Air Liquide
creative oxygen

Airgas
an Air Liquide company

Four Major Levers for Contribution of Glass Industry decarbonation

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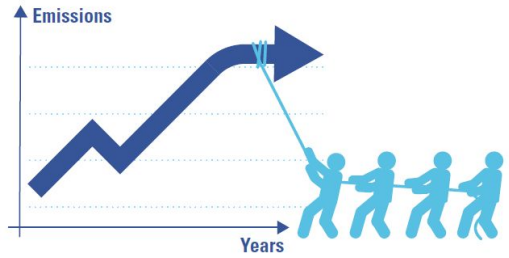
Date: June 2019

Name & Function Luc JARRY •

CO_2 : The energy transition – a necessity and a global challenge

Fossil fuels account for 82%



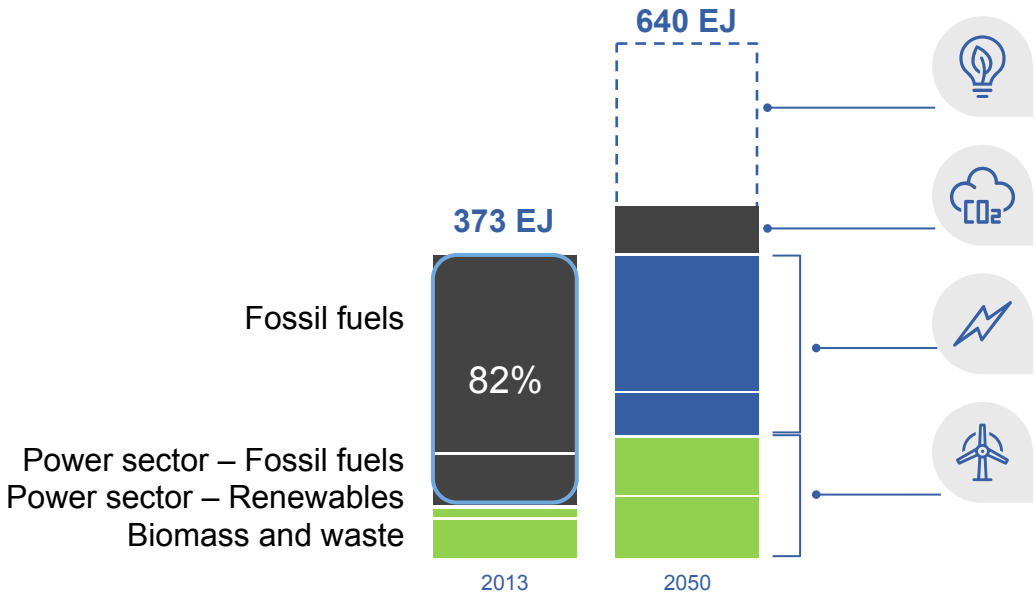
Keeping the rise in temperature **below 2°C**

