Numerical Simulation of Glass Fiber Manufacturing Processes: Overview and Challenges

Bruno Purnode, Pat Prescott, Jong Han

14th international Seminar on Furnace Simulation, Design & Operations

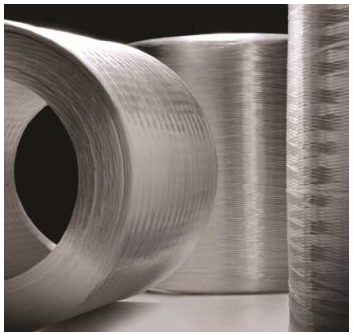
Velke Karlovice, Czech Republic – June 2017

Owens Corning at a Glance







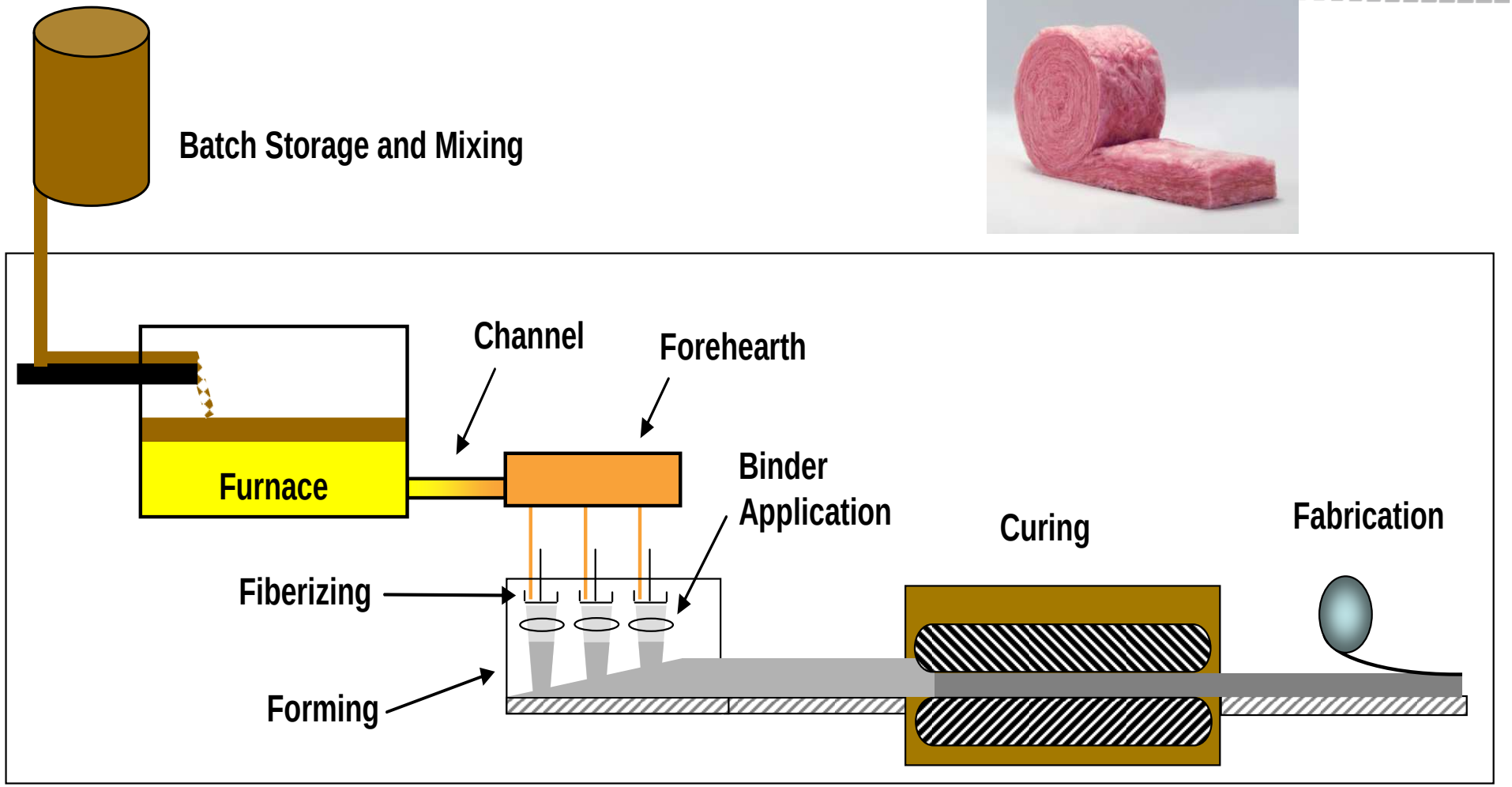


- Founded in 1938, an industry leader in glass fiber insulation, roofing and glass fiber reinforcements
- 2016 sales: $5.7 billion
- 15,000 employees in 26 countries
- Fortune® 500 company for 63 consecutive years
- Component of Dow Jones Sustainability World Index
- Three powerful businesses
  - Insulation
  - Roofing
  - Composites

