NSG

GROUP

Glass decarbonization

Kyle Sword
NSG Pilkington

Abstract

- The decarbonization pathway for glass manufacturing will require a multi-faceted approach to achieve the targeted 2050 results for the glass industries. Key to these strategies will be raw material sourcing, circular economy, alternative fuels, and electrification. Hydrogen firing appears to have relatively high chances of success as an alternative fuel, but the path from concept and pilot to full scale commercial adoption is complex and involves a wide variety of external entities so implementation and development will require collaboration and innovation.

It’s the end of the world

as we know it…

But there are real issues


The New York Times
SUBSCRIBE FOR $1/WEEK | LOG IN
19 Killed in New York City's Deadliest Fire in Decades
Nine children were among those who died when a space heater
building, city officials said.

WINTER FREEZE
Report: Rooftop solar could have played role in reducing impact of 2021 Texas freeze power crisis
BY STACY RICKARD | DALLAS
UPDATED 2:30 PM CT FEB. 19, 2022 | PUBLISHED 7:01 PM CT FEB. 18, 2022
TEXAS — A n
more than en
winter storm.

Los Angeles Times
OPINION
Editorial: Climate change fuels deadly heat waves. Ranking them like hurricanes could save lives

The New York Times
Climate Change Brings Warmer, Wetter Weather to Trinidad
Even as the leaders of Trinidad and Tobago double down on fossil fuels, climate change is bringing more extreme weather to the island...
14 hours ago

WEATHER
An unusually early heat wave in the Pacific Northwest is testing records
May 14, 2023 · 4:23 AM ET
By The Associated Press

IPCC reports implications of global warming of 1.5°C above pre-industrial levels dramatically increase the risk of extreme weather events, more frequent wildfires with higher intensity, sea level rise, and changes in flood and drought patterns with implications for food systems collapse, among other adverse impacts.

But there are real issues

Consumption and generation of power do have impacts and are being measured/metered/regulated/taxed

Product use, building resiliency, code, renewable energy – all have impacts

As a good engineer, I should understand this

Kyle Sword

- Certified Glass nerd - Passion for glass, networking, community, volunteering, the arts.

- Name calling and finger pointing

- Engineer – Problem solving
  - Collaboratively define problem
  - Macro limits and assumptions
    - Solving $1 or $1B problem
  - Brainstorm
  - Get team alignment, work together
  - List possible solutions, evaluate most attractive options
  - Hypothesis, model, implement
  - PDCA

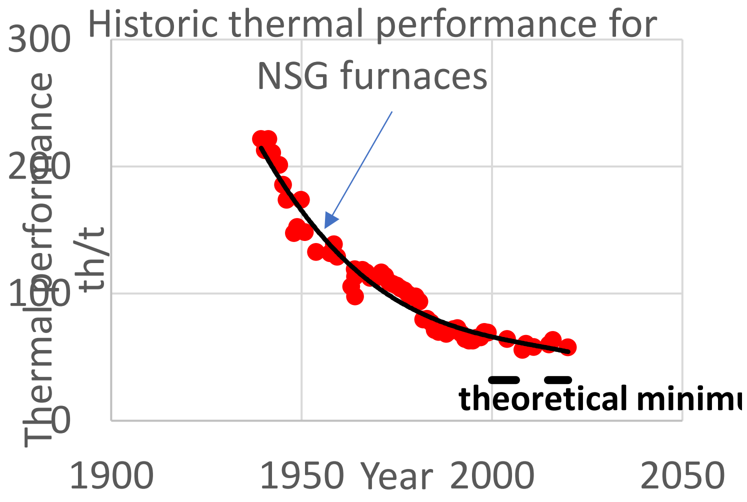
Agenda

- Macro level – Energy consumption
- Decarbonization – Where does CO_2 come from?
- Solutions – How can we help?
  - Process
- Collaborations

Macro – Energy usage

Historic progress

The benefits of glass are evident.
Glass components in all renewable energy.

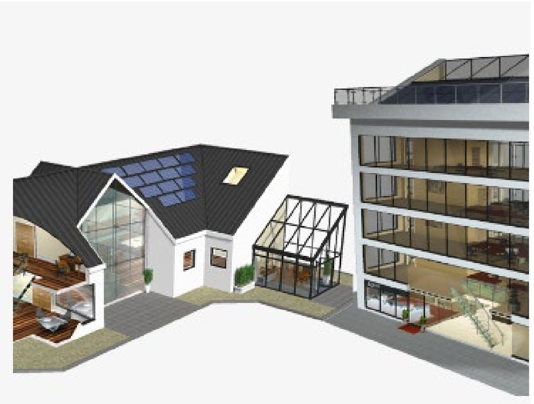


St Helens, UK 1935

We need a step change

CO2 payback

- New construction
- Solar panels (renewable energy)
- Building upgrades



Global warming and CO_2

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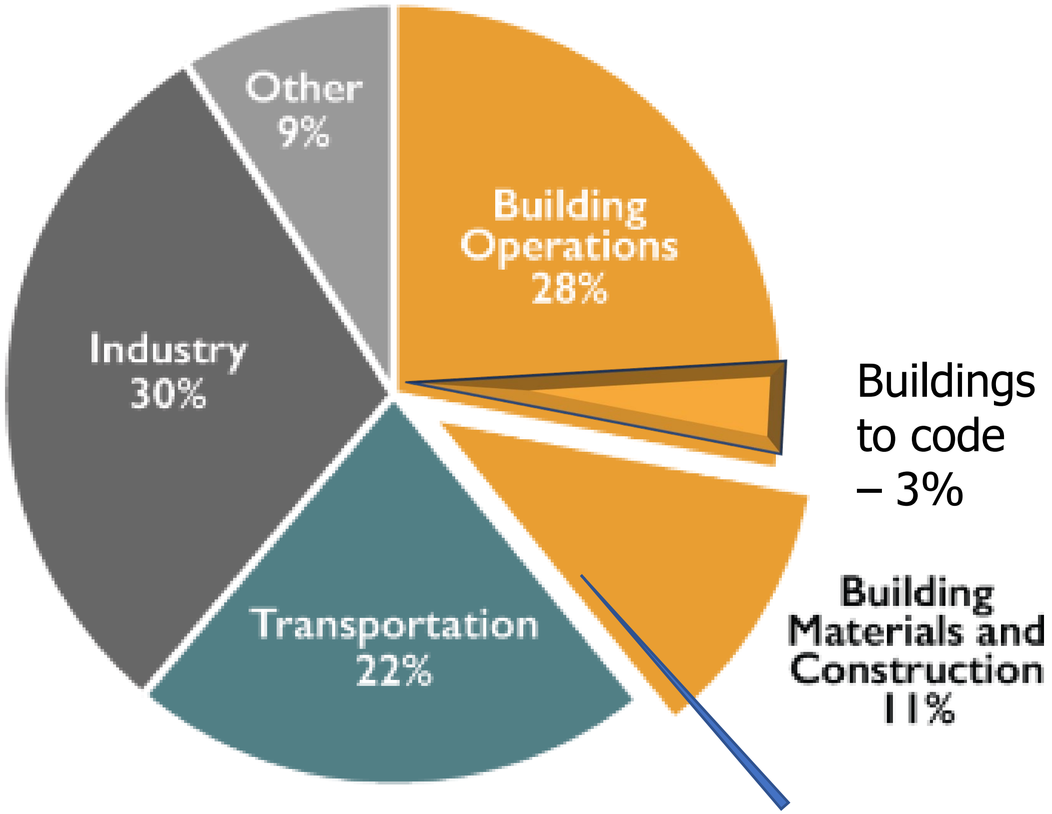
Global CO_2 Emissions by Sector