- less **than 1,000 gigatons** CO_2 "to be released"
- about **25 years**

Carbon budget

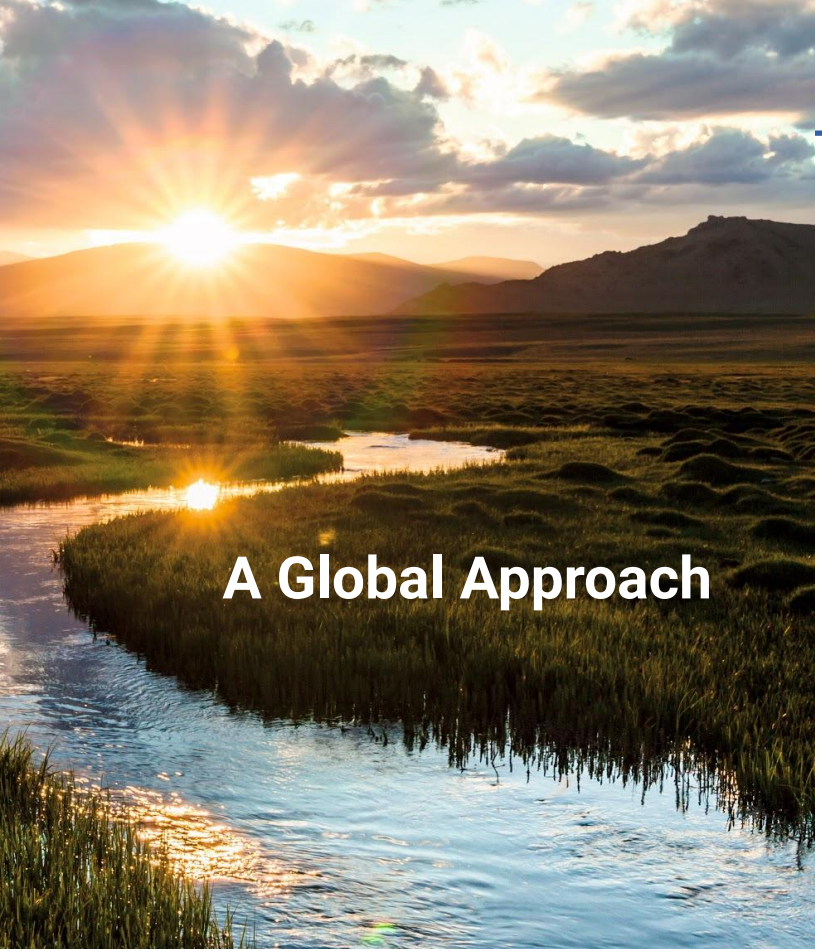
Decarbonize the energy system

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]
3. **Switch to zero emission energy carriers,** e.g., electricity or hydrogen
4. **Renewables** replace fossil fuels