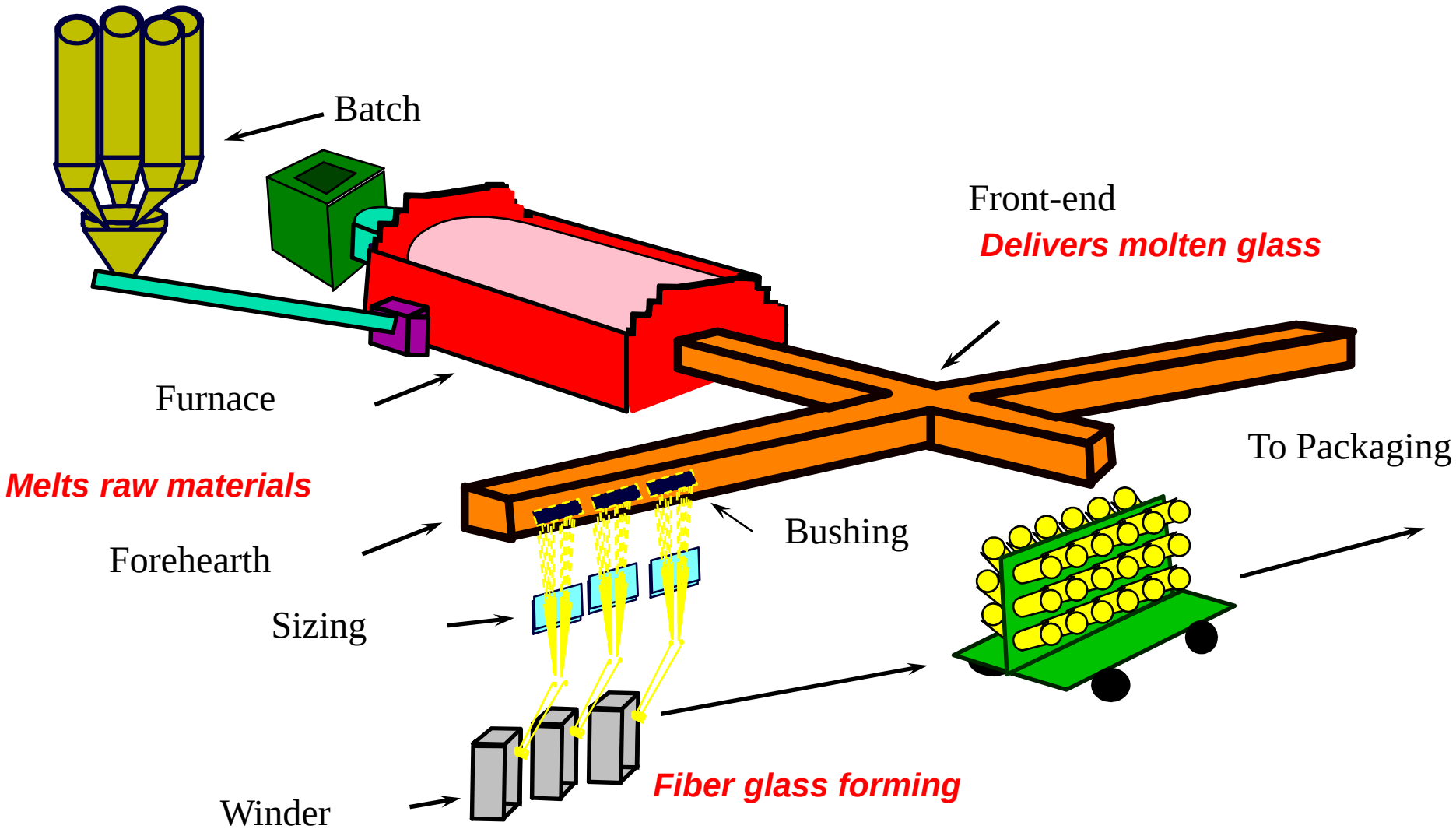
Presentation Outline

- Technologies:
  - Insulation Glass Fiber
  - Reinforcement Glass Fibers
- Different steps:
  - Glass Melting & Conditioning
  - Glass Forming
  - Downstream processes
- Simulation Results Management
- Concluding Remarks

Fiberglass Insulation Process Overview



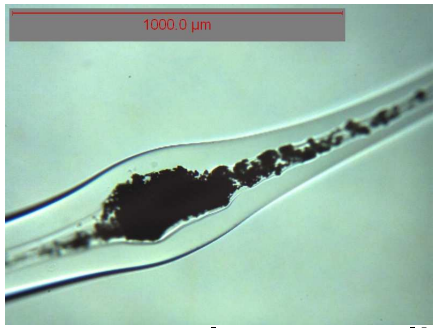
Reinforcement Glass Fiber Manufacturing Process



