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2018 GlassTrend Seminar
Combustion technologies and models helping carbon neutrality

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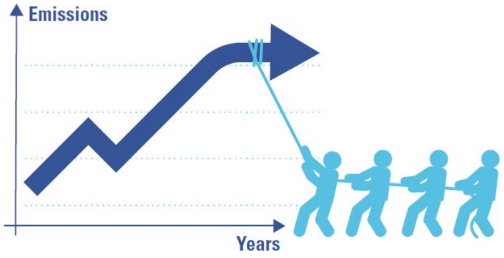
INDUSTRIAL MERCHANT

CO_2 : Where is the imbalance coming from?

Fossil fuels account for 82%



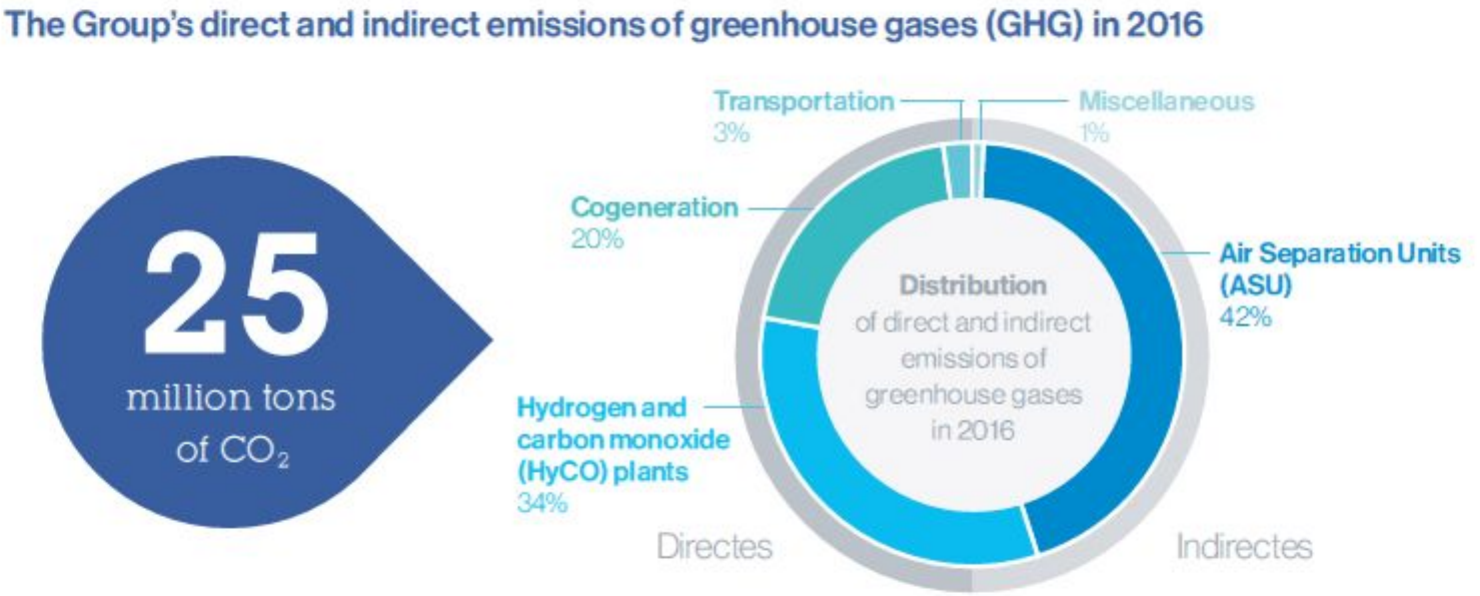
Keeping the rise in temperature **below 2°C**

- less **than 1,000 gigatons** CO2 “to be released”
- about **25 years**

Carbon budget

1
Air liquide emissions

The AIR LIQUIDE's direct and indirect emissions of greenhouse gases (GHG) in 2016



Producing and transforming while releasing less CO_2

PRODUCING OUR SMALL MOLECULES MORE EFFICIENTLY OXYGEN, WITH LESS ELECTRICITY

Constant innovation within the technologies reduces the use of electricity by our ASUs by about 12% in the last fifteen years.

HYDROGEN, WITH LESS NATURAL GAS (SMR-X)

The significant improvement in SMR technologies took shape in 2012 in the SMR-X in Antwerp, Belgium, enabling the production of hydrogen without the simultaneous production of steam. It reduces the amount of natural gas required by 5% compared with the technology without the economic valorisation of steam. This represents 20,000 tons of CO_2 avoided per year.

2

Decarbonize the energy system

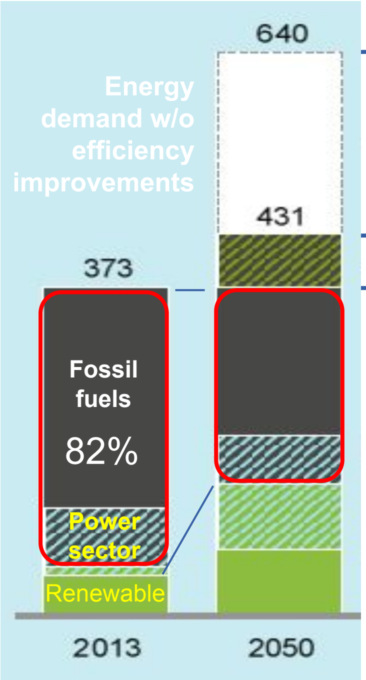
CO_2 : Where is the imbalance coming from?