Source: McKinsey & Hydrogen Council 2017



Climate Objectives

A ASSETS

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

C CUSTOMERS

Act for clean industry by developing low-carbon solutions

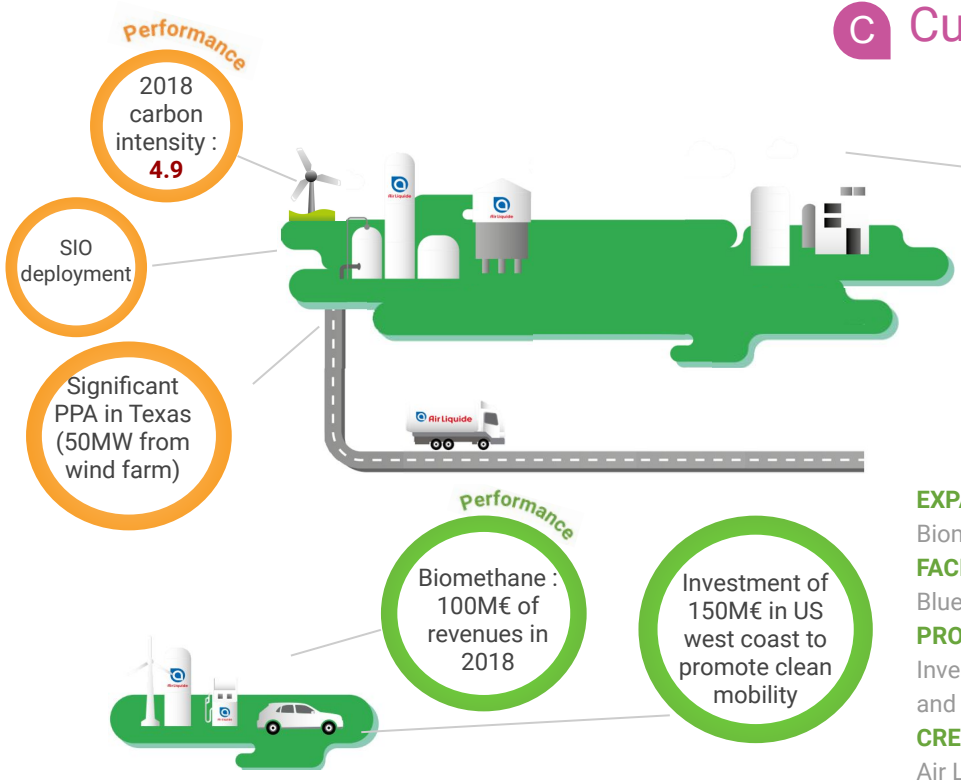
E ECOSYSTEMS

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%



C Customers

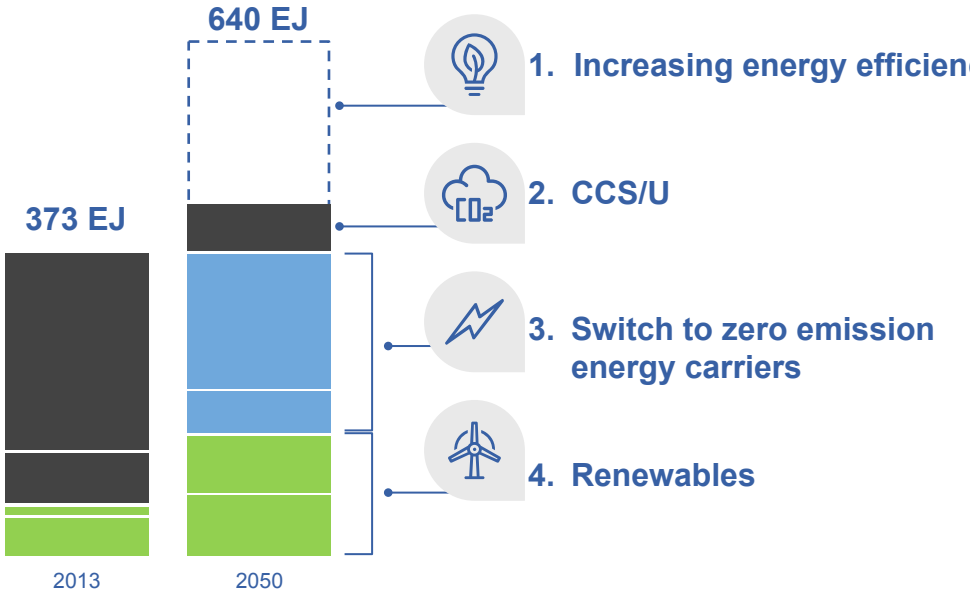
Performance
10,9 Mt avoided emissions

ROLLING OUT
Low-carbon offerings and solutions
CO-DEVELOPING
Innovative procedures with its customers

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

Four major levers are needed to enable the energy transition



solutions / developments for glass industry

Oxy-combustion + Heat recovery
Heat Oxy-Combustion

CO_2 capture technologies Absorption, Adsorption, Cryogenic, Membranes

Hydrogen combustion Oxy-Hydrogen combustion: exploratory study

Biomass and waste Digestor, pyrolysis

Source: McKinsey & Hydrogen Council 2017

2

Increasing energy efficiency

Driving performance to the next level

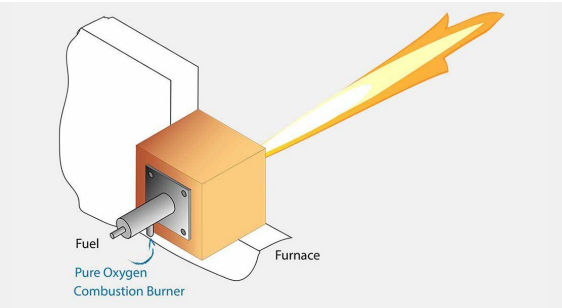
Oxy-Firing

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)