Forming & Size Application

Fiber forming

Sizing Application



=> Glass quality is key

Fiberglass Reinforcement Products

Fiberglass filament

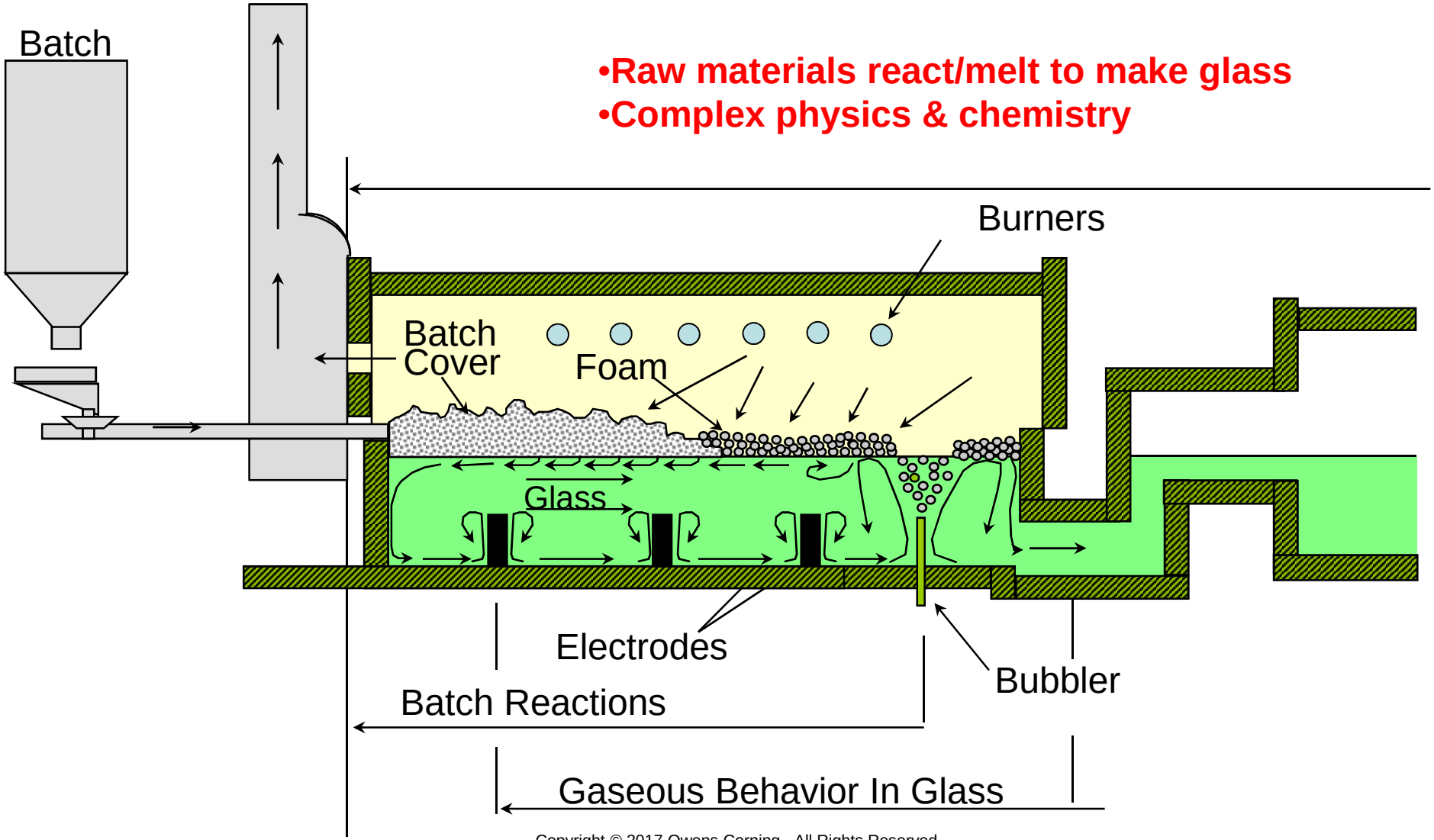
Roving

Fabric

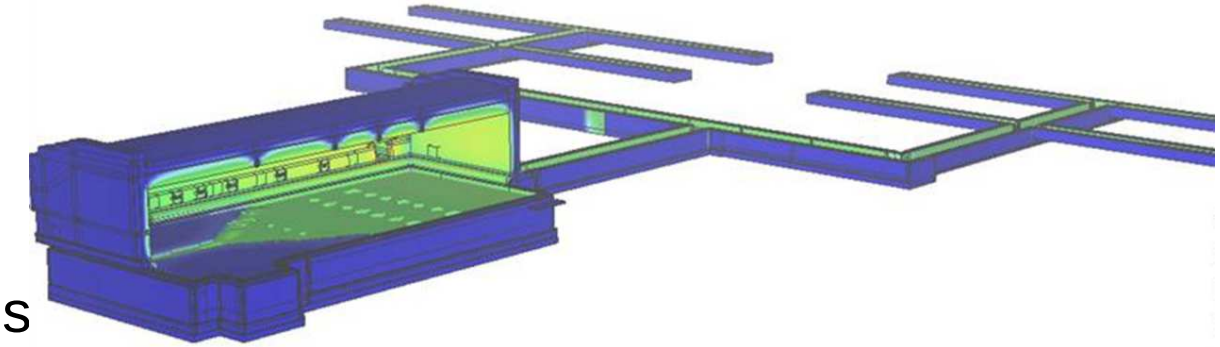
Final Applications

Melter Side View

- Raw materials react/melt to make glass
- Complex physics & chemistry

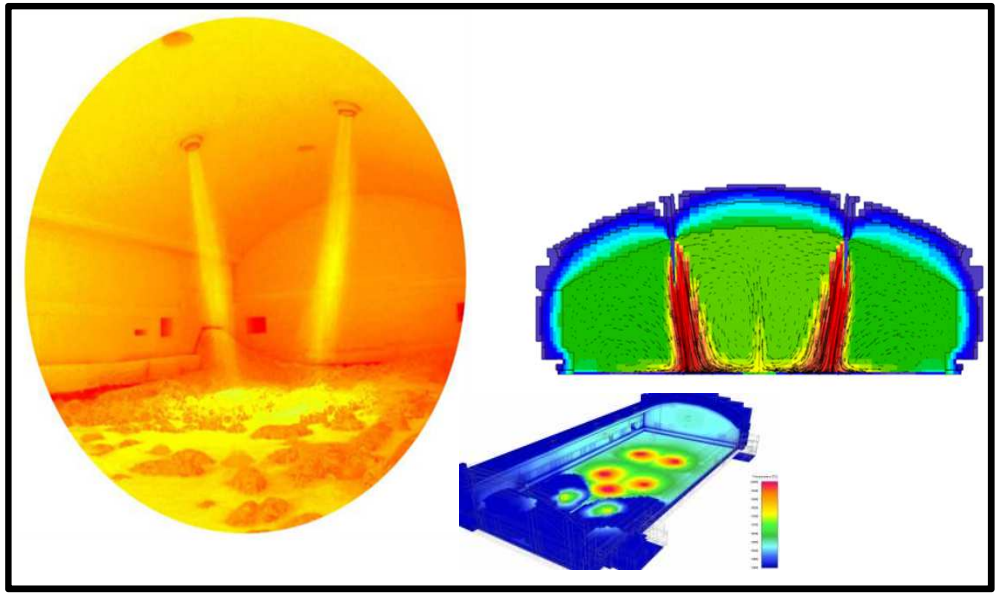


Glass Melting Furnace and Front End



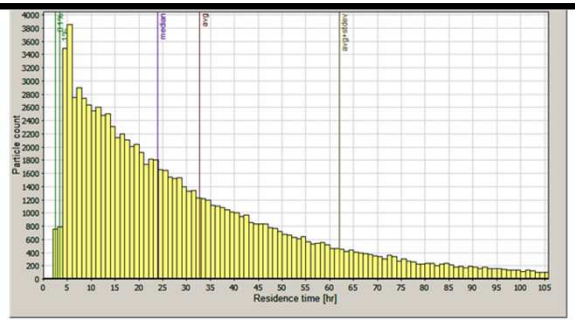
- High-cost process
  - Capital investment
  - Operating expenses
- Important to operate carefully and efficiently
  - Avoid damage and extend life
  - Assure complete melting, fining, and conditioning
- Numerical simulations assist design and operation

Modeling Capabilities

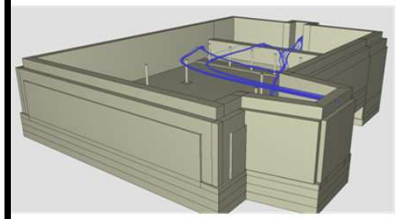


- Heat fluxes – conduction, convection, radiation
- Contours of unburned fuel
- Turbulence
- Energy input – fuel & electric
- Superstructure heat losses

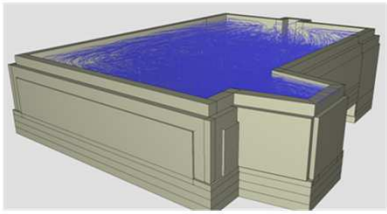
- Temperature contours & local values
- Electric Joule Heating – distribution, voltage potential, current
- Flow velocities and shear rates
- Batch position
- Particle residence times and other KPIs
- Sand dissolution rates
- Bubble paths



