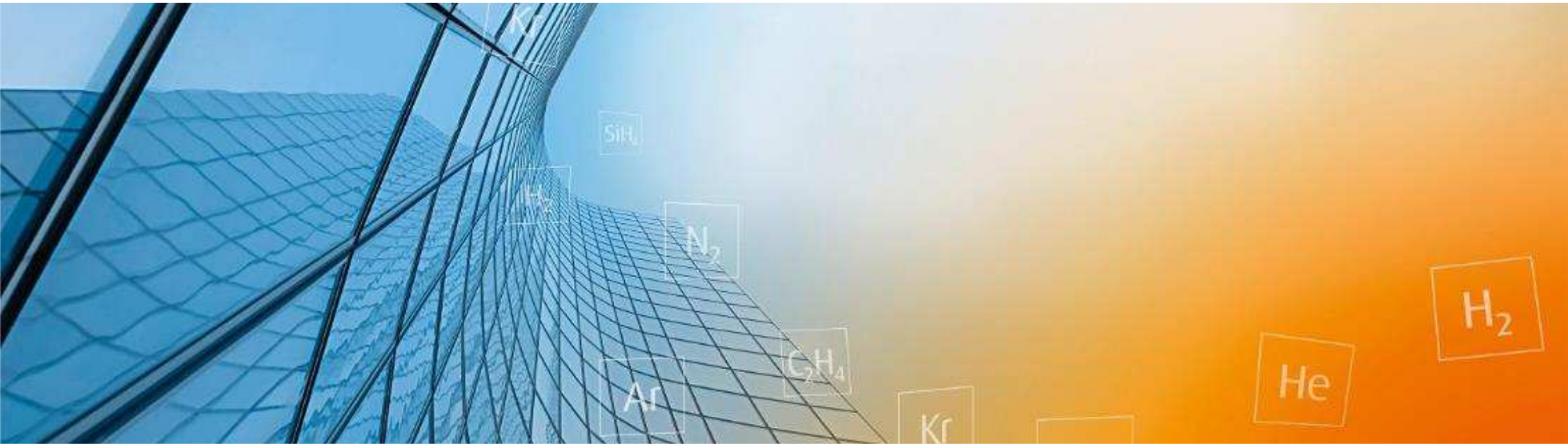



# Heat Recovery in Oxy-Fuel Glass Furnaces –

## A Path to Increased Efficiency and Lower $CO_2$ Emissions

Matthias Goerisch, Shrikar Chakravarti, Stefan Laux & Martin Adendorff

April 22, 2021

Making our world more productive

# Linde. Global presence, local support.

- The leading industrial gases and engineering company
- Formed in 2018 with the merger of Linde AG and Praxair, Inc – two world-class companies with nearly 140 years of shared history and successful achievements
- Proven critical project execution knowledge in diverse geographies
- Best-in-Class Safety Performance

## One Linde

Uniting with a shared Vision, Mission and Strategic Direction, and demonstrating our Values and Behaviors in everything we do

## 2 million+

customers

Establishing a more diverse and balanced portfolio

## 100+

countries

Enabling strong, complementary positions in all key geographies and end markets

## ~80,000

employees

Achieving our full potential, individually and collectively

## ~$15 million

charitable giving and sponsorships in 2018

Supporting our communities through contributions and employee volunteerism

## 6,500+

active patent assets worldwide

Leading with innovative products, solutions and technologies

## RECOGNITION

MEMBER OF

Dow Jones Sustainability Indices

In Collaboration with RobecoSAM

Forbes 2018 GLOBAL WORLD'S BEST EMPLOYERS 2000

2018 Bloomberg Gender-Equality Index

FTSE4Good

# Path to Decarbonizing Glass Melting

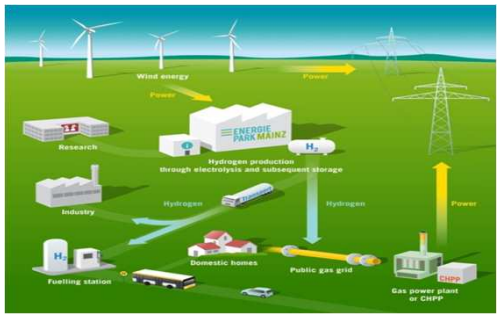
## Oxy-fuel combustion

- Oxygen Supply
  - Built on-site oxygen supply system for 1st large oxy-fuel glass furnace
  - **Installed over 60 VPSAs in glass plants**
- Burner Technologies
  - Developed 1st low NOx oxy-fuel burner
  - Broad portfolio of burners optimized for oxy-fuel furnaces