Today, **natural gas, coal, and oil** provide energy for industrial processes and thus generate about **20% of global emissions**.

For CO2 neutral glass production by 2030 ambition, some Energy transition scenarios are to be investigated

- Full electrical and hybrid furnace designs (oxy-firing)
- Co-Firing of Biogas or Hydrogen
- Carbon capture, valorization and heat recovery

Four major levers to decarbonize the energy system



Final energy consumption EJ

AL solutions contribution for glass industry

1 - Increasing energy efficiency
Limits the rise of energy consumption

Oxy-combustion + recovery
Heat Oxy Combustion…
From 20 to 50 % fuel saving

2 - Fossil fuels - CCS/U

CO2 capture technologies
Absorption, Adsorption, cryogenic, membranes.

3 - Switch to zero emission energy carriers, e.g. electricity or Hydrogen

Hydrogen energy
SMR, Methanol cracker, electrolyse

4 - Renewables
Replace fossil fuels

Biomass and waste
Digestor, pyrolyse….

3
Increasing energy efficiency

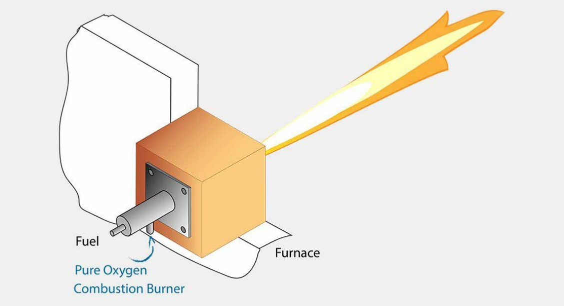
Driving performance to the next level

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 of 0–15%.

It can be said that from oxy-fuel melting : the reduced emissions will significantly outweigh the emissions associated with the oxygen production.



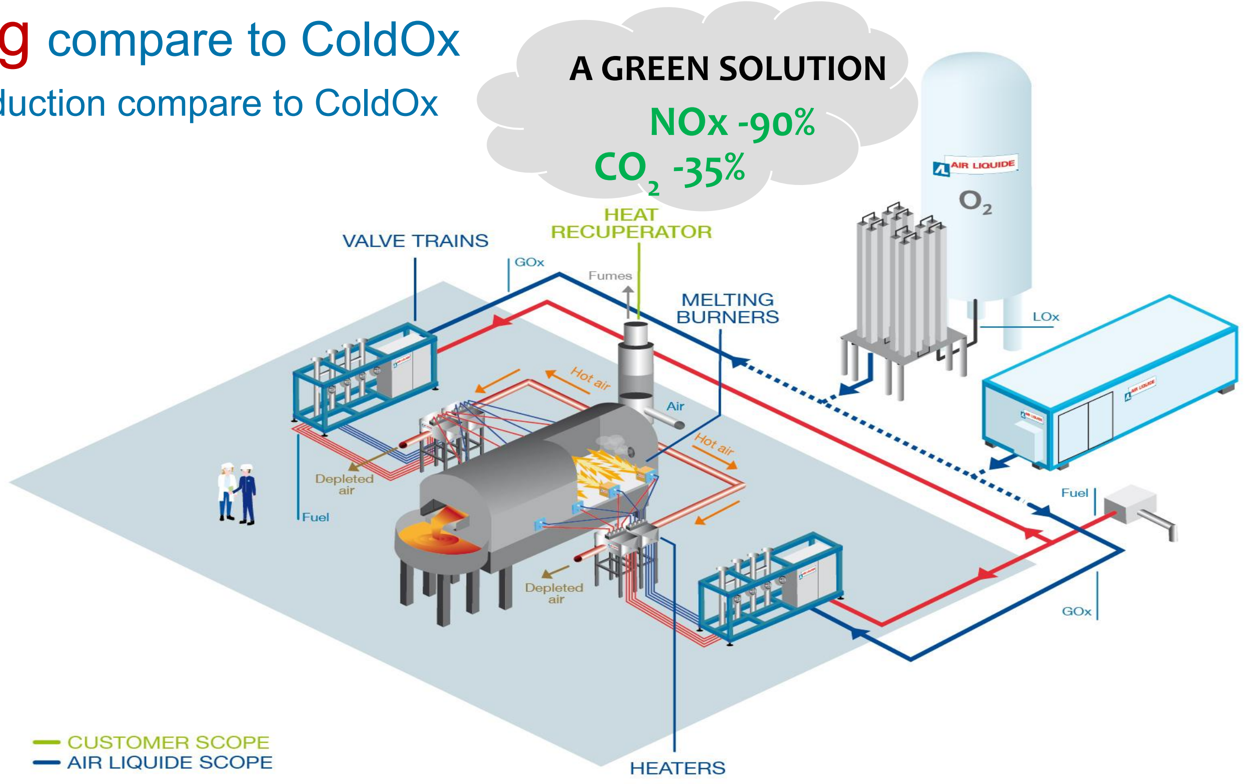
The Next Generation Oxy Combustion Technology

Fuel **more 10% saving** compare to ColdOx

- CO_2 (from combustion) 10% reduction compare to ColdOx
- NOx reduction

A COMPETITIVE SOLUTION …

Mixing advantage of oxy-fuel and heat recovery



3 references with proven results

Float glass

Tableware

Boussois (France) in 2009 &
Retenize (CZ) in 2014 - 600TPD

- Energy savings =
  - 25% vs Air combustion
- CO_2 emissions from combustion=
  - 25% vs Air
- NOx emissions from combustion =
  - 83% vs Air

