



Air Liquide

Illustrations de quelques défis technologiques de la chaîne CCUS

(Carbon Capture, Utilisation and Storage)

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Air Liquide en bref



Notre territoire scientifique : Les petites molécules essentielles

Oxygène, azote et hydrogène sont des petites molécules essentielles.
Elles incarnent le territoire scientifique d'Air Liquide et sont au cœur du métier du Groupe.

Séparer les **composants de l'air**
pour utiliser leurs propriétés



OXIGÈNE



AZOTE

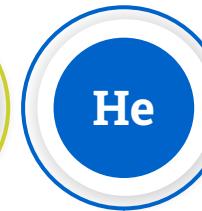


ARGON
ET GAZ RARES

Maîtriser des molécules à partir
des **ressources naturelles** de la planète



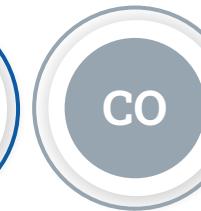
HYDROGÈNE



HÉLIUM

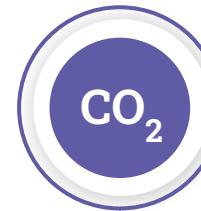


SILANE



MONOXYDE DE
CARBONE

Gérer des
molécules clés



DIOXYDE DE
CARBONE

Innovation & Technologie chez Air Liquide

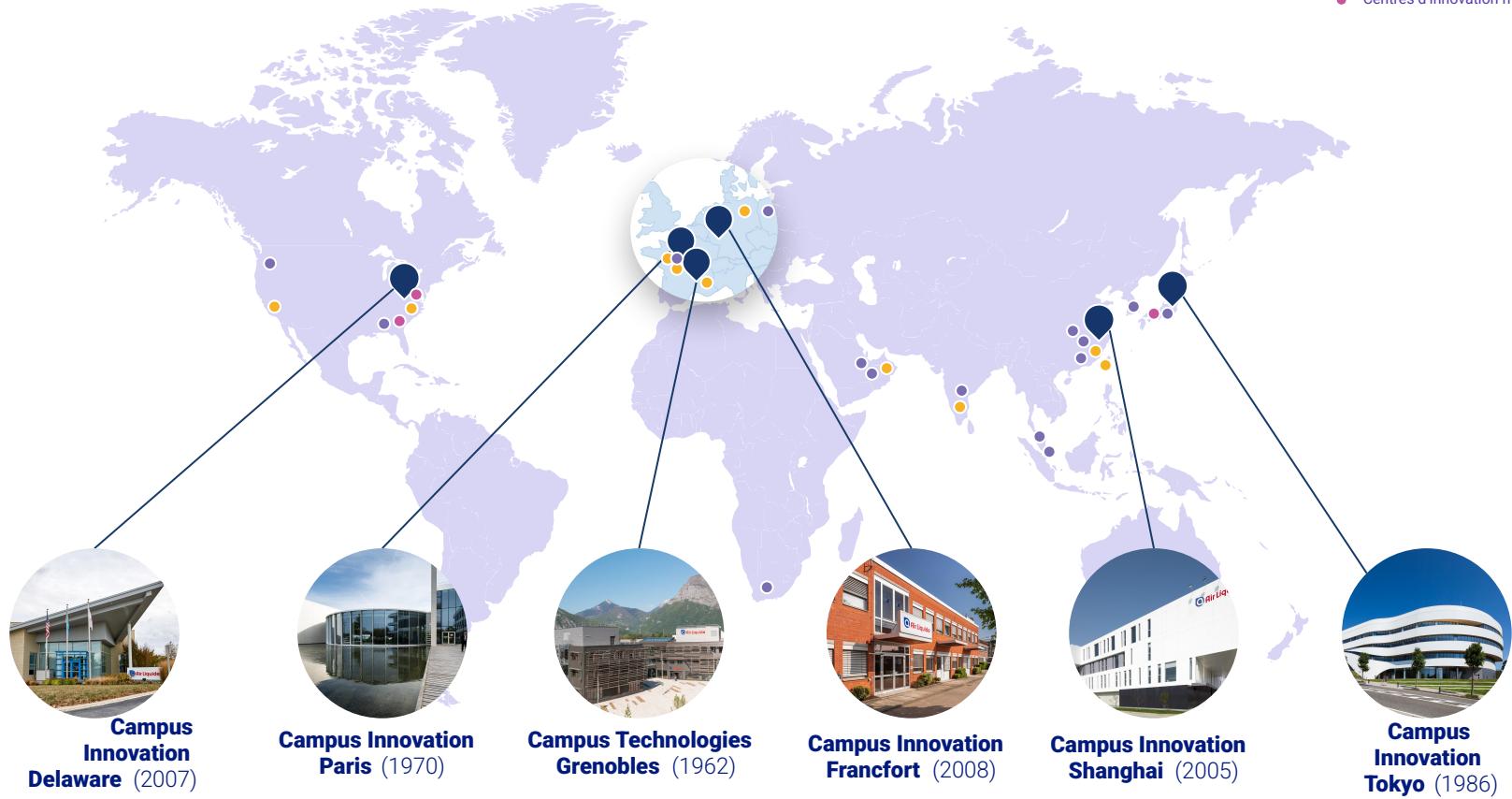
chiffres clés



Accélérer l'innovation

L'adoption d'une approche en écosystème

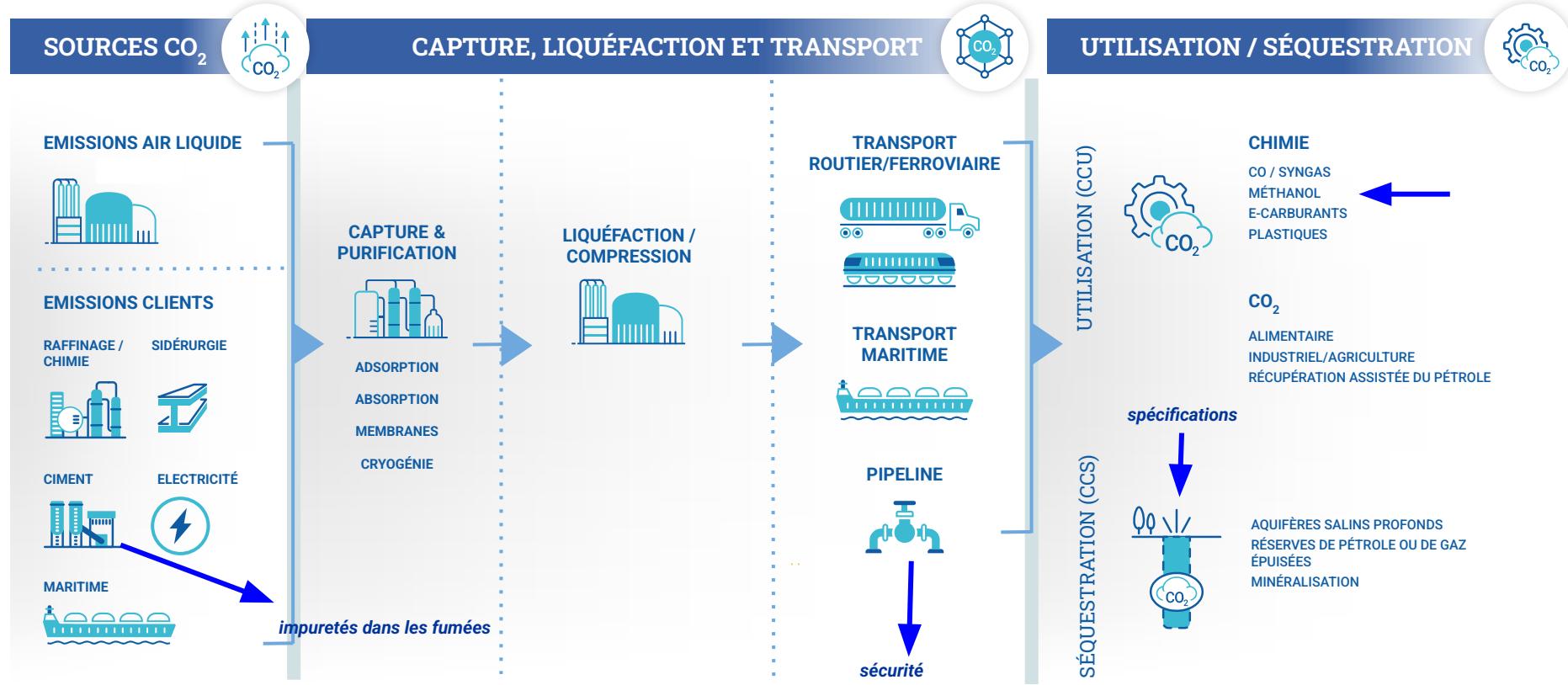
- Centres de fabrication
- Centres d'innovation matériaux avancés