## OPTIMELT® Waste Heat Recovery Systems

- ThermoChemical Regenerator (TCR) System
  - Reduces energy consumption and CO2 emissions by 20% vs oxy-fuel, 30% vs air-regen & 50% vs recuperative
  - Smaller regenerators relative to air-regen
- Batch and Cullet Preheating Systems
  - Exclusive access to commercially proven technology from Johansson Industries
- Compatible with oxy-$H_2$ furnaces

## Low Carbon Fuels




- Hydrogen Supply
  - 120+ SMRs
  - Largest liquid $H_2$ capacity
  - Electrolyzers: 80+ units (40 MW), JV ITM Linde Electrolysis GmbH
  - FOx SMR for blue $H_2$
- Oxy-$H_2$ firing to be more economic than air-$H_2$ firing
- Other low carbon fuels, e.g. biomass, biogas, ethanol
  - Refer to Kobayashi, H. et al., "Oxy-Fuel Combustion toward CO2 Neutral Glass Production", Glass Trend Seminar, April 2018

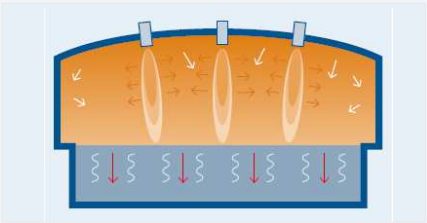
## $CO_2$ Capture

- Multiple carbon capture demonstrations
- Oxy-fuel simplifies $CO_2$ capture process relative to air-fuel
- Long term $CO_2$ offtake agreement can improve economic viability

# State of the art technologies. Linde's portfolio for glass melting.


## Linde's glass melting portfolio. Increasing process efficiency with oxygen.

### Oxyfuel melting



#### OPTIFIRE® CGM oxyfuel melting

Roof burner for enhanced heat transfer capabilities

- More melting capacity
- Less raw material needed
- Further energy savings
- Improved glass quality

#### OPTIFIRE® Wide Flame Burners

Wide flame coverage and high luminosity

- Low momentum flames that reduce particulate emissions and crown corrosion
- Significantly lower NOx vs conventional oxy-fuel burners
- Easy to install and maintain
- Effective at foam mitigation

#### OPTIFIRE® JL Burner

Oxygen staging allows for ultra-low NOx operation

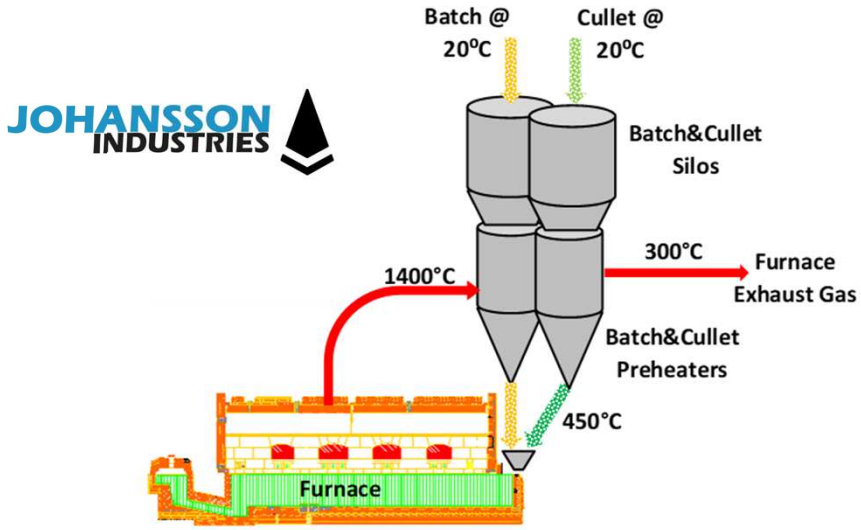
- No burner cooling required
- Works with liquid and gaseous fuels