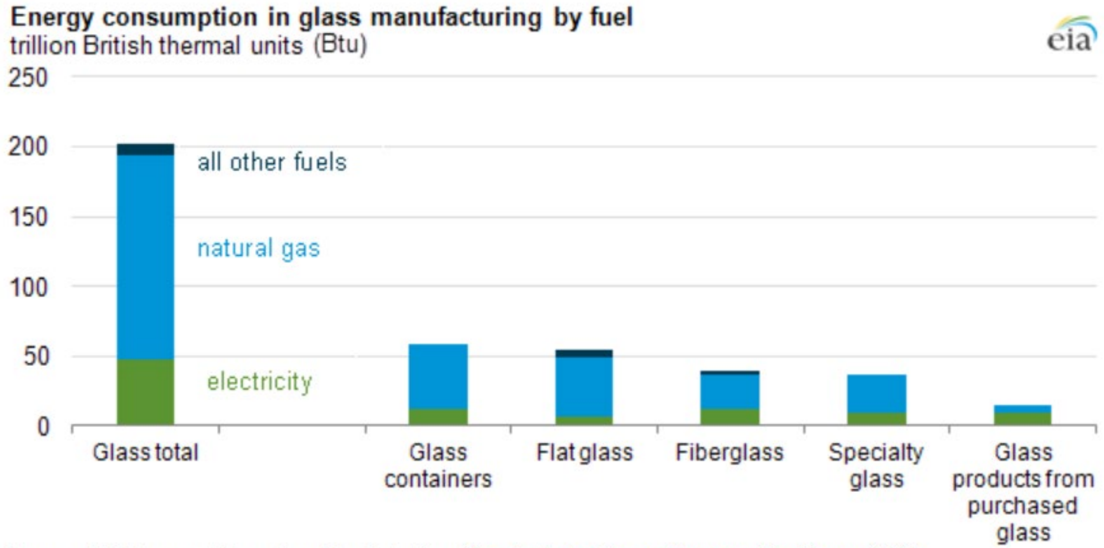


Flat glass manufacturing <0.05%
All glass manufacturing <0.2%

- **US Consumption = 100 Q BTU energy**

AUGUST 21, 2013

Glass manufacturing is an energy-intensive industry mainly fueled by natural gas



Source: U.S. Energy Information Administration, Manufacturing Energy Consumption Survey 2010

Roadmap to Carbon Neutrality for 2050

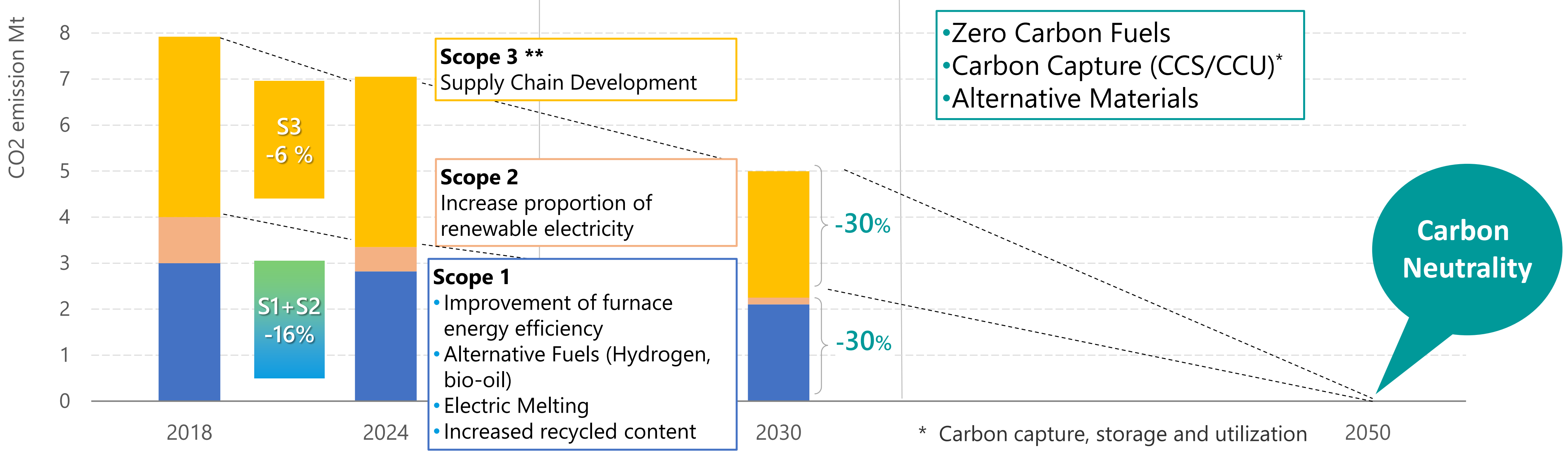
PILKINGTON NSG GROUP

Targets

2025-MTP-2027	2030	2050
Achieve 3% reduction of CO_2 p. a. during MTP	2030 targets (vs 2018) ・ Scope 1&2 ： - 30% ・ Scope 3 : - 30%	Achieve carbon neutrality

Key Initiatives

Existing technology improvement	Transition stage	Disruptive innovation

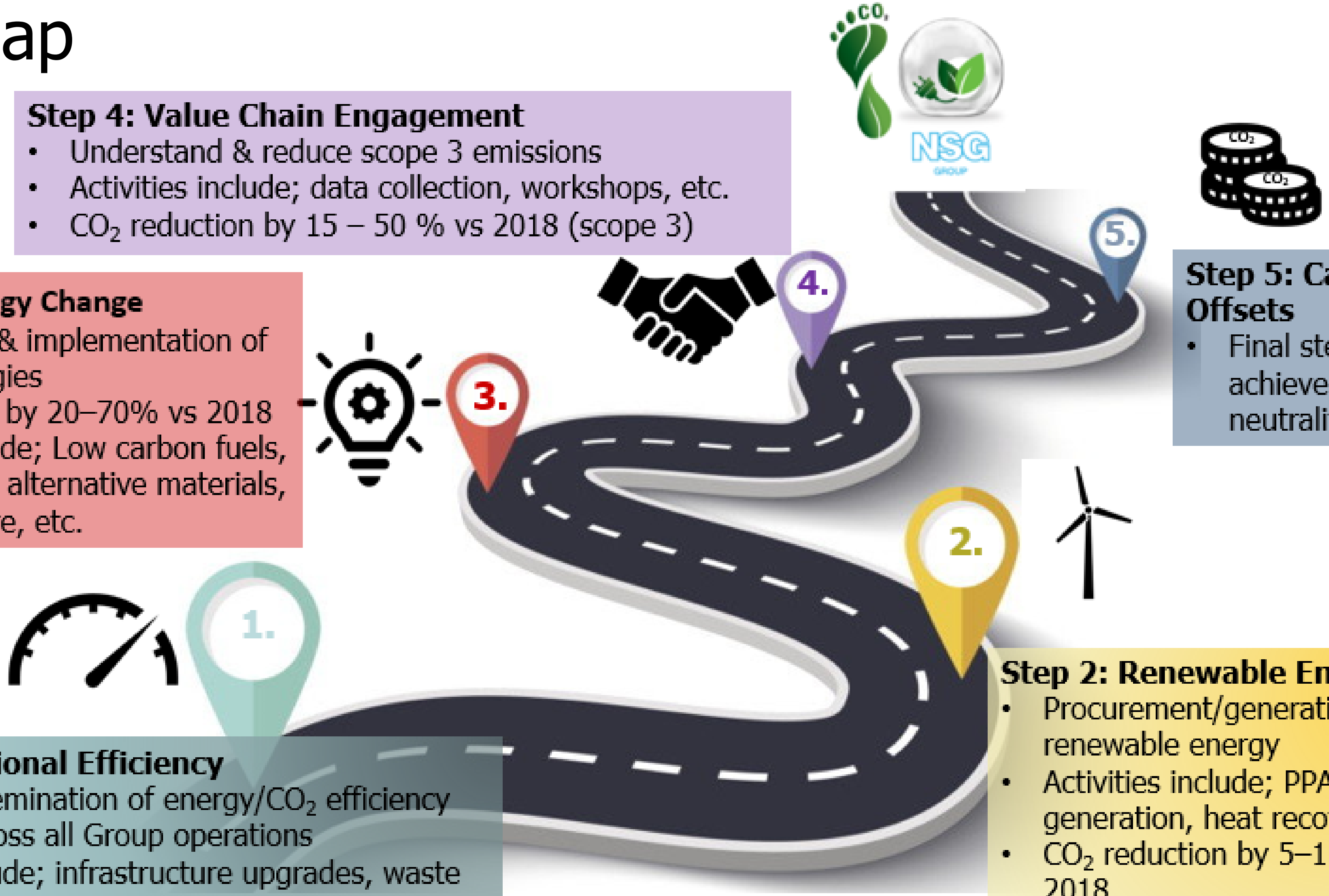


* Carbon capture, storage and utilization

** Scope 3 baseline has been updated with the review of data collecting method.

On track to deliver Scope 1 + 2 targets for 2030. Scope 3 becomes a key focus

Roadmap



Step 4: Value Chain Engagement
- Understand & reduce scope 3 emissions
- Activities include; data collection, workshops, etc.
- CO_2 reduction by 15 – 50 % vs 2018 (scope 3)

Step 3: Technology Change
- Development & implementation of new technologies
- CO_2 reduction by 20–70% vs 2018
- Activities include; Low carbon fuels, electrification, alternative materials, Carbon capture, etc.

