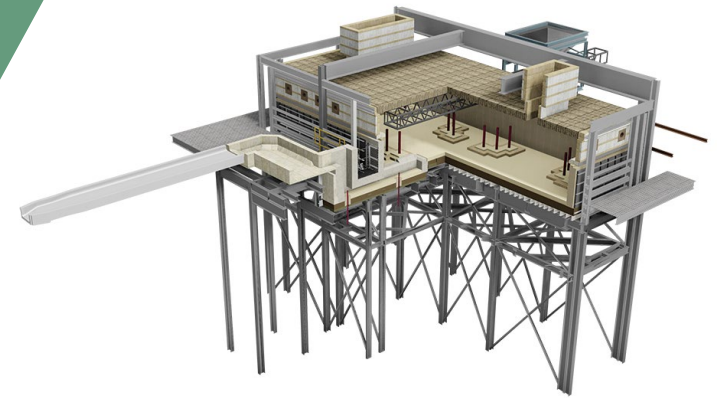


DOE-GMIC Glass Consortium on Advanced Electric Melting Industry Project Update

SCOTT COOPER, CELSIAN
JONATHAN BLEVINS, TECO

15 SEPTEMBER, 2026



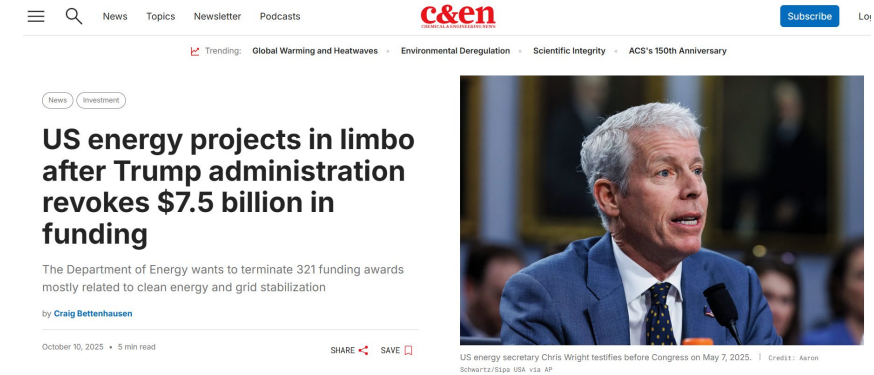
DOE Investment in Advancing Glass Industry

- March, 2023: Funding opportunity (85+% CO₂ reduction potential)
- January, 2024: Project selected for \$3M over 3 phases
- Sept. 2024: Official start of budget period 1
- January, 2025: New Administration
- Feb, 2025: Project placed under 'administrative review'
- Feb, 2026: End of budget period 1
- May, 2026: Admin hold lifted, approval for budget period 2
- August, 2026: Negotiations complete, budget period 2 begins

- ***Strengthen US Manufacturing***
- ***Broad Industrial collaboration***
- ***Productivity Improvement***

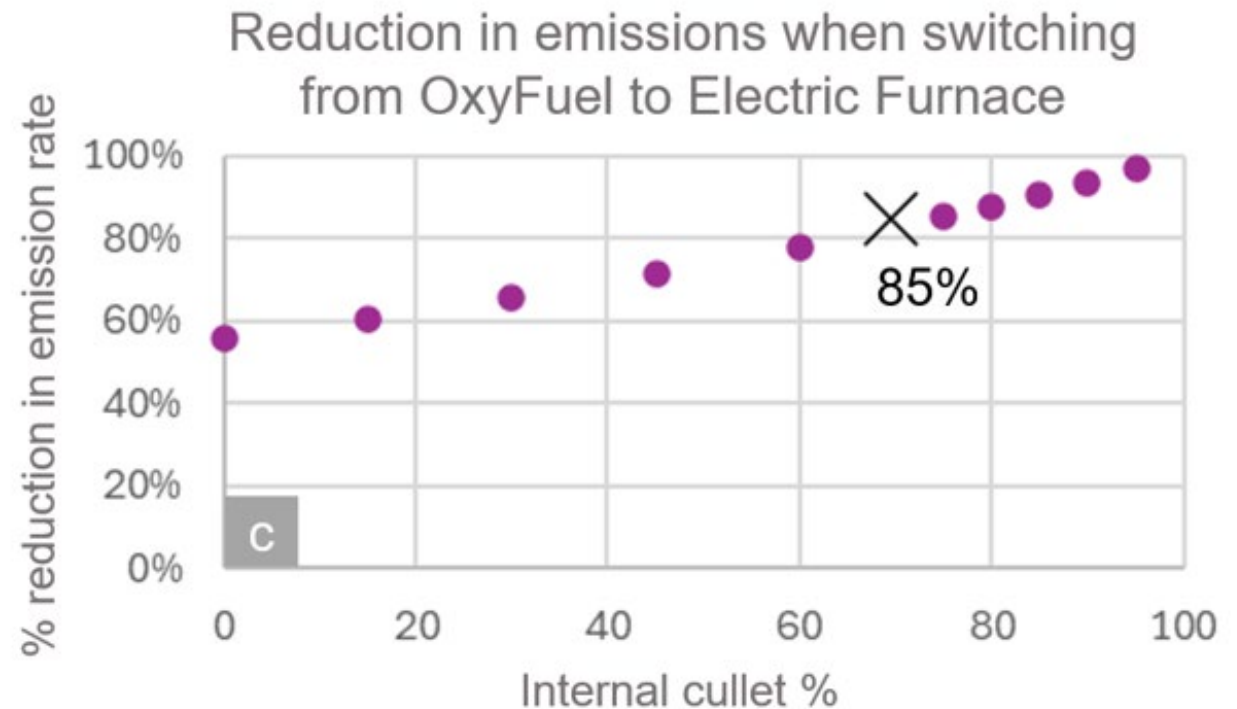
DOE Announces \$171 Million for 49 Projects to Decarbonize America's Industrial Sector

U.S. DEPARTMENT OF
ENERGY | Office of ENERGY EFFICIENCY
& RENEWABLE ENERGY
INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE



Industrial Electric Melting of Glass

- Air emissions (NO_x, SO_x)
- Energy efficiency
- Operational ease
- Fast rebuild time
- Scope 1 CO₂ reduction

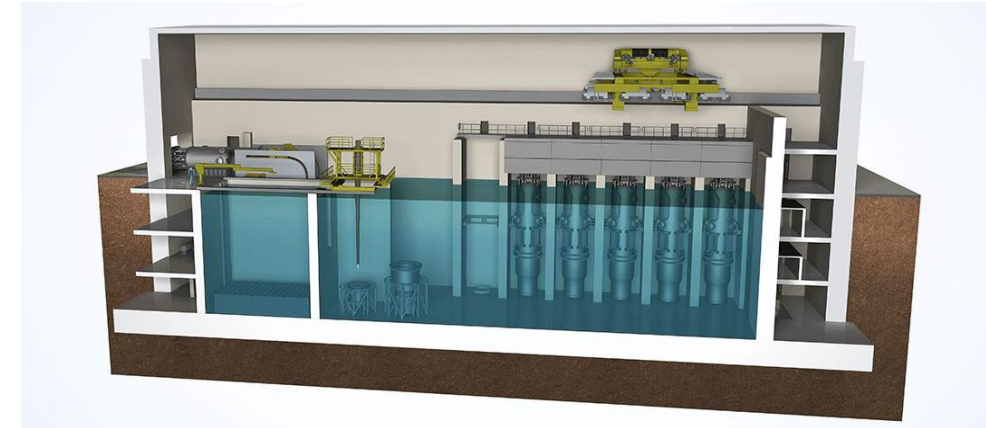


Looking into the Future

Small Modular Reactors (SMRs)

- From 2024 to 2030, AI's share of U.S. electricity demand is expected to triple
- Predictable, long-term stability of fuel (decades)
- Low carbon glass meets customer ESG
- Reduce carbon pricing exposure

Glass as a second-wave industrial user in the future?