### Comprehensive OPTIFIRE® Oxy-Fuel Burner Portfolio

| Type | Glass Type |
|---|---|
| J | Container, fiberglass, float |
| COROX I & II | Container, frit furnaces |
| CGM | Composite fiberglass |
| JL | Container, tableware, float |
| WFB | Container, float |
| XD | Fiberglass, container |

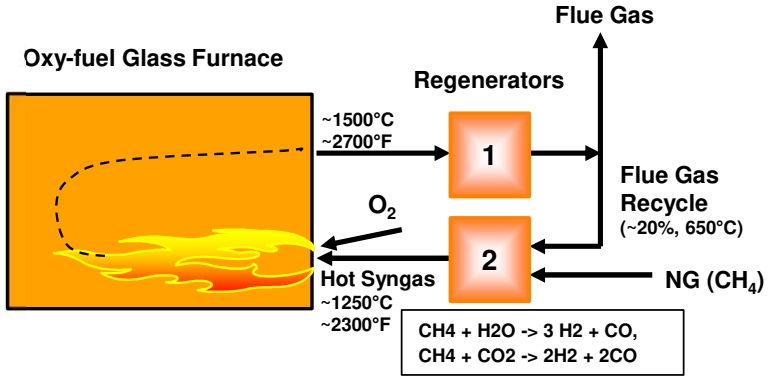
# OPTIMELT® Waste Heat Recovery Systems

## Batch Cullet Preheater (BCP)




- Exclusive agreement technology from Johansson Industries
- Several commercial references with multinational glass companies (US and EU)
- Energy savings of ~10 – 25% depending on cullet only or batch and cullet preheating

## Thermochemical Regenerator (TCR)




- Regenerative non-catalytic reforming of natural gas using high furnace operating temperatures
- Technology owned by Linde
- Two commercial references in Mexico and Europe
- Energy savings of ~15 – 25% depending on multiple factors