RESIDENCE TIME DISTRIBUTION



“SHORT CIRCUIT” PATHS



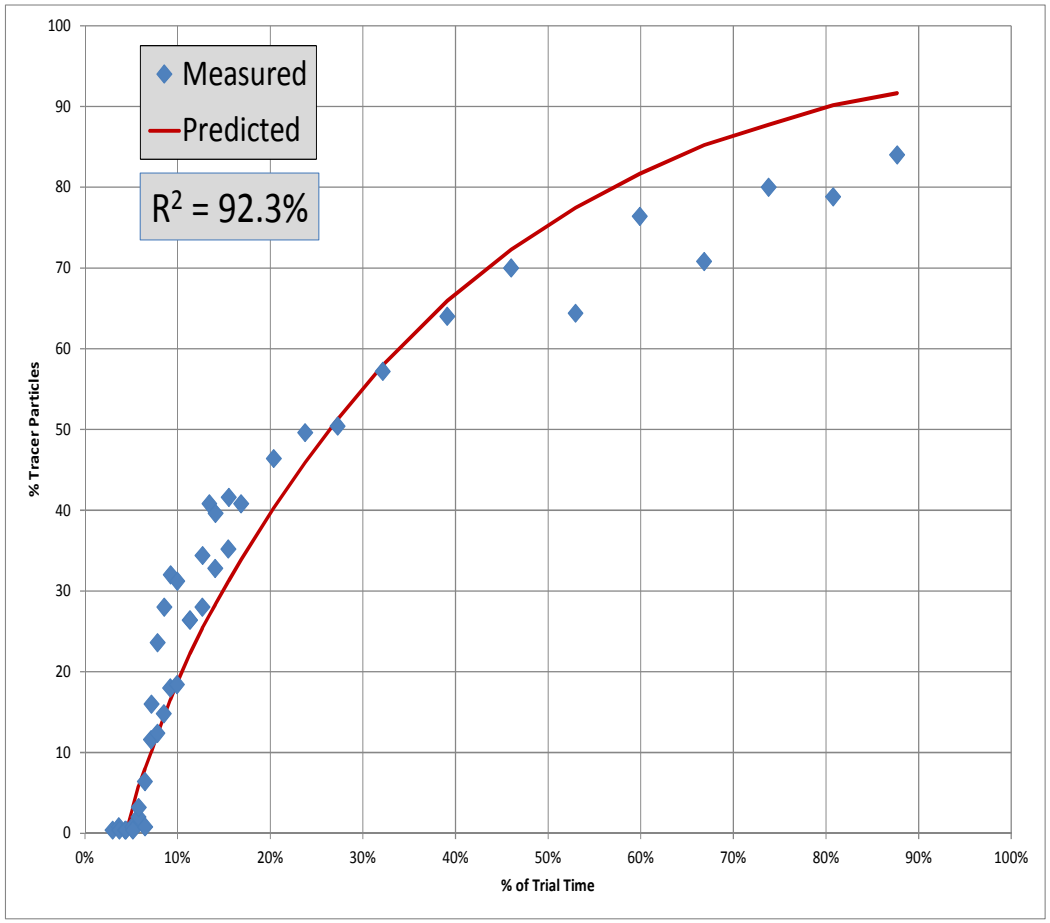
AVERAGE PATHS

Verification & Validation efforts

- Temperature values
  - Combustion space
  - Glass
- Tracer Tests

Cumulative Residence Times distribution

Predicted times are in good agreement with tracer trial measurements.

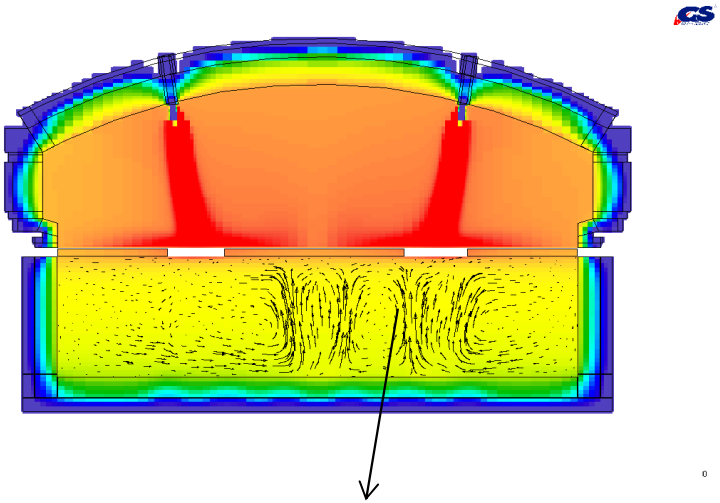


Example: Electric Boost and Glass Recirculations

PAST SITUATION:

Imbalance caused by electrode failures

Calculated Mixing index <1



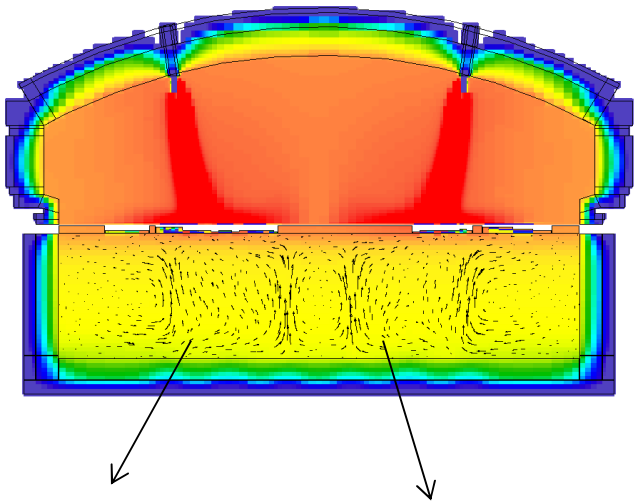
Clearly more glass recirculation on the right

=>Performance issues

NEW SITUATION:

Perfect Balance after recabling

Calculated Mixing index >2



Glass flow recirculation more balanced Left/Right !!!

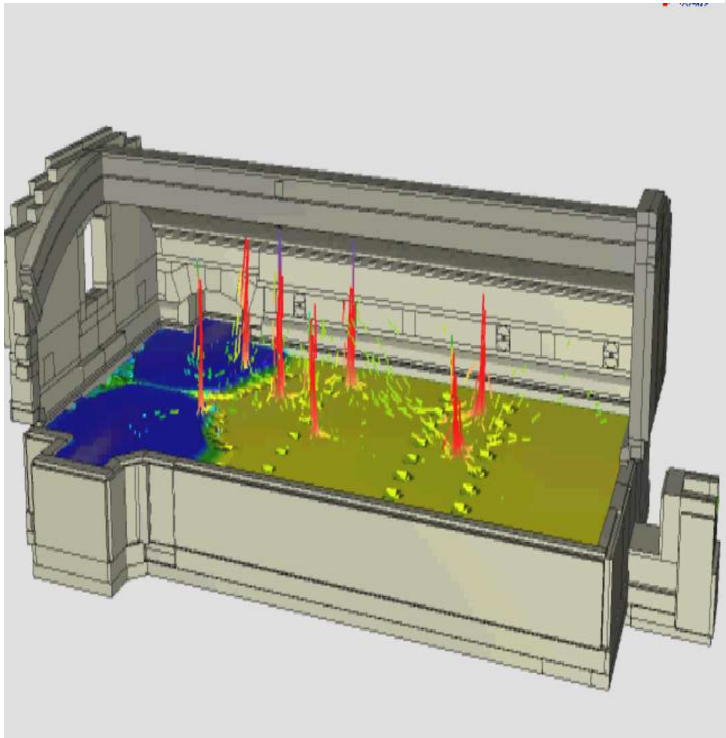
=> Better glass mixing improves furnace performance

Valuable Insights from Furnace & Front-end Simulations

- Melting Furnace
  - Profiling burners, E-boost, bubblers, etc.
  - Calculating & comparing residence times and other performance indices
- Front-end
  - Identifying cold, stagnant zones (risk of devit growth)
  - Assessing the effects of pull rate changes
  - Thermal disturbances and transient effects

