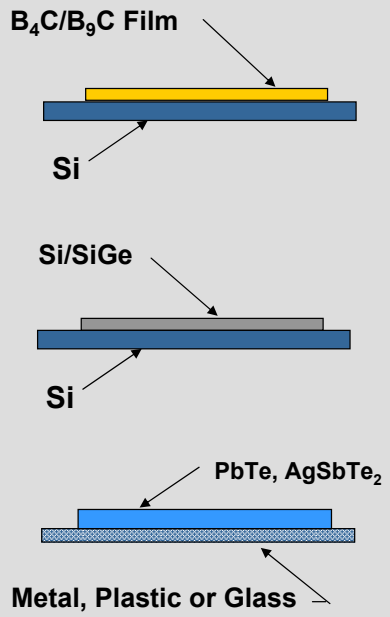
- Multi-layer films grown by RF magnetron sputtering from B_4C and B_9C Targets
- Best results require single crystal silicon substrates and annealing at 1000ºC

Si/SiGe Multilayers

- Multi-layer grown by RF magnetron sputtering from Si and SiGe Targets
- Best results require single crystal silicon substrates

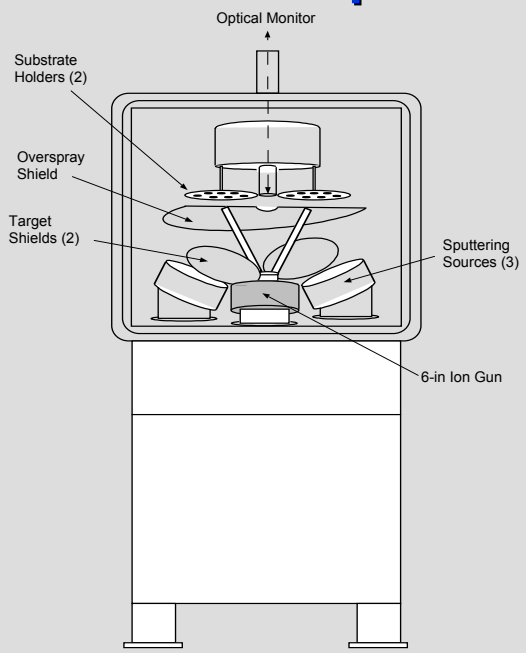
PbTe, $AgSbTe_2$ and Alloys

- Films grown by RF magnetron sputtering from two or three targets
- Films can be deposited on variety of substrates



Thermoelectric Materials Development

- Utilize Magnetron Sputtering
- Can Mix Three Components
- Substrate temperatures up to 800ºC
- Layered Materials Are Grown By Rotating Substrates Over Targets
- Approach Allows Investigation of A Broad Spectrum Of Materials In A In A Timely Manner



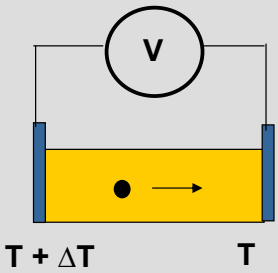
PbTe Based Alloys: Electrical properties

Results for Ag-PbTe Films

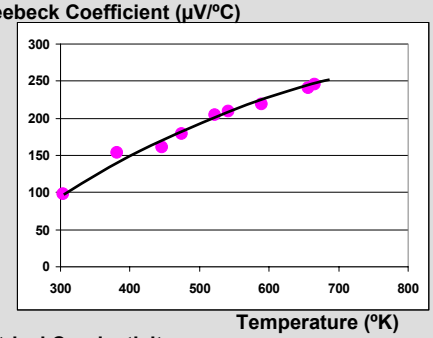
Seebeck Coefficient $= \dfrac{\Delta V}{\Delta T}$

Electrical Conductivity $= 1/\rho$

$R = \rho L/A$

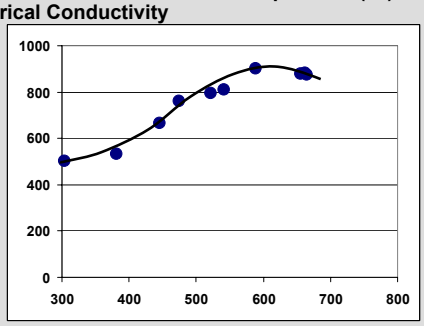


Seebeck Coefficient (μV/ºC)



Temperature (ºK)

Electrical Conductivity



PbTe Alloys: Figure of Merit

Results for Ag-PbTe Films

Efficiency = fct (ZT)

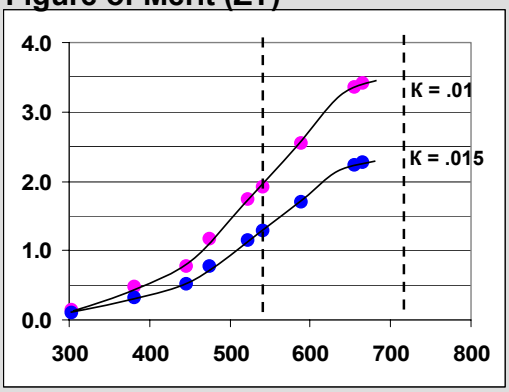
$ZT = S^2 T/(\rho\kappa)$

$= \dfrac{[S^2T/\rho]}{\kappa}$

ZT Values Assume

κ = .01 W/cm/ºC
And .015 W/cm/ºC

Figure of Merit (ZT)

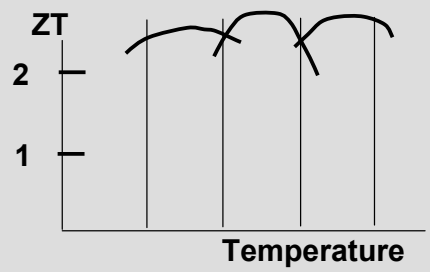


Temperature (ºK)

Application of TE Thin Films

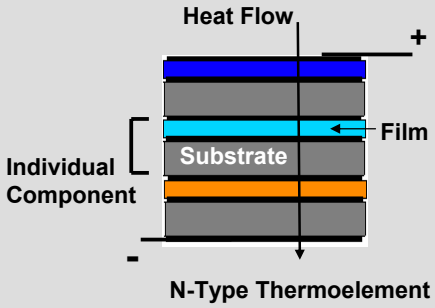
Segmented Thermoelements

- Utilize one alloy composition over 100ºC to 200ºC Temperature Interval
- Stack several elements in series to cover complete temperature range



Key Issues

- Films must be > 1000 µm thick
- Contact resistance must be very low
- Scaling up film deposition must allow economic growth of relatively thick films



Approach To Scale-Up

Approach will depend on material, substrates and configuration

Films on Flexible Substrates

- Large Sputtering system
- Roll Coater

Thick Films on Metal Discs

- Large Sputtering System
- Triode Sputtering
- Plasma Arc Deposition

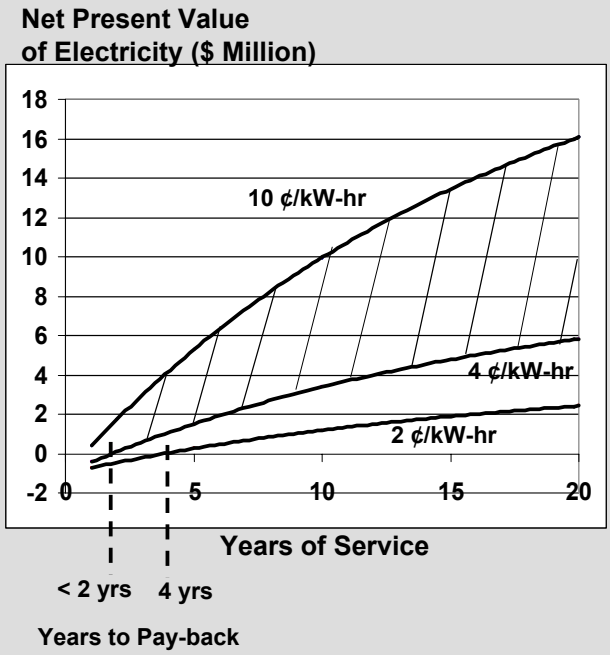
Cost/Benefit Analysis

Assumed Future Capabilities

- Assumed Thermal Energy Available: 58.3 MMBTU/hr = 17 x 10^6 W_T
- TEG's Intercept 50 % Of Thermal Energy in Off-gas Stream
- Converter Efficiency = 20 %
- Utilize 1000 TEGs, Each Producing 1.7 kW_E to Generate 1.7 MW_E
- Unit Cost assumed to be $1000

Calculated Net Present Value

- Capital Investment ($ 1 Million) 1st Yr
- NPV Based on 6% Discount Rate
- No Maintenance and Repair
- NPV = Present Value - $ 1 M



Accomplishments To Date

- Achieved excellent TE properties with sputtered Ag/PbTe films indicating possible ZT values > 2
- Established industry collaboration through monthly teleconferences and meeting held at Meadville PPG plant to discuss in-plant demonstration
- Constructed test bed at PNNL that simulates conditions at Meadville for up to 4% of furnace exhaust flow -- will be used to acquire data relevant to in-plant demonstrations, test modeling calculations and to test TEGs based on advanced materials
- Completed simple NPV analysis that shows future cost-effectiveness of power conversion and early capital payback when value of electricity produced is in the range 2 to 10 ¢/kW_h and above

Alfred University

Distance Learning for the Glass Industry

Thomas P. Seward III
Professor of Glass Science

Outline

- Identified Needs
- Project goals and tasks
- DOE industry support activities
- AU continuing education
- Initial courses being developed
- Benefits to Industry
- Your input?