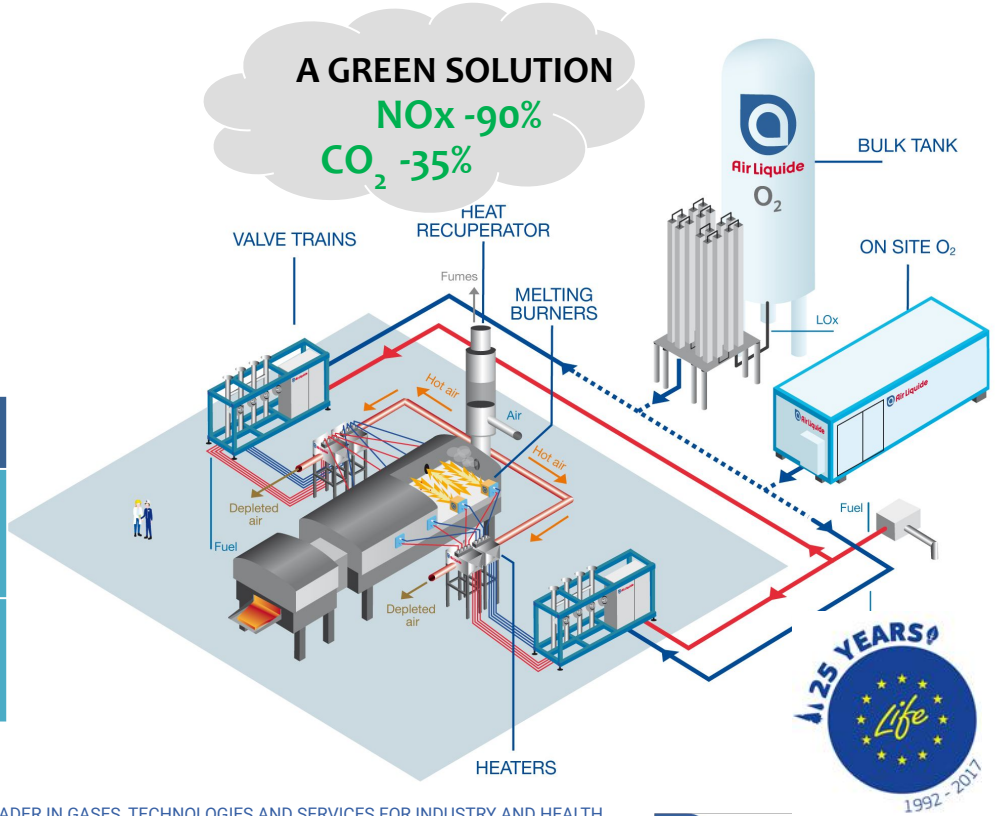


HeatOx : Proven today – even better tomorrow

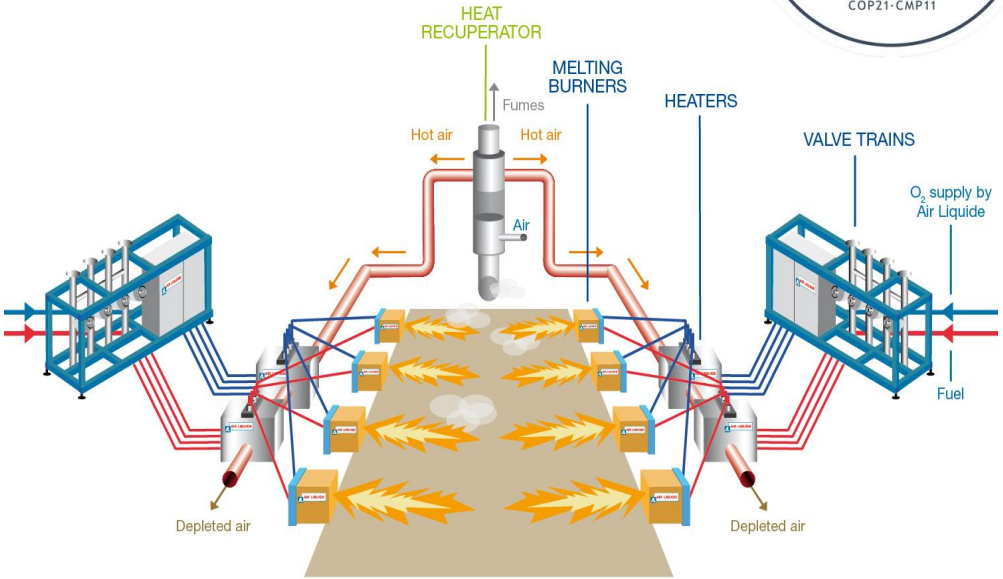
A COMPETITIVE SOLUTION …

Mixing advantage of oxy-fuel and heat recovery

	Technology	Energy Savings	Target CAPEX
HeatOx 1G	Air / Flue HX, O2 / air HX, NG / air HX	-10%	
HeatOx 2G	Radiative HX	-13%	-50% vs 1G