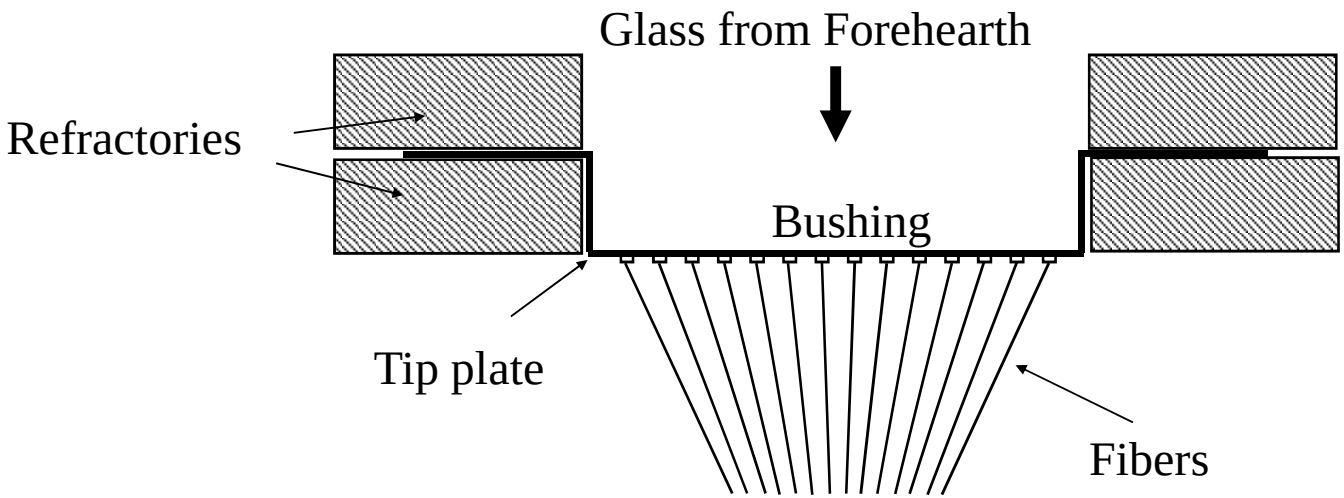
Furnace: Glass Melting & Conditioning

- Challenges of Furnace Numerical Modeling
  - *Validation data & accuracy*
  - *Material properties & aging*
  - *Process Changing Physical Properties*
    - Batch materials to glass
  - *Improved constitutive models*
    - Foam, refractory erosion



- Balance details with computation time
- Still need a high level of expertise to use such tools…

Fiber Forming

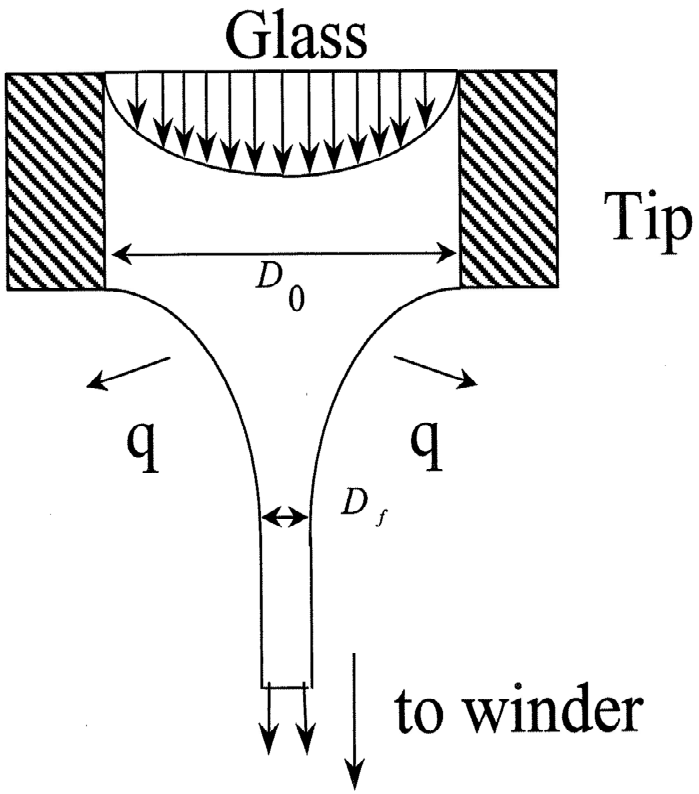


Bushing:
- Made of precious alloy
- electrically energized to control temperature

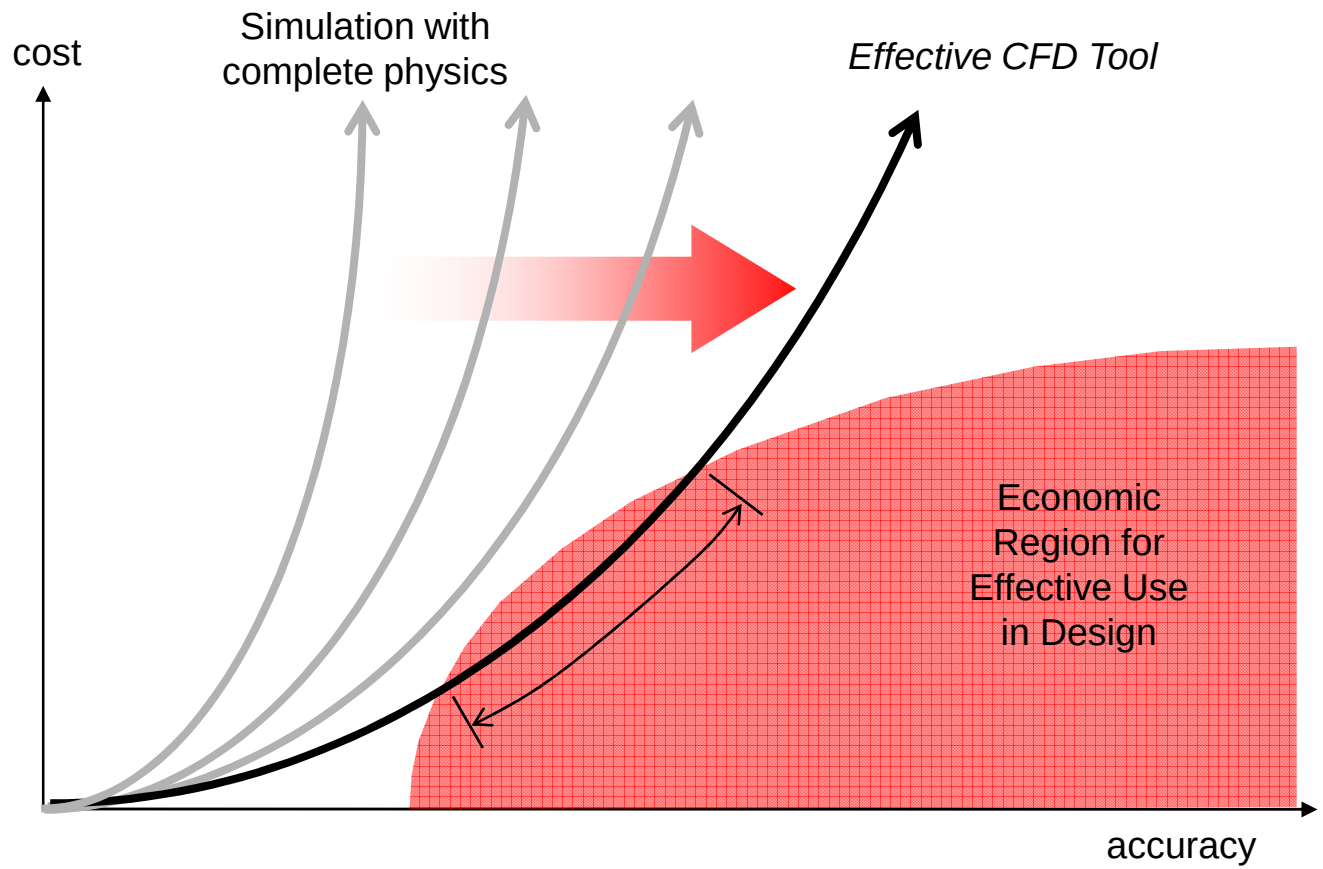
Fiber break @ forming leads to process interruption