Background

- Multiple Needs Identified - (see next slide)
- Opportunity - Seed funding from US DOE ITP to develop short courses for the glass industry
- Experience - Alfred University has experience delivering with summer short courses and specialized training at company sites
- Facilities - Alfred University has distance learning experience and capability - Video, VHS and DVD
- Experts - If not at Alfred, available to work with us

Education Needs

- Needs already identified
  - CGR member companies are concerned that
    - New hires to plant floor know nothing about glass
    - Process and applications engineers newly hired or coming from other companies don't understand glass properties and capabilities
    - New business leaders have no background in glass so don't understand their products or what it takes to make them
  - DOE ITP is concerned that
    - Companies are not concentrating on increasing their energy efficiencies
    - Tools and knowledge developed by DOE are going unused

Goal

- Develop a set of courses focused on glass industry needs
- emphasizing state-of-the art energy efficient technologies
- and delivered by “distance learning” techniques.

Project Tasks

- Define requirements for the course(s)
  - Seek input from various constituents
- Develop new courses (or modify current ones)
  - Involve qualified experts
- Pilot test the courses
- Time line - complete by summer 2007

Steering Committee

- Peter Angelini - Oak Ridge National Laboratory
- John Brown - Glass Manufacturing Industry Council
- Jim Shell - DOE consultant
- Arvind Thekdi - E3M Inc., DOE contractor
- Thomas Seward - Alfred University professor and project leader (PI) for this project
- Alexis Clare - Alfred University professor and experienced distance learning instructor
- Paul Johnson - Alfred University professor and distance learning technology expert

DOE IOF Support Activities

Current DOE support activities for Industries of the Future program

Development Tools	Training – 1 Day-2 1/2 day End User	
PHAST * Electric Motors Pumps Air Compressors Steam	- 1 day - 20 persons - 10 / year - sites in USA	Qualified specialists - consultants - paid by individual companies
DOE Web site available for free download	Qualified Specialist training - evaluate (certificate)	

PEP = Plant Energy Profiles

* PHAST - Process Heating Assessment & Survey Tool - Developed by Arvind Thekdi, E3M, Inc. with DOE funding

Curriculum

Alfred University Continuing Education

- Catalog courses for credit (at Alfred University, Corning, NY, or via “distance learning”)
- Short Courses (with industrial emphasis)
  - at Alfred University (summertime)
  - at ACerS and other society meetings
  - at company locations
- Visit: http://engineering.alfred.edu/outreach for details

Initial Courses - This Project

- First short course
  - "Energy Relevance of the Glassmaking Process"
  - Subtitle: "Energy Practices for Engineers and Plant Personnel"
  - Developer - Professor Thomas Seward
  - Instructors - various expert guest lecturers
- Second short course
  - "Glass Science for Managers"
  - Developer / instructor - Professor Alexis Clare

1st Course Concept

Concept for first Distance Learning for the Glass Industry short course

<u>Short Course</u>

"Energy Relevancy of Glass Making Process"

a) Glass Science and Processing
b) PHAST
c) Experimental fuel evaluation
   a. Burners (demo at Alfred Univ.)
   b. Annealing furnaces (lehrs)
   c. Instrumentation
d) Interactions (Best Practices – PEP)

b-1) Fundamentals of Thermal Processes
- heat transfer
- combustion
- emissions

<u>Approach</u>

a) Short Course
- Alfred
-1 week
- DOE $ for trainers / teachers
- low registration fee

b) Short Course "DVD"
- for limited $
- open registration
- using trainers / facilitators from a)

c) PHAST – update to be industry specific

2nd Course Concept

- Overview of glass science for managers (and applications engineers) coming from other disciplines
- Based on "Introduction to Glass Science" course at Alfred University
- Tailored to the industry sector of the enrolling company

Course Delivery Options

- Classroom offerings at university (or other site) *
- Interactive Web-based classes (asynchronous) *
- Interactive Web-based classes (synchronous)
- Self-study - Web based
- Self-study - DVD or CD (for individuals or groups)
- Other possibilities

* Currently used for credit-bearing courses

Benefits to Companies

- More efficient operations through better informed / trained workforce (and more efficient operations through better informed management)
- More efficient learning experiences (also save on travel, lodging, meals, etc)
- Access to perspective of leading experts in their field

Engineering Can be Fun

Discussion

- Your ideas?
  - Discuss here
  - Answer today's questionnaire
  - Help formulate course requirements
  - Offer suggestions / help / technical input
  - Follow up by telephone, e-mail, etc.

GPLUS Update

Peter Angelini
Program Manager
Oak Ridge National Laboratory

September 14, 2005

Introduction

- *Activities*
  - No new GPLUS efforts in FY 2005
  - Collecting final reports
  - Identifying relevancy of GPLUS efforts wrt *ITP mission of - increasing energy efficiency*
- *Why?*
  - DOE funded activities must relate to the mission of the Industrial Technologies Program (ITP)
    - -Continuation of GPLUS in question

Status

- *Where are we?*
  - Collected many final reports but others remain to be completed
    - GPLUS projects and reports are “open”
  - Discussed various projects and results with the industrial participants wrt Energy Efficiency
    - In many cases thus far it has been difficult to determine a strong energy efficiency component to the efforts
      - Many projects - energy efficiency goals secondary

What is the bottom line

- *Two areas need to be addressed*
  - Energy efficiency component needs to be the major justification
    - In contrast to: Other reasons often drive projects
  - Open approach to the projects and results of projects – can enable replication of results across the industry
    - In contrast to: Results not easily discussed or shared

Highlight

- *Project where a positive approach was the case*
  - Visteon;
    - Glass composition changes lead to increased energy efficiency (lower melting temperature), lower defects rates, and less costly batch materials
    - Open approach to the results

Highlight

- *Effort consisted of*
  - Visteon/ORNL (MPLUS) on Thermochemical Optimization of Float Glass Composition
    - To try to understand and reduce formation of crystals on glass surface; resulting in a lower melting point glass
  - Visteon/PNNL (GPLUS) on experimental validation of modeling results
    - Confirmed modeling results

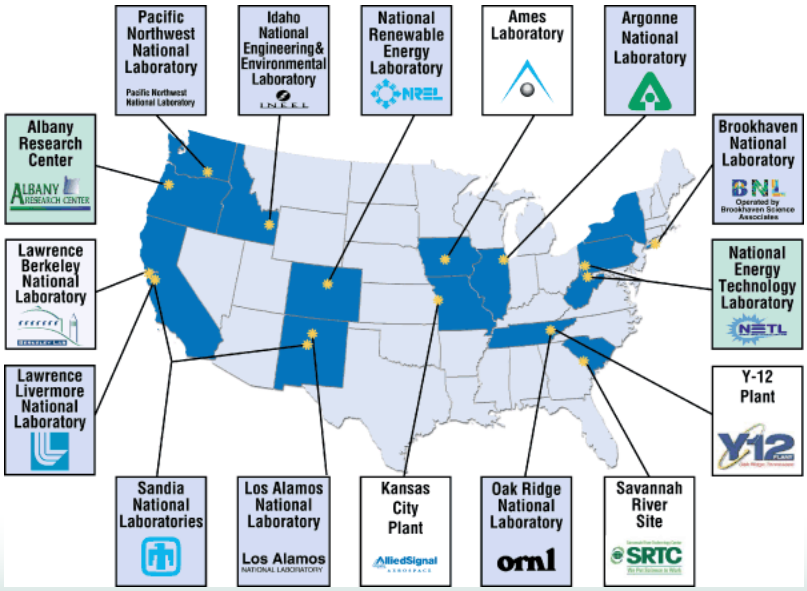
Highlight

- A commitment was then made by Visteon for full scale production runs at the float glass plant in Nashville, TN
  - **~ 45 Billion BTU/yr energy efficiency benefits** from 25° F lower glass melting temperature
  - **higher yield and quality due to lower defects**
    - "We check 50 windshield size pieces of glass from production each day here in Nashville and we found only one tridymite hexagonal plate on the top surface in the last 4 months. Previously, we were getting an average of 5-10 tridymite stones per ton of glass."
  - **a $300,000 / year productivity benefit in batch materials savings** by the elimination of one of the batch materials
- Replicated the use of the new glass compositions in two additional float glass furnaces at the Tulsa, OK plant with similar success
- Open approach to reports, discussion and effort

Where do we go from here ?

