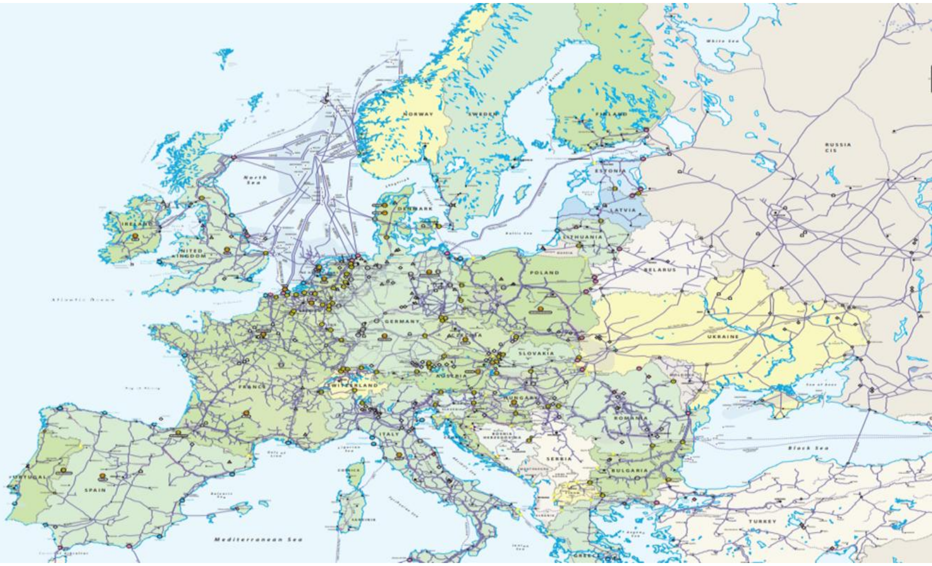
‘Making European gas grids ready for the energy transition’



ENTSOG Gas Quality workshop 2024

27 November 2024

Hybrid event

Table of content

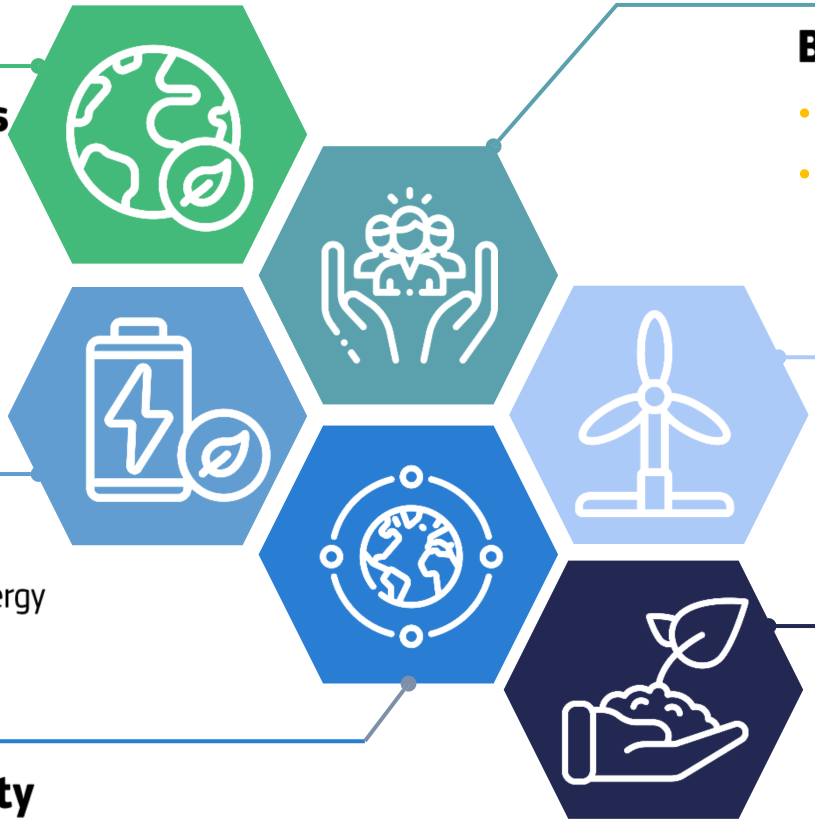
The Gas Quality in the new Hydrogen and Decarbonized Gas Market Package

Gas quality in the Hydrogen and Gas Markets Decarbonisation Package

ENTSOG Gas Quality Workshop 2024

27.11.2024

2021 Fit for 55 package



Cutting green-house gas emissions

- At least 55% by 2030
- fully decarbonising by 2050

Building & Renovating

- Reducing energy poverty
- Energy efficient infrastructure

Renewables

- Research, innovation
- Competitiveness

Energy efficiency

- Promoting values and practices (like new EU energy labels)