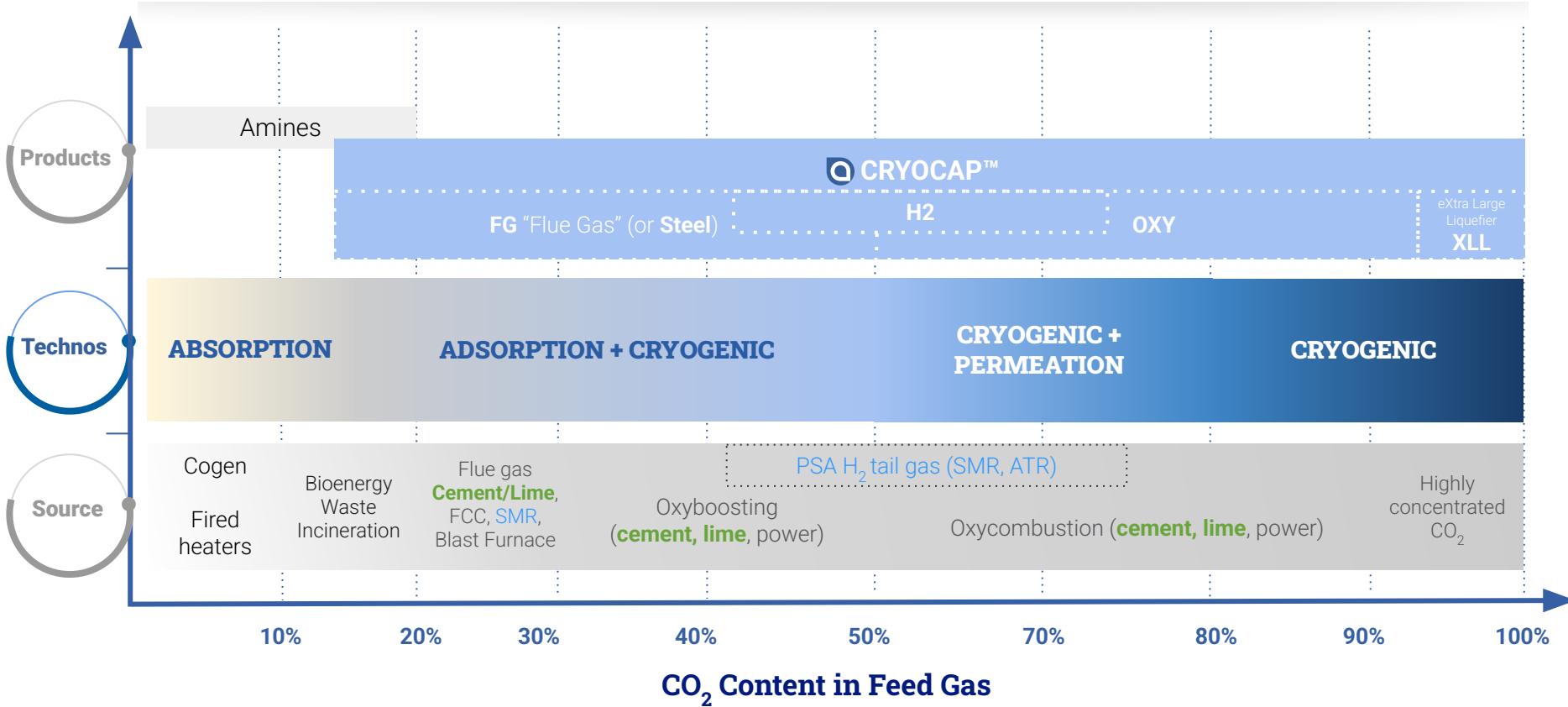
Technologies & défis du captage du CO2



Chaîne de valeur du CO₂, CCU et CCS



Air Liquide technology mapping for CO₂ capture on low pressure streams

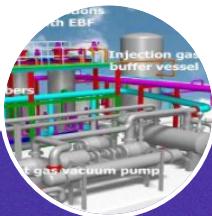


Du laboratoire à l'usine: innover aujourd'hui pour relever les défis de demain

Projets financés par le FIE et le CEF

CO₂

Capter le carbone des industries les plus difficiles à décarboner



2006

Premières études conceptuelles de Cryocap™ et essais technologiques individuels.

2008-12

Trois essais pilotes complets (~70, 75 et 200 tonnes de CO₂ par jour).

2015

Première usine de capture de carbone au monde pour produire de l'hydrogène bas carbone à Port-Jérôme, France.

2021