Trakya Glass (Bulgaria) in 2016 -
200TPD

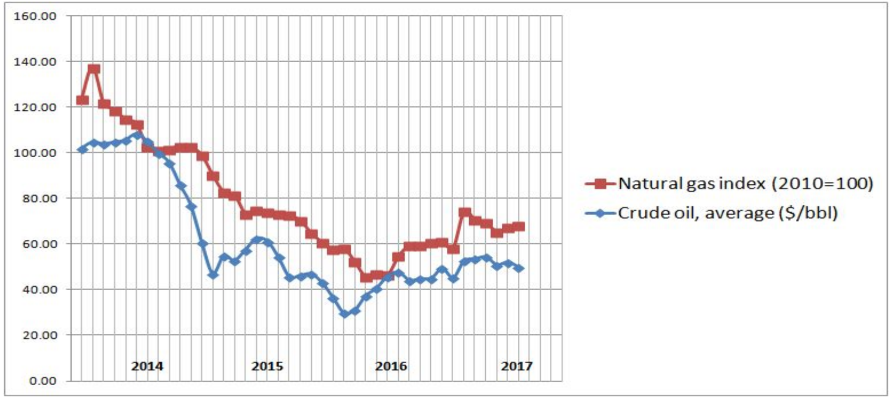
- Energy savings objectives =
  - 20% vs Air combustion
- CO_2 emissions from combustion=
  - 20% vs Air
- NOx emissions from combustion=
  - 90% vs Air

Energy cost variation

Natural gas and Crude oil still low.

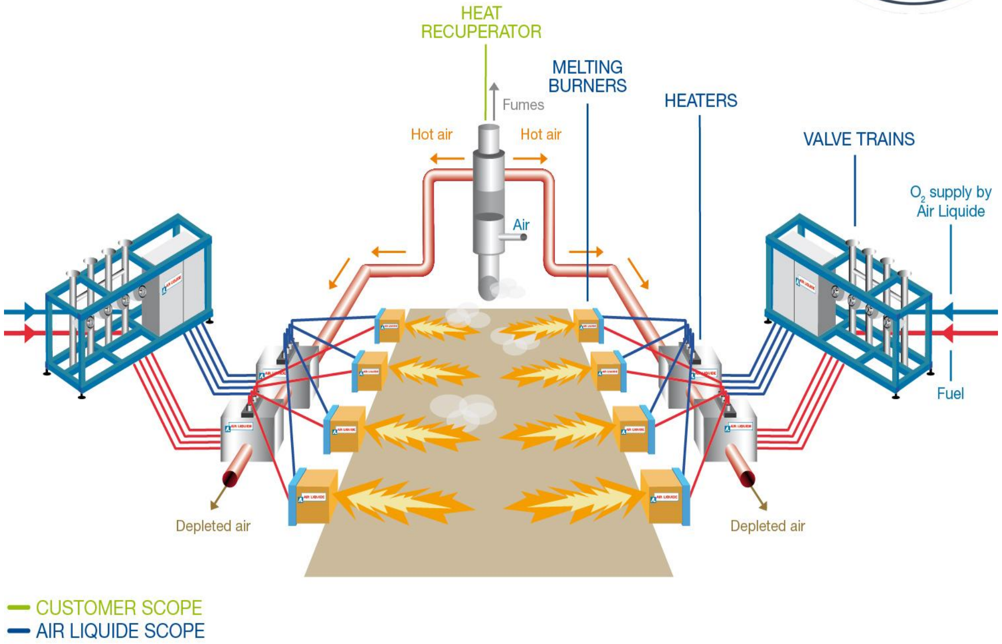
On an average, the energy costs in the glass industry accounts for about 14% of the total glass production costs.

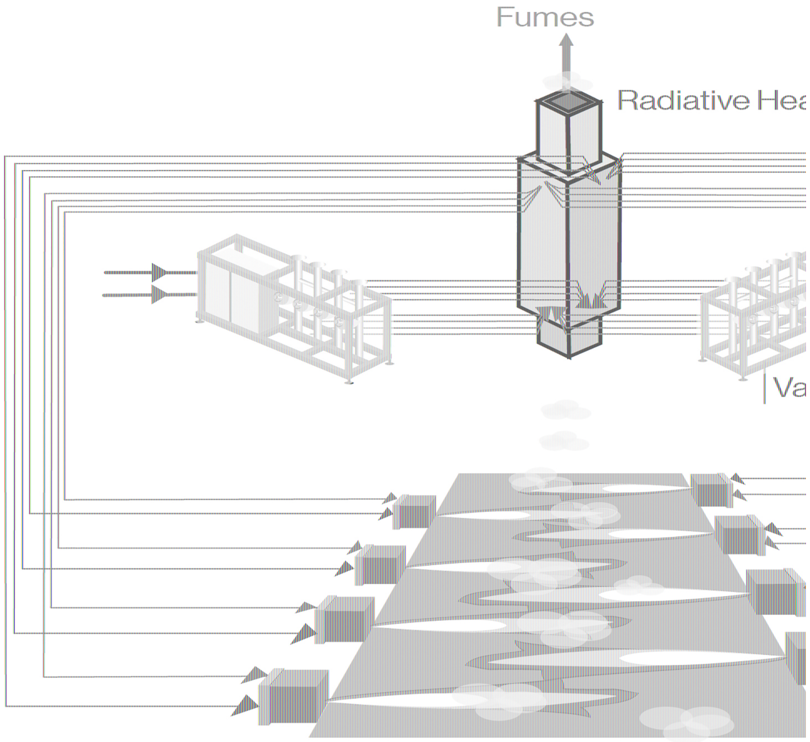
In the context where energy is decreasing, CAPEX of heat recovery system would have to be reduced proportionally.