Sustainability

- Industry
- Food systems and agriculture

Energy security

- Supply diversification
- Interconnectivity

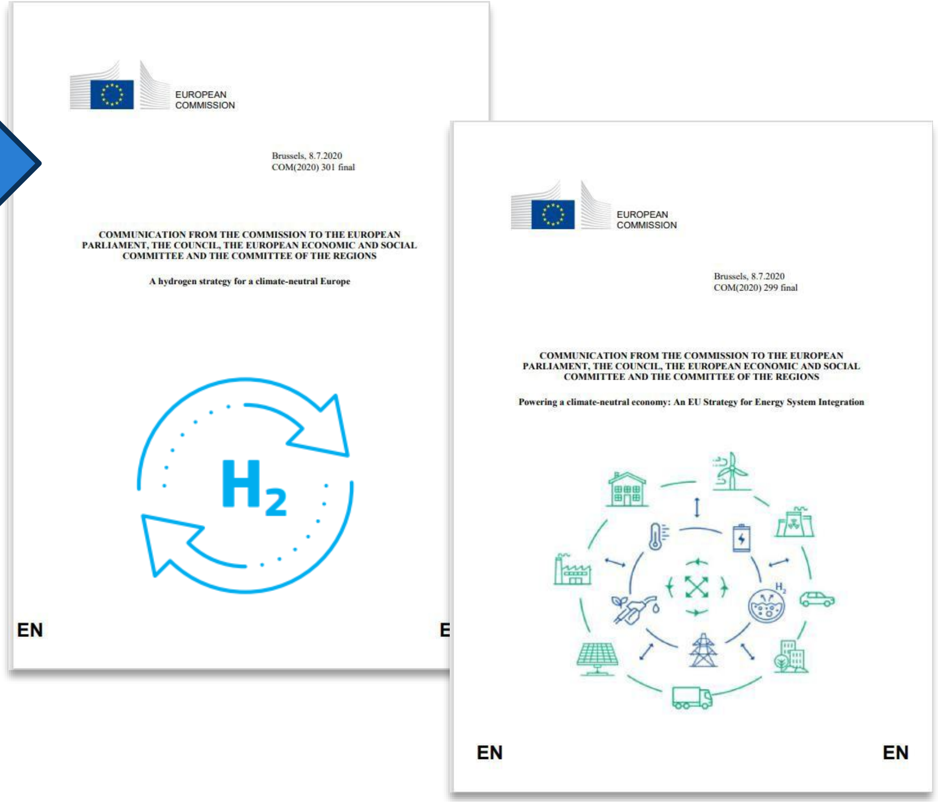
European Commission

Policy context and timeline

Jul '20

A hydrogen strategy for a climate-neutral Europe

EU strategy on energy system integration


EUROPEAN COMMISSION

Brussels, 8.7.2020
COM(2020) 301 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

A hydrogen strategy for a climate-neutral Europe

H_2

EN

EUROPEAN COMMISSION

Brussels, 8.7.2020
COM(2020) 299 final

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Powering a climate-neutral economy: An EU Strategy for Energy System Integration

EN EN

Dec '21 — **Commission Proposal** for Hydrogen and Gas Markets Decarbonisation Package

Mar '22 — **REPowerEU** and Emergency Regulations

Dec '23 — **Political agreement** by the co-legislators

European Commission

Where we came from…

- Building the EU internal energy market for gas

"The interoperability of gas systems requires greater harmonisation including co-ordination of the gas quality specifications at the EU entry points and within the EU to facilitate the development of a liberalised and competitive European gas market" (First Report of the High Level Group on Competitiveness, Energy and the Environment, Contributing to an integrated approach on competitiveness, energy and environment policies, June 2 2006)

- EC Mandate M/400 (2007) to CEN for standardization in the field of gas qualities
  - EN 16726:2015 Gas Infrastructure – Quality of gas – Group H ➡ Under revision

- Interoperability network code (Commission Regulation (EU) 2015/703)

(5) The provisions of this Regulation relating to gas quality should provide effective solutions without prejudice to the adoption of a European-wide standard for high-calorific gas as is being developed by CEN pursuant to the standardisation process under mandate M/400.

