Four Major Levers for Contribution of Glass Industry decarbonation
CO₂: The energy transition – a necessity and a global challenge

Fossil fuels account for 82%

17 GtCO₂ + 10 GtCO₂ + 8 GtCO₂ + 5 GtCO₂

Keeping the rise in temperature below 2°C

Less than 1,000 gigatons CO₂ “to be released”

About 25 years
Decarbonize the energy system
Four major levers are needed to enable the energy transition

1. Increasing energy efficiency limits the rise of energy consumption
2. CCS/U decarbonizes the use of fossil fuels
3. Switch to zero emission energy carriers, e.g., electricity or hydrogen
4. Renewables replace fossil fuels

Climate Objectives

A Global Approach

**ASSETS**
Reduce our carbon intensity in 2025 vs. 2015 by **-30%**

**CUSTOMERS**
Act for clean industry by developing low-carbon solutions

**ECOSYSTEMS**
Contribute to a new low-carbon society
Climate objectives by 2025 and performance in 2018

A Assets

- Increasing: Its purchases of renewable electricity by nearly 70%
- Improving: The energy efficiency of its production units by 5%
- Reducing: The carbon footprint of its bulk and cylinder by 10%

B Performance

- 2018 carbon intensity: 4.9
- SIO deployment
- Significant PPA in Texas (50MW from wind farm)

C Customers

- Performance
- 10.9 Mt avoided emissions
- Rolling out low-carbon offerings and solutions
- Co-developing innovative procedures with its customers

D Performance

- Biomethane: 100M€ of revenues in 2018
- Investment of 150M€ in US west coast to promote clean mobility

E Ecosystems

- Expanding the circular economy
- Biomethane value chain
- Facilitating clean refrigerated transport
- Blueeze & Cryocity
- Promoting hydrogen for clean mobility
- Investment in low-carbon H2 production, distribution and filling stations
- Creating a global hydrogen economy
- Air Liquide is the co-founder of the Hydrogen Council

Significant PPA in Texas (50MW from wind farm)

In 2018, Air Liquide increased its purchases of renewable electricity by nearly 70%, improved the energy efficiency of its production units by 5%, and reduced the carbon footprint of its bulk and cylinder by 10%.
Four major levers are needed to enable the energy transition

1. Increasing energy efficiency
2. CCS/U
3. Switch to zero emission energy carriers
4. Renewables

Final energy consumption 1, 2, 2013 and 2050, in EJ
- 2013: 373 EJ
- 2050: 640 EJ

Renewables
CCS/U

Increasing energy efficiency
Heat Oxy-Combustion
Oxy-combustion + Heat recovery

CO₂ capture technologies
Absorption, Adsorption, Cryogenic, Membranes

Hydrogen combustion: exploratory study

Biomass and waste
Digestor, pyrolysis

2

Increasing energy efficiency
Driving performance to the next level

Oxy-Firing

Without additional energy recovery measures, the average energy saving will be:

- In recuperative furnaces about 25 – 35 %, including the energy consumption for oxygen production.
- For large regenerative furnaces this value is in the range up to 15%.

Energy transition scenarios investigated

1. Oxy-firing with heat recovery
2. Carbon capture, valorization
3. (Co)Firing of Biogas or/and Hydrogen
4. Full electrical and hybrid furnace designs (oxy-firing)
HeatOx: Proven today – even better tomorrow

A COMPETITIVE SOLUTION ...

Mixing advantage of oxy-fuel and heat recovery

<table>
<thead>
<tr>
<th>Technology</th>
<th>Energy Savings</th>
<th>Target CAPEX</th>
</tr>
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<tbody>
<tr>
<td>HeatOx 1G</td>
<td>Air / Flue HX, O2 / air HX, NG / air HX</td>
<td>-10%</td>
</tr>
<tr>
<td>HeatOx 2G</td>
<td>Radiative HX</td>
<td>-13%</td>
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<td></td>
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<td>-50% vs 1G</td>
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</table>

A GREEN SOLUTION

NOx -90%
CO2 -35%
On Site Oxygen: VSA-i

- **Key benefits of VSA-i**
  - **Next generation** of the previous product lines, 100+ units worldwide
  - **Lower TCO**, including <12%> Specific Energy (kWh/Nm3)
  - **Packaged unit and easy installation**
  - Deployment since February 2019
3 -Carbon Capture Usage and Storage
Air Liquide full range of CO$_2$ capture technologies combined in CRYOCAP™ product line

**CRYOCAP™ OXY**
Glass plant: Oxy-Combustion

**CRYOCAP™ H$_2$**
Refining: Hydrogen Production, SMR, ATR, POx

Cryogenics

Adsorption

Absorption

Membranes
**CO₂ - Small scale applications & industries**

→ CO₂ is used under different forms: gaseous, liquid, solid or super critical

**Agri-production**
- Optimize plants growth in greenhouse

**Beverages**
- Carbonation and beverages dispensing

**Food industries**
- Food preservation, freezing, chilling, packaging

**Cold transportation**
- Maintain cold chain for fresh and frozen products

**Agricultural & Food**
- 60%

**Other industries**
- 40%

**Chemistry**
- Reactive agent

**Industrial cleaning**
- Solvent free cleaning of metallic and plastic surfaces

**Welding**
- Arc stabilisation in MAG welding

**Waste and water treatment**
- pH control

**CO₂: ~40,000 tpd**
Enhanced Oil Recovery will remain the largest profitable CO₂ output in the US

CO₂ EOR doubles the quantity of oil which can be recovered from a well

Over 4,500 miles of CO₂ pipelines and more than 80 billions barrels of technically recoverable oil

Source: National Energy Technology Laboratory
Development of CO₂ capture from flue gas and validation of new CCUS technologies

- **Industrial CO₂ utilization**
  - Partnering with Solidia Technologies

- **Direct capture from Air**
  - Partnering with start-ups
4 - Switch to zero emission energy carriers
Hydrogen can provide decarbonized high-heat for industrial processes

Hydrogen offers a viable solution:

Direct electrification is technologically challenging or uneconomical like for energy-intensive industries.

- **Hydrogen** combusted in hydrogen burners: zero-emission alternative for heating.
- **Burners can complement electric** heating.
- Burners require only adjustments of existing equipment.

- Evaluation by simulation and lab tests.
  - Impact on the Redox and water content - Foam formation
Oxy-hydrogen flame features

The $\text{O}_2/\text{H}_2$ flame:

- Produces essentially water
- Stoichiometric ratio the best deflagration speed = $10.7\text{ m/s}$
- High adiabatic temperature = $3080^\circ\text{C}$
- Produced a reddish-orange flame due to the strong emission band of $\text{H}_2\text{O}$ at $632\text{ nm}$
In a 2-degree-world, hydrogen could contribute ~18% of demand.
Deployment of Bio-methane

→ **Build** new biomethane plants
  - Air Liquide value in the biogas purification with proprietary membrane technology
  - 2 main regions:
    - Europe
    - USA
  - Capacity: 0.8 TWh/year today to 5 TWh/year in 2025

→ **Extended** usages
  - End-users: Industry and Transport
  - Injection into existing natural gas network
  - >60 Retail stations
  - >10 Production units

**Walnut - AL first biomethane plant in the US**
Thank you