Step 5: Carbon Offsets
- Final step to achieve carbon neutrality

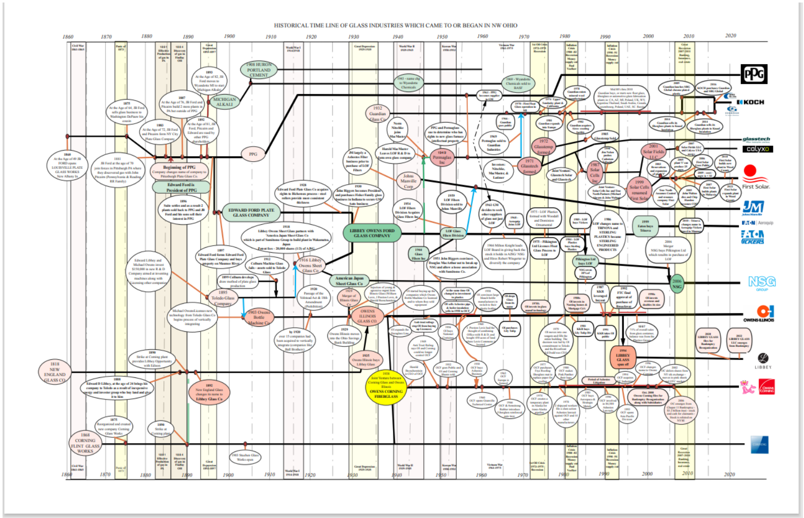
Step 2: Renewable Energy
- Procurement/generation of renewable energy
- Activities include; PPA, on site generation, heat recovery
- CO_2 reduction by 5–15 % vs 2018

Step 1: Operational Efficiency
- Effective dissemination of energy/CO_2 efficiency measures across all Group operations
- Activities include; infrastructure upgrades, waste glass (cullet) management, etc.
- CO_2 reduction by 5 – 15 % vs 2018

Collaboration

Toledo collaborations

- Going back to Toledo roots
- Collaborate, share, explore – <u>lead</u>



- Multiple areas – common problems
  - Decarbonization
  - Air/emissions
  - ESG activities
  - DEI activities

- Don't compete directly in markets – Why not share?

NOIC – Northwest Ohio Innovation Consortium

NSG GROUP

NOIC is a 501c6 Non-Profit Consortium

Vision - Make Northwest Ohio a national leader in innovation, creating new jobs, business opportunities, and supporting world-class research aligning with the needs of local industries.

Goal - Establish a Center of Excellence for Glass in Northwest Ohio

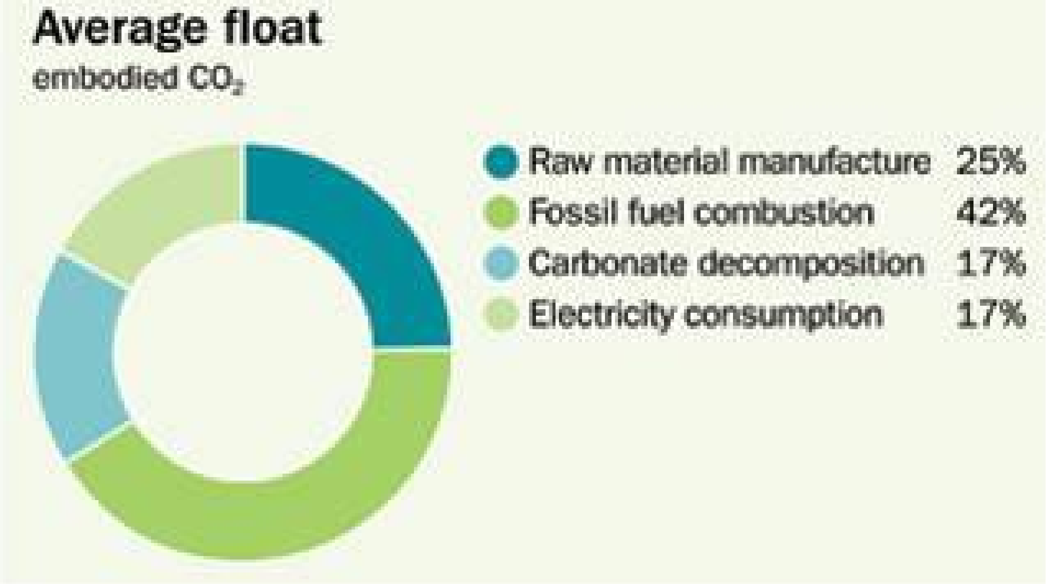
NOIC – Northwest Ohio Innovation Consortium

1. Talent Development Platform
2. Recycling System Optimization
3. Process Control AI Optimization
4. Melting Technology Performance
5. Glass Surface Treatment
6. Glass Melting Improvement
7. Electrification of Fining & Conditioning

Decarbonization – process

Technology Change - Decarbonization Projects

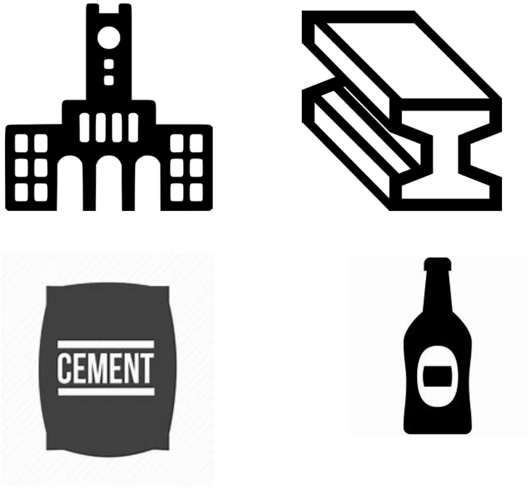
- Alternative Fuels
  - Includes hydrogen firing
- Carbon Reducing Raw Materials
- CCUS – carbon capture
- Cullet for decarbonisation
- Electric Melting



Multiple projects being run, some fully technically proven, others more medium to long-term.