HeatOx 1G

R- HeatOx 2G

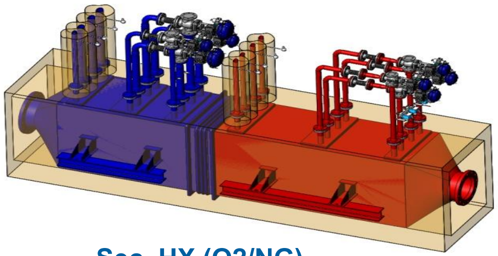




LIFE CleanOx (LIFE16 CCM/BG/000059) - Cleanest oxy-fuel combustion technology with radiation based waste heat recovery for glass melting furnaces: HeatOx 2G industrial prototype

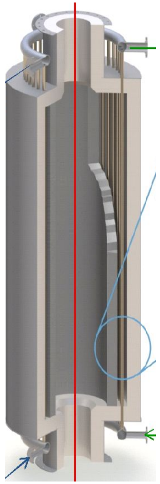
Technology route to a clear efficiency

1G



Sec. HX (O2/NG)
Primary HX (Flue/Air)

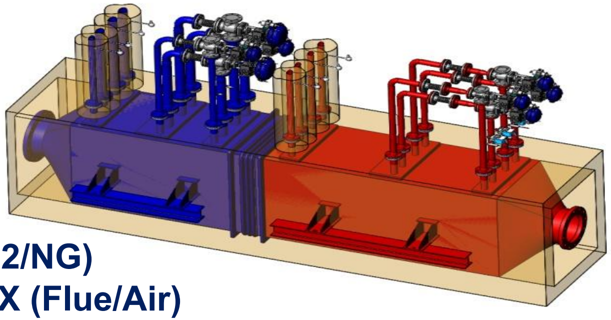
2G



Radiative heat exchanger installed to a flue

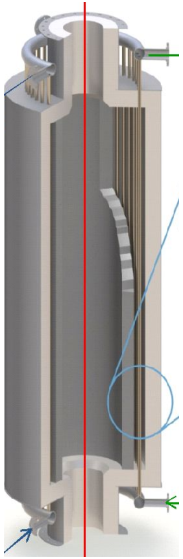
	Target O2 temp	Target NG temp	Technology	NG/O2 saving	Target CAPEX
HeatOx 1G	550C-600C	450C-500C	Air/Flue HX, O2/air HX, NG/air HX	-10%	
HeatOx 2G	800C	450C-500C	Radiative HX	-13%	> -50% compared to 1G CAPEX

Proven today – even better tomorrow



Sec. HX (O2/NG)
Primary HX (Flue/Air)

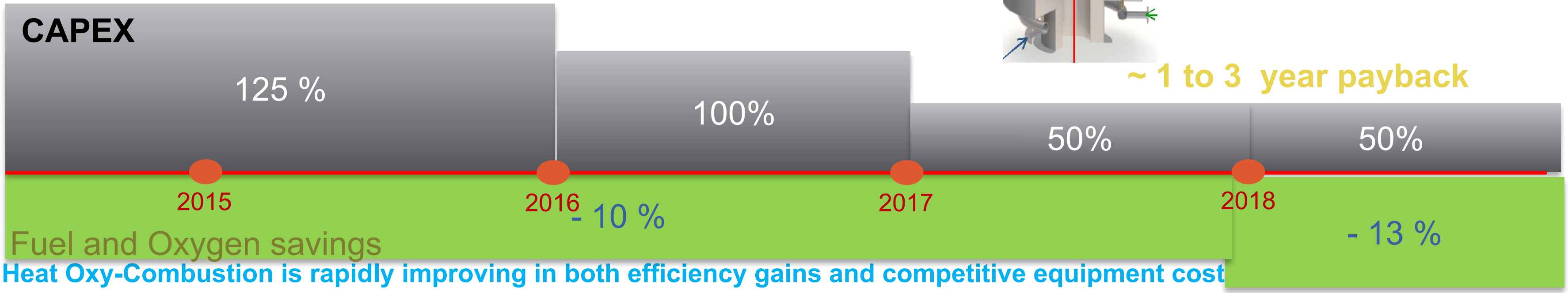
1G



Stand-alone radiative heat exchanger

2G

~ 1 to 3 year payback



Heat Oxy-Combustion is rapidly improving in both efficiency gains and competitive equipment cost