- Continue to obtain final reports and evaluate projects for energy efficiency aspects
- Need to review the approach of GPLUS
  - Address energy efficiency in a proposal from day one
    - (go - no go)
  - Open/timely dissemination and publishing of results; and completion of reports
  - Venue for presenting results - so that others can benefit
  - Open structure for access to GPLUS
    - Submittal and review
    - Note: Proprietary efforts can be funded directly by companies outside of the GPLUS activity

DOE National Laboratory Participants



Projects Have Addressed Various Areas of Glass Processing

- Properties
  - High Temp
    - Viscosity, Thermal Conductivity
- Process/Glass Behavior
  Thermodynamic
  - Furnace modeling
  - Fracture strength
- Sensing
  - Laser Induced Breakdown Spectroscopy - Flue gas, batch
  - Thermocouple degradation

- Melting
  - Furnace components
    - Refractory Metal degr.
  - Batch and Cullett
  - Encapsulants
- Process/Glass Behavior
  - Surface
    - Blisters, optical defects
    - Coatings
  - Bulk
    - Combustion atm. effects on glass oxidation
    - Foaming

Industrial Glass Bandwidth Analysis

DOE Glass Review
September 14, 2005
Presenter: David Rue, GTI

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

Goal: To identify the areas within the glass industry where energy can be saved, qualify the amount of potential energy that can be saved, and identify how to accomplish these savings

Challenge: The glass industry is often reluctant to reveal detailed energy data for proprietary reasons

Benefit: Identifying the route towards implementing state of the art technology in the glass industry is the first step towards saving trillions of Btus per year

Partners: GTI, Energetics, Dr. Warren Wolf, the many glass industry respondents

FY 2006 Activities: Activities will continue through providing more detailed methods of transitioning from current to state of the art practices

Approach

- Literature review and data compilation
- Surveys sent to industry representatives
- Interviews with industry representatives

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Energy Efficiency and Renewable Energy

Current Energy Usage Survey

		# of Votes For Each Score						
Category	**Score Average**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Raw Materials	4.8	0	2	2	8	4	5	4
Cullet Use	5.0	0	1	1	4	9	8	0
Preheat Batch & Cullet	5.9	0	2	1	1	1	5	12
Melt. Furnace	1.04	27	1	0	0	0	0	0
Refine/Cond.	2.7	1	16	5	4	1	0	1
Forming	3.5	1	4	14	6	1	1	0
Finishing	4.6	0	2	6	4	7	6	3

1: highest, 7: lowest

Areas For Energy Savings Survey

		# of Votes For Each Score						
Category	**Score Average**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Raw Materials	5.0	1	3	2	3	5	5	8
Cullet Use	3.9	3	5	1	6	5	4	1
Preheat Batch & Cullet	3.6	3	3	10	5	2	4	1
Melt. Furnace	1.6	19	4	2	2	1	0	0
Refine/Cond.	3.6	2	6	6	5	3	1	2
Forming	4.1	1	5	5	4	6	6	1
Finishing	5.5	1	1	1	5	3	5	11

1: highest, 7: lowest

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Energy Efficiency and Renewable Energy

Industry Interview Summary

- Flat, Fiber, and Container glass sectors are covered
- Flat
  - Two flat glass company representatives contributed
  - Current Melting/Refining Technologies:
    - Air-gas with some conversion to oxy-fuel
  - State of the Art Melting/Refining Technologies:
    - Oxy-fuel
  - Practical Minimum Melting/Refining Technology:
    - Refining improvements and better controls

Industry Interview Summary (cont.)

- Fiber
  - Two companies with large operations in string and wool contributed
  - Information within this sector must be separated into textile and wool
  - Current Melting/Refining Technologies:
    - Textile: Trend from air-fired furnaces to oxy-fuel; electric boost
    - Wool: Balance of air-fired, oxy-fuel and electric melters
  - State of the Art Melting/Refining Technologies:
    - Textile: electric boost, Electric or oxy-fuel front end
    - Wool: Batch production with moderate cullet percentage
  - Practical Minimum Melting/Refining Technology:
    - Textile & Wool: Extensive preheating

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

Industry Interview Summary (cont.)

- Container
  - Two container glass production experts contributed
  - Current Melting/Refining Technologies:
    - Air-fired and oxy-fuel with electric boost
  - State of the Art Melting/Refining Technologies:
    - Oxy-fuel
  - Practical Minimum Melting/Refining Technology:
    - Extensive preheating

Flat Production Energy Use

	Current Average[1,4] (MMBtu/ton)	(%)	State of the Art[3] (MMBtu/ton)	Practical Minimum[3] (MMBtu/ton)	Theoretical Minimum[3,4] (MMBtu/ton)
Mixing[1]	0.68	6%	-	-	-
Melting / Refining[4]	6.5	60%	4.7	3.5	2.8
Forming[1]	1.5	14%	-	-	-
Post-Forming[1]	2.2	20%	-	-	-

1: Energy and Environmental Profile of the U.S. Glass Industry, Energetics Inc., 2002.
3: Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Glass Manufacturing Industry, 2001.
4: Data obtained by Dr. Warren Wolf from surveys conducted with glass industry representatives.

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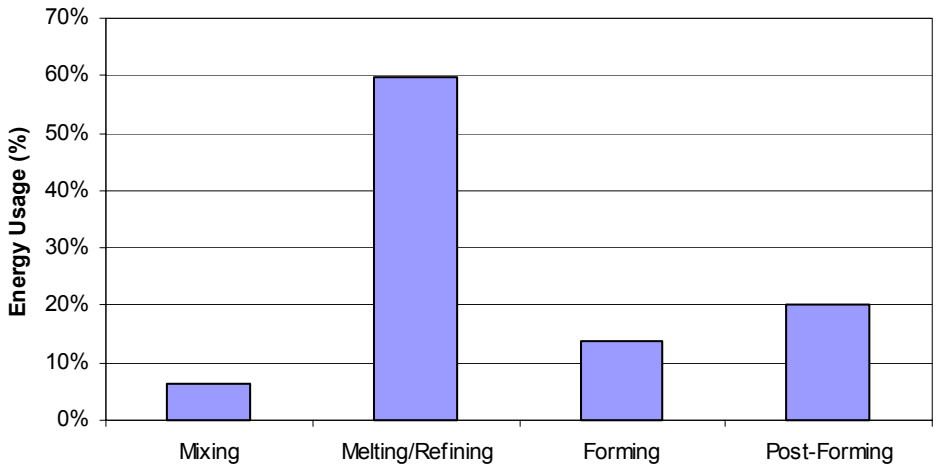
Flat Current Average Distribution



Fiber Production Energy Use

	Current Average[1,4]				State of the Art[4]		Practical Minimum[4]		Theoretical Minimum[3,4]
	Wool		Textile		Wool	Textile	Wool	Textile	
	(MMBtu/ton)	(%)	(MMBtu/ton)	(%)	(MMBtu/ton)		(MMBtu/ton)		(MMBtu/ton)
Mixing	0.68	6%	0.68	7%	-	-	-	-	-
Melting / Refining	4.5	37%	6.5	64%	2.8	3.8	2.3	3	2.3
Forming	5.0	41%	1.5	15%	-	-	-	-	-
Post-Forming	2.0	16%	1.5	15%	-	-	-	-	-

1: Energy and Environmental Profile of the U.S. Glass Industry, Energetics Inc., 2002.
3: Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Glass Manufacturing Industry, 2001.
4: Data obtained by Dr. Warren Wolf from surveys conducted with glass industry representatives.

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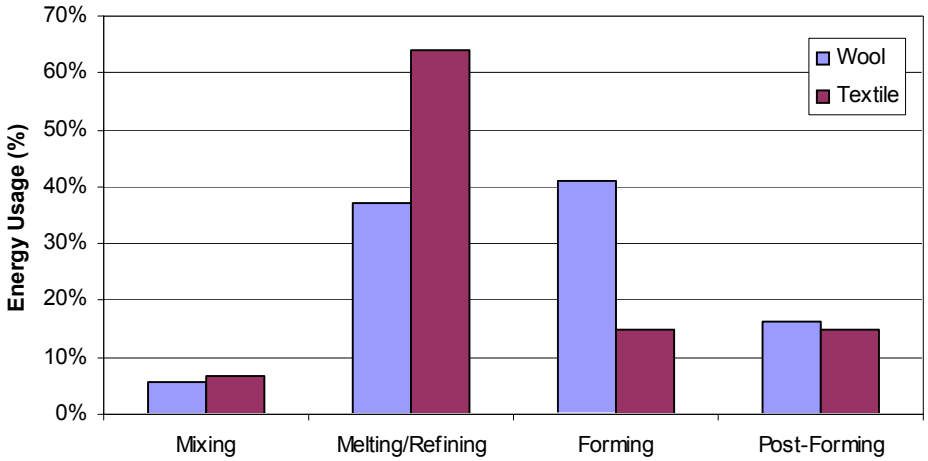
Fiber Current Average Distribution



Container Glass Production Energy Use

	Current Average[1,4] (MMBtu/ton)	(%)	State of the Art[3] (MMBtu/ton)	Practical Minimum[3] (MMBtu/ton)	Theoretical Minimum[3] (MMBtu/ton)
Mixing	0.68	10%	-	-	-
Melting / Refining	5.75	81%	3.4	2.7	2.2
Forming	0.12	2%	-	-	-
Post-Forming	0.56	8%	-	-	-

1: Energy and Environmental Profile of the U.S. Glass Industry, Energetics Inc., 2002.
3: Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Glass Manufacturing Industry, 2001.
4: Data obtained by Dr. Warren Wolf from surveys conducted with glass industry representatives.