Routes to Low Carbon Melting

Partnerships



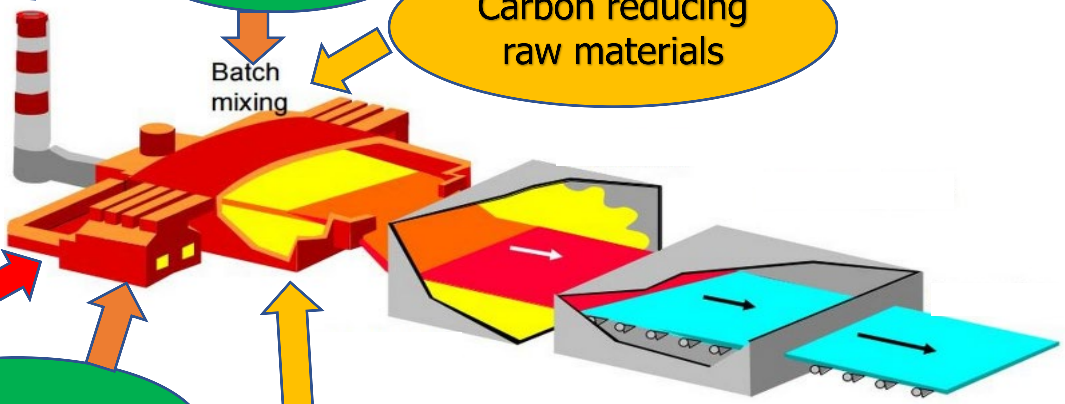
Materials

Cullet

Carbon reducing raw materials

Carbon Capture usage and storage

CO$_2$ from Melting
- Batch 26%
- Fuel 74%



Hydrogen Combustion

Alt Fuels

Electric Melting

Energy

Process Control:
Artificial intelligence
Machine learning

Supporters

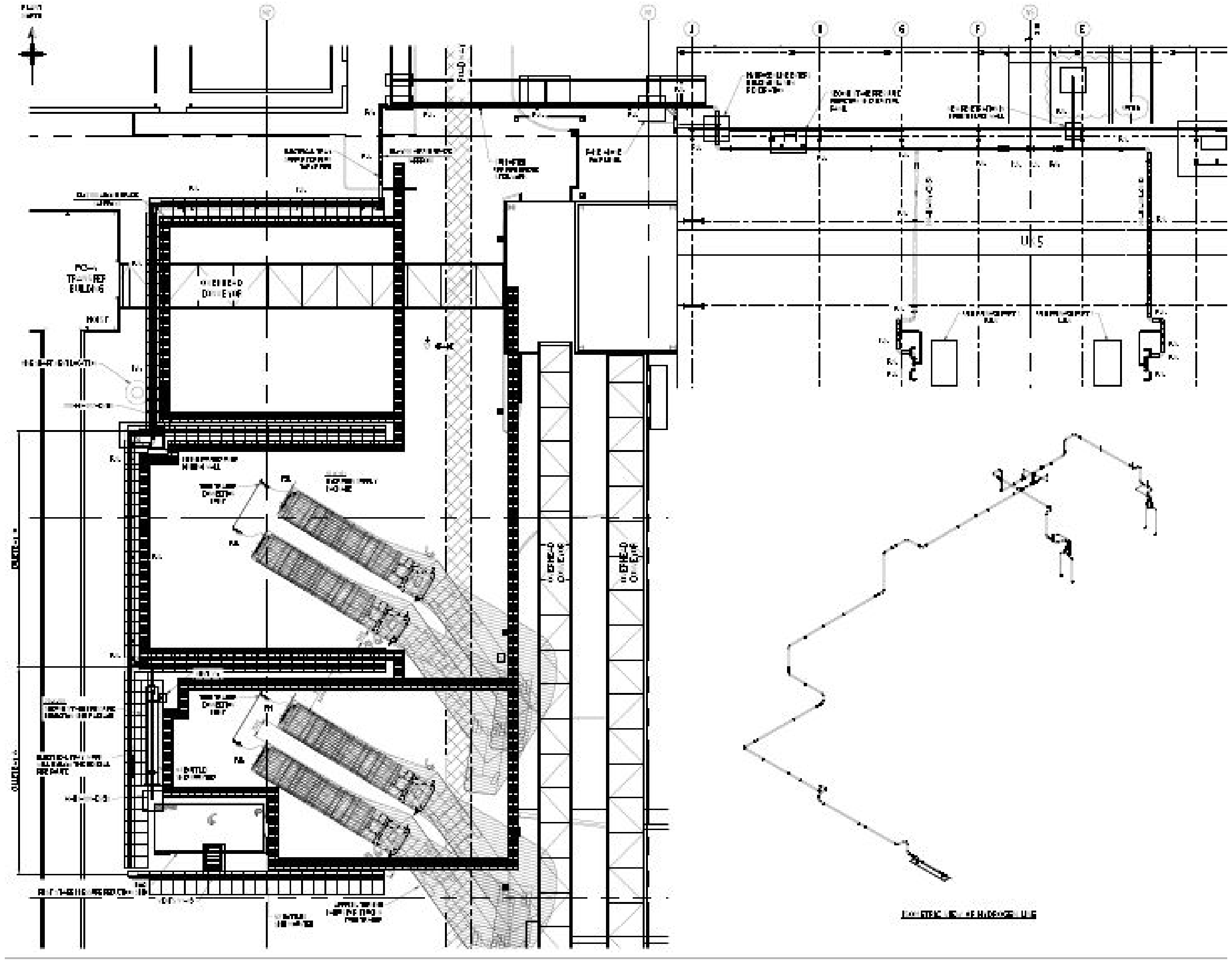
UK Research and Innovati

"Glassmaking" CO2 emissions from two sources – Fuel and Batch.

Hydrogen

Hazard Studies 1 & 2

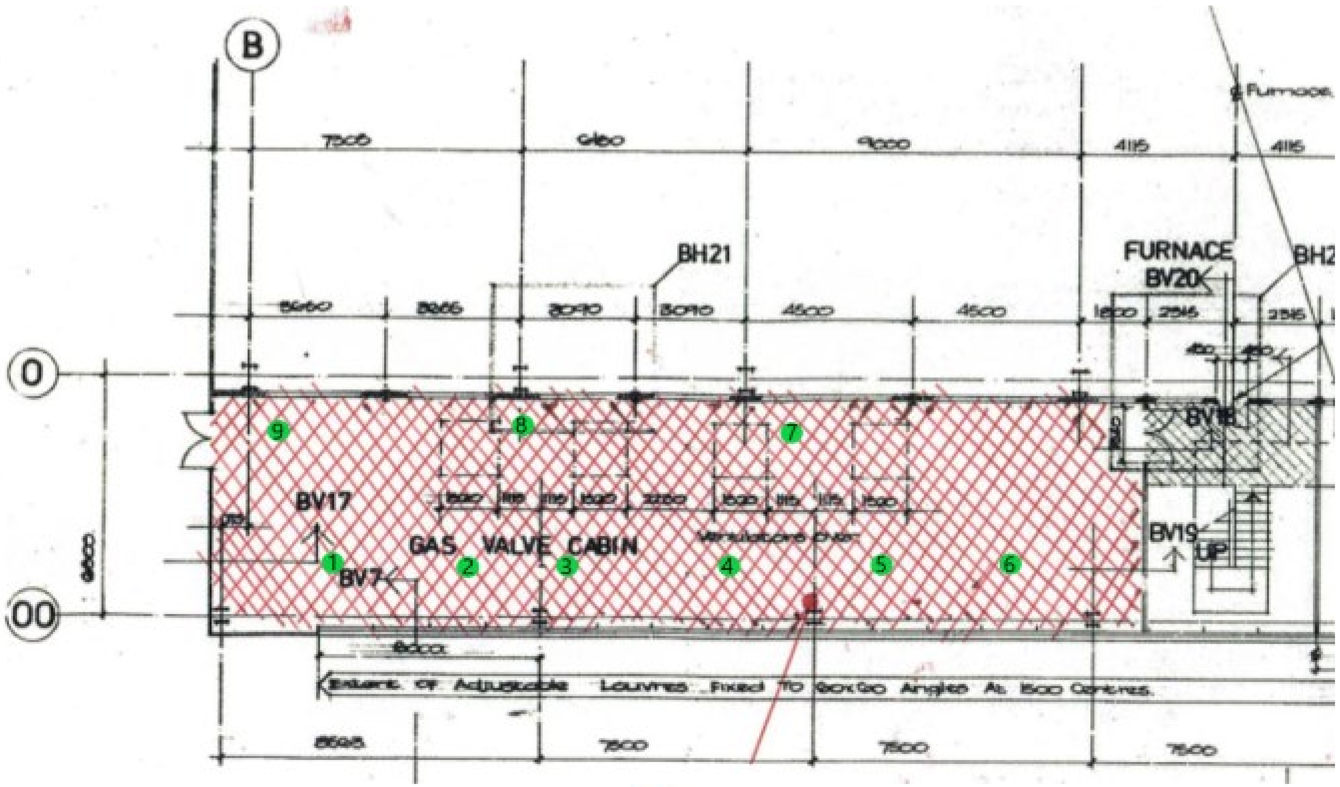
- Identifying inherent hazards of dealing with Hydrogen - flammability, diffusivity, buoyancy, hydrogen embrittlement
- Identifying potential building, infrastructure, layout and transport issues
- Paying attention to ventilation, hydrogen accumulation at high points, leak detection
- Pinpointing key activities, such as changeover of duty to/from hydrogen and blends and purging
- Agreement of risk tolerability criteria, regulations, standards, codes and guidance