# “LIFE OPTIMELT” Program for Tableware Furnace at Libbey, Leerdam

https://lifeoptimelt.com/pdf/Life-Optimelt-a4-EN.pdf

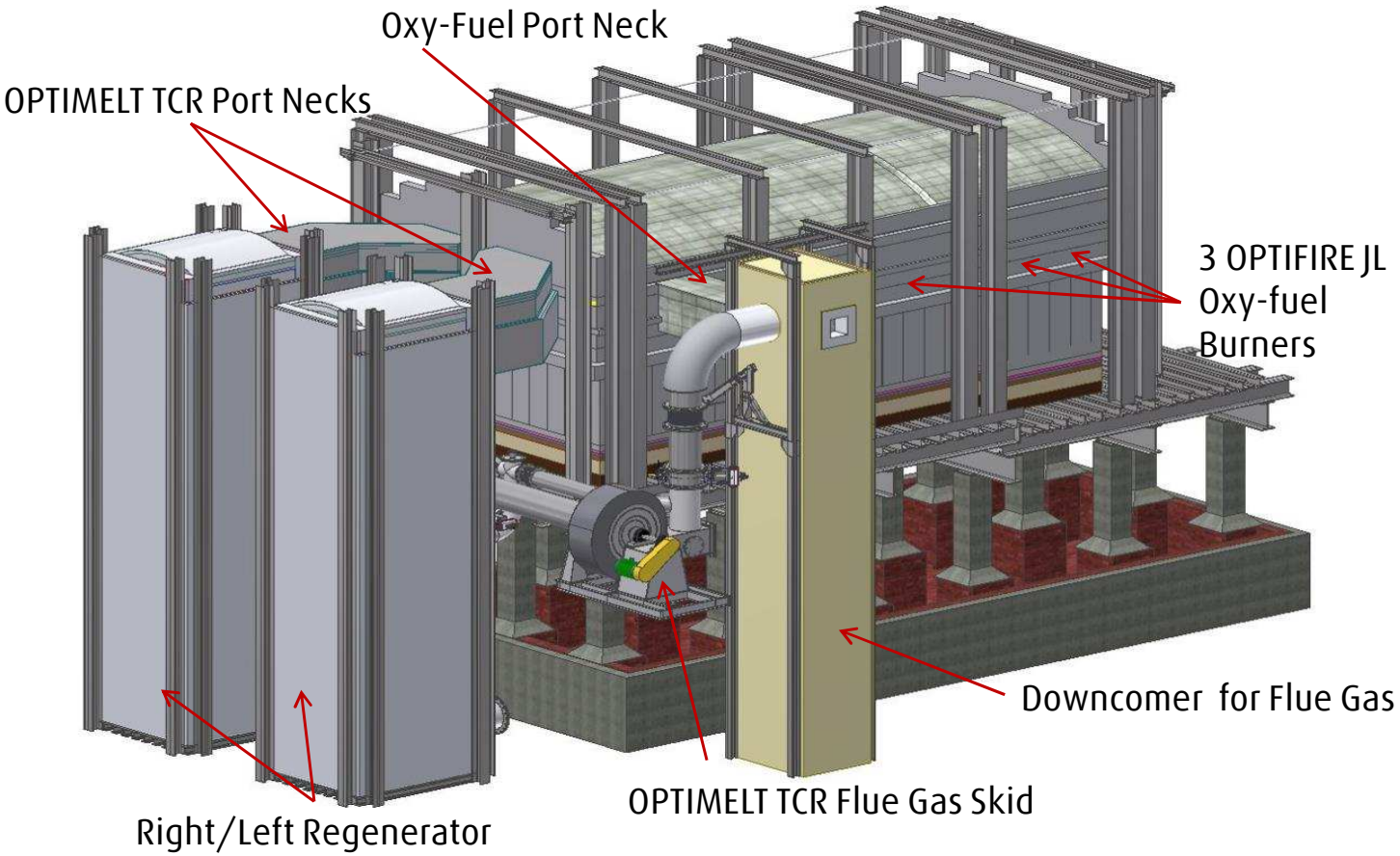
## The Program’s Results

A considerable reduction in emissions has been achieved at Libbey’s factory in Leerdam. The innovative OPTIMELT™ Technology has been implemented in oven L1 at Leerdam’s glass plant, with a capacity of 80 tons of glass/day, replacing two old 40 tons of glass/day furnaces.

**Natural Gas** consumption dropped by 48% = 131,238 GJ / year equivalent to the power produced by 4 super modern wind turbines / year = Heating of 2750 houses / year.

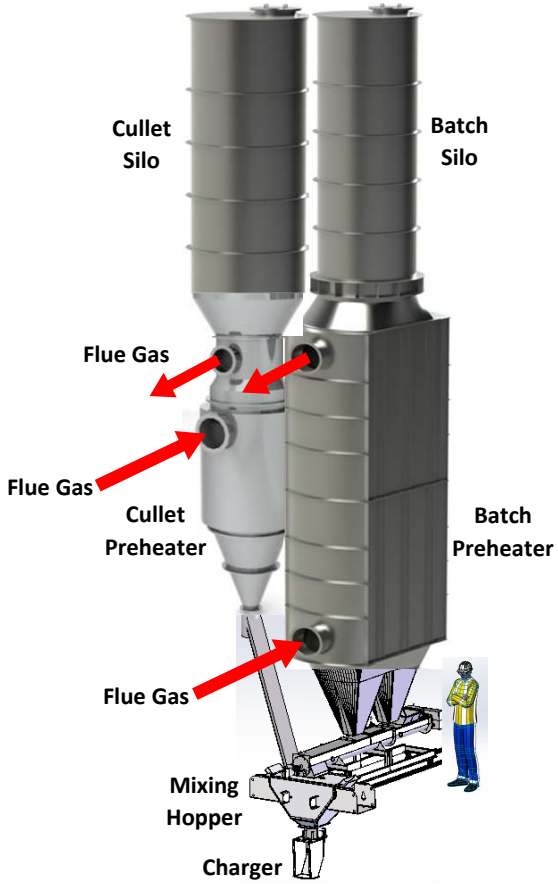
- $CO_2$ emissions dropped **by 47%** = 6940 tons / year.
  **Equivalent to the $CO_2$ emitted by 4,500 cars / year.**
- NOx emissions dropped **by 86%** = 117 tons / year.
  **Equivalent to the NOx emitted by 11.700 cars / year.**
- SOx emissions dropped **by 80%** = 35 tons / year.
  **Equivalent to the SOx emitted by 140.000 cars / year.**