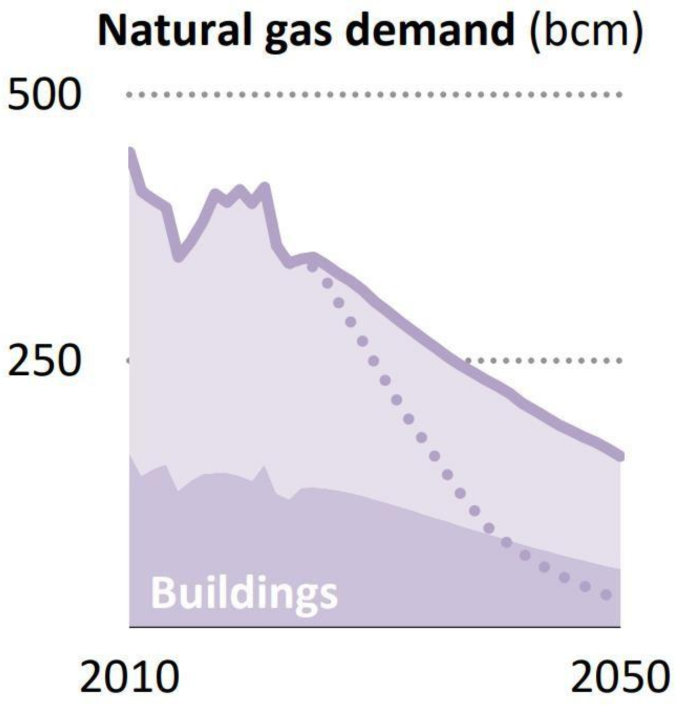
…where we are going to

Decarbonisation will lead to

- Less gas in the system
- A greening of the remaining gas

Changed circumstances since the energy crisis

- Higher importance of LNG
- Accelerated supply diversification



World Energy Outlook 2023, IEA

Novelties in the new package

Governance

- ✓ Clear and harmonised roles and responsibilities assigned to system operators
- ✓ Regulatory oversight

Monitoring

- ✓ Transparency on gas quality developments and quality management cost in the natural gas system
- ✓ Reports on gas quality in the natural gas system + volumes of RES and LC gas injected into the network

Facilitating cross-border flow

- ✓ dispute settlement mechanism for disagreements at cross-border points, including on H2 blending

European Commission

System operators’ tasks of gas quality management

Transmission system operators

- Article 39(4) of new Gas Directive

4. Transmission system operators shall ensure efficient gas quality management in their facilities in line with applicable gas quality standards

Distribution system operators

- Article 44(2) of new Gas Directive

2. When so decided by regulatory authorities, distribution system operators may be responsible for ensuring efficient gas quality management in their systems in line with applicable gas quality standards, where necessary for system management due to the injection of renewable gas and low-carbon gas.

Monitoring and regulatory oversight

- Article 77 (1), point (g) ➡ General objectives of the regulatory authorities

(g) monitoring the development of gas qualities and gas quality management by transmission system operators and where relevant by distribution system operators, including monitoring the development of costs related to the management of gas quality by system operators and the developments related to the blending and deblending of hydrogen into the natural gas system, by natural gas storage system operators and by LNG facility operators […]

- Article 64(11) of the gas Directive and Article 38 of the gas Regulation

➡ TSOs and (where relevant) DSOs shall make public detailed information regarding the quality of the natural gas transported in its networks, based on Articles 16 and 17 of the INT NC

Article 26, para (3), point (g) and (i) = ENTSOG and EU DSO monitoring reports on gas quality and RES and LC gases

Cross-border coordination

Policy objective: Diverging specifications should not restrict cross-border flows and fragment the internal market

Dedicated dispute settlement process for cross-border issues
Art. 21 Gas Regulation

Build on the design of the procedure in Article 15 of INT NC

Embedded in the new governance set by the package= TSOs and NRAs with clear roles

Applicable to hydrogen blending

Up to 2% of hydrogen content blended into the natural gas system
Cap on the procedure – no blending obligation!

European Commission

Gas quality and biometane integration

Article 23 Gas regulation : facilitating the timely and efficient integration of large volumes of biomethane in the natural gas system

- What: Establishment of common specifications for biomethane
- How: adoption of implementing acts
- When: 1) requirement not covered by existing harmonized standards, OR

  2)EC request for developing standards is:

  - a) not accepted,
  - Adoption of standards is undue delayed or
  - Standards delivered are not satisfactory

Last ratio and temporary option!!

European Commission

Thank you

Latest developments on gas quality parameters for natural gas and renewable and low-carbon gases

Revision of the European H-Gas Standard

Introduction of Wobbe-Index and facilitation of renewable and low-carbon gases

Tobias van Almsick, Convenor CEN/TC 234 / WG 11

ENTSOG Gas Quality Workshop, Bruxelles, Nov. 27th , 2024

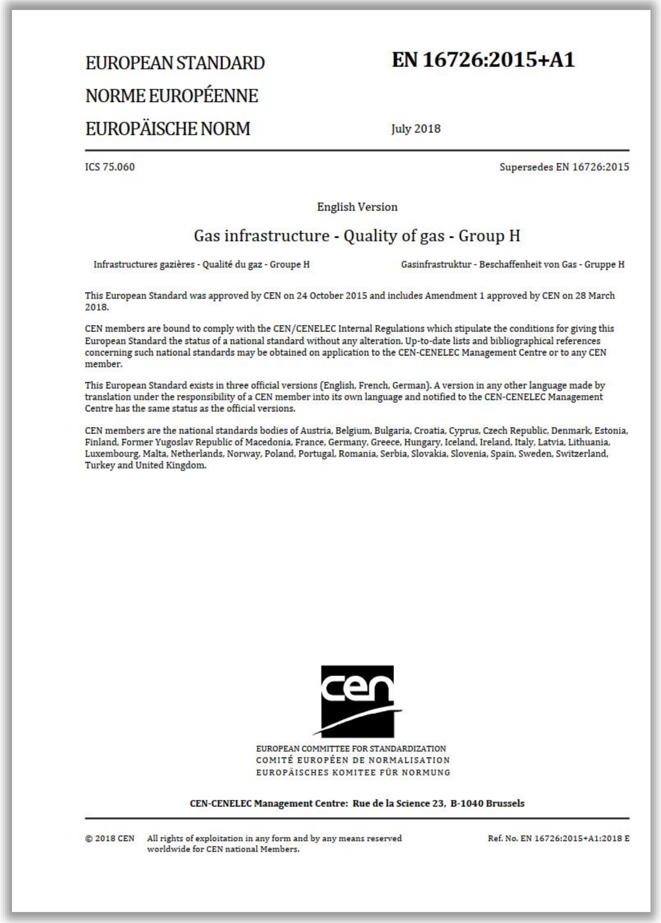
Revision of EN 16726 – Quality of Gas – Group H