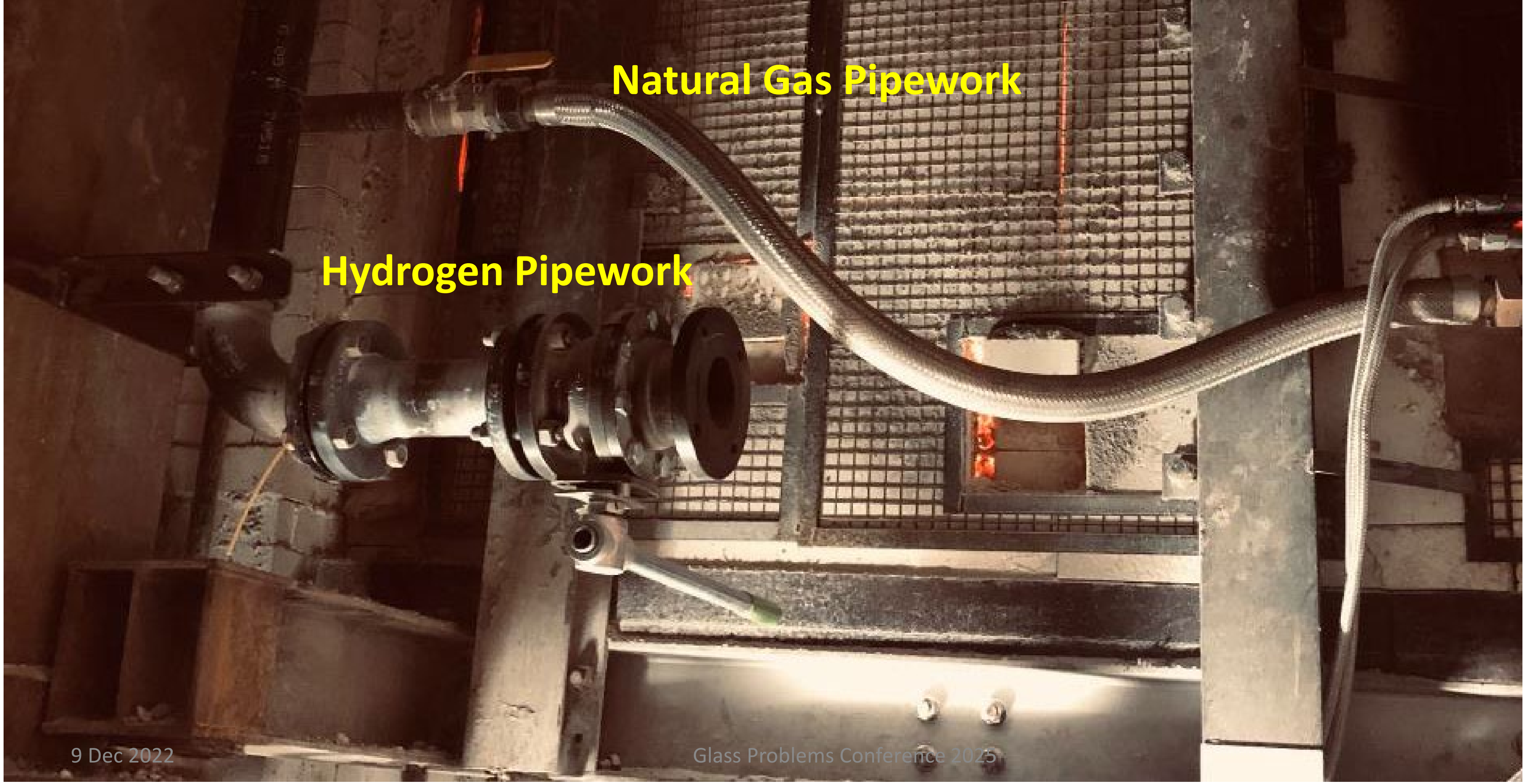
Gas Detection and Fire Risk Assessments

- Fire Risk Assessments conducted
- Ventilation Assessments in furnace room including air flow monitoring
- No accumulation of hydrogen or NG within furnace building unless a very large leak.
- Smoke bomb assessment of air flows in furnace building completed.
- Hot surfaces = auto-ignition
- Gas Cabin has 9 Gas Detectors installed
- Hydrogen Detectors are cross-sensitive to NG
  - Move from 10% LEL to 20% LEL detection

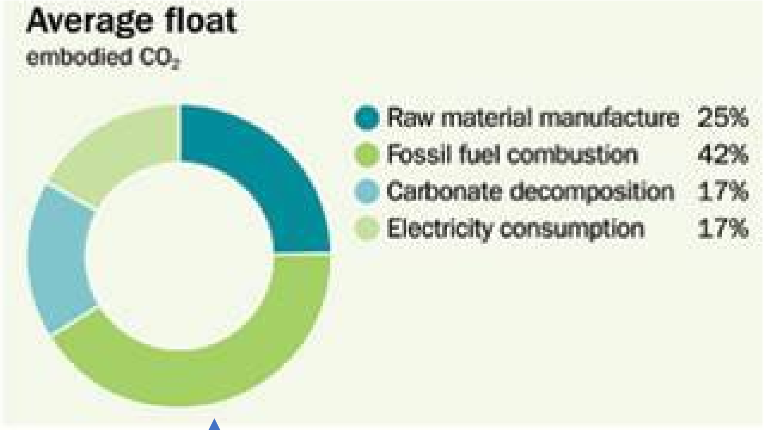
- Welded fittings v. flange
- Energy content by volume



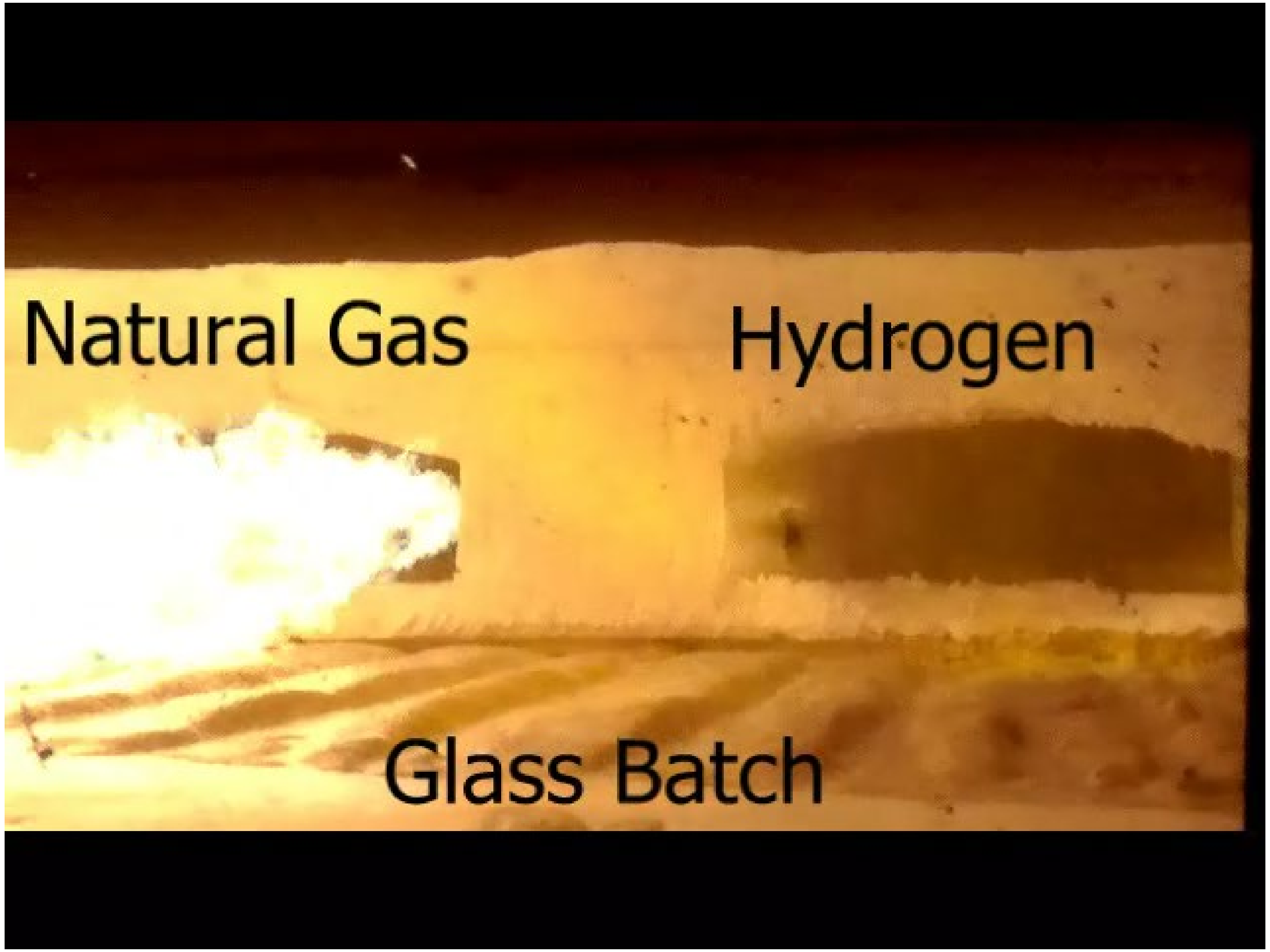
Comparison of Hydrogen Pipework at side of port with original natural gas supply = 3x more by volume for H2