# Furnace L1 with OPTIMELT TCR at Libbey Leerdam (Netherlands)




- **Dual Firing Systems**
  1. TCR Syngas Firing
  2. Oxy-fuel Cross Firing
- **Programmed switching of two firing modes**

# Batch Cullet Preheating System




- **Separate Batch & Cullet Preheaters**
- **Direct contact heat exchange**
- **Batch & Cullet preheated to 450°C**
- **Substantially improves waste heat recovery**
- **Relative to BCP Systems for air-fuel furnaces**
  - Smaller sized modules
  - Reduced gas flow to ceramic filter by 75%
  - No air dilution required
- **Benefits**
  - 20%+ fuel, oxygen savings
  - Faster melting of batch / cullet mixture shortens batch line
  - Potential to increase pull rate similar to electric boost
  - Better glass redox control

# Oxyfuel with Batch/Cullet Preheater (BPH/CPH) Commercial Installation Summary

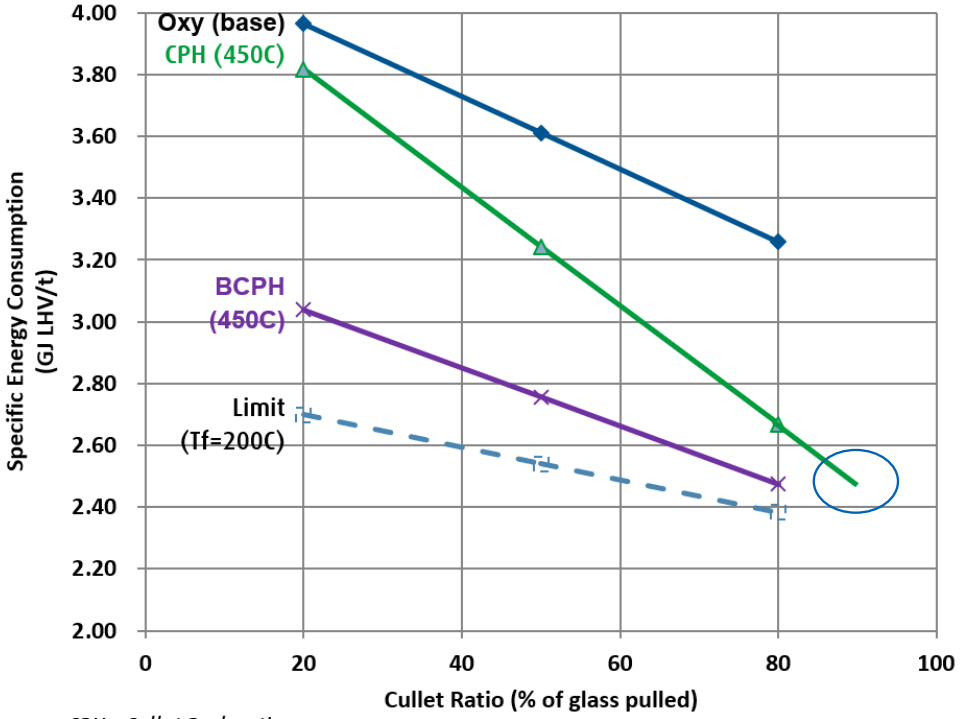
| Location | Pull Rate (t/d) | Year Installed (BPH/CPH) | Glass | Cullet Ratio | Cullet Rate (t/d) |
|---|---|---|---|---|---|
| US | 250 | 1997 (CPH) | Flint | 50% | 130 |
| US | 330 | 2011 (BCPH) | Flint | 50% | 160 |
| Europe | 270 | 2014 (CPH) | Flint | 50% | 135 |
| Europe | 170 | 2015 (CPH) | Flint | 80% | 140 |
| Europe | 410^ | 2016 (CPH) | Green/ Amber | 75% | 310 |
| Europe | 340 | 2017 (CPH) | Flint | 70% | 240 |