Core Project Team



Scott Cooper
CelSian



Brian Naveken
TECO



Jesse Lang
PNNL



Eric Muskovin
CelSian



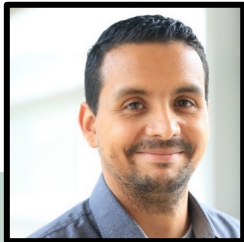
Jonathan Blevins
TECO



Jess Rigby
PNNL



Katelyn Kirchner
CelSian



Cristian Hernández
CelSian



Jaime George
PNNL



Stan Rutkowski
RoMan Manufacturing



David Rue
GMIC Program Manager

Stakeholders



Kerry Ward
GMIC



Keith Jameson
DOE



Lexie Kim
DOE

GMIC Industrial Steering Committee BP1

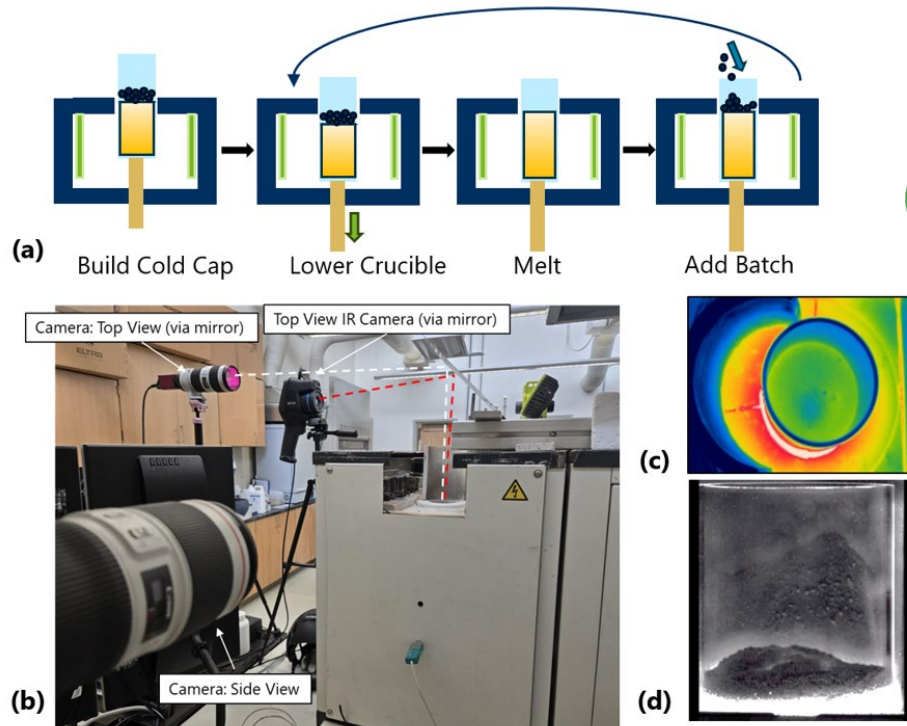
- Aaron Huber (Johns Manville)
- Bruno Purnode (Owens Corning)
- Daniel Johnson / Chris Brenna (Libbey)
- Jan Schep (O-I)
- Ufuk Senturk (Potters Industries)
- Darryl Shaffer (Gallo Glass)



Budget Period 1

Key Learnings

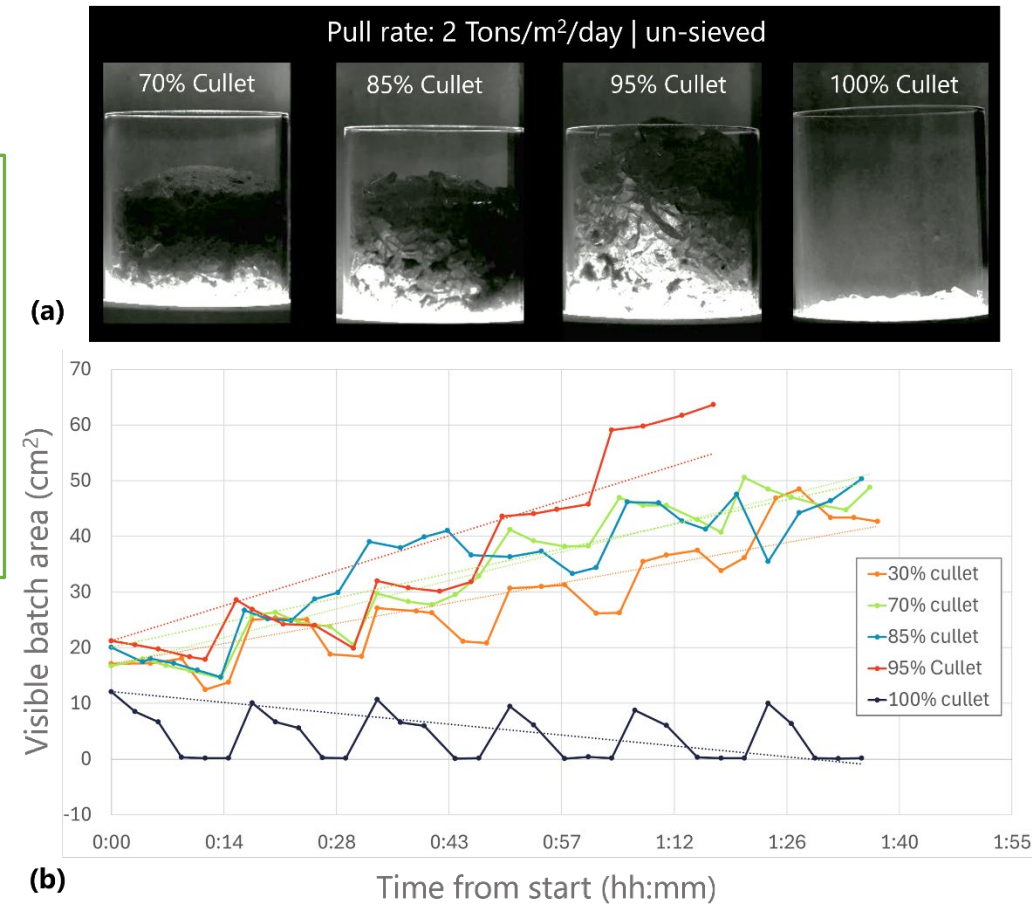
Key Learning: Impact of Cullet in Cold Top Melting



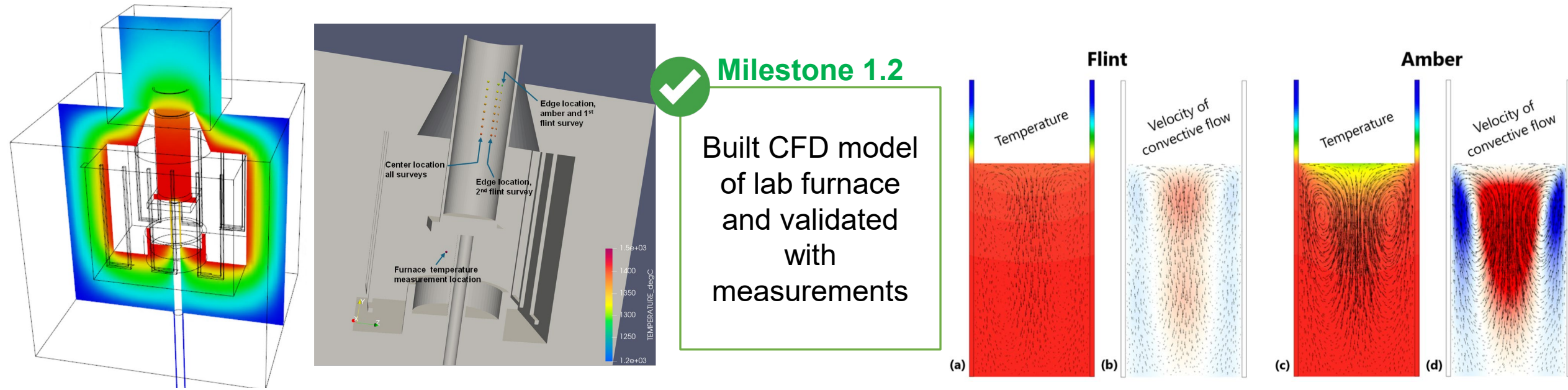
Milestone 1.1

Benchmarked
several
conditions of
cullet use and
85+% CO₂
reduction

- Minimal change in melt rate observed between 30 - 70% cullet.
- Batch foaming/instability above approx. 90% cullet
- Burnt lime shows similar behavior (at 70% cullet)
- Smaller cullet particle size → foaming behavior increases