Hydrogen firing



This proportion of CO_2 emission will reduce from use of Hydrogen & biofuel



Gas tube trucks – 5 days firing = 1 year available capacity H2

Hydrogen Firing Modes

100% NG

80% NG:20% H_2 by Volume

92.6% NG:7.4% H_2 by Energy

70% NG:30% H_2 by Volume

87.9% NG:12.1% H_2 by Energy

60% NG:40% H_2 by Volume

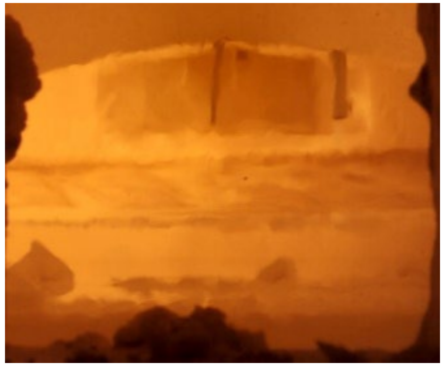
82.4% NG:17.6% H_2 by Energy

50% NG:50% H_2 by Volume

75.7% NG:24.3% H_2 by Energy

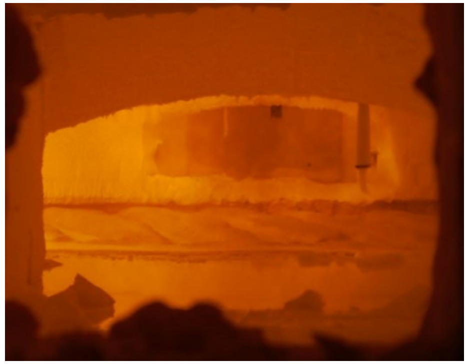
40% NG:60% H_2 by Volume

67.6% NG:32.4% H_2 by Energy



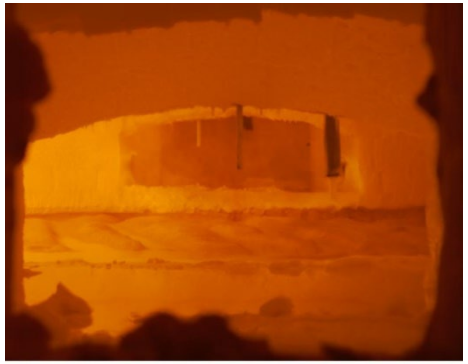
30% NG:70% H_2 by Volume

57.2% NG:42.8% H_2 by Energy



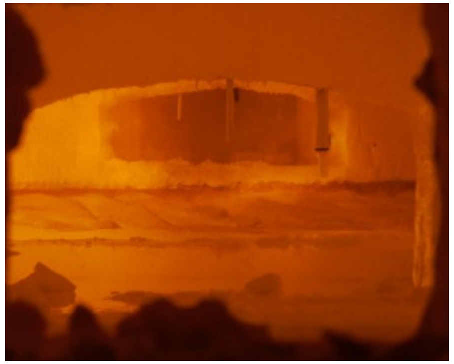
20% NG:80% H_2 by Volume

43.9% NG:56.1% H_2 by Energy



10% NG:90% H_2 by Volume

25.8% NG:74.2% H_2 by Energy



100% H_2

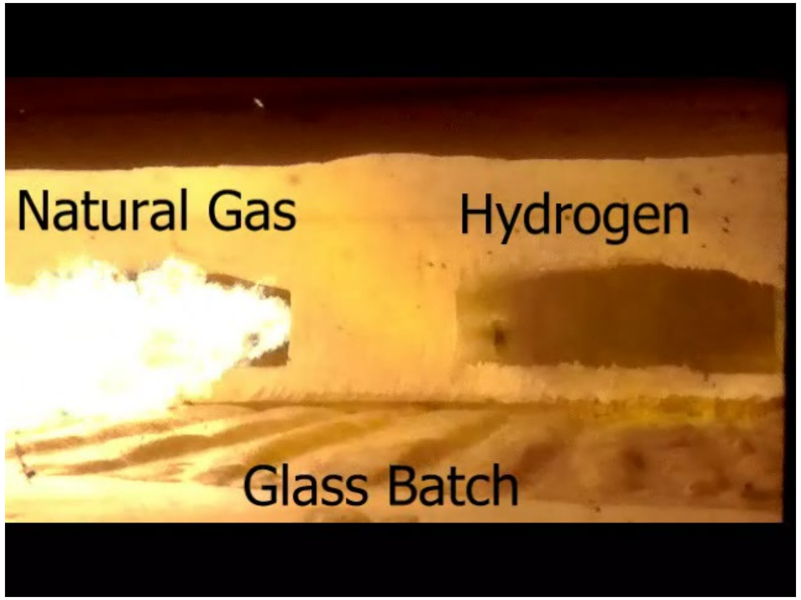
Hydrogen Firing Trials Summary

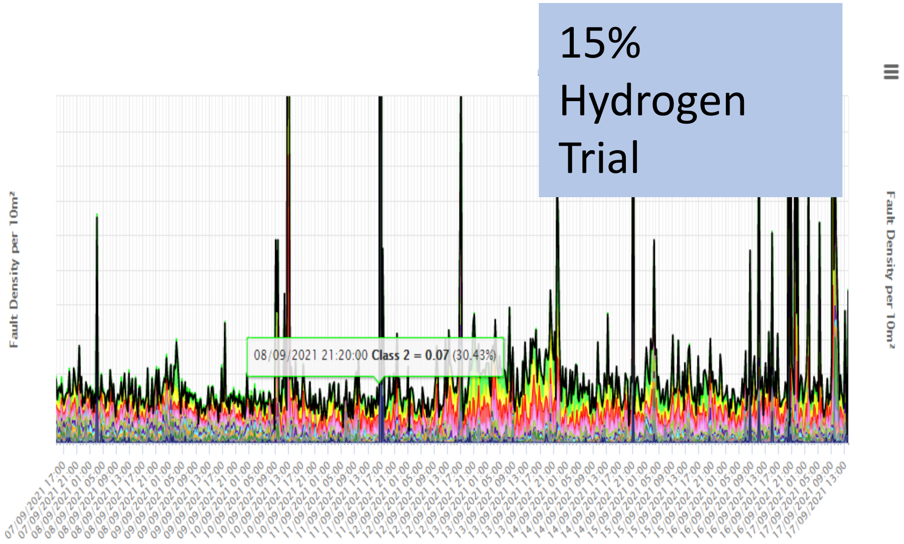
Port 1 Trials

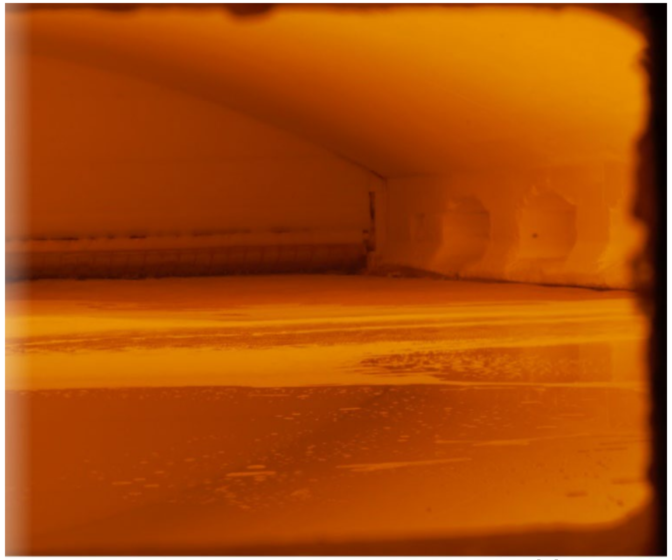
- Successfully fired 100% hydrogen
- Heat transfer, melting performance, emission characteristics (NOx, soda) were measured
- No adverse effect on melting observed
- Viable fuel for melting

Full Furnace Trial

- Successfully fired 15% hydrogen on all ports
- Heat transfer, melting performance, emission characteristics (Nox, soda) were measured
- Glass quality remained stable, no adverse effect on melting operation observed
- Scope for improved performance (burners, nozzles)

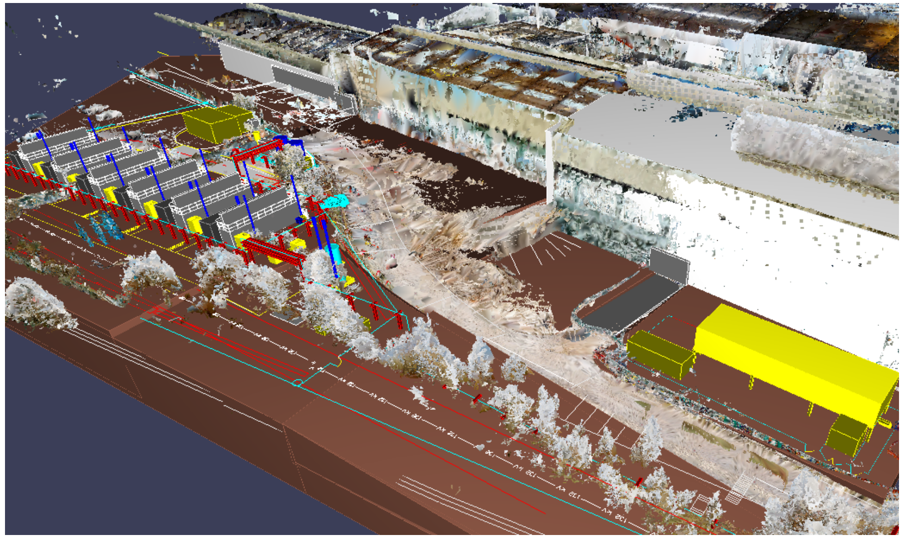






Evaluation of on-site Production of Green Hydrogen

Looking at green hydrogen production on site utilizing Proton Exchange Membrane (PEM) Electrolysers at our Greengate Site.



Hydrogen is produced through the usage of green electricity sources.

Annual production hydrogen volumes vary from 58.2-65.7GWh/annum

Project is to tie in the hydrogen produced by the electrolysers into Port 1 of NSG's Furnace.

Subsidized project, but long-term contracts, and challenging conditions to progress research.