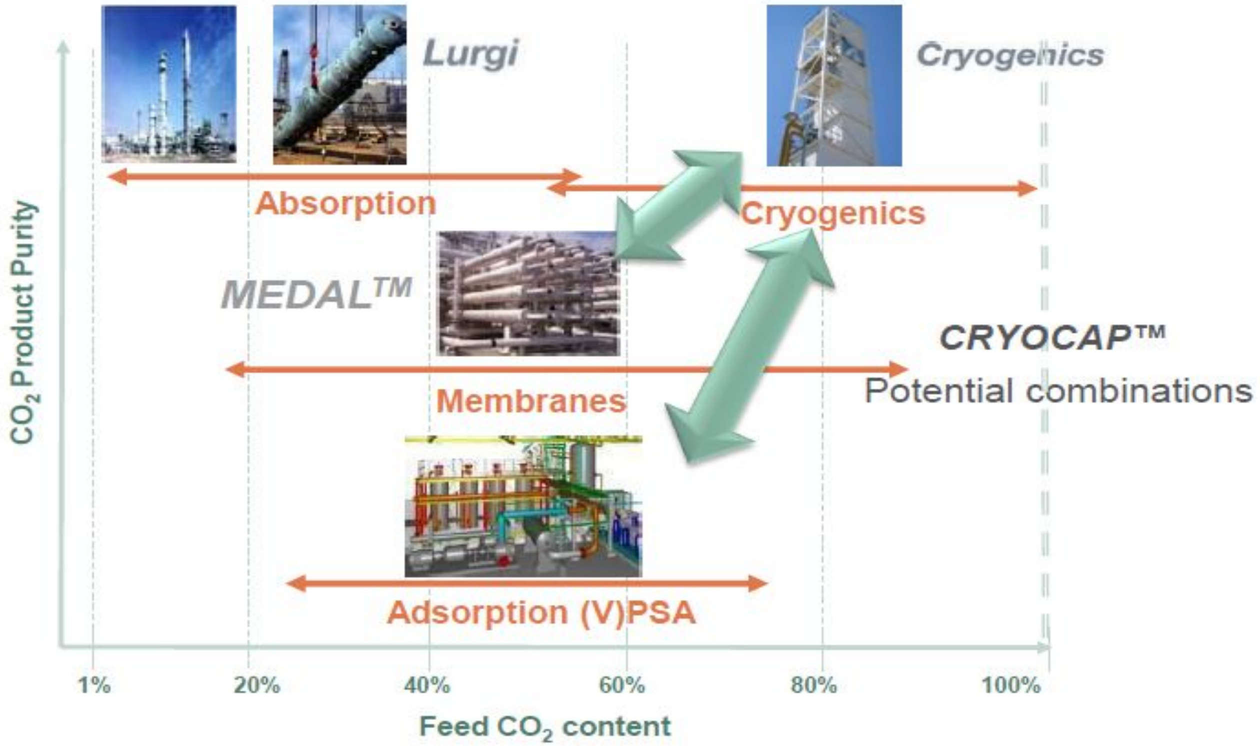
HeatOx 2G: CleanOx

- **LIFE+ CleanOx**: new funded project by European Commission (July 2017)
- **Demonstration** of an innovative **radiative heat exchanger** based HeatOx solution.
- **Process benefit targets:**
  - Reduction of GHG emissions linked to tableware glass production: 30% less CO_2 and 90% less NOx emissions compared to end-fired regenerative air-fuel furnace.
  - Increase of thermal efficiency in tableware glass plants: 13% (Phase I) compared to traditionnel oxy-fuel furnace & 18% (Phase II)/ColdOx
  - Lower 1G CAPEX: up to 75% savings
- **The project** is running **from 01/07/2017 until 30/06/2021 with Şişecam and Paşabahçe.**