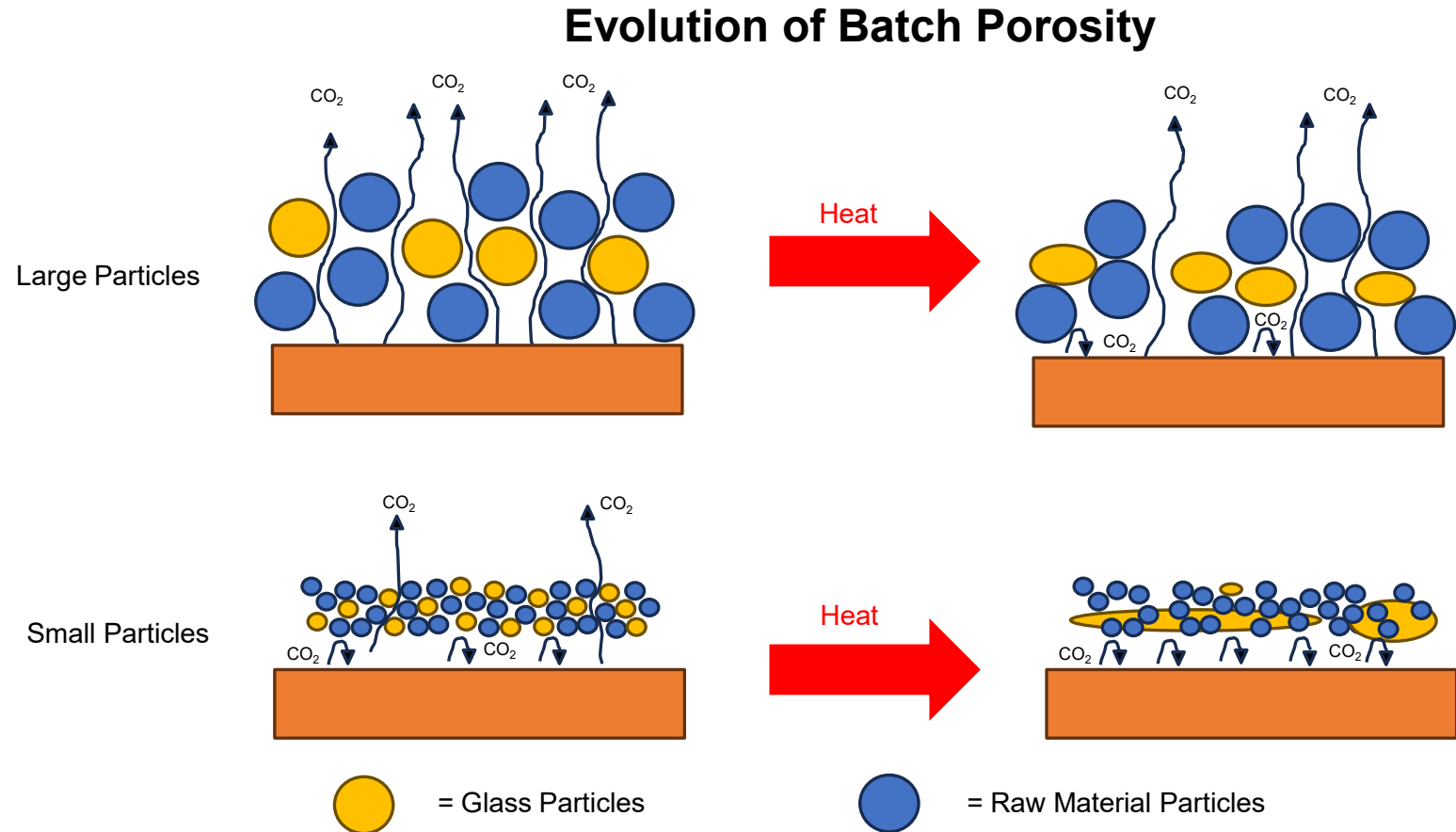


Key Learning: Thermal Conductivity of Dark Glass

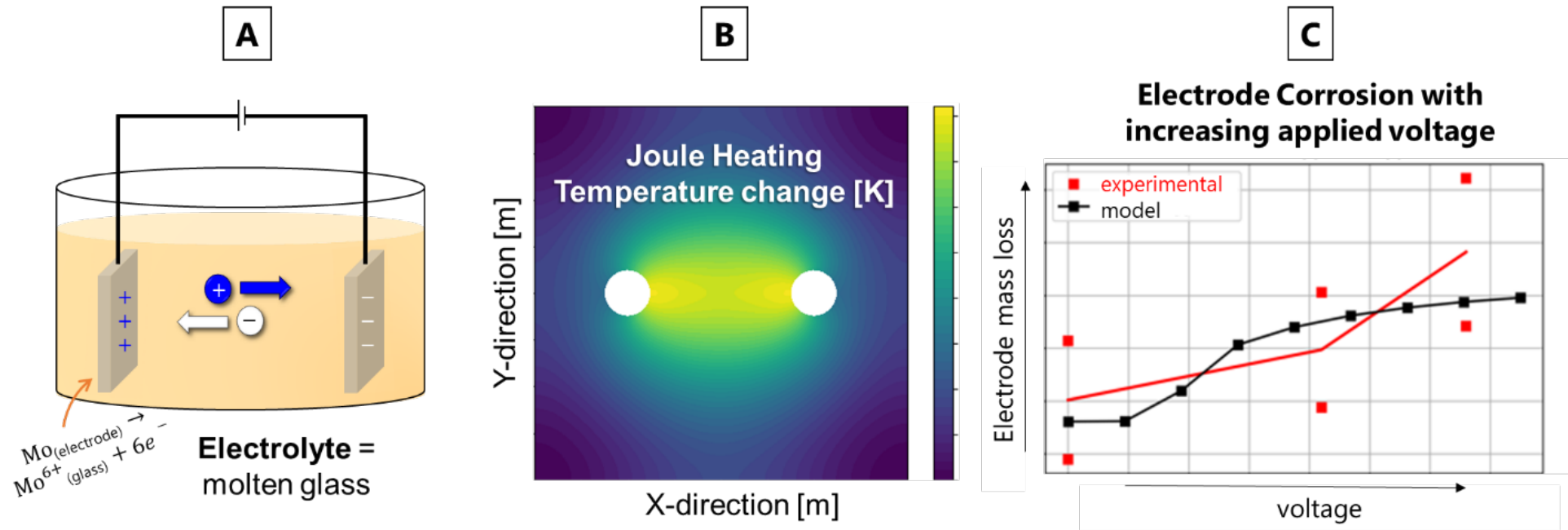


- The low thermal conductivity (radiative heat transfer) of dark glass plays an equal (or perhaps greater) role in slowing the melting rate as batch chemistry

Transient Chemical Reactions



Key Learning: Beginning to Model Electrode Corrosion



Built a theoretical/modeling framework for looking at time-dependent redox changes in the glass/electrode system

Budget Period 1 Accomplishments

- US Glass Industry Education:
 - 5 steering committee technical reviews
 - 4 technical papers presented at GPC
 - 3 webinar talks on electric melting
 - 3 glass manufacturer bilateral reviews
 - 1 scientific paper for publication (drafted)
- Wide engagement base:
 - Feedback at GPC → team actions
 - DOE national lab focus on industry challenges
 - Connection to research in Germany
- Strengthening GMIC
 - 2 Members joining attributed to DOE project
 - 1 Report on status of electric melting (in prep.)
 - Pre-competitive, technical R&D



Leveraging our Steering Committee



Feedback:

- Cullet studies of most interest → directly applicable knowledge
- Fiberglass segment particularly engaged
- Guiding whether or not to invest in electric melters (specialty)

Huge possible “wins”:

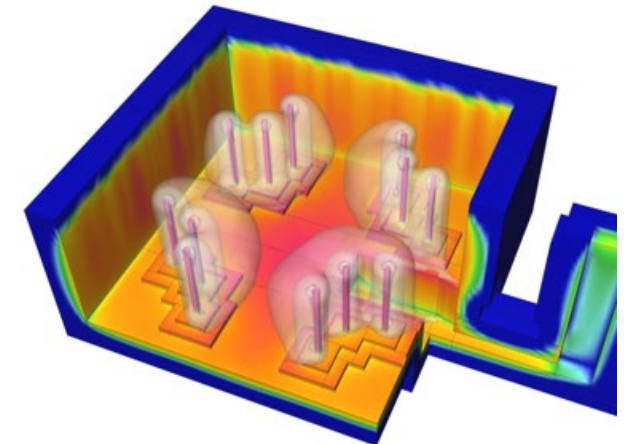
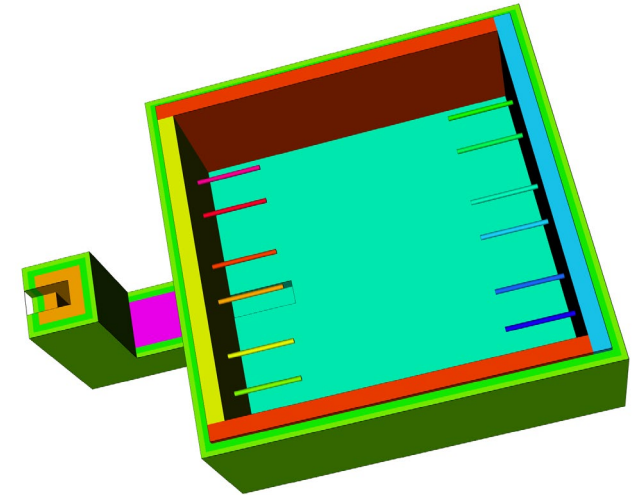
- \$10s-100s million in industry-wide savings:
 - If fiberglass could use amber cullet
 - If fiberglass could prevent usage of oxidizers
- Sensor to measure thickness of cold top blanket (closed loop control)
- Extra furnace life (even 1 year is meaningful)

The background features a large, dark green parallelogram on the left side, tilted slightly to the right. A horizontal dark green bar runs across the top. A light green horizontal bar is positioned near the bottom, partially overlapping the dark green shape. The right side of the image is white.

Furnace Design Studies

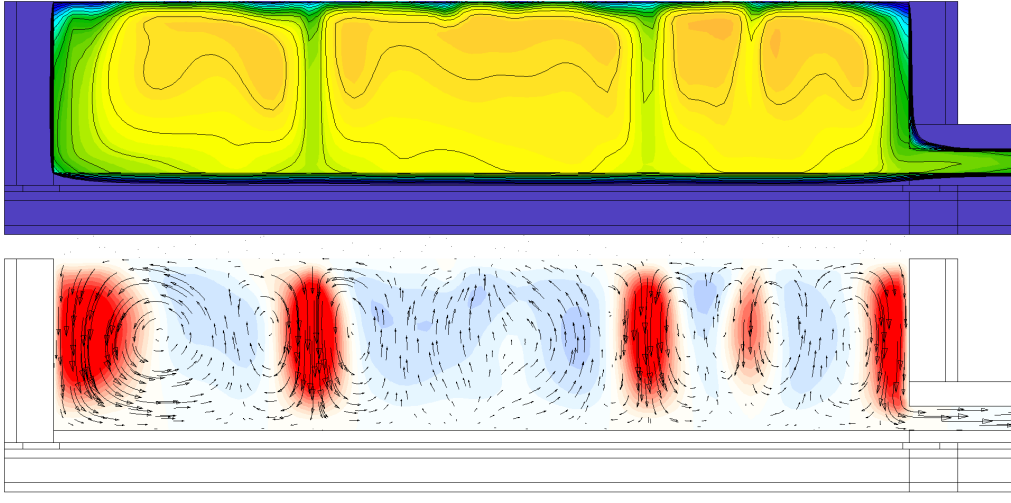
Life Extension Study

- Primary objective was to evaluate different means of extending furnace life through reducing wall temperatures while maintaining quality
- A large parametric space of electrode configurations was explored – these however did not lead to significant reductions in wall temperatures
- 3 different approaches were explored to reduce the glass temperatures near the melter sidewalls
 - Radiant edge
 - A radiant edge was applied to the circumference of the top of the melter
 - Increased sidewall cooling of the refractory sidewalls
 - Impacts were assessed at sidewall thicknesses of 250, 200, 150, and 100mm
 - Power was increased to keep quality results similar to the Baseline model
 - Running the melter colder (less power)
 - Reduced wall temperatures & velocities, reduced energy
 - Quality out of the melter itself was worse
 - Later combined with a secondary chamber to improve quality



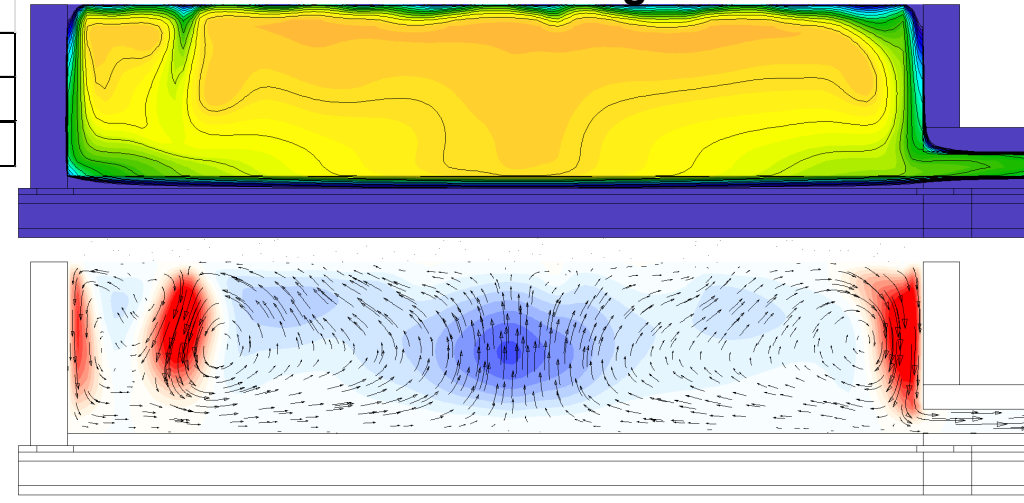
Life Extension Study Results

Baseline



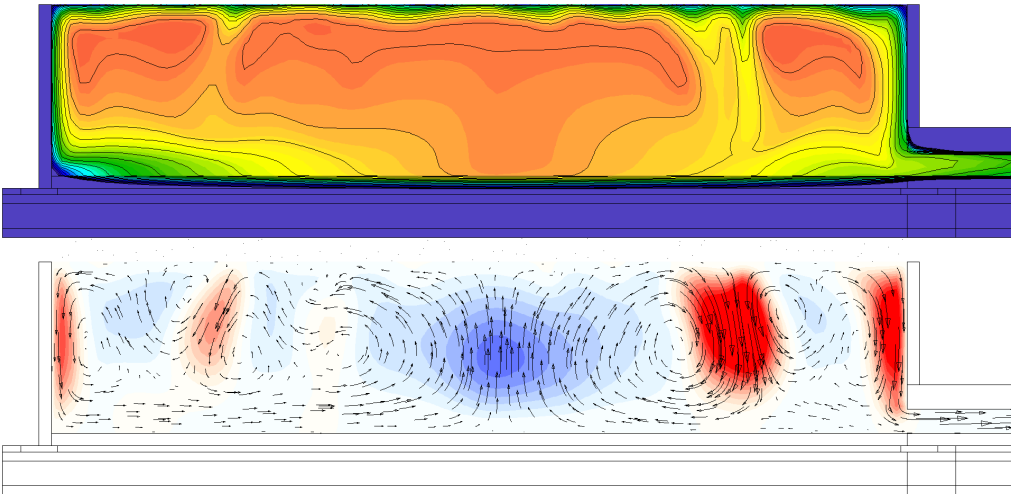
Near Walls	
T _{delta}	0.00
V _{delta}	0.00
P _{delta}	0.00