"Kairos@C", la plus grande chaîne de valeur CCS transfrontalière du monde, développée avec BASF.

2024

Près de Rotterdam, dans le cadre du projet Porthos, le plus grand programme de réduction des émissions de CO₂ des Pays-Bas, Air Liquide décarbonera son propre site de production d'hydrogène

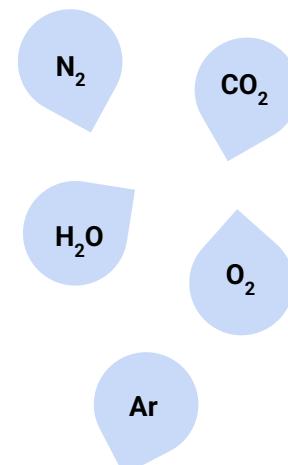
Futurs projets pour décarboner les industries de la chaux et du ciment en France et en Europe

Impuretés dans les fumées

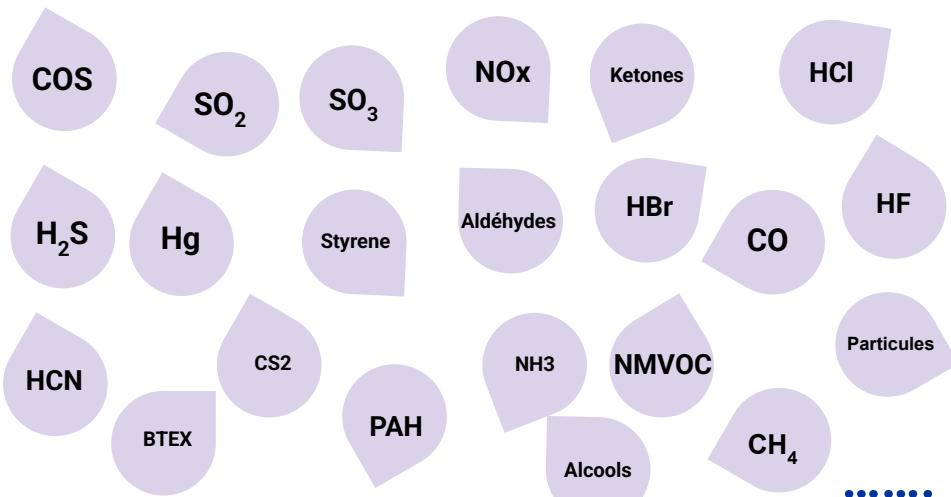
Principaux défis

- Compatibilité matériaux
- CO₂ specifications
- Solidification pour les procédés cryogéniques
- Dégradation de catalyseurs en CCU
-

Composants principaux



Impuretés



CO₂ quality requirements



CCS-ARAMIS Project

Specification for CO₂ supplied to Aramis via:

Class	Component	Constraint	unit	Ships	Pipeline infrastructure
	CO ₂	larger than	mol%	balance	95
Inerts	H ₂ O	less than	ppmmol	30	70 ⁽¹⁾
	N ₂	less than	mol%	-	≤ 4
	O ₂	less than	ppmmol	10	40
	H ₂	less than	ppmmol	500	7500
	Ar	less than	mol%	-	0.4
	CH ₄	less than	mol%	-	1
	CO	less than	ppmmol	1200	750
sulphur	O ₂ +N ₂ +H ₂ +Ar+CH ₄ +CO	sum less than	ppmmol	2000	40000
	NO _x	sum less than	ppmmol	1.5	2.5 ⁽⁴⁾
	SO _x	sum less than	ppmmol	10	-
	H ₂ S	less than	ppmmol	5	5
	CarbonylSulphide	less than	ppmmol	-	-(¹)
	DimethylSulphide	less than	ppmmol	-	-(¹)
	H ₂ S + COS + SO _x + DMS	sum less than	ppmmol	-	20
Volatile organic components	Amine	less than	ppmmol	10	1
	Formaldehyde	less than	ppmmol	20	-
	Acetaldehyde	less than	ppmmol	20	-(¹)
	Aldehydes	sum less than	ppmmol	-	10
	carboxylic acids & amides	sum less than	ppmmol	-	1
	phosphorus-containing compounds	sum less than	ppmmol	-	1
	NH ₃	less than	ppmmol	10	3
	Ethylene (C ₂ H ₄)	sum less than	ppmmol	-	-(¹)
	H-Cyanide (HCN)	less than	ppmmol	-	2
	Total volatile organic compounds (excl. MeOH, EtOH, aldehydes)	sum less than	ppmmol	10	10
	Methanol	less than	ppmmol	40	620
	Ethanol	less than	ppmmol	20	20
	glycols (TEG)	sum less than	-	-	Follow dew-point specification
Metals	C ₂ x (aliphatic hydrocarbons)	sum less than	ppmmol	-	1200
	Aromatic Hydrocarbons	sum less than	ppmmol	-	0.1
	Hg	less than	ppbmol	30	-
Dew-point	Cadmium + Thalium	sum less than	ppbmol	30	-
	Dew point (any liquid phase)	sum less than	°C (@ 20 bar)	-	-10 ⁽²⁾
Solids	Full removal cut-off diameter	Less than	micron	1 ⁽³⁾	1 ⁽³⁾

<https://www.aramis-ccs.com/file/13032025-ARM-CPT-BB8-PRO-MEM-0033-rev.6.2-public-version-NEW.pdf>



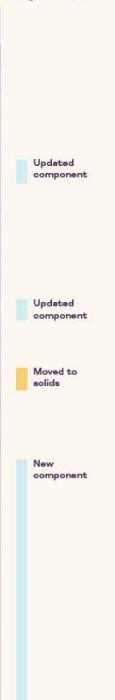
CO₂ specifications

Component	Mole Base
CO ₂	≥ 95%
H ₂ O	≤ 70 ppm
Sum [H ₂ +N ₂ +Ar+CH ₄ +CO+O ₂]	
H ₂	≤ 0.75%
N ₂	≤ 2.4%
Ar	≤ 0.4%
CH ₄	≤ 1%
CO	≤ 750 ppm
O ₂	≤ 40 ppm
Total sulfur-contained compounds (COS, DMS, H ₂ S, SO _x , Mercaptan)	≤ 20 ppm Of which H ₂ S ≤ 5 ppm
Total NO _x	≤ 5 ppm
Total aliphatic hydrocarbons (C ₂ to C ₁₀)	≤ 1200 ppm
Total aromatic hydrocarbons (C ₆ to C ₁₀ , incl. BTEX) ⁽¹⁾	≤ 0.1 ppm
Total volatile organic compounds ⁽¹⁾ (excl. methane, total aliphatic HC (C ₂ to C ₁₀), methanol, ethanol, and aldehydes)	≤ 10 ppm
Total aldehyde compounds	≤ 10 ppm
Ethanol	≤ 20 ppm
Methanol	≤ 620 ppm
Hydrogen cyanide (HCN)	≤ 2 ppm
Total amine compounds	≤ 1 ppm
Total glycol compounds	Follow dew point specification
Ammonia (NH ₃)	≤ 3 ppm
Total carboxylic acid and amide compounds	≤ 1 ppm
Total phosphorus-contained compounds	≤ 1 ppm
Toxic compounds ⁽²⁾	≤ 1 ppm
Dew point limit value measurement (for all liquids, i.e. for complete CO ₂ composition)	< -10 °C (at 20 bara)