Public enquiry: 2023-12-21 – 2024-03-14

Comments received: approx. 650

- National mirror commitees (mainly: D, NL, F, DK, BE)
- Organisations (mainly: Marcogaz, ENTSOG, Euromot)

- **Comments treatment: From April 24th until September 10th**
- 10 sessions (5 physical meetings, 5 online meetings)
- More than 70 hours of intense discussion
- Final draft send to CEN TC 234 on November, 15th



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 16726:2015+A1

July 2018

ICS 75.060

Supersedes EN 16726:2015

English Version

Gas infrastructure - Quality of gas - Group H

Infrastructures gazières - Qualité du gaz - Groupe H

Gasinfrastruktur - Beschaffenheit von Gas - Gruppe H

This European Standard was approved by CEN on 24 October 2015 and includes Amendment 1 approved by CEN on 28 March 2018.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Ref. No. EN 16726:2015+A1:2018 E

Revision of EN 16726 – Quality of Gas – Group H

Major changes:

- Wobbe-Index
- Hydrogen
- Relative density
- Oxygen
- Methane number

CEN/TC 234

Date: 2024-09

FprEN 16726:2024

Secretariat: DIN

Gas infrastructure — Quality of gas — Group H

Gasinfrastruktur — Beschaffenheit von Gas — Gruppe H

Infrastructure gazière — Qualité du gaz — Groupe H

Revision of EN 16726 – Wobbe-Index

- Introduction of Wobbe-Index originated in Mandate M/400 (2007)
- Specifications for both
  - Entry-Points
  - Exit-Points
    - Class Specified
    - Class Extended
- Concept for Wobbe can only be applied if accompanying rules / legislation is in place (e.g. NC Int)

Revision of EN 16726 – Wobbe-Index - Entry

5.2 Entry point Wobbe index range (recommendation)

The Wobbe index entry range should be within 46,44 MJ/m³ and 54,00 MJ/m³ [15 °C/15 °C] (see Table 2).

Table 2 —Wobbe index entry range recommendation

Parameter	Unit	Limits based on standard reference condition 15 °C/15 °C	
		Min.	Max.
Wobbe index at entry points	MJ/m^3	46,44	54,00

NOTE 1 The Wobbe index limit values at entry points need to comply with the national requirements on the Wobbe index entry range.

Revision of EN 16726 – Wobbe-Index - Exit

5.3.2 Class 'Specified'

Class Specified shall be assigned to exit points (or to a cluster of exit points) for the distributed gases if the following conditions apply:

— Wobbe index bandwidth of ≤ 3,7 MJ/m³;

— within the Wobbe index range of 46,44 MJ/m³ to 53,00 MJ/m³ [15 °C/ 15 °C at 1 013,25 mbar].

- Downstream Sector / End users shall be informed about the assignation.
- No further action to be taken.

Revision of EN 16726 – Wobbe-Index - Exit

5.3.3 Class 'Extended'

Class Extended shall be assigned to exit points (or a clusters of exit points) for distributed gases which are not covered by the Class Specified within the recommended Wobbe index entry range of 46,44 MJ/m³ to 54 MJ/m³ (5.3) or within the national Wobbe index specification for H-gas (see Annex E).

NOTE 1 In many countries national legal Wobbe index ranges exist, which can differ from the recommended Wobbe index entry range; in other countries generally acknowledged national standards and/or codes of practices apply.

Allocating Class Extended to exit points (or clusters of exit points) requires

— unbiased assessment of the presence of users' applications sensitive to Wobbe index at the concerned exit point or cluster of exit points and,

— if any, the implementation of appropriate mitigating measures in cooperation with all parties involved (Annex C).

5.3.6 Implementation of Wobbe index classification

The Wobbe index classification system in this document shall apply, if the corresponding national/European framework is available to support it.

At least the assessment procedure for identification of applications sensitive to Wobbe index, the assignation and change of classes, related time scales and responsibilities need to be stipulated to enable an implementation of the classification system.