Fiber Forming physics

- Combination of fluid dynamics and heat transfer
  - Surface tension and viscosity=f(T)
  - Radiation and convection heat transfer

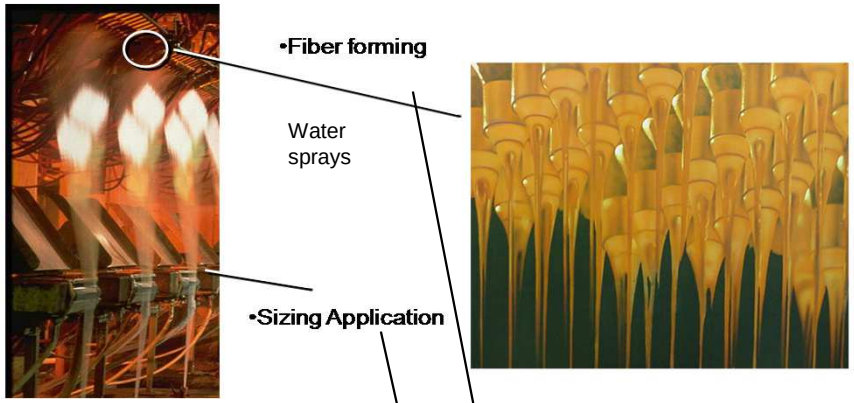


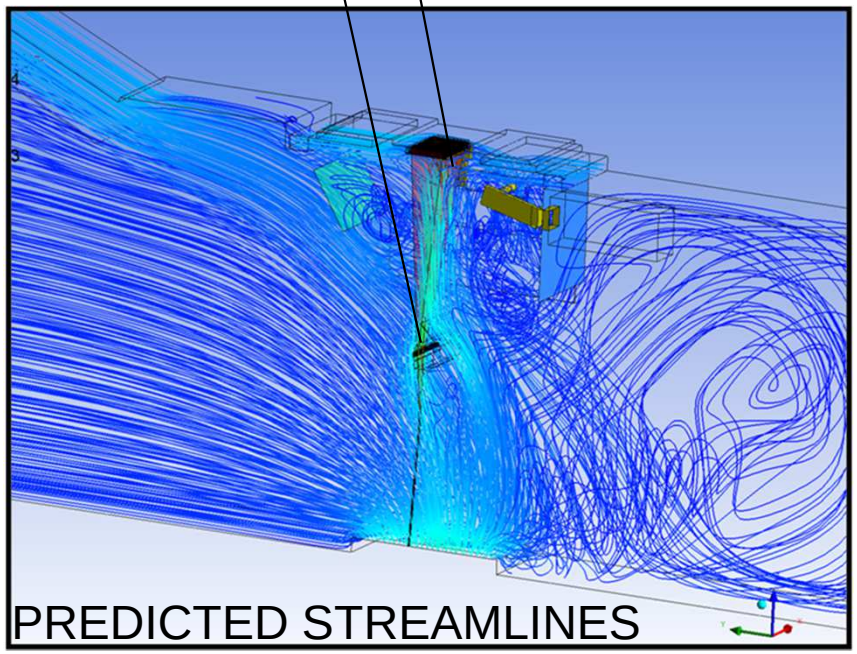
Balancing Accuracy and Cost



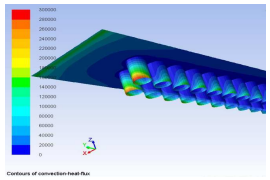
Cost = human hours & computational time
Accuracy = geometrical details, physics & chemistry

Forming Position Simulations

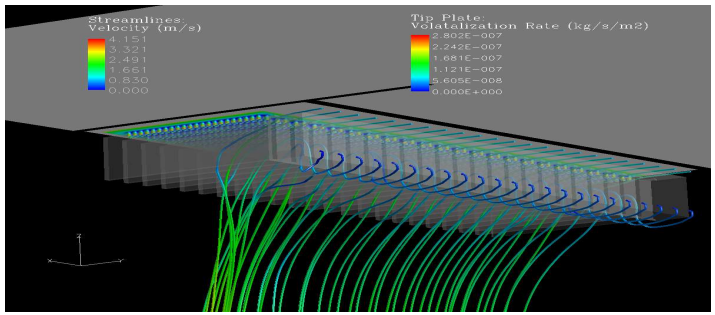




- Rich in Physics
  - Complicated flow patterns
  - Multi-phase
    - *Water sprays*
    - *Coupled & interacting*
  - Complex heat transfer



- Different length scales
  - *Forming Tunnel, Forehearth, Positions*
  - *Bushing, tip plate, fins, & tips*
  - *Fibers*