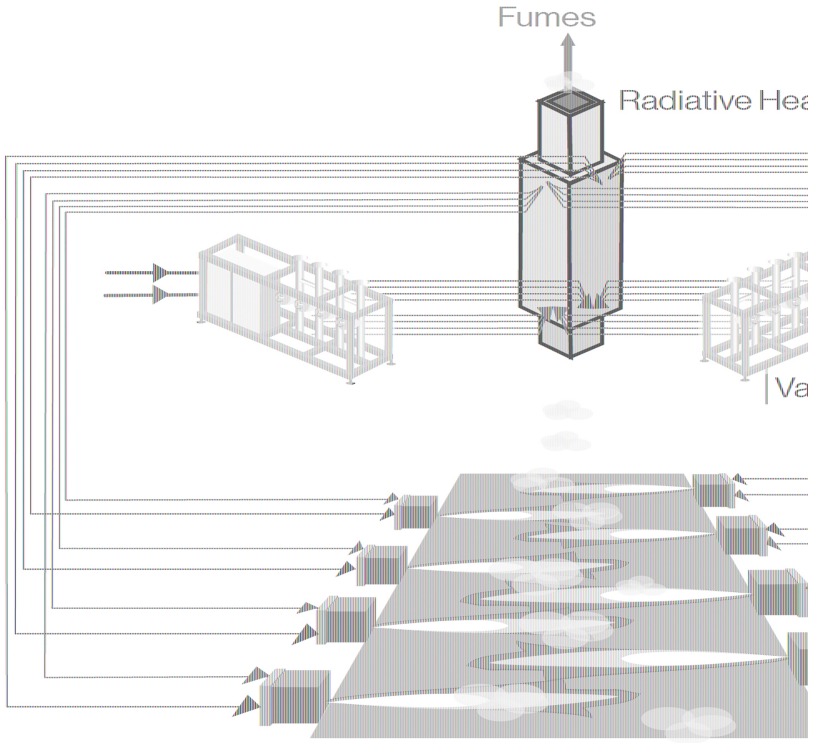


HeatOx 1G

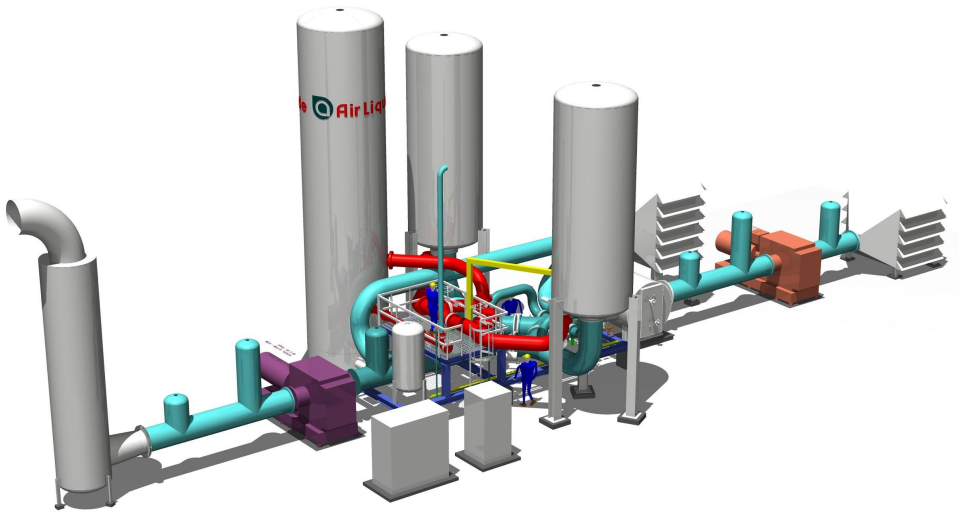


CUSTOMER SCOPE
AIR LIQUIDE SCOPE

R- HeatOx 2G



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

Cryogenics

Adsorption

Absorption

Membranes

CRYOCAP™ OXY
Glass plant: Oxy-Combustion

CRYOCAP™ H_2
Refining: Hydrogen Production, SMR, ATR, POx

CO_2 - Small scale applications & industries

CO_2: ~40,000 tpd

➔ CO_2 is used under different forms: gaseous, liquid, solid or super critical

Agri-production

Optimize plants growth in greenhouse

Beverages

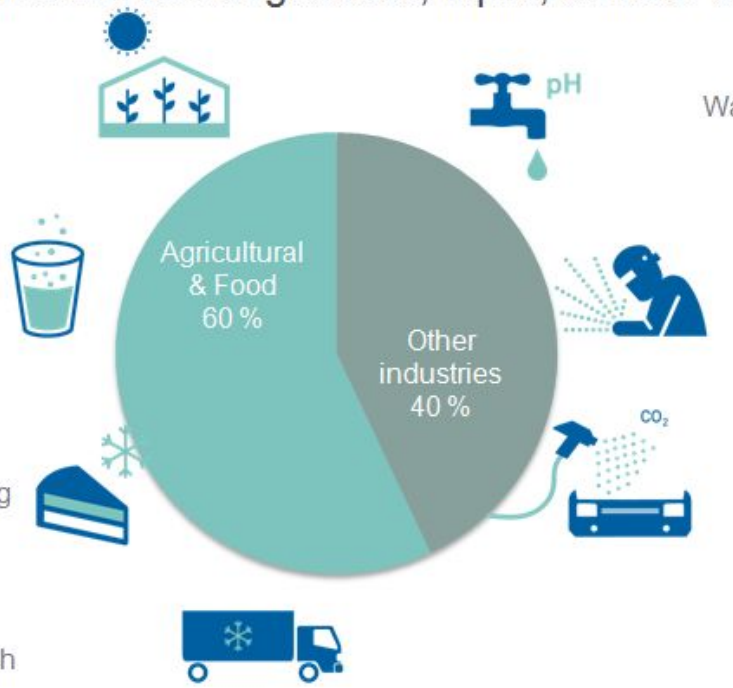
Carbonation and beverages dispensing