Revision of EN 16726 – Hydrogen / relative Density

Relative density [a]	no unit	0,45	0,70	EN ISO 6976, EN ISO 15970
Hydrogen	mol/mol	not applicable	2 %	None
	A hydrogen concentration shall be accepted up to two percent by mol across the whole value chain. It may deviate nationally, regionally or locally for higher values than 2 mol/mol of hydrogen concentration provided that the requirements of the applications sensitive to hydrogen are met for lower values than 2 mol/mol of hydrogen concentration in case of proven sensitivity of installations to hydrogen, e.g. some underground gas storage and some gas turbines. For further information reference is made to 5.4 and Annex K.			

- In alignment with European Gas package
  - Directive (EU) 2024/1788
  - Regulation (EU) 2024/573

- Facilitating the introduction of (green) hydrogen into the market.

Revision of EN 16726 – Oxygen

<table>
<tr><td rowspan="2">Oxygen</td><td>mol/mol</td><td>not applicable</td><td>1 % or
below 1% to 0,01 %
or
below 0,01 % to 0,001 %,
according to assessment process (see below)</td><td>EN ISO 6974-3,
EN ISO 6974-6,
EN ISO 6975</td></tr>
<tr><td colspan="4">In the gas infrastructure the concentration of oxygen shall be no more than 1 %. However, if it can be demonstrated by an assessment process that a gas with oxygen content can flow to installations with proven sensitivity to oxygen at the level:
— of below 1 % to 0,01 %, the maximum limit shall be lowered to the maximum acceptable limit, expressed as a moving 24-hour-average.
— of below 0,01 %, the maximum limit shall be limited to 0,001 % at the lowest, expressed as a moving 24-hour average. Solutions for protecting these specific installations shall be defined in co-operation of the parties concerned, as part of the assessment.
NOTE 1 Most applications can accept a level of 0,01 % of oxygen or higher; certain types of underground storages are sensitive to oxygen contents higher than 0,001 %.
On a case-by-case basis, it can be required to identify the techno-economical optimal solution enabling the level of O_2 acceptable for the part of the gas grid affected, e.g. from biomethane producers to installations sensitive to O_2.
The assessment process for identification of installations sensitive to O_2, and evaluation of the applicable threshold and responsibilities need to be stipulated to facilitate the application of the standard requirement on O_2 content.
NOTE 2 Considering the expected development of biomethane production, the lower maximum limit of 0,01% will probably have to be reassessed upwards in the coming years.
NOTE 3 0,01 mol/mol is equal to 100 ppm(mol) and 0,001 mol/mol is equal to 10 ppm (mol).
More information on oxygen origin, challenges, mitigation measures and measurement are given in Annex I.</td></tr>
</table>

- Facilitating the market ramp up of renewable gases
- Oxygen removal from biogas is cost expensive
- Higher limiting values for oxygen incentivise biomethane injection
- Assessment process to clarify details in case of possible issues.

Revision of EN 16726 - next steps

Phase of revision process	Date
Circulation of 1st Working Draft	2023-05-17
Acceptance of the draft	2023-09-21
Start of draft translation	2023-10-19
Submission to Enquiry	2023-12-21
Closure of Enquiry	2024-03-14
Acceptance of draft for Formal Vote (plan)	2024-10-01
Acceptance of draft for Formal Vote (intended)	2024-12-20
Submission to Formal Vote	2025-03
Closure of Formal Vote	2025-05
Ratification	2025-06
Definitive text available	2025-07
Announcement	2025-10
Completion all national publications	2026-01
Completion withdrawal national standards	2026-01
Start of review	2030

Contact

Hiltrud Schülken,
CEN/TC 234 Gas infrastructure

Secretary

hiltrud.schuelken@dvgw.de

Tobias van Almsick
CEN/TC 234 WG 11 Gas quality

Convenor

tobias.vanalmsick@oge.net

Uwe Klaas
CEN/TC 234 WG 11 Gas quality

Secretary

uwe.klaas@dvgw.de

ENTSOG Gas Quality Workshop 27/11/2024
Biomethane and other renewable and low-carbon methane rich gases

- by Christophe Erhel, secretary of CEN/TC 408

Background

- Standardization request M/475 from European Commission in 2010
- Creation of CEN/TC 408, *Biomethane*, in 2011

- EN 16723-1 on biomethane for injection published in 2016
- EN 16723-2 on natural gas and biomethane as fuel published in 2017

- Lack of information on impact of sulphur and siloxanes on engines, impact of oxygen on underground storages and impact on health: GERG projects Phase 2a (2017-2018), Phase 2b (2019-2020), Phase 2c (2022-2024)
- Lack of analysis methods on biomethane components: ISO/TC 193/SC 1/WG25, *Biomethane*