Note I: Specification values are molecular based
Note II: VOC definition according to Dutch policy
Note III: Toxic compounds: although CO₂ and other gases like i.e. H₂ and N₂ can form a risk of asphyxiation, Porthos would like to know other components within the stream which impose a risk on personal safety to be taken into account in Porthos HSE policy

<https://www.porthosco2.nl/wp-content/uploads/2021/09/CO2-specifications.pdf>

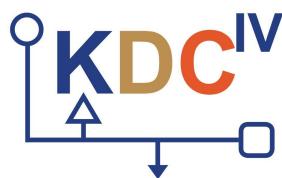
Component	Unit	Limit for CO ₂ Carge within Reference Condition ⁽¹⁾
Carbon Dioxide (CO ₂)	mol-%	Balance (Minimum: 99.81%)
Water (H ₂ O)	ppm-mol	≤ 30
Oxygen (O ₂)	ppm-mol	≤ 10
Sulphur Oxides (SO _x)	ppm-mol	≤ 10
Nitrogen Oxides (NO _x)	ppm-mol	≤ 9
Hydrogen Sulfide (H ₂ S)	ppm-mol	≤ 9
Amine (NH ₃)	ppm-mol	≤ 10
Formaldehyde (CH ₂ O)	ppm-mol	≤ 20
Acetaldehyde (CH ₃ CHO)	ppm-mol	≤ 20
Mercury (Hg)	ppm-mol	≤ 0.0003
Carbon Monoxide (CO)	ppm-mol	≤ 100
Hydrogen (H ₂)	ppm-mol	≤ 60
Cadmium (Cd), Thallium (Tl)	ppm-mol	Sum ≤ 0.03
Methane (CH ₄)	ppm-mol	≤ 100
Nitrogen (N ₂)	ppm-mol	≤ 50
Argon (Ar)	ppm-mol	≤ 100
Methanol (CH ₃ OH)	ppm-mol	≤ 30
Ethanol (C ₂ H ₅ OH)	ppm-mol	≤ 1
Total Volatile Organic Compounds (VOC) ⁽²⁾	ppm-mol	≤ 10
Mono-Ethylene Glycol (MEG)	ppm-mol	≤ 0.006
Tri-Ethylene Glycol (TEG)	ppm-mol	Not allowed
BTEX ⁽³⁾	ppm-mol	≤ 0.5
Ethylene (C ₂ H ₄)	ppm-mol	≤ 0.5
Hydrogen Cyanide (HCN)	ppm-mol	≤ 100
Aliphatic Hydrocarbons (C ₂ -C ₁₀) ⁽⁴⁾	ppm-mol	≤ 1,100
Ethane (C ₂ H ₆)	ppm-mol	≤ 75
Solids, particles, dust	Micro-meter (µm)	≤ 1



https://safety4sea.com/wp-content/uploads/2024/03/Northern-Lights-GS-co2-2024_03.pdf

Different consortiums / Joint Industry Projects, examples

- Lack of data on solutions to mitigate impurities impacts
- Current recommendations impurities limits very low (ppm)
- Uncertainty regarding corrosive and solid-forming during storage and transport
- Lack of official european standards → CEN/TC 474 in progress