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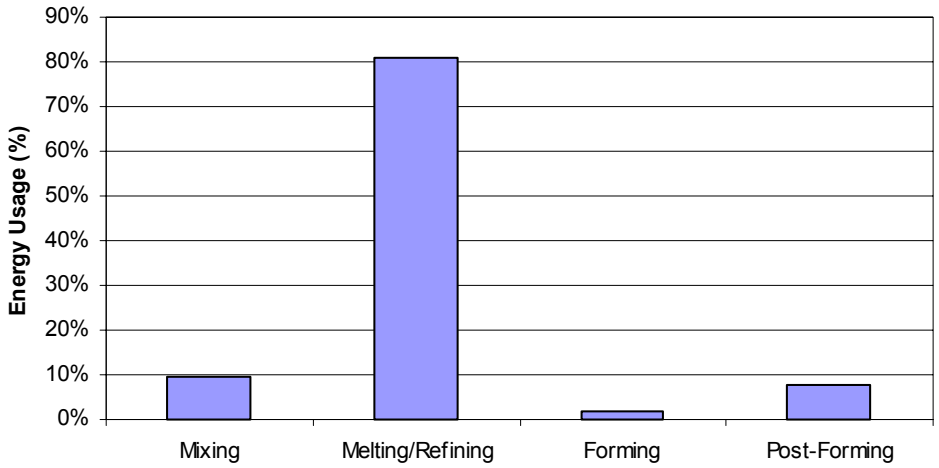
Container Current Average Distribution



Pressed & Blown Production Energy Use

	Current Average[1] (MMBtu/ton)	(%)	State of the Art[1] (MMBtu/ton)	Practical Minimum (MMBtu/ton)	Theoretical Minimum[3] (MMBtu/ton)
Mixing	0.68	4%	-	-	-
Melting / Refining	7.3	45%	5.6		2.3
Forming	5.3	33%	-	-	-
Post-Forming	3.0	18%	-	-	-

1: Energy and Environmental Profile of the U.S. Glass Industry, Energetics Inc., 2002.
3: Integrated Pollution Prevention and Control, Reference Document on Best Available Techniques in the Glass Manufacturing Industry, 2001.

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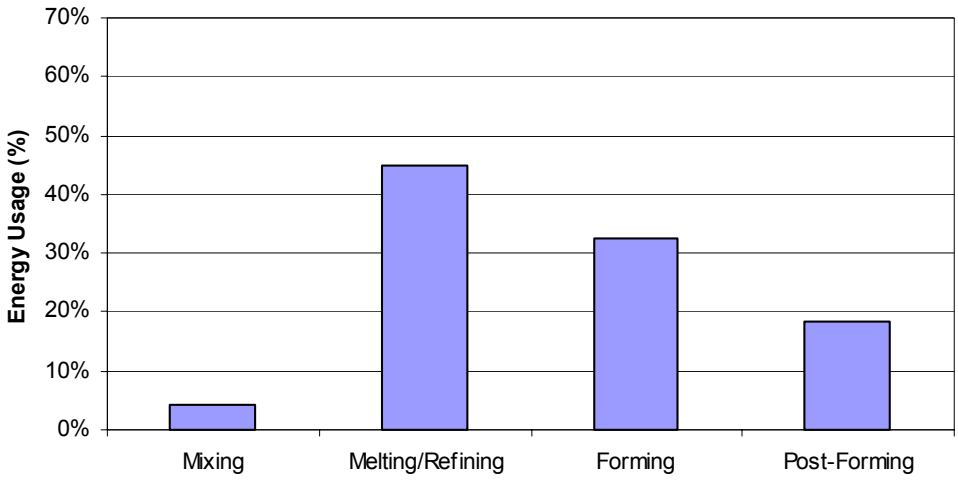
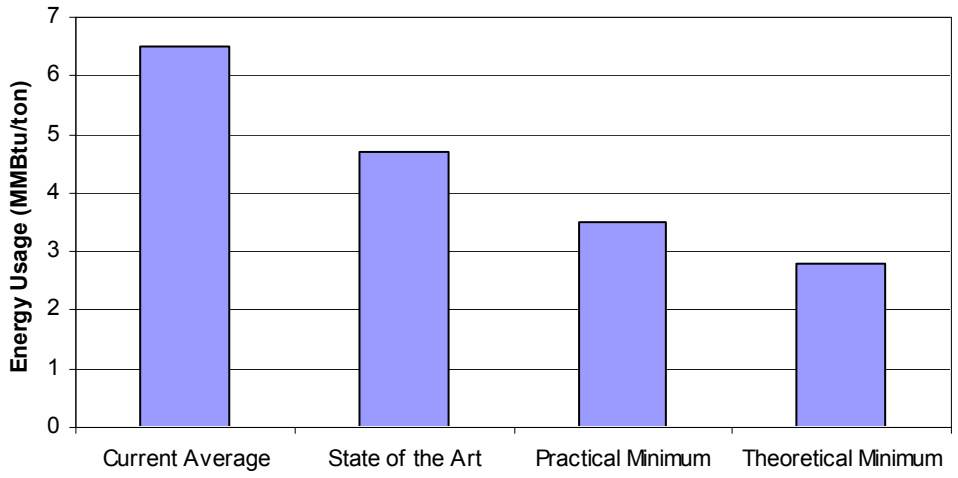
Pressed & Blown Current Average Distribution



Flat Melting/Refining Energy Reduction Potential



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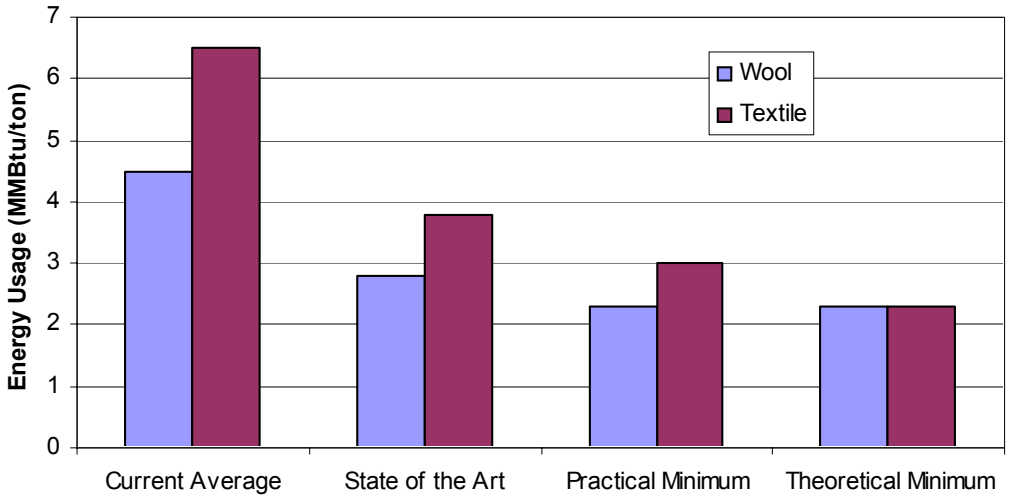
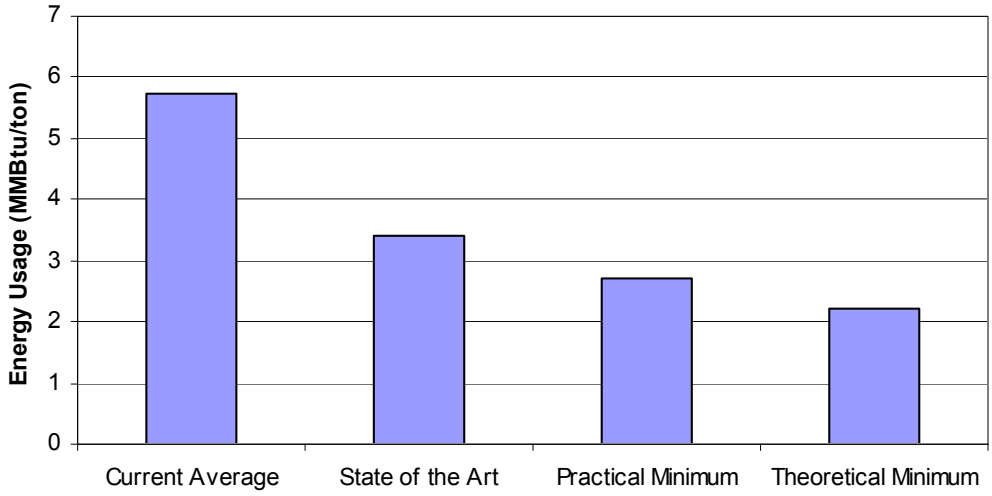
Fiber Melting/Refining Energy Reduction Potential