4

CO2 Capture Technologies

AL's portfolio of CO2 capture technologies

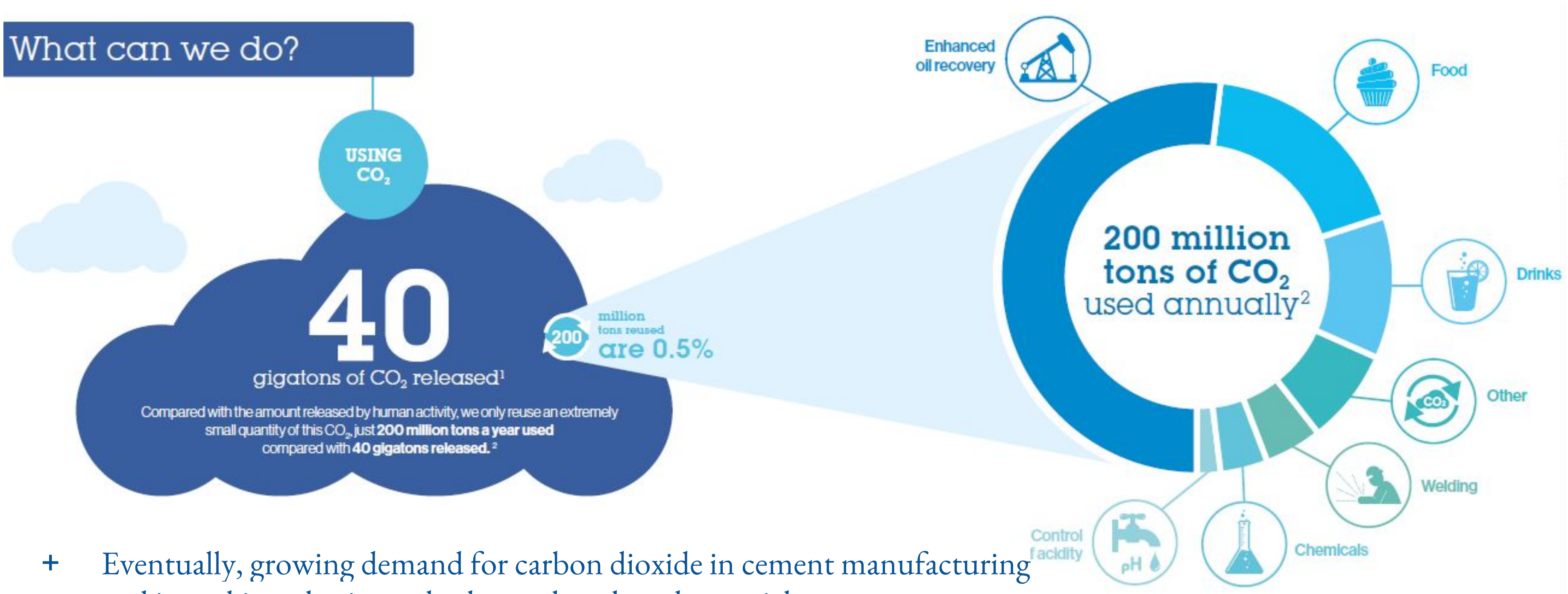


CRYOCAP™: A line of products for CO2 capture

Air Liquide Global E&C Solutions has developed a range of CPU (Cryogenic Purification Units) dedicated to CO2 capture:

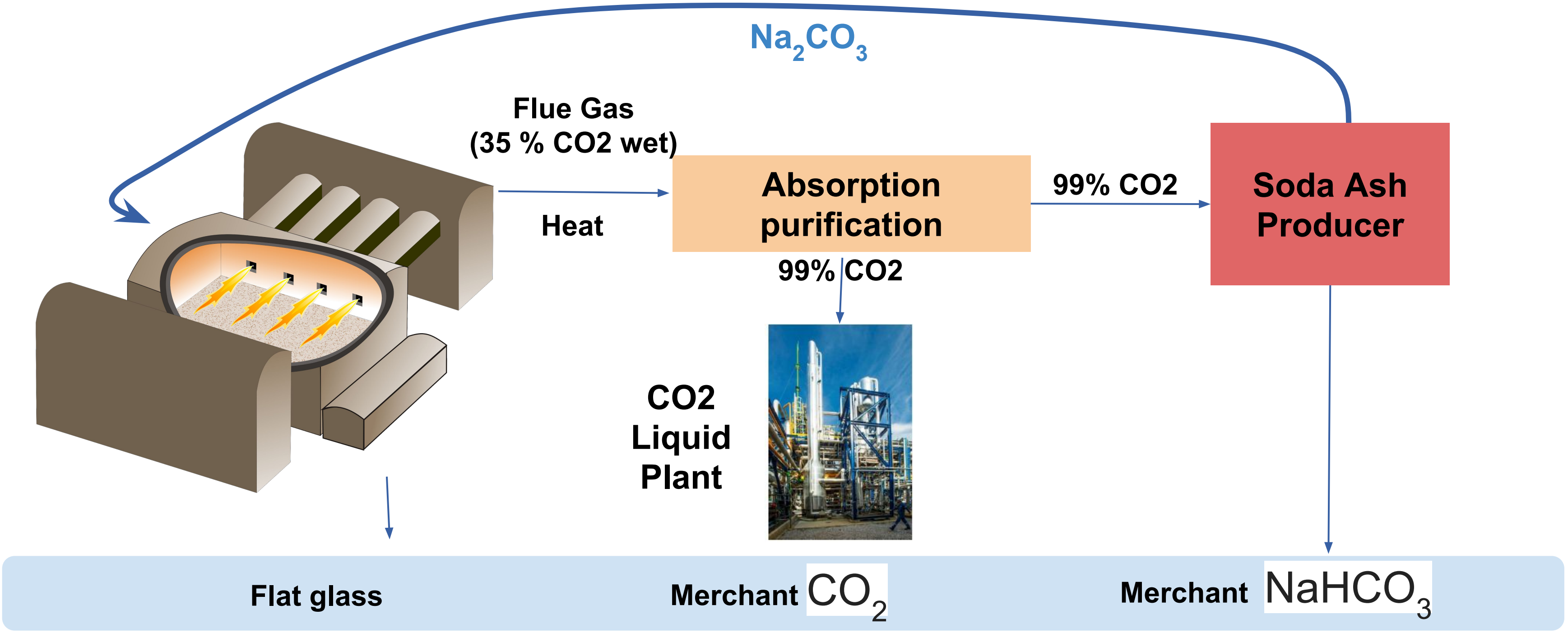
CO2 capture from H2 production plants (SMR / Refineries)	**CRYOCAP™ H2**
CO2 capture from oxy-combustion flue gas	**CRYOCAP™ Oxy**
CO2 capture from blast furnaces	**CRYOCAP™ Steel**
CO2 capture from CO2 rich Natural Gas (> 30%)	**CRYOCAP™ NG**

CO2 reuse?



+ Eventually, growing demand for carbon dioxide in cement manufacturing and in making plastics and other carbon-based materials.