IFE (KDC-IV) Dense
phase CO₂
corrosion



European project :
HORIZON-CL5-2025
-D3-25

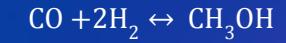
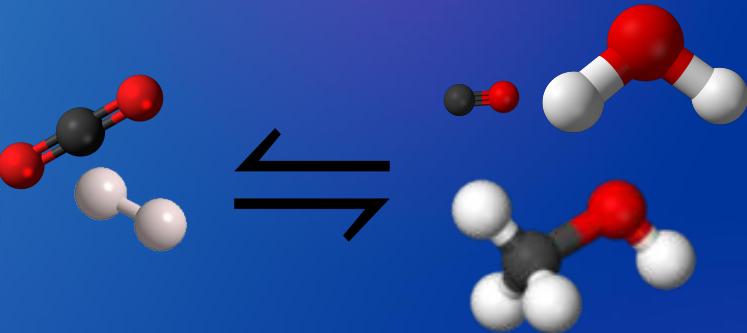
Safety standards in CO₂ pipelines operations



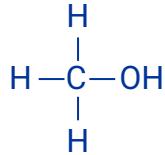
- Working group
GESIP CO₂
- JIP Skylark
- EPRG



Exemple de CCU CO₂ to Methanol



Methanol can Play a Key Role in Decreasing GHG Emissions in Global Shipping



Methanol poses **lower environmental risks** compared to conventional fuels

Up to
80%

Of **CO₂ emission savings** are possible by **switching** from conventional fossil-based maritime fuels **to methanol**

246

Container vessels operated or on-order capable of **running on methanol**¹



¹ Source: [DNV](#) (as of 15 October 2024)



01 Dec. 2023 - 31 May 2027



Renewable H₂



Mapping bio-CO₂ feedstocks for its conversion into Maritime Methanol



CO₂ to MeOH Synthesis

Demonstrating production of Maritime Methanol from CO₂



GEN2 CO₂ to MeOH

Development of a new reactor concept (GEN2) for methanol synthesis



Simplified Purification

Development of a simplified process for production of Maritime Methanol



Engine Tests

Validation of the new Maritime Methanol in marine engines



Roadmap

Value chain analysis and scale-up roadmap for the production of Maritime Methanol

CCUS : la valorisation du CO₂

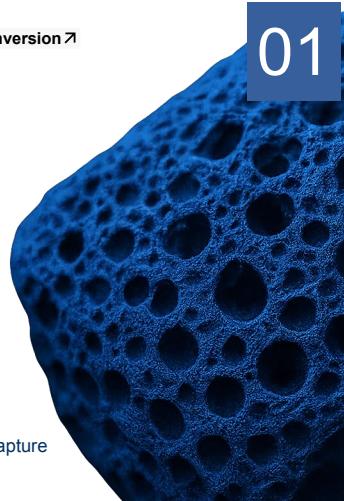
Accompagnement par Accelair de la startup Aerleum

Introduction de l'utilisation directe du carbone: DCU®.

Aerleum a inventé un procédé novateur (DCU®) permettant la conversion directe du CO₂ en méthanol grâce à une combinaison propriétaire d'architecture de réacteur, de matériaux bifonctionnels et de gestion thermique à haute efficacité.

Adsorption ↗ Conversion ↗

01



Un matériau permettant la capture et la conversion in-situ.

CAPEX ↘

02



Un processus intégré, un système, deux étapes.

Speed ↗

03



Un système électrifié avec chauffage rapide et haute efficacité.

Aerleum®

Développement des technologies pour le captage et la conversion du CO₂ en e-carburants et produits chimiques

ACCELAIR
by Air Liquide

Conclusions

Défis

Spécifications CCS vs impuretés dans les fumées

Renchérissement des technologies avec des spécifications de plus en plus exigeantes

Méthodes d'échantillonnage et d'analyse

Comités de normalisation en même temps que des projets industriels !



Perspectives

Un travail commun de tous les acteurs de la chaîne de valeur

Des innovations pour diminuer le coût total d'exploitation

Des aides nationales et de l'Europe pour travailler sur ces sujets



Merci !

Abstract graphic elements: a red horizontal line, a white square, and a blue curved line forming a loop.