Food industries

Food preservation, freezing, chilling, packaging

Cold transportation

Maintain cold chain for fresh and frozen products



pH control

Waste and water treatment

Welding

Arc stabilisation in MAG welding

Industrial cleaning

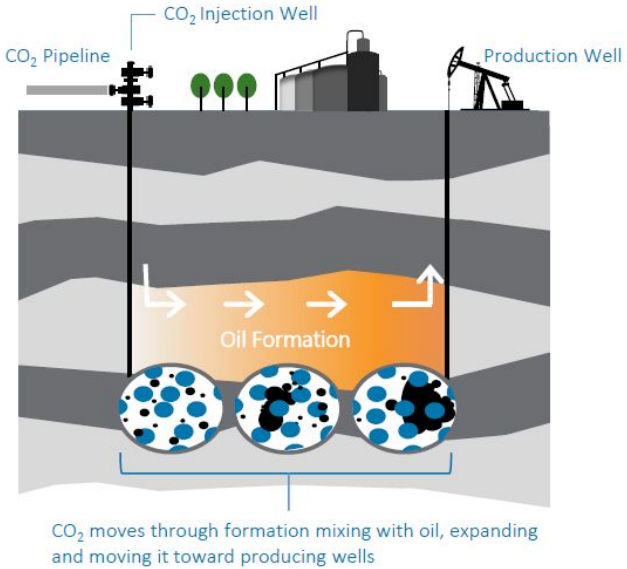
Solvent free cleaning of metallic and plastic surfaces

Chemistry

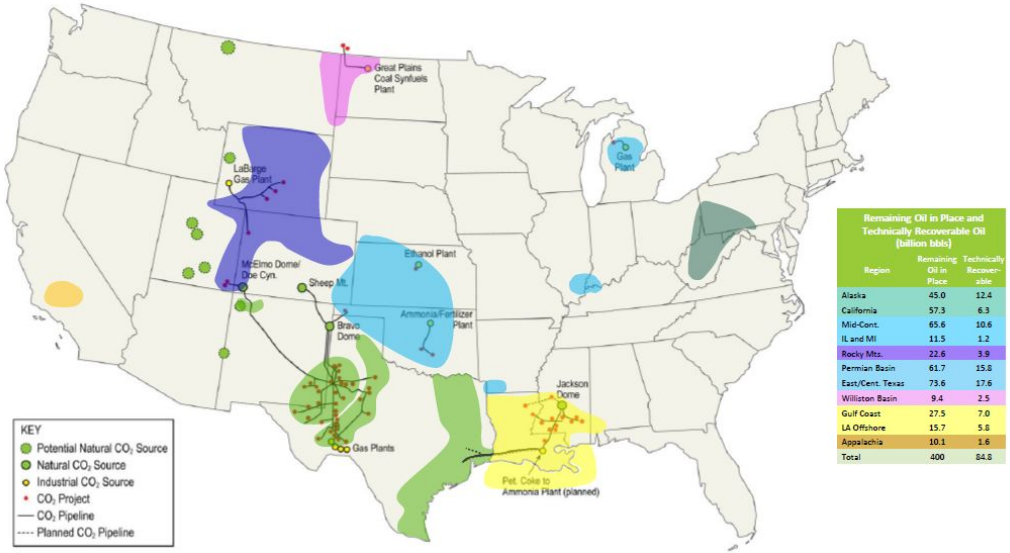
Reactive agent

Enhanced Oil Recovery will remain the largest profitable CO_2 output in the US

CO_2: ~300,000 tpd



CO_2 EOR doubles the quantity of oil which can be recovered from a well



Remaining Oil in Place and Technically Recoverable Oil (billion bbls)