Container Melting/Refining Energy Reduction Potential



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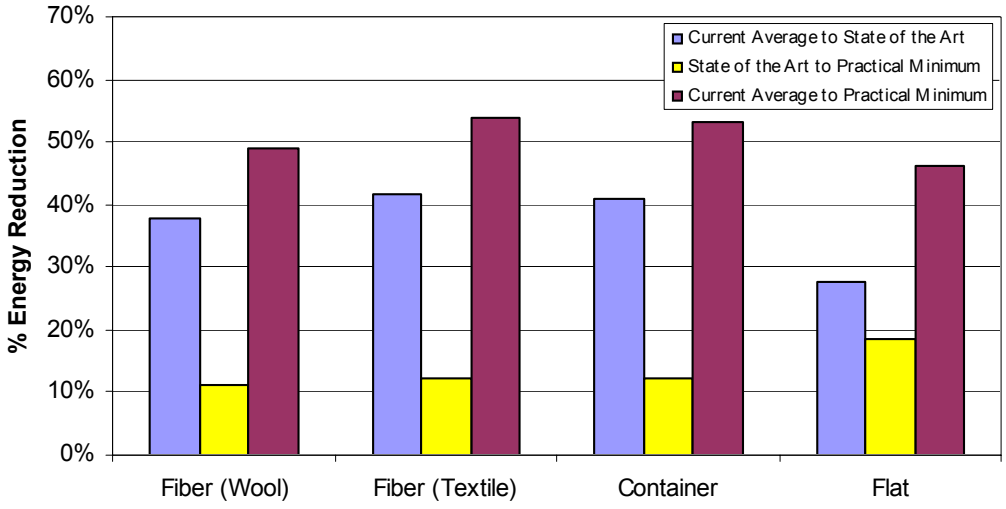
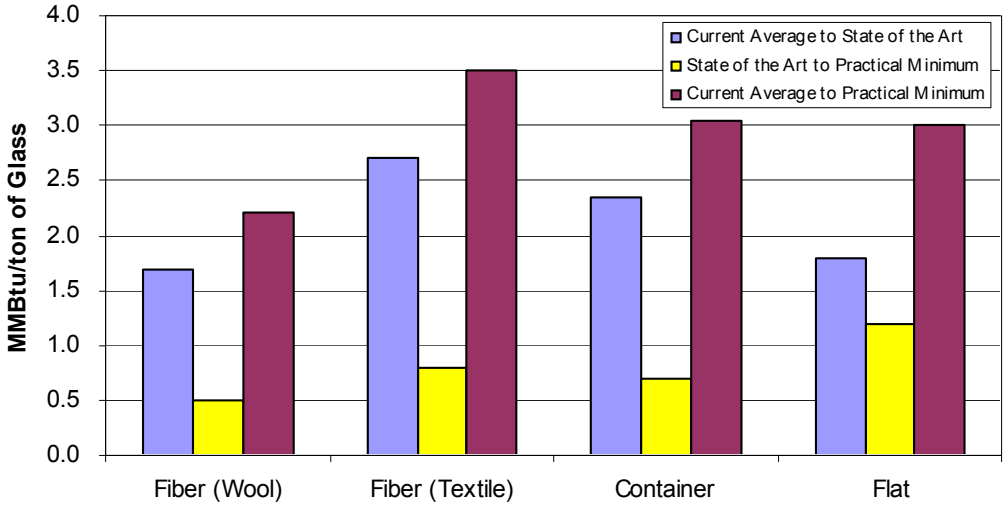
Potential Percent Melting/Refining Energy Reduction



Potential Melting/Refining Energy Reduction Per Ton Produced



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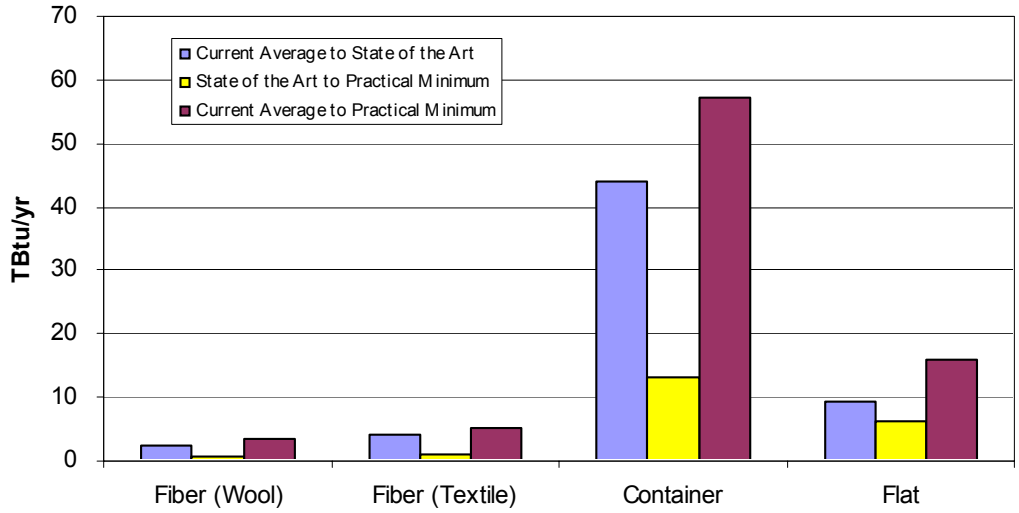
Glass Production and Market Information

Sector	Production [MMton/yr]	% of Market	Current Average Energy, Melting/Refining [MMBtu/ton]	Total Energy, Melting/Refining [TBtu/yr]
Fiber (Wool)	3.0 [1]	10%	4.5	13.7
Fiber (Textile)	0.8 [1]	3%	6.5	5.3
Container	18.8 [2]	64%	5.75	108.0
Flat	5.3 [2]	18%	6.5	34.2
Specialty (Pressed & Blown)	1.7 [1]	6%	7.3	12.1
Total	29.6	100%		173.4

[1] Energy and Environmental Profile of the U.S. Glass Industry, Energetics Inc., 2002.
[2] US Census Bureau, "Glass Containers: 2001", 2002, *http://www.census.gov/industry/1/m327g0113.pdf*.
[3] US Census Bureau, "Flat Glass: 2002", 2003, *http://www.census.gov/industry/1/ma327a02.pdf* .

Total Potential Melting/Refining Energy Reduction Per Year



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Glass Melting/Refining Technologies Evaluated Qualitatively

Technology	Technology Maturity [1-10]				Rebuild Required?				Cost of Implementation [1-10]				Energy Savings Benefit [1-10]			
	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container
Cullet Percentage	2	8	8	10	N	N	N	N	3	3	3	2	2	4	2	2
Batch Preheat	2	2	2	2	Y	Y	Y	Y	8	8	10	8	8	8	8	8
Cullet Preheat	2	2	2	2	Y	Y	Y	Y	5	5	5	5	6	6	6	6
Oxy-fuel Conversion	10	10	4	7	Y	Y	Y	Y	9	9	9	9	5	5	5	5
Partial Oxy-fuel Conversion	10	10	8	10	N	N	N	N	1	1	1	1	2	2	2	2
More Efficient Air-Fuel Burners	8	8	8	8	N	N	N	N	2	2	2	2	3	3	3	3

Glass Melting/Refining Technologies Evaluated Qualitatively

Technology	Technology Maturity [1-10]				Rebuild Required?				Cost of Implementation [1-10]				Energy Savings Benefit [1-10]			
	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container	Textile Fiber	Wool Fiber	Flat	Container
Improve Refractory	6	6	6	6	Y	Y	Y	Y	4	4	6	5	1	1	1	1
Improve Control System	6	6	6	6	N	N	N	N	3	3	2	2	2	2	2	2
Alternate Fuel Gas	1	1	1	1	N	N	N	N	2	2	2	2	1	1	1	1
Exhaust Gas Heat Recovery	4	4	4	4	N	N	N	N	7	7	7	7	8	8	8	8
Convective Melting	3	3	3	4	N	N	N	N	3	3	3	3	3	3	3	3

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Transition to State of the Art Melting/Refining Technology

	State of the Art Melting/Refining Technology	Potential Energy Savings after Adopting SOTA [1-10]	Cost of Transition to SOTA [1-10]	Perceived Willingness of Sector to Adopt SOTA [1-10]
Wool Fiber	Oxy-fuel / Electric	1	4	8
Textile Fiber	Oxy-fuel / Electric	1	6	6
Container Glass	Oxy-fuel	10	8	2
Flat Glass	Oxy-fuel	2	10	4

Conclusions

- Survey results revealed that, on average, the glass industry believes that the manufacturing step with the most room for energy savings is the melting furnace
  - The second place average score in the survey was found to be both refining/conditioning and preheat batch & cullet
  - Forming and cullet use were also believed to be steps with significant room for energy savings
- Interviews showed all glass sectors believe the largest amount of energy can be saved by improving melting/refining efficiency, except for the glass fiber (wool) sub-sector
- There is a very large potential for energy savings by moving from current practice to state of the art melting technology for the entire glass industry

U.S. Department of Energy
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Conclusions (cont.)

- Due to much larger production rates, container glass has the largest potential for energy savings per year for implementing both the state of the art technology and the practical minimum
- The glass industry (not including the specialty glass sector) stands to reduce energy usage by 61 TBtu/yr by implementing state of the art melting/refining technology
- The cost of transition to state of the art technology show flat glass with the highest cost followed by container glass, textile fiber, and wool fiber
- Willingness of glass sectors to adopt these new technologies are wool fiber followed by textile fiber, flat, and container glass

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ITP Glass Program: Portfolio and Strategy

Elliott Levine

September 16, 2005

U.S. Department of Energy
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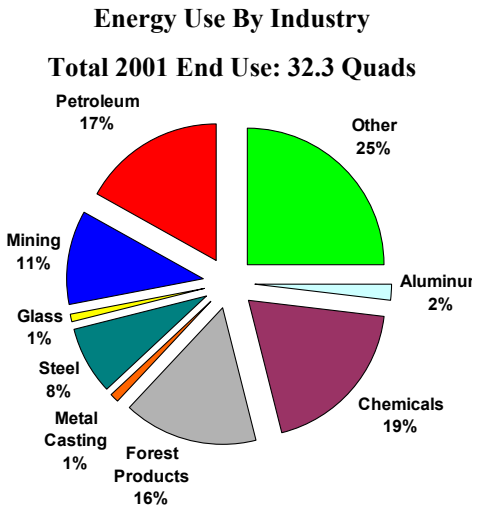
Industrial Technologies Program

MISSION

Improve the energy efficiency of U.S. industry through coordinated research and development, validation, and dissemination of innovative technologies and practices.