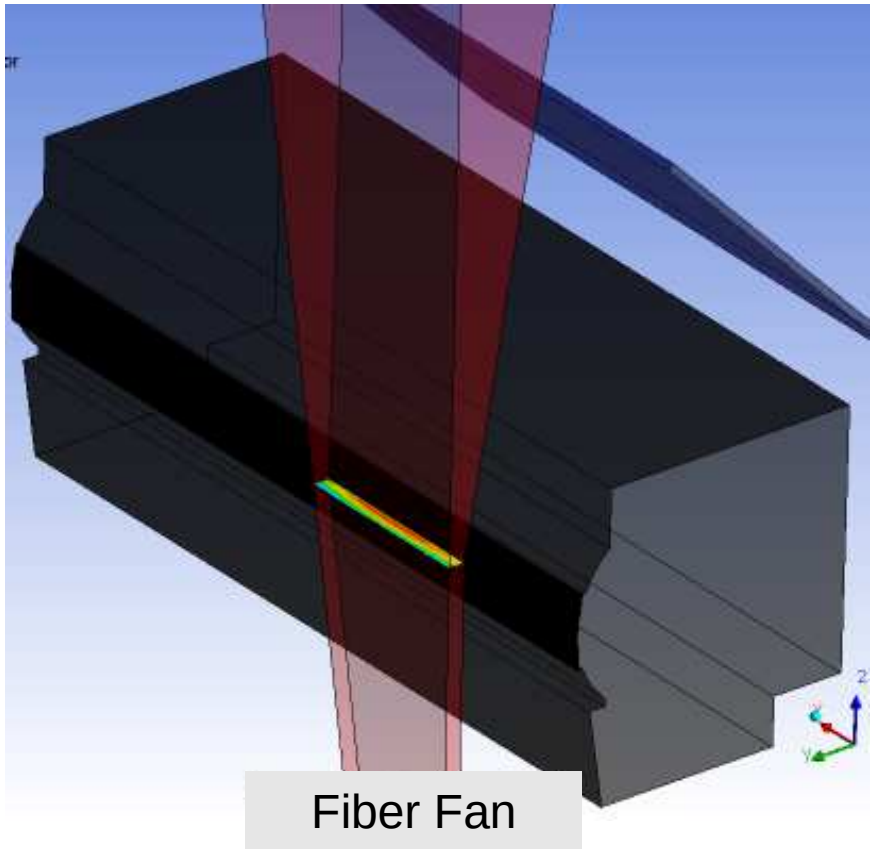


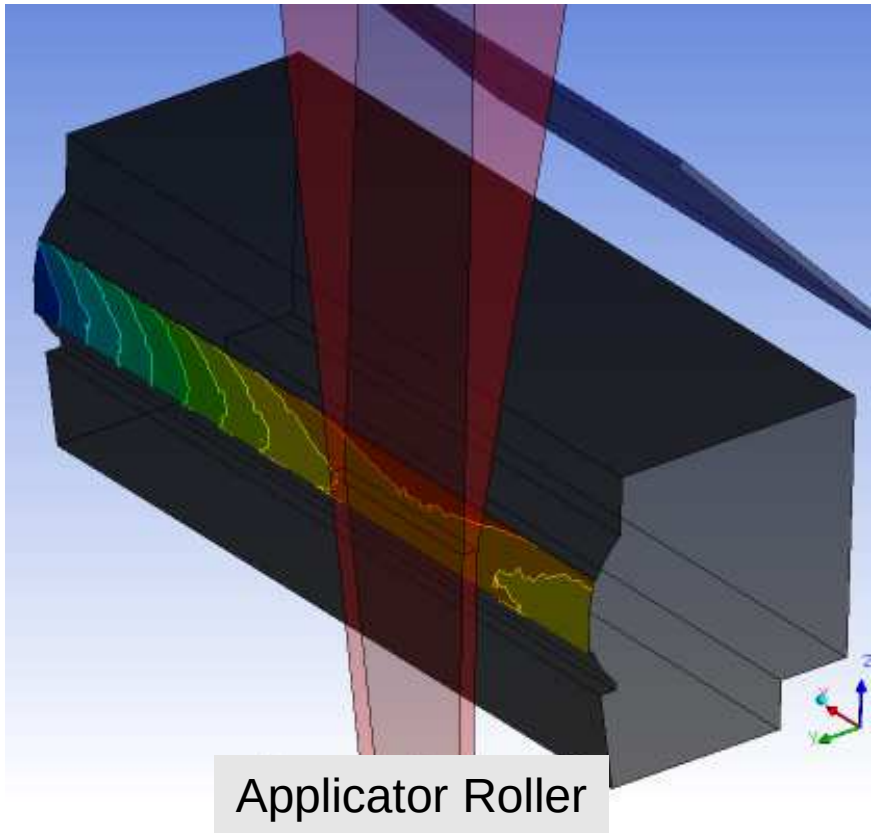
POST-PROCESSING

- *Air entrainment into fiber fan*
- *Temperature at applicator*
- *Moisture concentration (vapor and liquid)*

Temperatures at the Applicator

Validation Metric



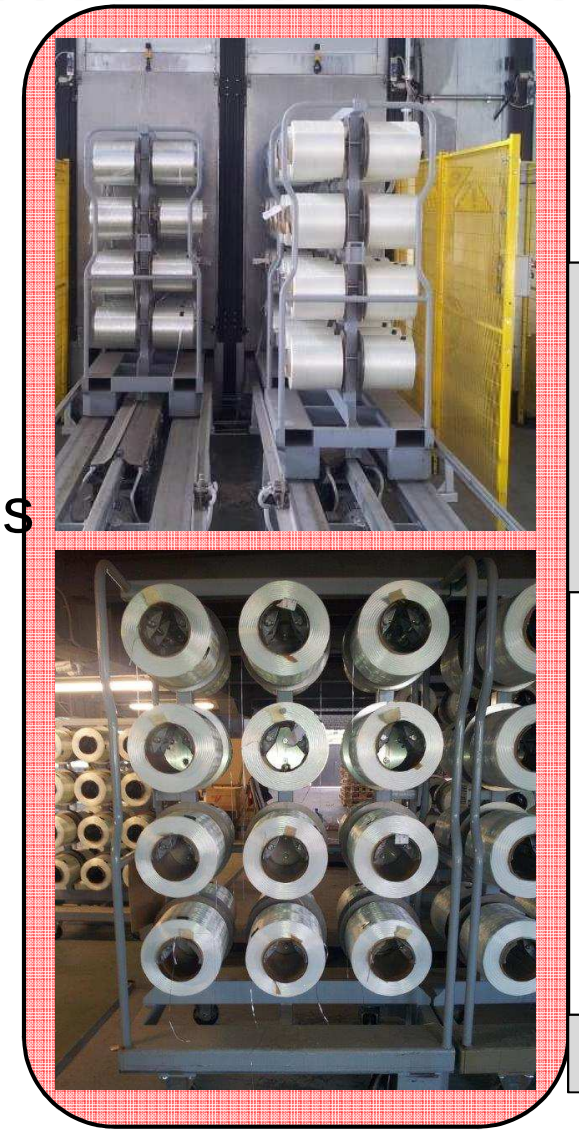


Forming Position - Challenges

- Validation
  - Limited quantitative data
  - Qualitative – flow pattern descriptions
- Uncertain performance indices
  - How air flow relates to fiber breaks ?
  - How to assess and compare configurations ?
- Full forming tunnel simulations require very large computational resources

Drying Oven Simulations

- Drying time
- Uniformity
  - Over-dried packages
  - Under-dried packages
- Product Quality
- Energy Efficiency



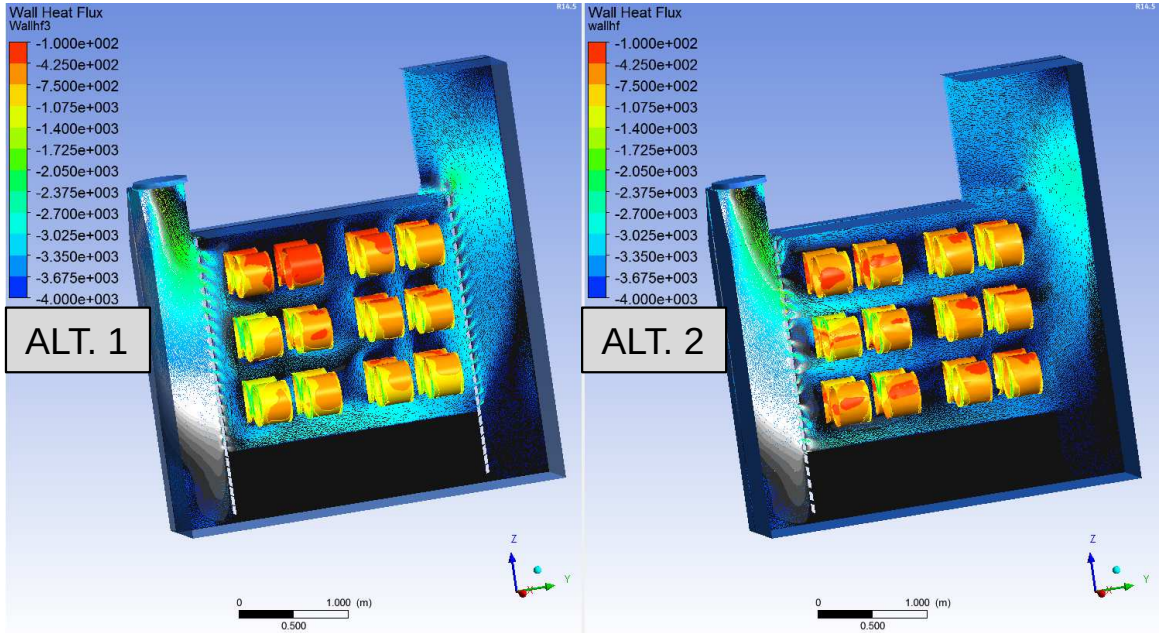
Wound fiberglass packages on carriers ready to enter drying oven