Radiant Edge



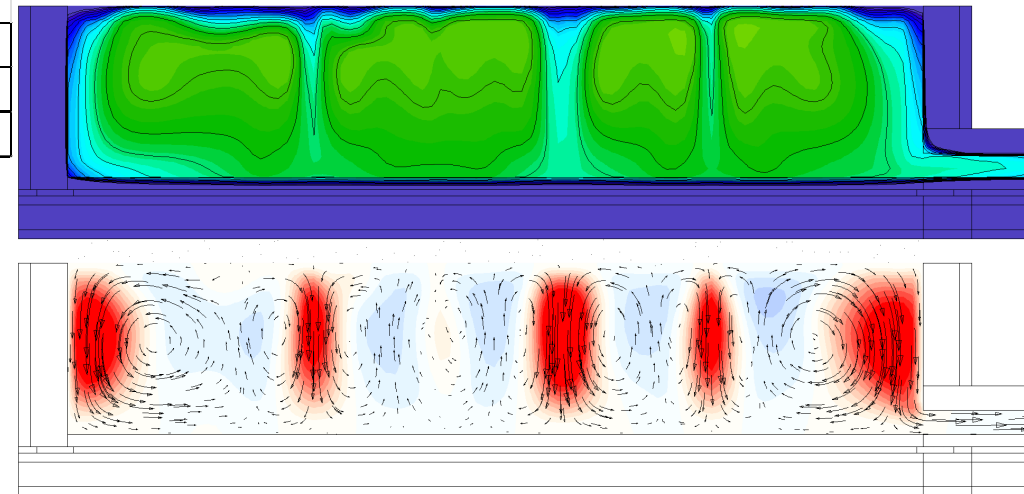
Near Walls	
T _{delta}	-19.3°C
V _{delta}	+50.0%
P _{delta}	+33.8%

Cooled Wall



Near Walls	
T _{delta}	-19.1°C
V _{delta}	+44.9%
P _{delta}	+43.9%

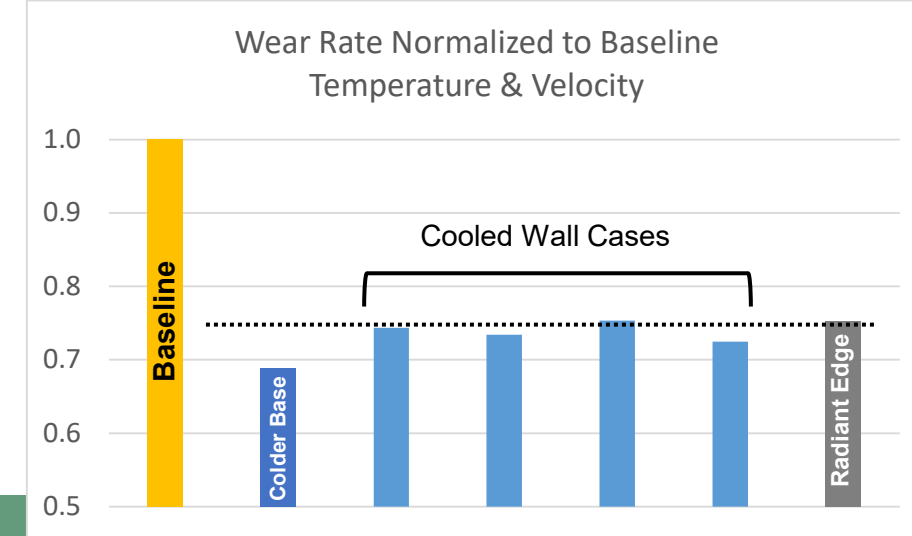
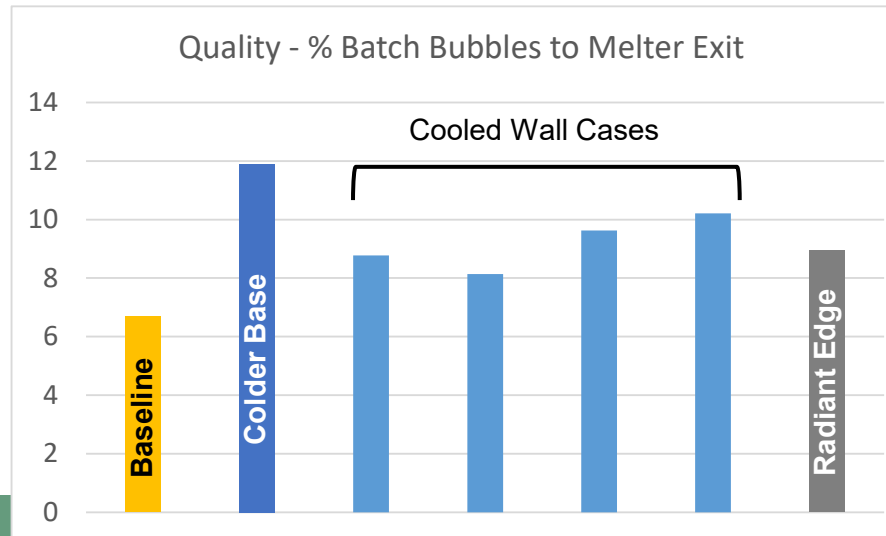
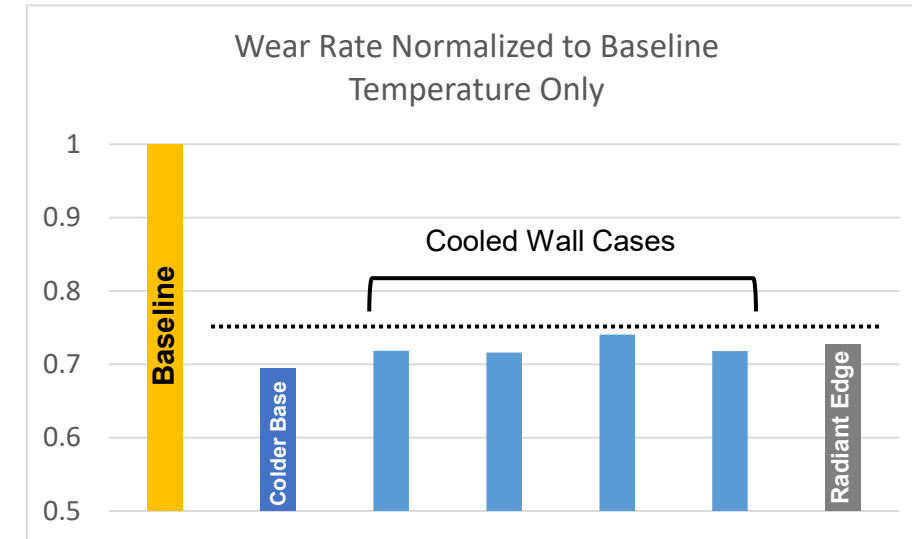
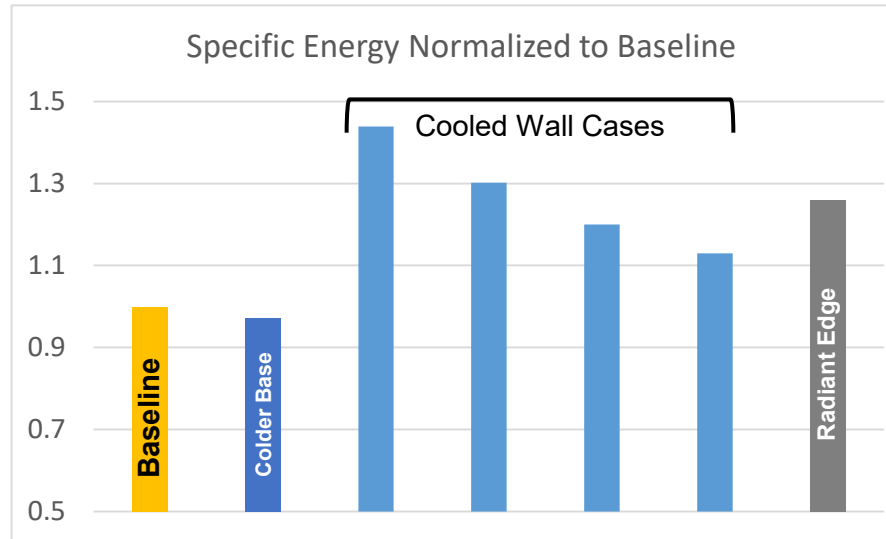
Baseline – Colder