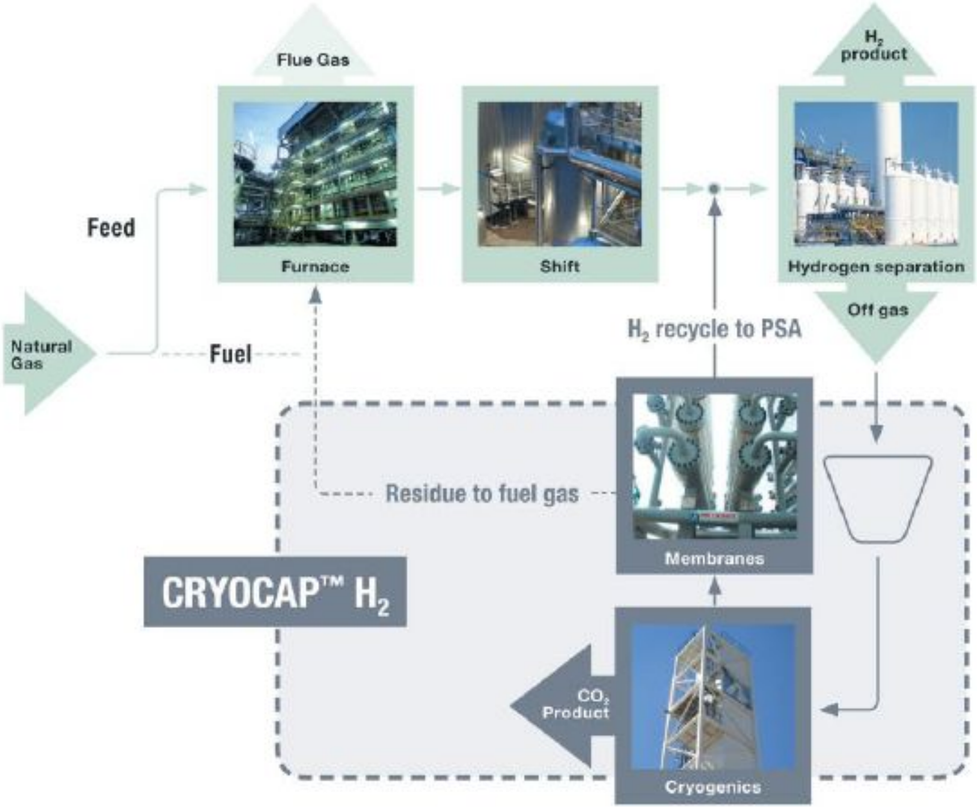
Large Float Furnace - Oxy Combustion Case



CRYOCAP™ H2 Port Jérôme - Key facts

- **First reference at industrial scale at Port Jérôme, Normandie, France**
  - Plant built, owned & operated by Air Liquide group
  - Start up in H1 2015
- **CRYOCAP figures:**
  - Existing SMR : 50 000 Nm3/h H2 production
  - PSA off gas treated: 17 000 m3/h
  - Liquid CO2 production: 300 tons/day
  - Food Grade CO2
- **Successful operation**
  - Performance: CO2 purity and recovery achieved
  - Stable industrial operation
  - H2 production: +2800 Nm3/h, i.e. ≈ +5% (only partial flow treated)
  - Plant efficiency increased by 2%

CRYOCAP™ H2 = the lowest cost of capture for SMR

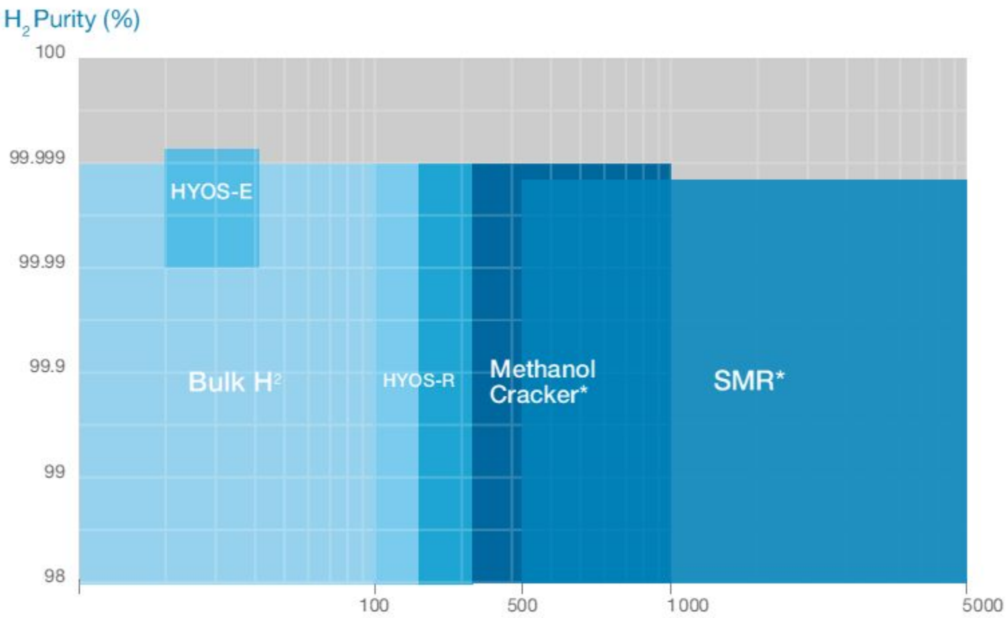


Key features:

- Combination of cryogenics and membranes technologies
- Extra H_2 production: by 10 to 20%
- CO_2 capture rate: 98% CO_2 from syngas
- Cost reduction: -30% to -40% compared to aMDEA