Current ITP Program Areas

Industry Specific

- Aluminum
- Chemicals
- Forest Products
- Glass
- Metal Casting
- Mining
- Steel

Crosscutting Technologies

- Combustion
- Sensors & Automation
- Materials
- Supporting Industries

Best Practices

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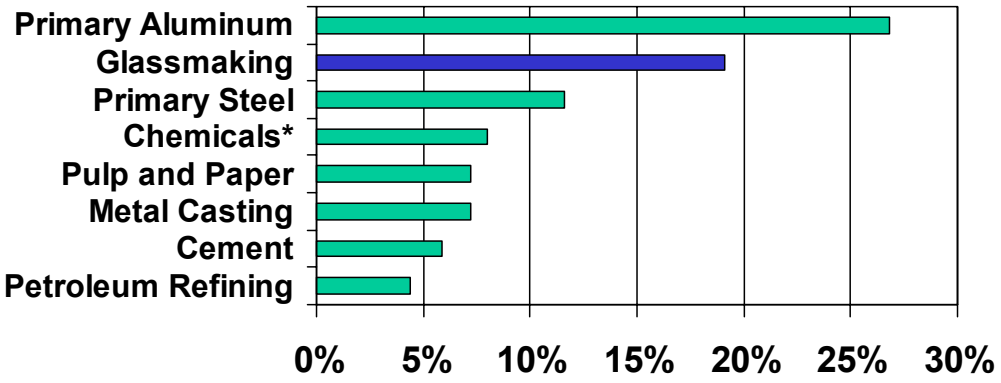
Pathways to Near and Long Term Success

- Collaborate with industry and industry groups to plan & implement R&D programs and design transformational technologies – collaborative, focused, larger R&D projects which are long-term, and high return
- Utilize our primary partner for glass, GMIC, as coordinating organization for industry interests
- Enlist other government organizations in EE, DOE, Federal and State governments to leverage resources
- Utilize Allied Partners to help communicate energy options to industry and facilitate technology replication

Glass: An Energy-Intensive Industry

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



* Excludes pharmaceuticals

Data derived from 2001 Annual Survey of Manufactures, Department of Commerce

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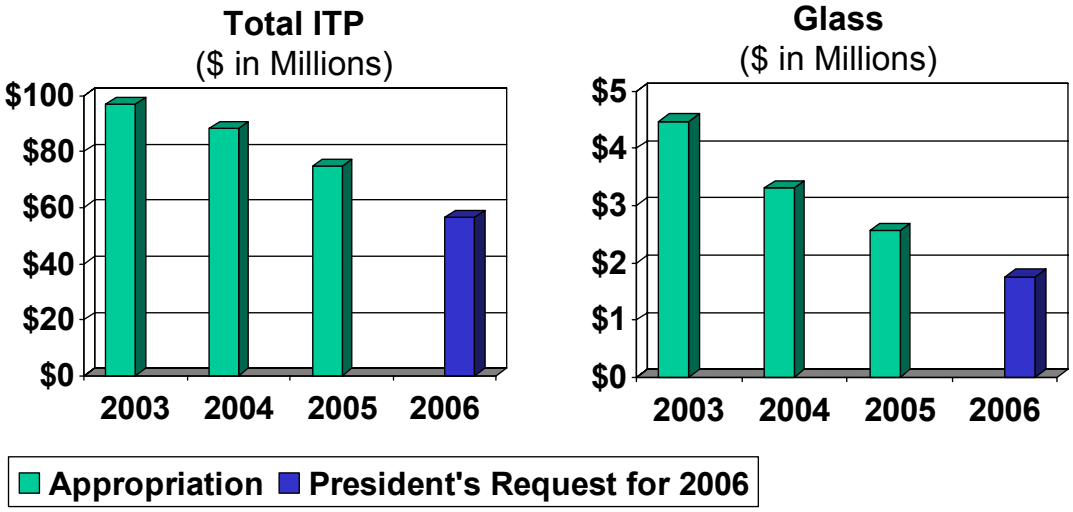
Challenging Budget Outlook



Portfolio Review Methodology

Goal: Connect Portfolio Content to Strategy (within Glass program and ITP)

- Level 1: Portfolio Direction
- Level 2: Portfolio Content: Focus Areas
- Level 3: Project Performance

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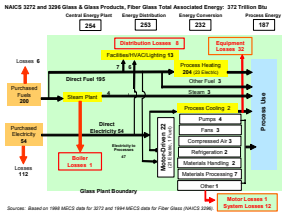
Level 1

Portfolio Direction

- Maximizing energy saving benefits through analytical basis for activities
- Develop and implement a portfolio and focus areas with clear goals and strategies
  - Balance between nearer-term and longer-term R&D in three primary focus areas
  - Allocation of resources guided by analysis results
  - Support technology transfer efforts

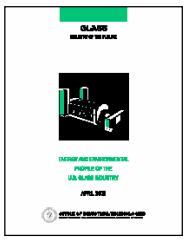
Analytic Tools and Resources for Glass Program Planning

EIA MECS data
DOC Census data



Energy Footprint Analysis

Glass Industry Energy and Environmental Profile



Technical and Economic Assessment

Bandwidth Study (draft)

Energy Bandwidth Analysis (draft)

Technical and Economic Assessment for Advanced Glass Melting Technologies

Analyses underpin focus areas

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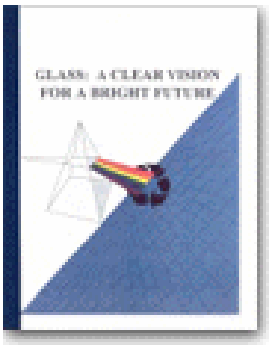
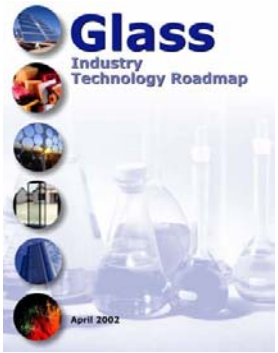
Industry Inputs

- *Glass Industry Vision*
  - Published 1996
  - Identifies industry goals and priorities

    By 2020, reduce the gap between actual and theoretical energy use by 50%

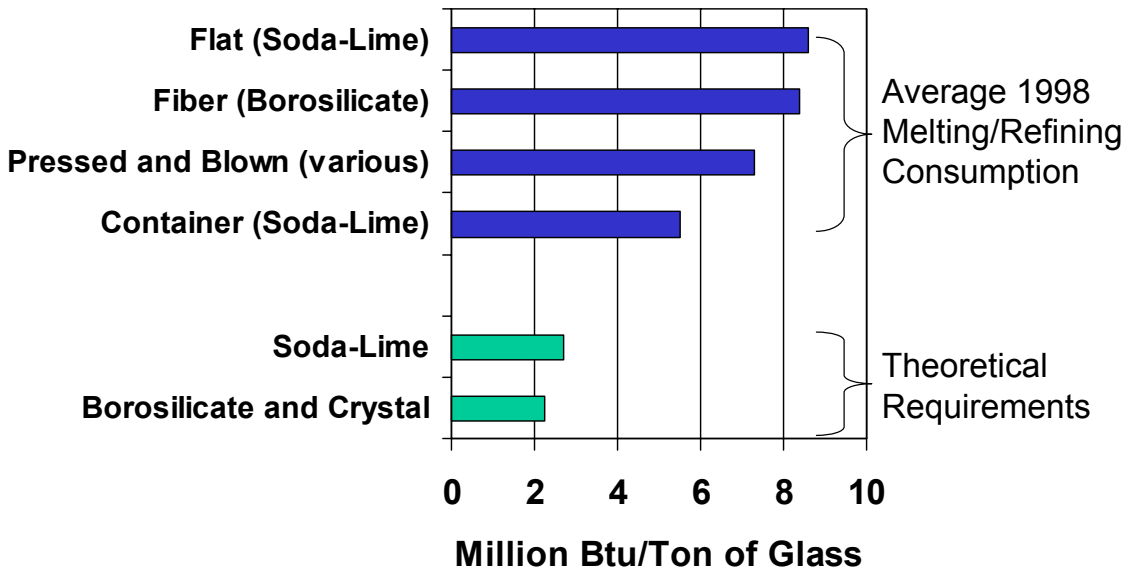


- *Glass Industry Technology Roadmap*
  - Published 2002 by the Glass Manufacturing Industry Council (GMIC)
  - Identifies technical barriers and priority research needs in four technical areas
    - Production Efficiency
    - Energy Efficiency
    - Environmental Performance
    - Innovative Uses



- Technology Workshops

Theoretical and Average Melting Requirements



Glass furnaces use significantly more energy than theory requires

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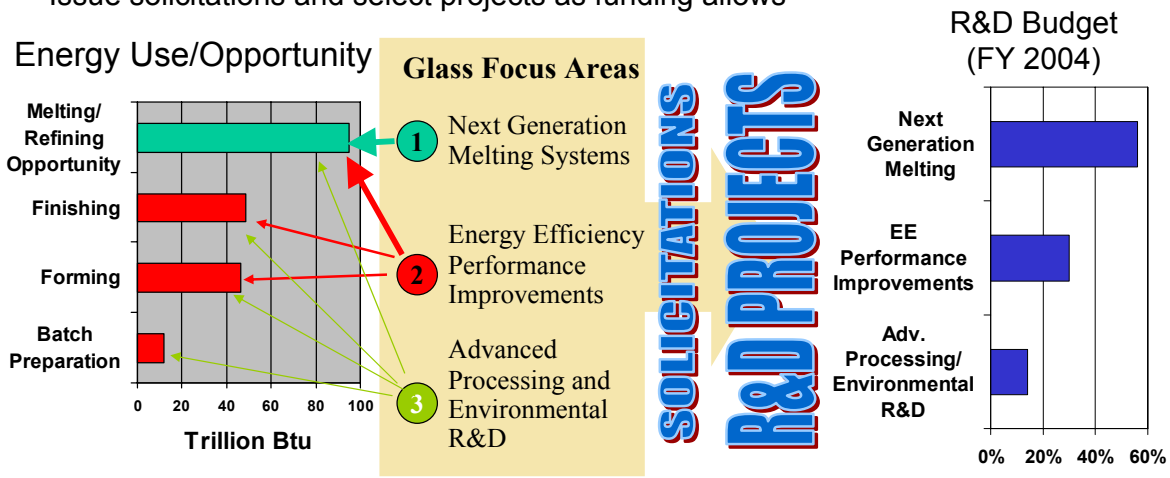
Key Variables Affecting Glass Energy Use