Next steps and progress

- Decision to merge EN 16723-1 and EN 16723-2
- Title of CEN/TC 408 extended to “Biomethane and other renewable and low-carbon methane rich gases“ and scope extended to other production processes, e.g. pyrolysis, gasification, methanation, power-to-gas
- Intention to specify required analysis depending on intrants and production processes
- Revision with input from GERG and ISO/TC 193/SC 1/WG25
- Creation of WG1 and first draft circulated

For more information

or to join CEN/TC 408,

contact
christophe.erhel@francegaz.fr

Francegaz

ENSEMBLE, TRANSFORMONS L'ÉNERGIE

francegaz.fr @FrancegazFR Francegaz

ENTSOG Gas Quality Workshop 2024

27.11.2024, Brussels

Francegaz
ENSEMBLE, TRANSFORMONS L'ÉNERGIE

GERG
THE EUROPEAN GAS RESEARCH GROUP

BioStAR2c

BioStAR2C – final phase of GERG Biomethane Project

Biomethane trace components and their potential impact on the European gas industry

Gaspard Bouteau, ENGIE lab CRIGEN

Florent Huet, ENGIE Lab CRIGEN

Robert Judd, GERG

Alexandra Kostareva, GERG

Tamara Sarac, GERG

Funded by the European Union

Objectives of the project

- Supporting the CEN European standardization process through reducing or removing technical barriers to the injection of biomethane in the natural gas network:
  - Developing and sharing knowledge on biomethane quality & impacts
  - Studying the real impact of biomethane quality on gas chain
  - Anticipating potential operational issues for gas operators

Standard published in 2016

- **16723 -1 :** Specifications for biomethane for injection in the natural gas network
- **16723-2 :** Automotive fuel specification

- These standards specify the biomethane quality expected for injection in gas network and usage as gas fuel regarding the maximum trace compound concentrations

BioStAR2c

Objective : Realizing prenormative work assessing the impact of several trace compound on end user appliances

The overall objective of the project is to offer the conditions to a safe development and a competitive positioning of the biomethane chain on the market

Timeline Towards the removing of technical barriers to biomethane injection into the natural gas grids

GERG
THE EUROPEAN GAS RESEARCH GROUP

GERG biomethane project → Biostar2C project
A multi-phase project aiming to revise the standards limits regarding trace component in biomethane with scientifically based data

First standard published in 2016 with trace compound limit not al based on scientific studies

Phase 1

GERG gas industry priorities:
Status review and gap analysis:
- Siloxanes
- Corrosive components
- Micro-organisms

Phase 2a
January 2018

Combination of GERG priorities & CEN immediate priorities:
- Status review and gap analysis
  - Sulfur
  - Oxygen
  - Health impact assessment
- Experimental program: impact of siloxane on:
  - Industrial boilers
  - Heavy duty vehicles performance

SA/CEN/RESEARCH/475/2017-07

Phase 2b
October 2020

Follow up from Phases 1 & 2a
WP1: Experimental program on siloxanes impacts
- Engines: test on switching type oxygen sensors

WP2: Experimental program on the impact of sulfur on vehicles After Treatment System (Catalysts)
- Lab test using dedicated burner with given sulfur concentration in natural gas

WP3: preparation for Experimental program on the impact of oxygen and corrosive components on gas facilities:
- Gas grid
- Underground Gas Storage

WP4: Improve knowledge on biomethane
- Biomethane quality database (UK data)
- Literature review on siloxane purification process

CEN/2019/ENER/C2/452-2019

Phase 2c
Dec 2022

BioStAR2c

Follow up from Phases 1, 2a & 2b

WP2: Experimental program on siloxanes impacts
- Industrial boilers: cycling mode (start and stop)

WP3: Experimental program on the impact of sulfur on vehicles After Treatment System (Catalysts)
- Ageing test
- Vehicle test
- Sulfur ageing modeling