*^Two identical CPHs installed*

- **Multiple references with multinational glass companies**
- **Demonstrated energy savings of 11 – 15% with CPH and 20% with batch cullet preheater (BCPH) vs oxy-fuel**

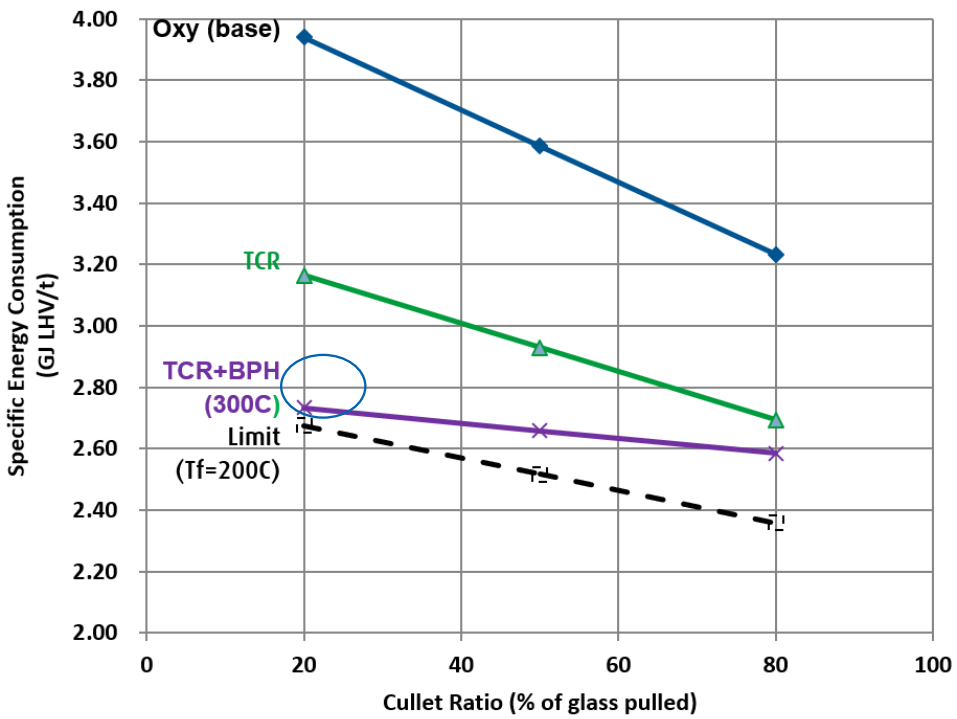
# Energy Consumption and Heat Recovery Options: CPH, BCPH, BPH and TCR
## (Oxy-Fuel Fired Container Furnace at 350 mTPD with 1000 kW electric boost)