Hydrogen

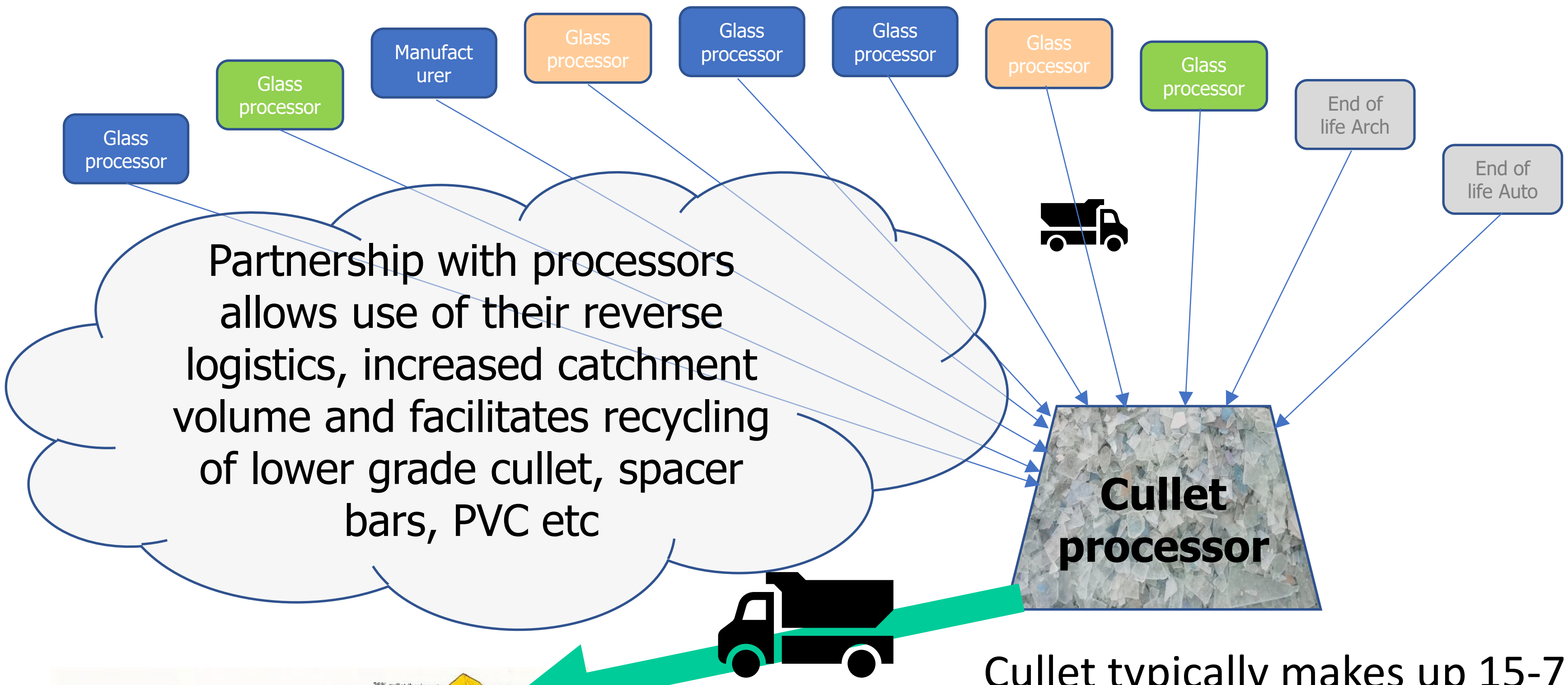
- The good news
  - Technical pathway to execute

- The not-so good news
  - Commercial scale production isn't yet available – ~~buy green hydrogen in volume~~
  - What is available is extremely expensive or reliant on subsidies.
  - On-site generation is more expensive – ~~Not likely~~
  - Difficult to study – Product availability, line availability, cost
  - Significant costs to test and/or convert

- To be done
  - Refractory wear of hydrogen firing
  - Forehearth firing of hydrogen
  - Study impact on CO2 and blending
  - Long-term operational impact, refining, quality
  - Burner design

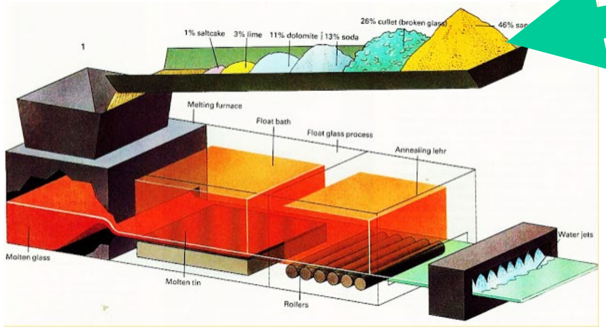
Cullet for decarbonisation

Improving cullet ecosystem in US



Challenges

- Infrastructure – collection, sorting
- Freight cost
- Capex – Processing
- Legislation
- Low cost of landfill
- Contamination risk



Cullet typically makes up 15-75% of NSG melted glass

5% cullet ≅ 1.5% less fuel

Goal - enable a further 5%+ NSG group increase through addition of more complex and external cullet streams

Increasing cullet = reduced batch carbon + reduced energy to melt

Cullet Collaborations

- NOIC – MRF
- NOIC – Blitz
- NGA - Ecosystem

Recycling Optimization - MRF Working Team

Objectives: Define cullet baselines in Lucas County, Blend and inspect fines, create cullet steams for solar & flint container, create sorting technology specification for new Lucas County MRF, create innovative methods of CSP removal.

Alignment
- Recycling MRF

Team
- Board Advisor: Kyle Sword
- B. Hippert (OI)
- B. Stansley (RS)
- D. Lancaster (OC)
- Matt Franchetti (UT)
J. Riley (LCSWMD)
- M. Kirian (NOIC PM)

Metrics
- Reduce fines going to waste by 7%
- Expand Fines Inclusion 5%
- Expand overall Clean Cullet Supply by 7%

Budget
- $5,065,140

Updates

Recent achievements
- Comprehensive Lucas County Waste Stream Materials Audit completed by UT team led by Professor Matt Franchetti
- Kicked off a study to highlight all market-ready sorting and handling technologies for cullet, and their associated costs and value propositions
- Created and updated of a value chain proposition for certain cullet technologies to determine best ROI for certain equipment types for MRF's and processors

Upcoming activities
- Plan to test samples and test capabilities through the Steinert MSort Operations in Kentucky to create performance data set for project team
- Deploy next round of GRIT collection system in Northwest Ohio and publish white paper on location selection process

- Additional comments
- The team hs set up a research support contract with the University of Toledo team who has PhD's and undergraduate students experienced in consulting for Lucas County SWMD
- The team recently held a comprehensive half day brainstorming around how to influence and support increased glass collection over time for Lucas County and RS

Milestones	Status
Complete glass sorting technologies market study	July 2025
Complete trial of new sorting process for fines sensing and sorting (TBD)	TBD
Support the deployment of GRIT initiatives	June 2025
Support Lucas County MRF Glass Stream Creation and Education Center Design & Procurement	2025-2026

NORTHWEST OHIO INNOVATION CONSORTIUM

NOIC First Annual Earth Week Glass Recycling Blitz Report

Executive Summary

The Northwest Ohio Innovation Consortium (NOIC) is thrilled to announce the outcomes of the first annual NOIC Earth Week Glass Recycling Blitz Event, held during the week of April 16-22, 2025. The event aimed to increase glass recycling rates and raise awareness about the importance of glass recycling. Key metrics, including baseline tonnage, blitz tonnage, carbon offsets, consumer engagement, and industries served were tracked and analyzed. This report highlights the success of the event and provides insights into future initiatives. The blitz resulted in significant increases in glass recycling tonnage and consumer engagement, contributing to substantial carbon offsets. The recycled glass cullet will be used to support various industries of the Northwest Ohio Innovation Consortium. The quality of the recycled glass upon collection pickup was determined to be extremely clean with a remarkably low % of contamination, continually validating the economic and quality potential of separated glass stream collection.