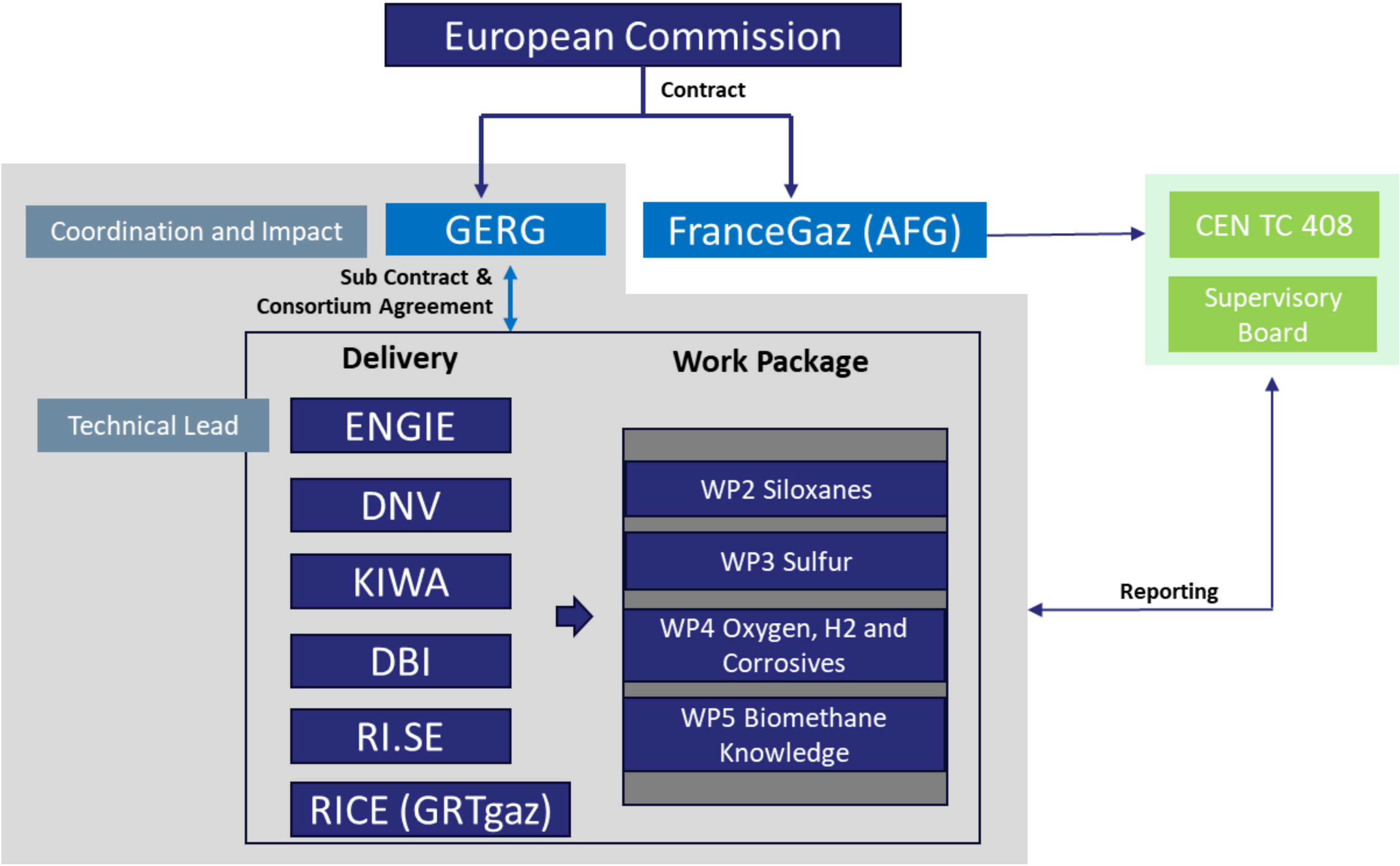
WP4: Experimental program on the impact of oxygen and corrosive components on gas facilities:
- Gas grid
- Underground Gas Storage
- Impact of hydrogen on type 1 CNG steel tanks

WP5: Improve knowledge on biomethane
- Biomethane quality database (Swedish data)
- BioSNG & bioLNG quality data (French data)
- Upgrading process database

Horizon Europe Grant Agreement No 101112475

Phase 3
Revision of standard EN 16723 part 1&2

Structure


European Commission
Contract
Coordination and Impact
GERG
FranceGaz (AFG)
Sub Contract &
Consortium Agreement
Delivery
Work Package
Technical Lead
ENGIE
DNV
KIWA
DBI
RI.SE
RICE (GRTgaz)
WP2 Siloxanes
WP3 Sulfur
WP4 Oxygen, H2 and Corrosives
WP5 Biomethane Knowledge
CEN TC 408
Supervisory Board
Reporting

Work Package 2 Status

impact of siloxanes on industrial boilers

Objective and structure of the WP

- **OBJECTIVE** : gathering data on the impact of siloxane presence within biomethane on the performance of industrial boilers.
  - the boiler was operated in power modulation mode in order to mimic real usage of such systems in industrial environment.
  - Previous work on continuous mode highlighted a decrease of the ionization signal over test period due to silica deposition on the ionization probe → leading to misfire od the boiler
- **METHODOLOGY** :
  - 4 siloxane concentrations: 5 mgSi/Nm3, 2.5 mgSi/Nm3 , 1.5 mgSi/Nm3 and 1 mgSi/Nm3
  - Power modulation : 450 KW / 90 kW
  - Each concentration tested for a period of 5 cycles (1 cycle/week)
  - Monitored parameters :
    - General performances/heat loss along the 5 cycles for each concentration
    - Pollutant emissions (CO, CO2, NOx, …)
    - Ionization signal degradation
  - At the end of each concentration testing, the boilers will be open in order to gather the silica deposition that will be analyzed