	Variable	Energy	Driver
Melter	Larger size	Lower	Market
	Longer campaign	Higher	Operations, safety
	Better refractory	Lower	Cost
	Switch to oxy-gas	Lower	Oxygen cost, quality
Operations	Lower seed count	Higher	Quality demands
	Higher cullet proportion	Lower	Cullet availability, glass quality
	Higher pull rate	Lower	Higher temperature, shorter campaign
	Glass color/composition	Either	More energy with higher silica, color

Difficult to adjust energy consumption without affecting other production parameters, such as quality, throughput, and overall costs

Analytic Basis for Glass Program Priorities

- Use analytic tools to identify the best opportunities for reducing energy intensity
- Set focus areas based on gap between current use and theoretical need
- Quantify potential energy savings in each focus area
- Issue solicitations and select projects as funding allows



Summary of Glass R&D Focus Areas

Focus Areas	Goal	Timeframe and Risk
1. Next Generation Melting Systems	Dramatically reduce melting energy intensity through new technology	Long-Term High-Risk
2. Energy Efficiency Performance Improvement (model validation, glass compositions, materials, preheating, combustion optimization)	Maximize energy efficiency utilizing existing plant structure	Mid-Term Medium-Risk
3. Advanced Processing and Environmental R&D (robust sensors, predictive control systems and emission tools and abatement techniques)	Improve production efficiency/yield and reduce environmental impact	Mid-Term Medium-Risk

Glass FY 2005 Portfolio

Projects by Focus Area

- Next Generation Melting Systems (2)
- Energy Efficiency Performance Improvements (3)
- Advanced Processing and Environmental R&D (3)

For each focus area has distinct energy saving opportunities, resource allocation, technical barriers and pathways, and solicitation of projects

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Glass FY05 Project Portfolio by Focus Area

- Next Generation Melting Systems
  - Submerged Combustion Melting, GTI
  - High Intensity Plasma Melting, Plasmelt
- Energy Efficiency Performance Improvements
  - Oxy-Fuel Fired Front-End System, Owens Corning
  - Coupled Combustion Space/Glass Bath Simulation, ANL
  - Optimization of Online Coating for Float Glass, SNL
- Advanced Processing and Environmental R&D
  - Measurement and Control of Glass Feedstocks, Energy Research
  - Monitoring and Control of Alkali Volatilization, SNL
  - Fiber Drawing Yield Improvement, Cleveland State (States IOF)

Level 2

Portfolio Content: Focus Areas

- Energy savings
- Barriers/pathways/end states
- Resource distribution
- Solicitation

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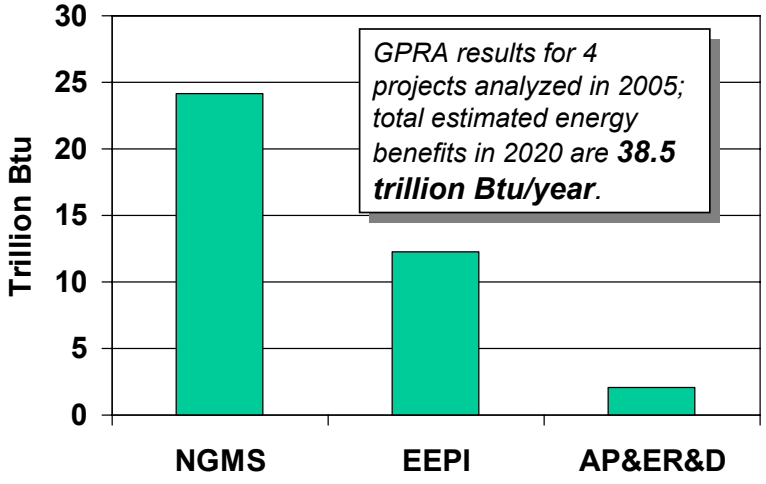
Estimated Energy Benefits in 2020 (GPRA Results, 2005 glass portfolio)



Focus Area #1: Next Generation Melting Systems

Barriers

- Reduce energy use without reducing glass quality and production rate
- Reduce need for additional refining and conditioning
- Reduce risk of scale-up to >500 t/day plant size

Pathways

- Demonstrate alternative approaches to melting and evaluate at pilot-scale
- Validate achievement of technical targets and required integration with refining/ conditioning and other plant systems
- Expand industry collaboration for broader commercial adoption

Metrics

Metric	End State
Melting System Energy Efficiency (MMBtu/ton glass) -Container: 3.4 -Flat: 5.0 -Fiber: 3.0	Commercial scale demonstrations of integrated advanced melting and refining system in major glass sectors

- **Solicited for advanced melting concepts in 2002, selected two projects**
  - **Submerged Combustion Melting**
  - **High-Intensity Plasma Melting**
- **Solicited for advanced refining concepts in 2005**

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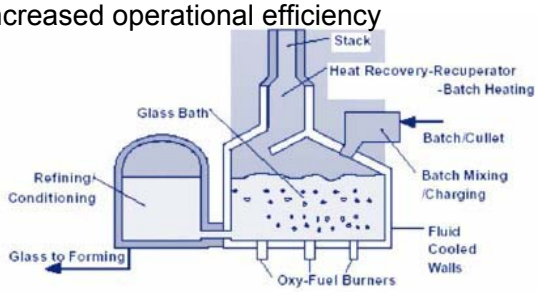
Next Generation Melting Systems Example

Submerged Combustion Melting

Technology Description:

- New glass melting technique employing direct heat transfer and turbulent mixing through submerged oxy-fuel burners
- Addressing stable, controlled combustion through modeling and pilot testing

- **Benefits**
  - Up to 23% energy savings and associated combustion-related emissions
  - Significant reduction in capital costs and increased operational efficiency
  - Up to 50% reduction in NOx emissions
  - Up to 80% reduction in refractory usage
- **Status**
  - Melter modeling and design underway
  - Pilot-scale fabrication planned for FY05 (subject to availability of funding)



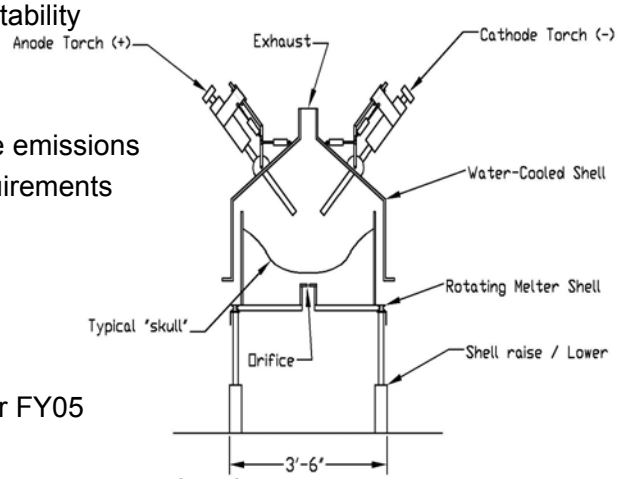
Partners: Gas Technology Institute, Corning, PPG Industries, Owens Corning, Schott Glass Technologies, Johns Manville, CertainTeed, Combustion Tec/Eclipse, Praxair, Fluent, A.C. Leadbetter and Son, NYSERDA

Next Generation Melting Systems Example

High-Intensity Plasma Melting

Technology Description:

- Modular, electricity-based melter design utilizing dual-torch plasma arc melting technology for production of high quality glass
- Addressing torch life and process stability



- **Benefits**
  - Up to 40% energy savings
  - Reduced CO_2, NO_X, and particulate emissions
  - Lower capital costs and space requirements
  - Improved operability and flexibility
  - Reduction in refractory usage
- **Status**
  - Melter design nearing completion
  - Prototype melter testing planned for FY05

Partners: Plasmelt Glass Technologies, Johns Manville, Advanced Glassfiber Yarns

Focus Area #2: Energy Efficiency Performance Improvements

Barrier-Pathway Approach and Project Selection

Barriers → ***Pathways*** → ***Metrics***

- Energy requirements of current glass compositions
- Limitations of existing simulation tools and materials
- Ineffective use of waste furnace heat
- Lack systems to optimize combustion heat transfer

- Continue development of existing projects and award new projects for advanced, energy-efficient process technology
- Demonstrate and evaluate advanced technology
- Integrate technological advances into existing glass plant operations

Metric	End State
Energy Efficiency (MMBtu/ton glass) -Container: 5.5 -Flat: 7.7 -Fiber: 12.0	Demonstrate increase in efficiency through the application of advanced technology outside advanced melting/refining