NORTHWEST OHIO INNOVATION CONSORTIUM

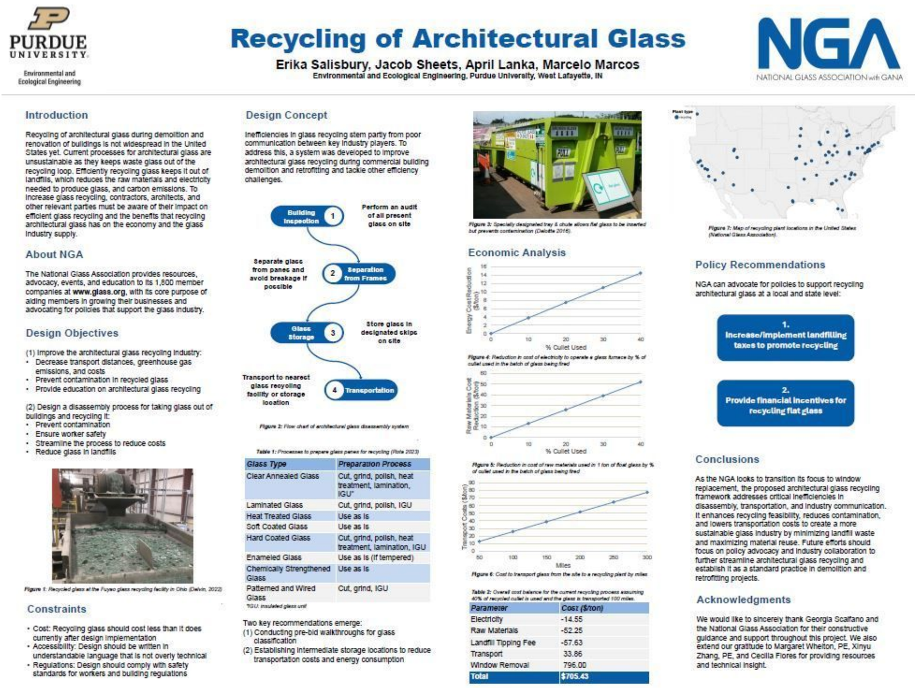
Earth Week Event Key Performance Metrics

The following table summarizes the key performance metrics of the Earth Week Glass Recycling Blitz Event:

Table 1: Blitz Collection Metrics

Metric	Value	Description
Baseline Weekly Tonnage	4,800 Pounds	Average weekly glass recycling amount in Northwest Ohio before the blitz
Earth Week Blitz Tonnage	6,800 Pounds	Total glass recycling amount collected during the blitz week
Increase in Tonnage over Baseline	2,000 Pounds	Difference between blitz tonnage and baseline tonnage
Approximate Carbon Offsets	2,566 Pounds CO2e	Estimated carbon dioxide equivalent emissions avoided due to recycling: equivalent to driving a car from Boston to LA.[1]
Raw Materials Saved	8,686 Pounds	Total Amount of Raw Materials Saved

[1] "Greenhouse Gas Emissions from a typical passenger vehicle", EPA, 2025 https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle#:~:text=including%20the%20calculations.-,How%20much%20tailpipe%20carbon%20dioxide%20(CO2)%20is%20emitted%20from,of%20CO2%20per%20mile.



NGA
NATIONAL GLASS ASSOCIATION with GANA

Glass Technical Paper **AD01-25**

Overcoming Challenges of Circularity and Architectural Glass Recycling

Introduction

The National Glass Association's (NGA) FB40-25 *Recyclability of Architectural Glass Products* explains the types of glass products that can be recycled, clarifies misconceptions about recycling in the industry, details some of the benefits and value creation from glass recycling, and describes many of the end use products that can be created using cullet.[1] Because of these values, many types of glass industries have described increased cullet use as a key strategy to achieving their 2050 sustainability goals. Despite these values, rates of recycling of all types of glass in the U.S. remain much lower than in Europe and other places in the world.[2] While glazed enclosures allow for daylight and visual connection between spaces, their performance requirements are evolving. Single glazed windows are being replaced by more energy efficient ones, generating, in the process, volumes of architectural glass typically not recycled in the U.S. On the other hand, leveraging post-consumer materials is one of the simplest ways to decrease the embodied carbon of glass, keeping it a material of choice at the intersection of durability, cost-effectiveness, and sustainability. Expanding circular practices in the field of architectural glass create opportunities to not only strengthen local labor markets, but to enhance the glass industry's reputation as an effective and sustainable solution.

The primary objective of this Technical Paper is to explain many of the challenges currently within the U.S., describe some of the key risks involved with cullet reuse, communicate some of the global activities around cullet reuse, and propose some paths forward that members of the National Glass Association can proactively implement to help move cullet up the value chain and maximize cullet reuse value.

Key drivers supporting the development of increased recycling in North America include:

- Economic and environmental value
- Benefits at all levels of supply chain
- Creation of a circular economy and domestic raw material and supply
- Job growth
- Reduced waste to landfill
- Improvements in glass furnace operations
- Reduction in glass furnace emissions

Cullet Goal

- Understand / build ecosystem around cullet

- Pilot program – Improved collection, processing, classification, quantify economic and CO_2 impacts within a processing radius.
  - ID pilot model to replicate
  - Involve stake holders in ecosystem

Other activities

Process AI Optimization

Objectives: Furnace stability and energy reduction per melted ton of 4%, implementation of state-of-the-art sensor systems, development where necessary, implementation of data / knowledge / model reaction based on first principles, recovery from upset optimization, raw material control and optimization

Alignment

Process AI: O-I Toano Furnace Analysis

Team

Board Advisor: Matthew Kirian
M. Kirian (NOIC PM)
J. Bryant (O-I)
J. Peeno (NOIC)
T. Bush (ART)
M. Abouheaf (BGSU)

Metrics

Energy reduction per melted ton of 4%

Predictive color and job change upset control

Updates

Recent achievements

- Project kickoff and data sharing from O-I to Actual Reality Technologies (ART)
- ART performed first two rounds of process and quality data analysis to identify significant indicator tags between process, quality, and energy
- The project team has worked closely with the O-I Toano Team to understand data anomalies, sensing systems, and data naming structure

Upcoming activities

- Continued communication with the O-I Toano team to understand batch and quality controls and operations
- ART's next iteration of statistical significance analysis of process data parameters in conjunction with energy and quality data analysis
- Predictive model feasibility report to identify current predictive capabilities and limitations
- Final strategic report and roadmap with recommendations for additional data required to further optimize model performance, AI/ML implementation and deployment strategy, and next steps

Roadblocks

- Logistics of the payment structure, and O-I's internal vendor and customer creation systems – not stopping work, but using a lot of resource time
- Lack of member agreement required additional agreements to be drafted and is preventing BGSU from participating at this time

Milestones	Status
Furnace Data Correlation Analysis	May 2025
Data Prediction of what's Currently Possible	July 2025
Art of the possible Workshop	October 2025
Determine Additional Instrumentation needed	Q4 2025
Install New Sensors	Q1 2026
Move controls to the edge	Q2 2026

Additional comments

Toano Plant has two furnaces included in the data sets being analyzed.

The two furnaces have slight tonnage and cullet differences.

Melting Technology Improvement

Alignment
- Melting Technology Performance

Team
- D. Imbrogno (NSG)
- J. Strohscher (Libbey)
- J. Schep (O-I Glass)
- M. Menczywor (Owens Corning)
- H. Sojoudi (UT)
- J. Watts (CelSianUSA)
- Z. Islam (BGSU)
- N. Valette (NOIC PM)

OBJECTIVE - Improve efficiency in the glass melting furnace

UPDATES

- Conducted brainstorming sessions and ranked research ideas according to expected impacts and industry needs
- Identified (2) highest priority topics:
  - **Improve burner design**
  - **Capture & reuse energy from flue gas heat**
- Market studies to be conducted
  - Scope of work defined
  - (2) Grad students (UT) over the summer

Milestones	Status
Brainstorming	2025 Q1
Prioritize research topics	Apr-May 2025
Market studies	May-Aug 2025

	Budget
Initial budget	$ 1,749k
Market studies	$ 20k

Prioritized research ideas

Tier 1	Tier 2	Tier 3
• Meter geometry - optimal ratio length/width/depth • Energy from flue gas heat capture and reuse • Burner design • Improved regenerator refractory - extend asset lifespan • Advanced refractory maintenance techniques	• Optimized meter geometry (spherical, igloo shape, rotating...) • Burner for hydrogen firing / ammonia • New melter refractory formulation • Refractory for hydrogen firing • Periodic or real time refractory monitoring systems	• Lower product specs (around bubbles etc.) • Refractory cooling with energy capture & reuse • Improve insulation properties • Refractory testing system used at the manufacturer and/or build site.

Tier 1 research ideas ranking

Innovation Topics	O-I	OC	NSG	Libbey	Prelim. Ranking	Impacts
Burner design	1		2.1	1	1	- **Process stability** - **Energy use optimization** - **Environmental**
Energy from flue gas heat capture and reuse	2		1	2	2	- **Energy use reduction** - **Stability**
Improved regenerator refractory - extend asset lifespan	5		2.2	3	3.1	- Capital cost reduction
Advanced refractory maintenance techniques	4		3	4	3.2	- Capital cost reduction
Melter geometry - optimal ratio length/width/depth	3		4	5	4	- Stability - Production capacity increase - Energy use reduction - Quality (defect reduction)

Summary

- Toledo = Center of Glass excellence and CdTe PV – globally.
- Collaboration will drive better results.
- Hydrogen has good potential, but difficult and expensive to progress. Need infrastructure at scale.
- Need to understand – CO_2 creation and savings.
- Lead innovation change, replicate across industry/geography.

Questions?

NSG

GROUP