Configurations can vary

Virtual trial reveals improved uniformity

Heat Flux	Alternative 1	Alternative 2
(SCALED)		
Avg	**748**	**671**
Min	329	551
Max	1063	916
Stdev	206	95
CV(%)	28	14

- Alternative 2 has lower average but *higher minimum*
- Also, *less* pkg-to-pkg *variation*



CHALLENGES

Validation – mainly qualitative
Full oven
Complete drying cycle

→ *Limited by opportunities*

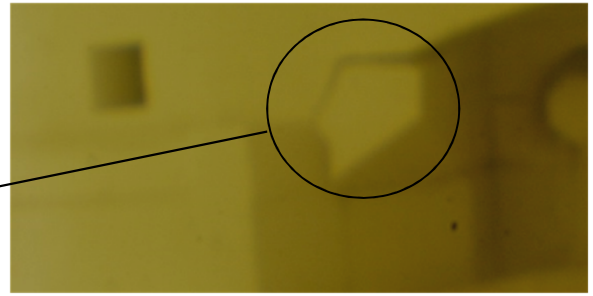
→ *Limited by computational resources*

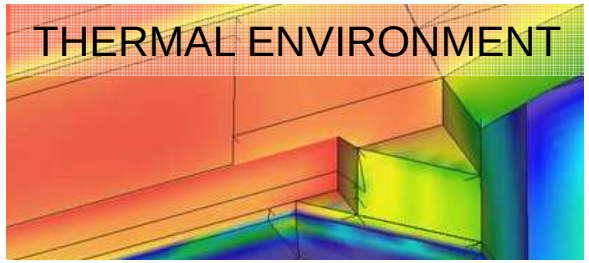
Summarizing CFD Simulations in Glass Fiber Manufacturing

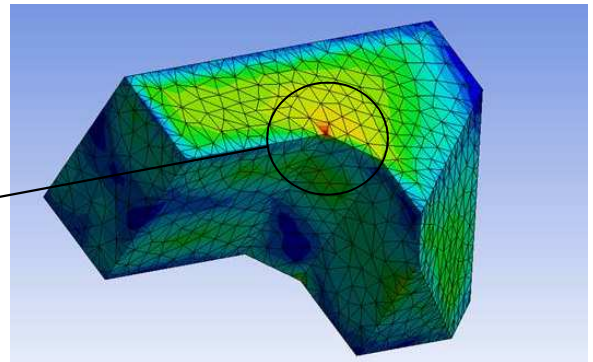
- Several process applications
- Complex systems with coupled transport phenomena and interacting materials/zones/domains
- Challenges
  - Characterizing materials and interactions
  - Balancing geometrical fidelity with computational efficiency
  - Post-processing to make sound operational and/or business decisions
  - Obtaining sufficient and/or accurate validation data

Structural Simulations: Irregular-Shaped Brick in a Melting Furnace

- Failure during early stage of furnace campaign
  - Large crack → 2 pieces
- Transient thermal conditions
  - Stress build-up during heat up
  - Introduction of cold batch causing radiative heat loss
  - Burner air (without fuel) leading to sudden cooling
- Complex shape imposing stress concentration





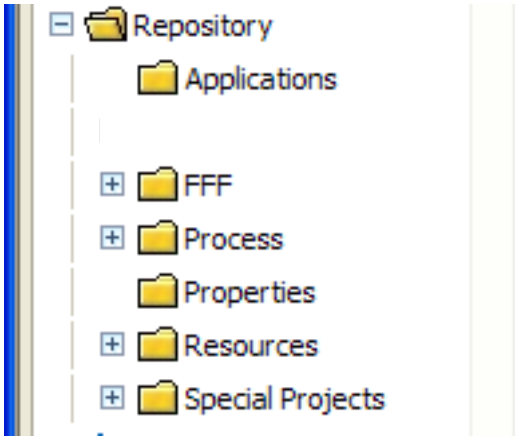


Need to Manage Modeling & Simulation Activity and Data

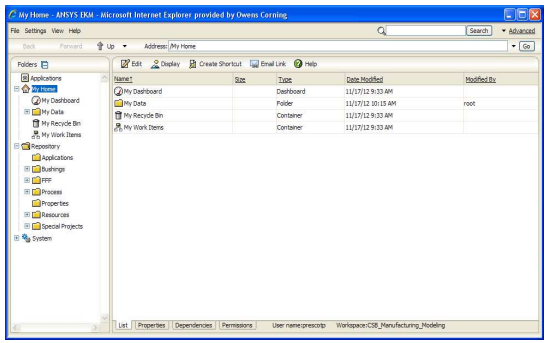
- Ever larger & complex simulations
- More participants in simulations & Multi-disciplinary Engineering Roles
  - Modelers & Analysts
  - Designers & Plant Support Engineers
  - R&D Engineers
- Need for organizing, scheduling, and prioritizing simulations
- Sharing simulation results across the globe

Numerous Advantages identified

- Facilitates collaboration
  - Eliminates extra copies of modeling files
  - Keeps various data files “in sync”
    - *Geometry*
    - *Mesh*
    - *Model data (i.e. properties, bc’s, etc)*
    - *Post-processing reports*



- Searching
  - Common repository



- Recycling/Resurrecting Data
  - Model data
  - Quickly launch a comparative study to help decision-making
- Data Security

Conclusions

- Modeling is a critical tool in design & operations
  - Furnace
  - Frontend
  - Fiber forming & downstream processes
- Challenges of Numerical Modeling
  - *Validation*
  - *Physical Properties*
    - e.g. Batch materials
  - *Need Improved models*
    - Foam, refractory erosion
- Simulation Data Management a must have

Acknowledgments

- P. Prescott, M. Korwin –Edson, Josh Rowe, Pete McGinnis & Jong Han for feedback and help with presentation content
- Owens Corning management for allowing to present at this 14th international Seminar on Furnace Simulation, Design & Operations.