Region	Remaining Oil in Place	Technically Recoverable
Alaska	45.0	12.4
California	57.3	6.3
Mid-Cont.	65.6	10.6
IL and MI	11.5	1.2
Rocky Mts.	22.6	3.9
Permian Basin	61.7	15.8
East/Cent. Texas	73.6	17.6
Williston Basin	9.4	2.5
Gulf Coast	27.5	7.0
LA Offshore	15.7	5.8
Appalachia	10.1	1.6
Total	400	84.8

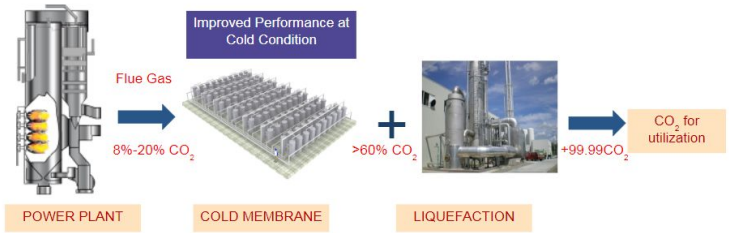
Over 4,500 miles of CO_2 pipelines and more than 80 billions barrels of technically recoverable oil

Source: National Energy Technology Laboratory

Development of CO_2 capture from flue gas and validation of new CCUS technologies

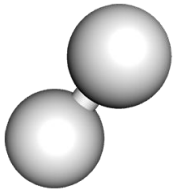
- **Industrial CO_2 utilization**
  - Partnering with Solidia Technologies

- **Direct capture from Air**
  - Partnering with start-ups



4 - Switch to zero emission energy carriers

Hydrogen can provide decarbonized high-heat for industrial processes

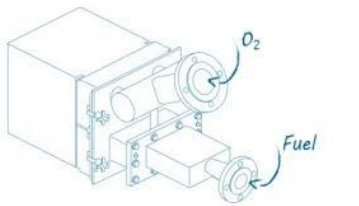


Hydrogen offers a viable solution:

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



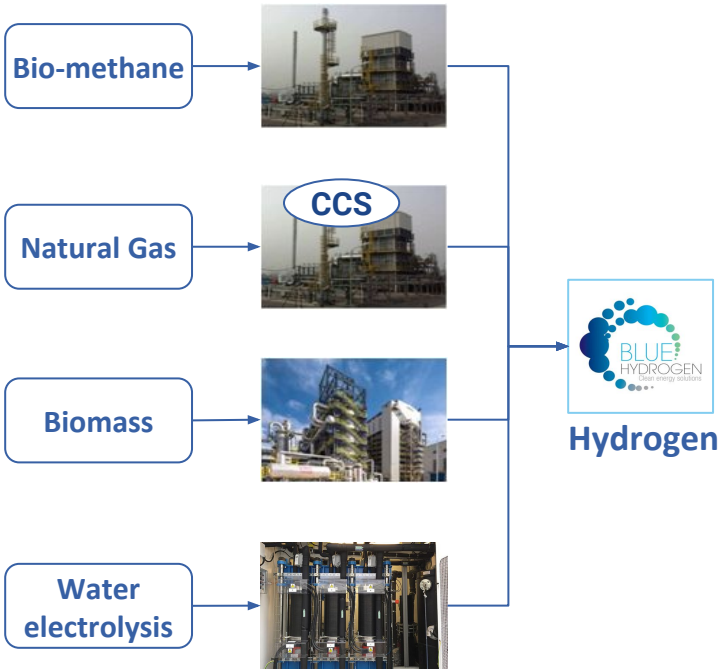
Oxy-hydrogen flame features

The 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

Emissivity

In a 2-degree-world, hydrogen could contribute ~18% of demand



18%
of final energy demand

Deployment of Bio-methane

Walnut - AL first biomethane plant in the US

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

x6

Extended usages

- **End-users**: Industry and Transport
- **Injection into existing natural gas network**

> 60 Retail stations

> 10 Production units

Thank you

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INDUSTRIAL MERCHANT

Doc Glass problems

Title For a clear efficiency

NOLOGIES AND SERVICES FOR INDUSTRY AND HEALTH

25 YEARS Life 1992 - 2017

Air Liquide creative oxygen