Near Walls	
T _{delta}	-21.1°C
V _{delta}	-10.3%
P _{delta}	-2.9%

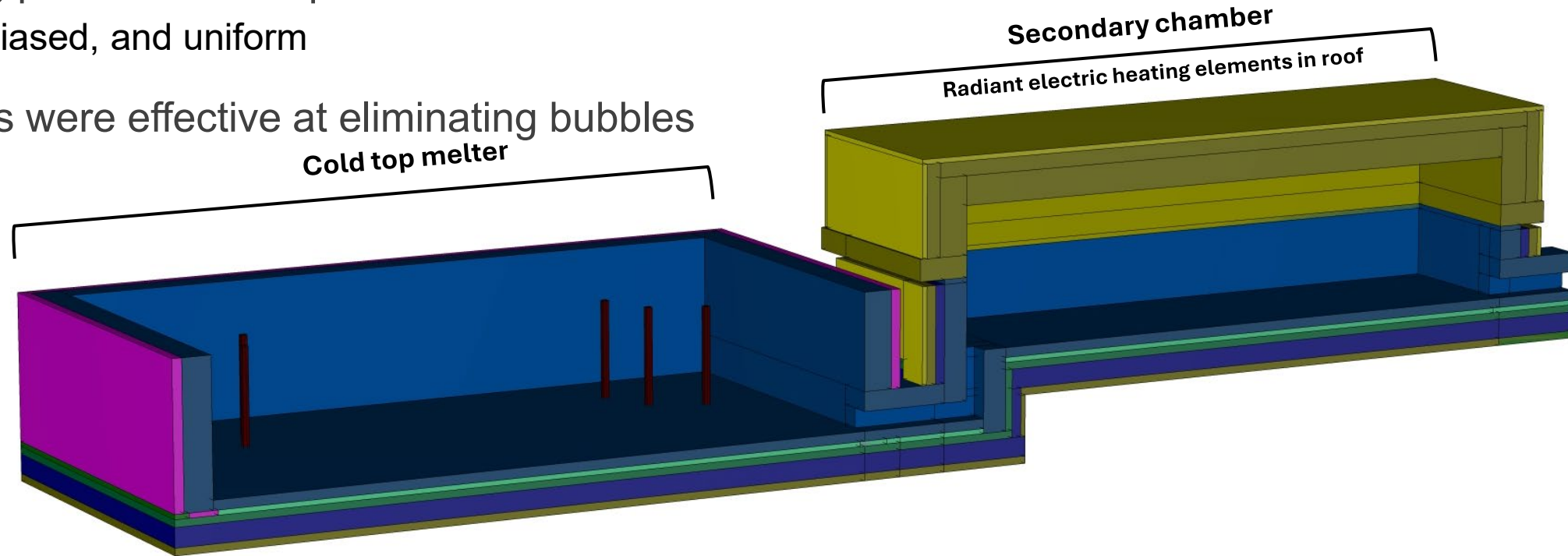
Life Extension Study Results

- Colder Baseline was better in every area except quality
- Both Cooled Walls and Radiant Edge approaches increase energy demand and increase velocities near walls
- Results led to exploring use of a secondary chamber for quality improvement



Electric Secondary Chamber Concept

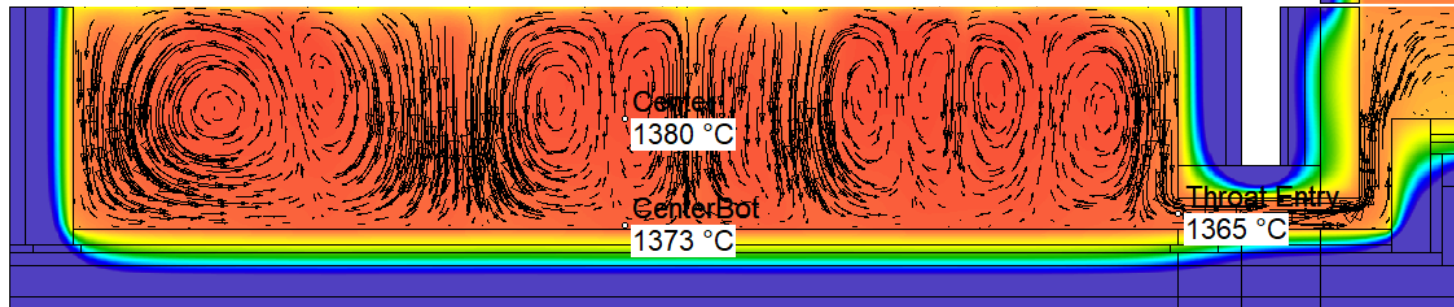
- A secondary chamber was constructed with 3 radiant heat zones in its superstructure
- Heating sections are located aft, middle, front
- 3 different heating profiles were explored
 - Aft biased, front biased, and uniform
- All heating profiles were effective at eliminating bubbles



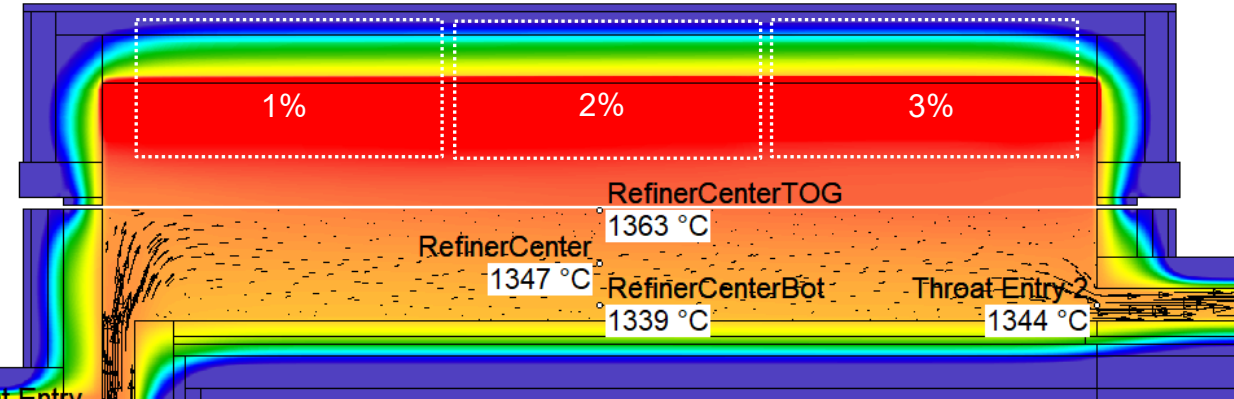
Electric Secondary Chamber Concept (cont.)