- **Select high energy impact efficiency projects as funding permits**
- **One project funded in FY 2003: Oxy-Fuel Fired Front-End System**

Energy Efficiency Performance Improvement Projects

- Oxy-Fuel Fired Front-End System
- Coupled Combustion Space/Glass Bath Simulation
- High-Luminosity, Low-NOx Burner Demonstration (NICE3)
- Optimization of On-Line Coating for Float Glass
- GPLUS Exploratory Research Program

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Focus Area #3: Advanced Processing and Environmental R&D

Barrier-Pathway Approach and Project Selection

Barriers → ***Pathways*** → ***Metrics***

- Lack robust, cost-effective sensing capability
- Lack sufficient understanding of physical processes
- Lack predictive and analytic tools for fabrication and emissions
- Regulatory risk for environmental improvements

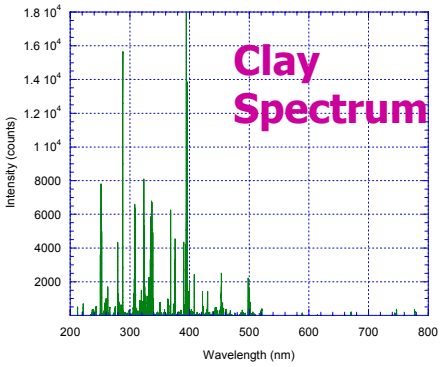
- Continue development of existing projects and award new projects to increase glassmaking productivity
- Demonstrate and evaluate advanced technology
- Integrate technological advances into existing glass plant operations

Metric	End State
Yield (%) -Container: 96 -Flat: 80 -Textile Fiber: 94 -Insulation Fiber: 90 -Melting: 98	Demonstrate increase in yield improvement and significant economic benefit per unit of product

- **Select high energy and productivity impact projects as funding permits**

Advanced Processing and Environmental R&D Projects

- Measurement and Control of Glass Feedstocks
- Monitoring and Control of Alkali Volatilization
- Fiber Drawing Yield Improvement (States IOF)



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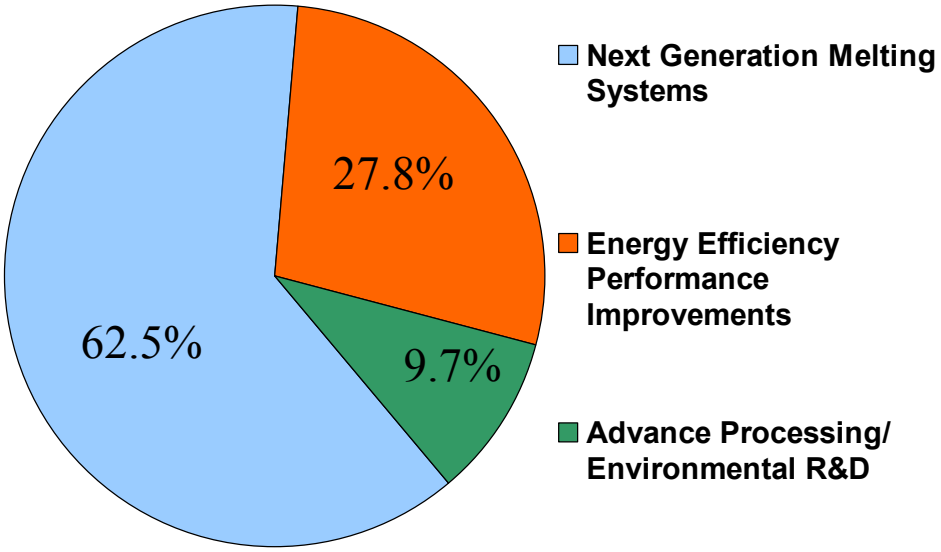
DOE Dollars by Focus Area FY05



Glass Solicitation

- Closed April 1, 2005
- Category A Topics
  - Refining and Conditioning
  - Batch/Cullet Preheating
- Category B Topics
  - Glass Composition and Raw Materials
  - Forming and Finishing
- Status:
  - New ITP Program Manager reviewing existing program areas
  - Final determination on solicitation awards has not been made

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Level 3

Level 3: Project Performance

- Review of projects (conducted earlier)
- Benefits analysis (GPRA)
- Results

Results

- Recent Commercial Successes
  - High Luminosity, Low NOx Burner
  - Oxy-Fuel Optimization Protocol

- Recent Technical Successes
  - Advanced Glass Furnace Model
  - Oxy-Fuel Front-End System
  - Glass Melt Properties Database
  - ERCo LIBS sensor for glass feedstocks
  - Online coatings for float glass

- Other Activities
  - Technical and economic assessment of glass melting technology published
  - Distance learning course for energy management being developed through CGR
  - Stakeholder engagement tool developed to increase interaction (www.govforums.org/glass)

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Upcoming Ohio Technology Showcase

September 27-29 in Cleveland

- Two "Best Practices" Training Sessions:
  - Melting and High Temperature Processes
  - Compressed Air Systems
- Visit to Cleveland State University and its Fiberglass Drawing Pilot Plant as well as several other industry plants in the Cleveland area
- A breakfast session to discuss the possibilities of Clean Coal Gasification Synfuel as a lower priced alternative to Natural Gas for industrial applications
- Glass Breakout Session covering:
  - CFD Simulation of Glass Furnaces and other Industrial Processes
  - Measurement and Control of Glass Feedstocks
  - Development/Demonstration of an Advanced Oxy-Fuel Fired Front-end System
  - Submerged Combustion Melting - the Next Generation Melter

Visit the GMIC and GTI booths

http://www.ohioshowcase.org/

Questions?
(~ 30 minutes)

Facilitated discussion
(~ 45 minutes)

Thank you for your participation

B

Appendix B

Sample Evaluation Forms

Reviewer Assessment Form for Projects

Project No.	Project Title

Contracting Organization	Principal Investigator

Project Goal

Energy Savings in 2020	Energy Savings in 2025	Energy Savings in 2030
TBtu	TBtu	TBtu

SECTION I: COMMENTS ON ENERGY SAVINGS ESTIMATES

Please revise estimates used in energy savings calculations:

Variables	Estimates	Suggested Revisions	Reviewer Comments
Current Energy Use			
Market Size			
Market Growth Rate			
Year of Technology Introduction			
Market Penetration			

SECTION II: PROJECT RATINGS

Please rate this project on a scale of 1 to 10 on the following:

Value	Comments
Technical Risk of the Technology Being Developed *Where 10 is very high technical risk (i.e., difficult technical challenges are barriers to success, may not succeed) and 1 is very low technical risk (i.e., only incremental engineering improvements needed; knowledge base already exists)*	
1 2 3 4 5 6 7 8 9 10	

Commercial Risk of the Technology Being Developed *Where 10 is very high commercial risk (i.e., strong competition and/or barriers to market entry such as high relative cost) and 1 is very low commercial risk (i.e., market entry, first end-users, infrastructure already in place)*
1 2 3 4 5 6 7 8 9 10
Attractiveness of the Investment for DOE *Where 10 is very high attractiveness for DOE (i.e., energy benefits highly probable, project strongly supports portfolio and focus area goals) and 1 is very low attractiveness for DOE (i.e., low or negligible energy savings probable, no clear fit in portfolio or focus areas)*
1 2 3 4 5 6 7 8 9 10

SECTION III: QUESTIONS

Please answer the questions below that are appropriate to this Project type. Delete the two remaining irrelevant sections.

First Year Projects

1. What are the major technical barriers and problems being addressed with this project?
2. What focus area(s) does this project relate to?
3. What synergies exist between this project and others in the focus area and overall portfolio?
4. What actions would improve chances of this project's technical success?
5. What actions would improve chances of this project's commercial success?

On-going Projects

1. Discuss industry's need for this project.
2. Is the economic justification for this project convincing to the end-user?
3. Has the project been making the expected technical progress?
4. Discuss the strengths and weaknesses of the proposed commercialization plan.
5. How could the applicability of this project be enhanced and broadened beyond the targeted market within the project?
6. How could the project team and DOE reduce the technical and commercial risks associated with this project?

Final Year Projects

1. To what extent has the project achieved technical success? What technical knowledge has be contributed to the technical community? What intellectual property has been filed and secured? What's the implication of the IP position of the project team?

2. Are the team's plans for commercialization/continuation adequate?

3. What additional options for commercialization/continuation might the team consider?

4. Please identify opportunities for showcasing this technology and explain the role that DOE might play.

5. What mechanism should be used to communicate future impacts from this technology to the Portfolio Manager?

[Insert Name] Portfolio Reviewer Instrument

(Each reviewer is asked to respond to the following questions. The responses will be collected, consolidated and edited to produce the final report on Level 1—Portfolio Direction and Level 2—Portfolio Content issues.)

1. What problems or issues do you see with the strategy that is being used to direct this portfolio?

2. How well does this strategy meet the future needs of DOE, industry, and other stakeholders?

3. What changes to the portfolio strategy would you suggest be investigated given available funding?

4. What problems or issues do you see with the focus areas selected for this portfolio?

5. Have the direction and end state of the focus areas been adequately defined and supported by data?

6. What changes in focus areas or pathways would you recommend?

7. What action steps would you suggest the Portfolio Manager undertake to more effectively manage this portfolio?

C

Appendix C

Attendees

Attendees

U.S. Department of Energy

GLASS PORTFOLIO REVIEW

Chicago, Illinois

September 14-16, 2005

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