2.5 GJ/t feasible with CPH at 90% cullet




*CPH – Cullet Preheating*
*BCPH – Batch & Cullet Preheating*

2.8 GJ/t feasible with TCR+BPH at 20% cullet

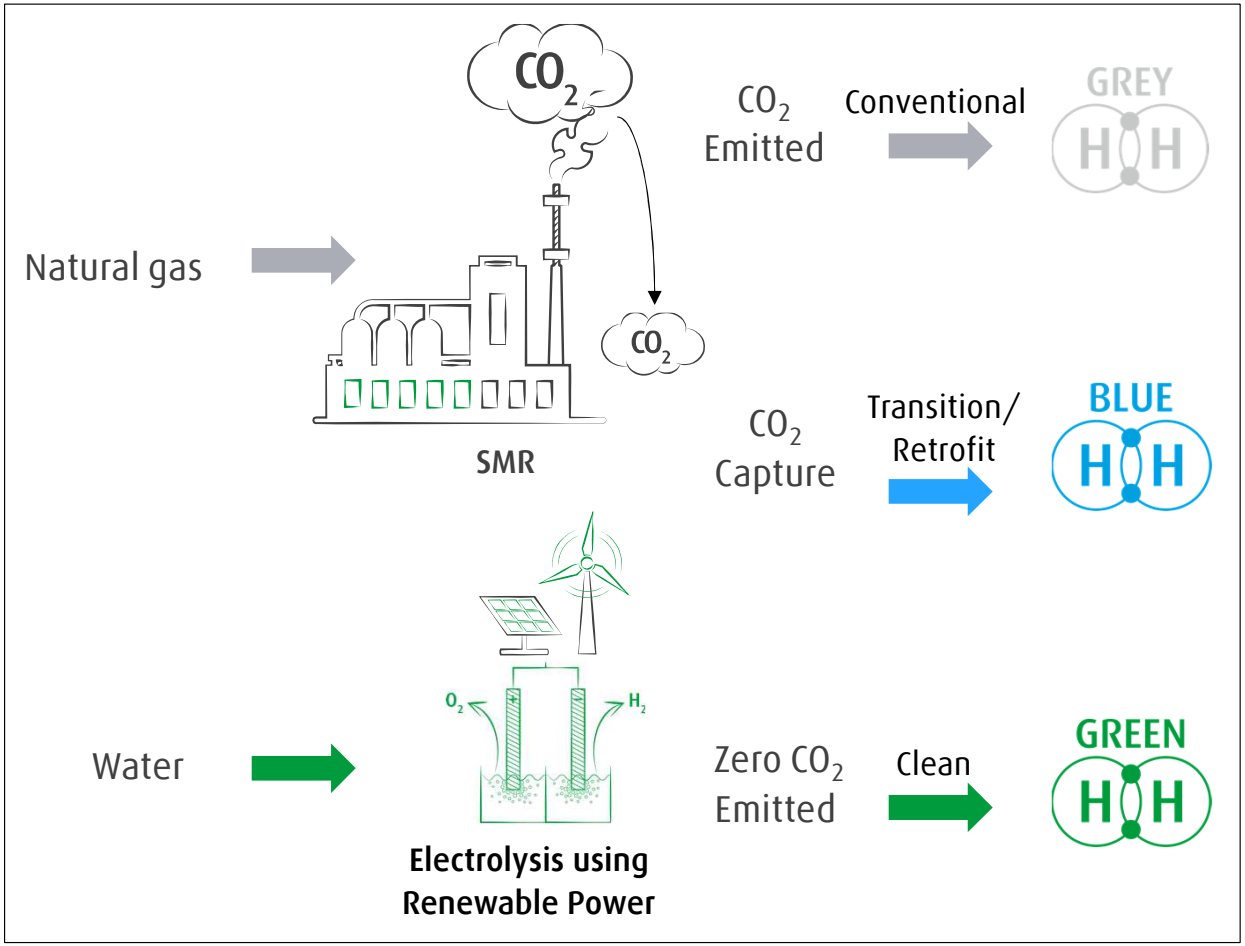



*TCR – Thermochemical Regenerator*
*BPH – Batch Preheating*

***Specific energy consumption includes fuel + 0.25 GJ/t of electric boost.***

# Linde activities: $H_2$ for Glass

- Development of hydrogen fired oxyfuel burners
  - Testing underway at Combustion Labs in US and Germany
- External collaborations
  - CelSian R&D Projects (Glass industry)
    - Heat transfer from H2-rich flames in glass tanks
    - Effects of H2-rich combustion on foam and on heat transfer to glass melts
  - DNV (GL) Project (Glass, steel, ceramic industries)
    - H2 as a fuel for industrial heating processes
- OPTIMELT® Waste Heat Recovery technologies
  - Compatible with oxy-H2 furnaces
  - Bridge to future with H2 or blends of H2-NG
- Clean H2 production
  - Blue H2: SMR + CO2 capture
    - Diverse portfolio of SMR & CO2 capture technologies
  - Green H2: PEM Electrolysis
    - ITM Linde Electrolysis – JV between ITM Power and Linde Engineering



Making our world more productive


# Thank you for your attention.

Matthias Görisch

Linde GmbH
Gases Division
Vogelweiherstr. 73
90441 Nürnberg

Tel.: +49 911 4238-175
E-Mail: matthias.goerisch@linde.com
Internet: www.lindeus.com/industries/glass/optimelt