Front Biased Heating in Secondary Chamber

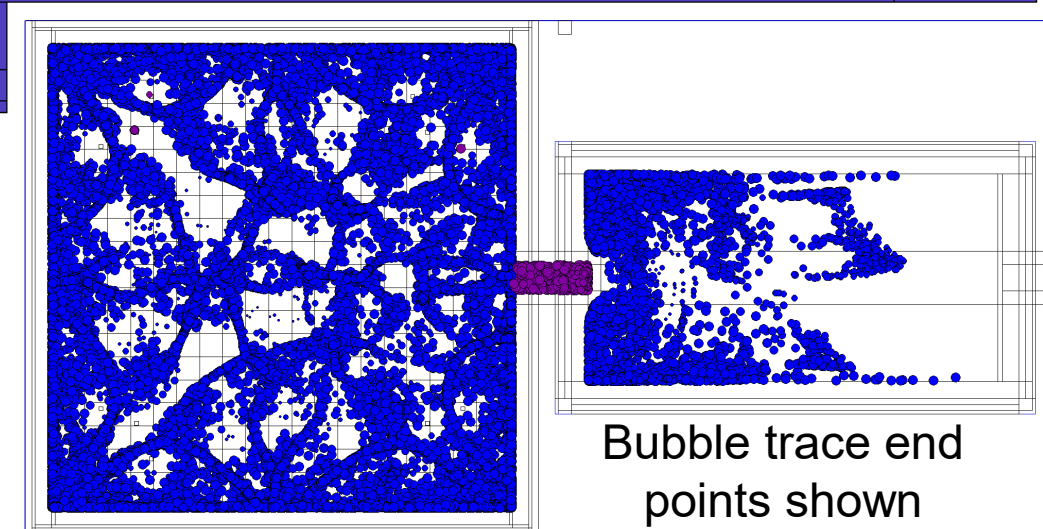
Baseline Melter run 25°C colder



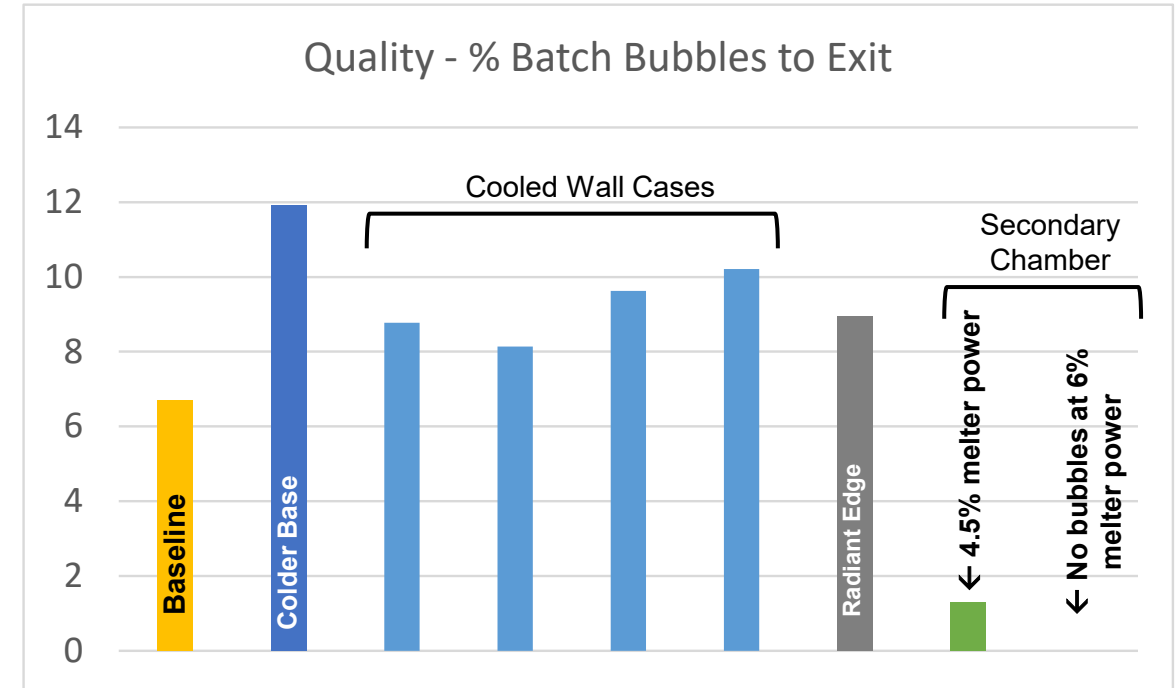
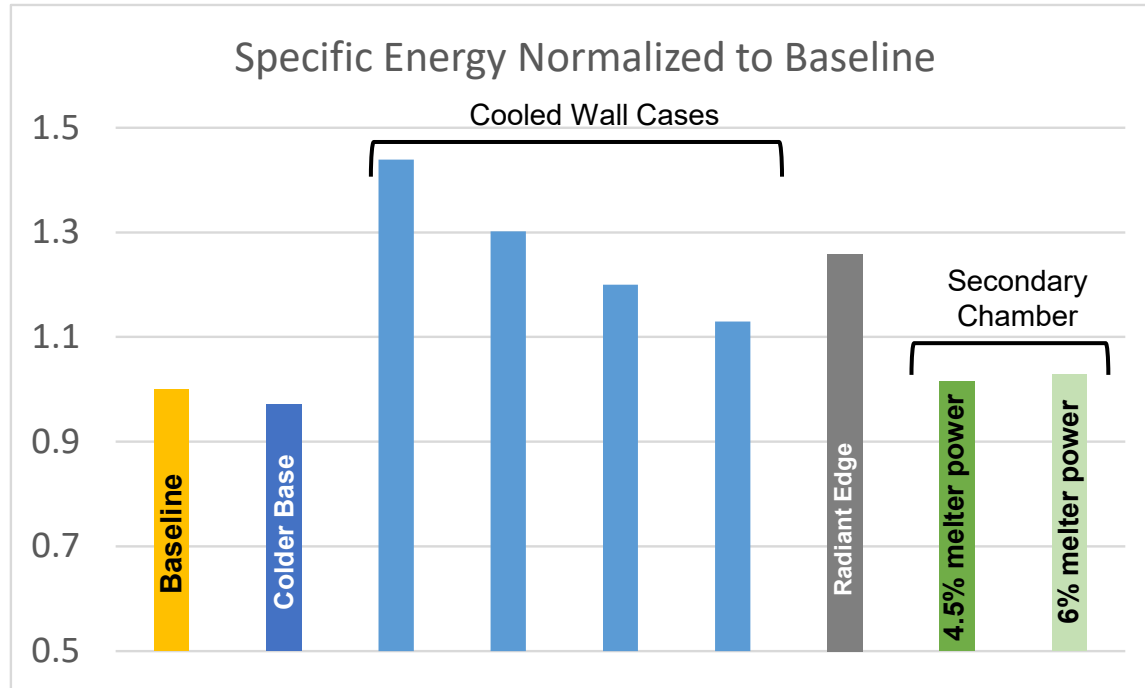
Secondary Chamber at 6% melter power



- Melter alone showed 11.9% of bubbles reaching its exit
- At 4.5% of melter power, 1.3% of bubbles reached the exit
- At 6% of melter power, 0 bubbles reached the exit (shown here)



Electric Secondary Chamber Concept (cont.)



- Specific Energy of Secondary Chamber models is similar to the Baseline
- Secondary Chamber runs shown were with colder Base model for improved life
- Quality target is exceeded with Secondary Chamber
- Size and CAPEX optimization of Secondary Chamber being addressed in ongoing work

Design Studies Summary

- Both a radiant edge and wall cooling showed the potential to achieve cooler wall temperatures, but at a significant energy efficiency penalty
- Running the melter at lower temperature reduces wall temperature and velocity, improving life, and also reduces energy demand
 - It reduces glass quality however and impacts to melt rate capacity need to be considered
- Adding a secondary chamber showed quality improvement and also less energy demand than a radiant edge or wall cooling
- All permutations of the secondary chamber thus far have exceeded the quality objectives (25% improvement over Baseline)
- Ongoing work is focused on optimizing the secondary chamber and further expanding cold-top capabilities to melt a wide range of colors