5
Hydrogen energy

Hydrogen mode of supply



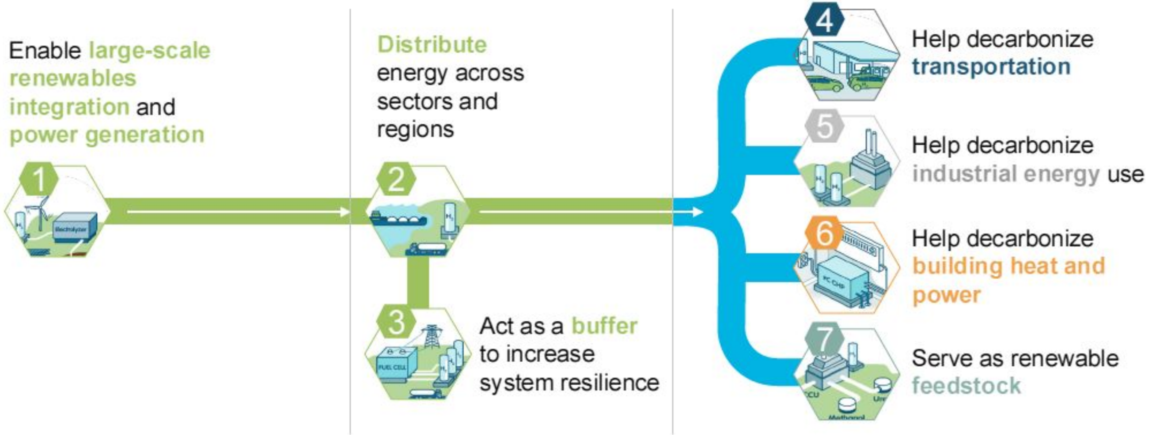
- Hydrogen has been almost entirely (99%) used as feedstock for industrial applications
- The use of hydrogen as an energy carrier is beginning to accelerate

Zero-emission hydrogen

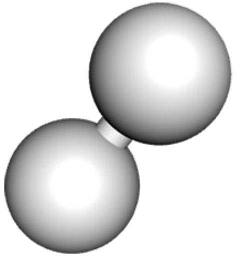
Today, 99% of hydrogen is produced through fossil fuel reforming

Pathways to produce zero-emission hydrogen:

- Steam methane reforming (SMR), using bio-methane , or combined with CCS/U
- Electrolysis using electricity generated by renewables
- Gasification of biomass



Hydrogen empowers the energy transition



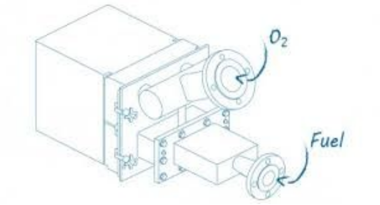
Hydrogen offers a viable solution:

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

High-grade heat - above 400°C - is harder to decarbonize. **Hydrogen burners can complement electric** heating.

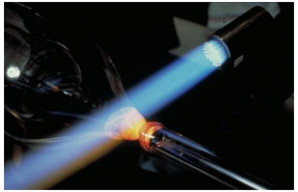
Fuel cells have a higher efficiency than burners but their deployment still requires significant investment.

Burners require only adjustments of existing equipment.



Oxy-hydrogen flame features

The 02/H2 flame: $O2 + 2H2 \rightarrow 2H2O$ Water



- Produces essentially water
- Stoichiometric ratio the best deflagration speed = **10,7m/s**
- High adiabatic temperature = **3080°C**
- produced a reddish-orange flame due to the strong emission band of H2O at 632 nm

The oxy-hydrogen flame radiates the major part of its energy in wavelengths above **2.4 µm.**

- The radiant energy above 2.4 µm is absorbed at the glass surface
- Favors solely a surface heating

Emissivity

Does oxy-hydrogen flames suit for glass melting

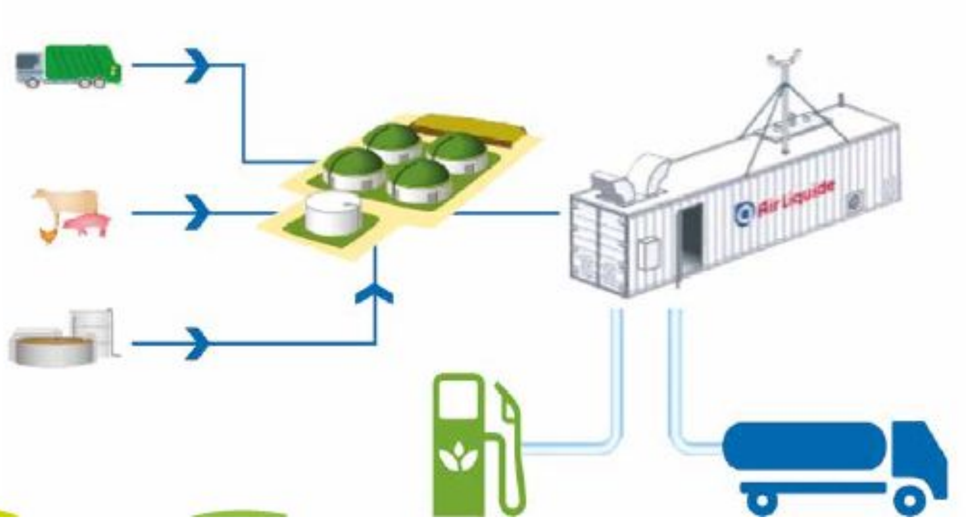
- Polishing with oxy-hydrogen flames creates a limited remelting of the glass surface. The oxy-hydrogen flame is well adapted to this operation.

- For melting, ful Oxy-Hydric flame will :
  - Increase of water content changes Redox of the combustion atmosphere as well as for the glass
  - Heat transfer due to flame emissivity different from fossil fuel combustion
  - Flame shape control and burners design must been adapted

Biomass

Air Liquide has developed technologies and know-how that span the entire biomethane or natural gas value chain:

the purification of biogas into biomethane, liquefaction, packaging, and the injection of biomethane into the natural gas grid for clean transportation.



Air Liquide
creative oxygen

Thank you

25 YEARS
Life
1992 - 2017

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