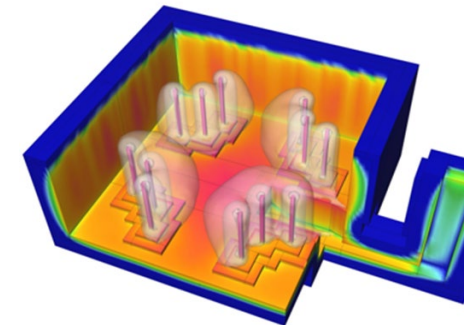
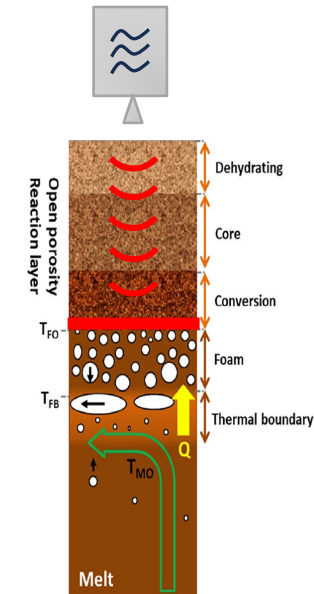
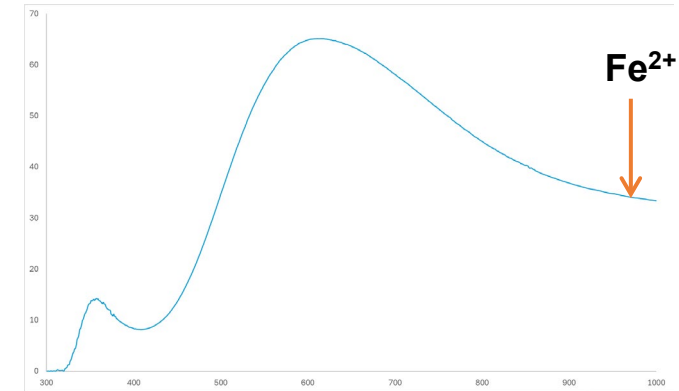
Budget Period 2 – What Comes Next

Demonstrate Solutions that Advance Electric Melting

	Milestone	Statement of Work Description	
Dark Glass	5.1	Demonstrate a solution that simulates producing a dark glass with a cold-top melting rate within 25% of a representative clear glass baseline	} Container
	5.2	Demonstrate a solution that shows flexibility to make dark and clear glasses with the same all-electric melter design	
Oxidized Glass Manufacturing Productivity	6.1	Demonstrate a solution that mitigates foaming caused by cullet redox.	} Fiber
	6.2	Demonstrate a solution at lab-scale that allows for continuous or automatic measurement of cold-cap thickness.	
Extended Furnace Life	7.1	Demonstrate electrical input strategies that decrease glass melting electrode material loss rate – targeting a 25% reduction.	} All segments
	7.2	Demonstrate at least 1 solution that reduces secondary heated chamber footprint by $\geq 20\%$ while maintaining target glass quality.	
	7.3	Identify at least 1 innovative glass property, sensing technique, or modeling capability related to the method of applying power.	

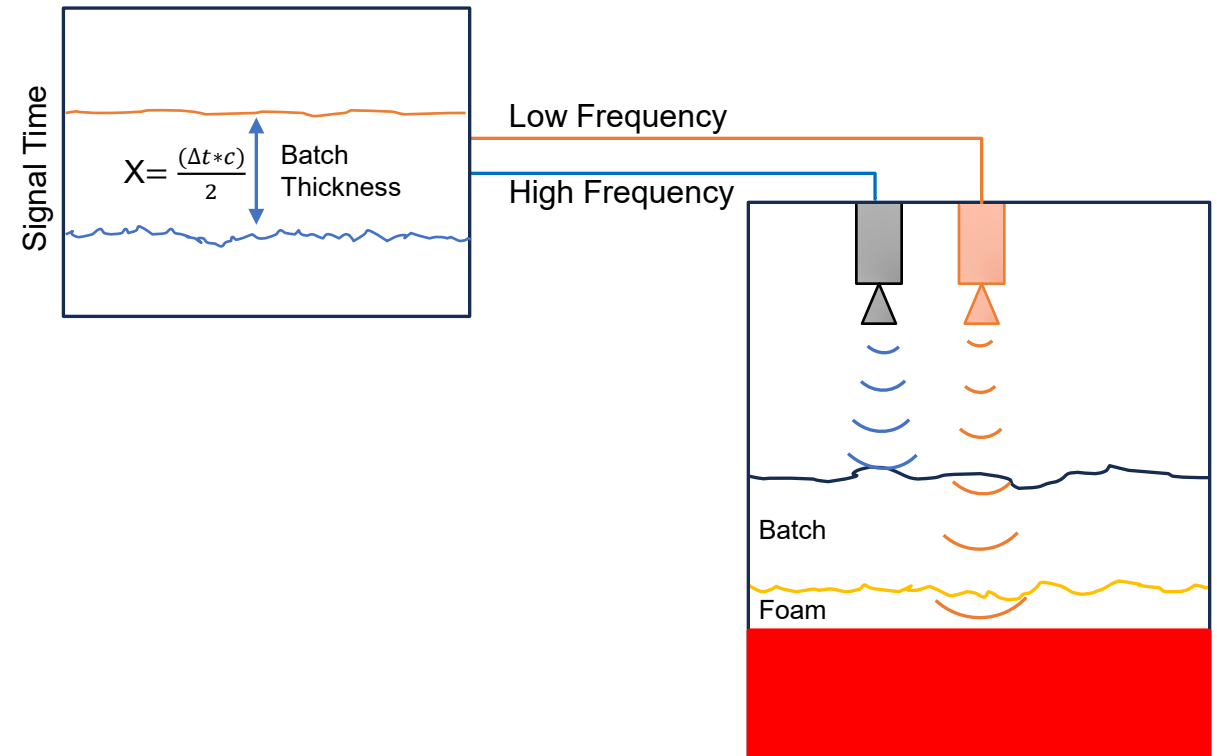
Budget Period 2 - Dark Glass

- Explore amber chemistries with lower Fe^{2+} concentration to increase thermal conductivity of melt
- Test dielectric heating through batch/foam layer to accelerate melting rate
- Demonstration via modeling of flexible melter designs capable of switching between dark and clear glass



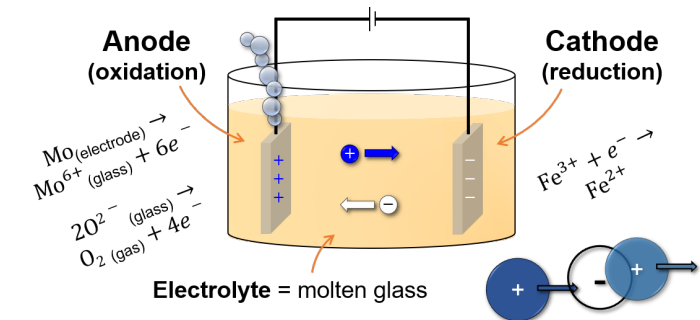
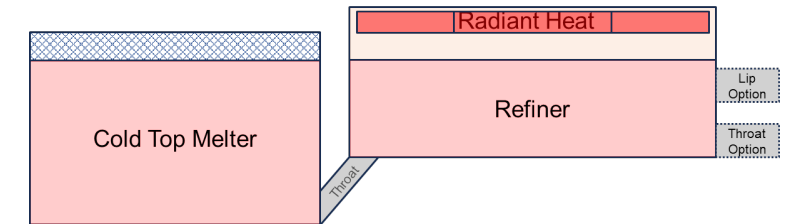
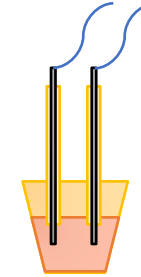
Budget Period 2 - Oxidized Glass Manufacturing Productivity

- Lab demonstration of how to mitigate foaming caused by cullet redox in oxidized glass
 - E.g. additives, agitation
- Demonstration of lab scale, continuous or automatic measurement of cold-cap thickness.
 - E.g. Radar gauge sensors



Budget Period 2 – Furnace Lifetime – Reduce Rate of Electrode Loss

- Demonstrate electrical input strategies that decrease electrode loss rate by 25%.
- Explore electrically heated refiner and reduce secondary heated chamber footprint by $\geq 20\%$ while maintaining target glass quality.
- Identify at least 1 innovative glass property, sensing technique, or modeling capability related to the method of applying power



THANK YOU!