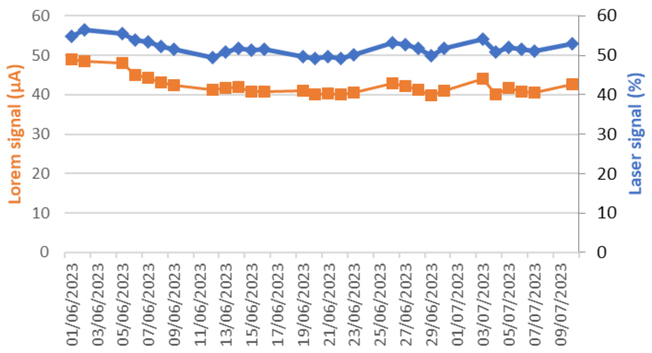
1 MW boiler operated in ENGIE lab CRIGEN (Stains – France)

RESULTS EXPLOITATION:
Extrapolation towards realistic biomethane usage for commendations of adapted siloxane concentration to be implemented in EN 16723 standard revision

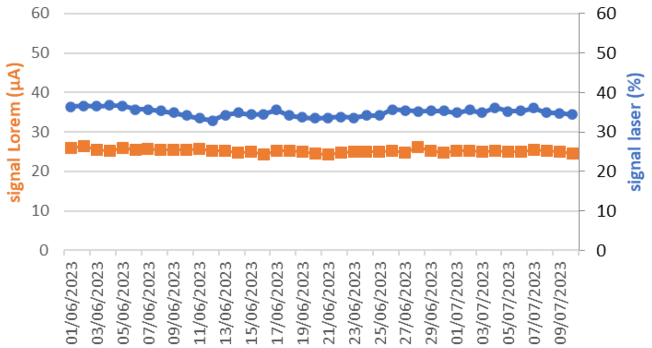
WP2 : siloxane impact on industrial boilers

No decrease of the ionisation signal observed → power modulation seems to have beneficial effect

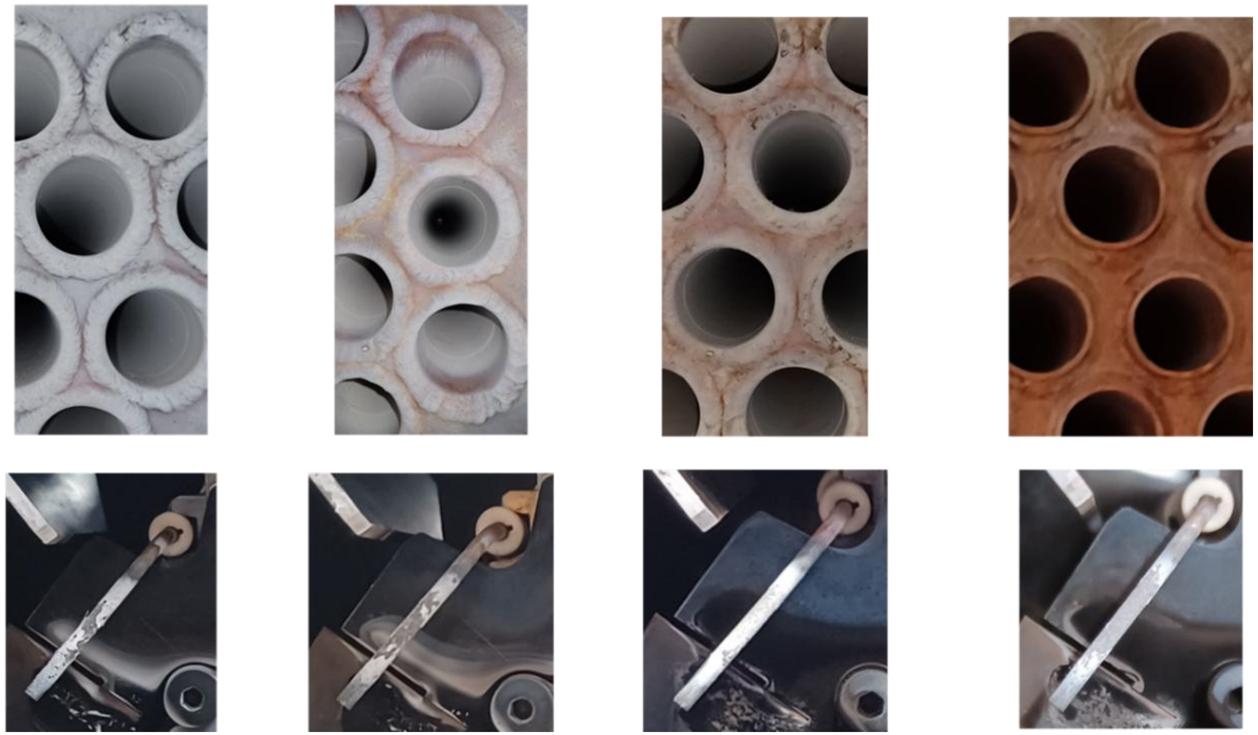
Raw ionisation signal Pmax



Raw ionisation signal Pmin



	5 mgSi/Nm3	2.5 mgSi/Nm3	1.5 mgSi/Nm3	1 mgSi/Nm3
smoketubes				
Ionisation probe				



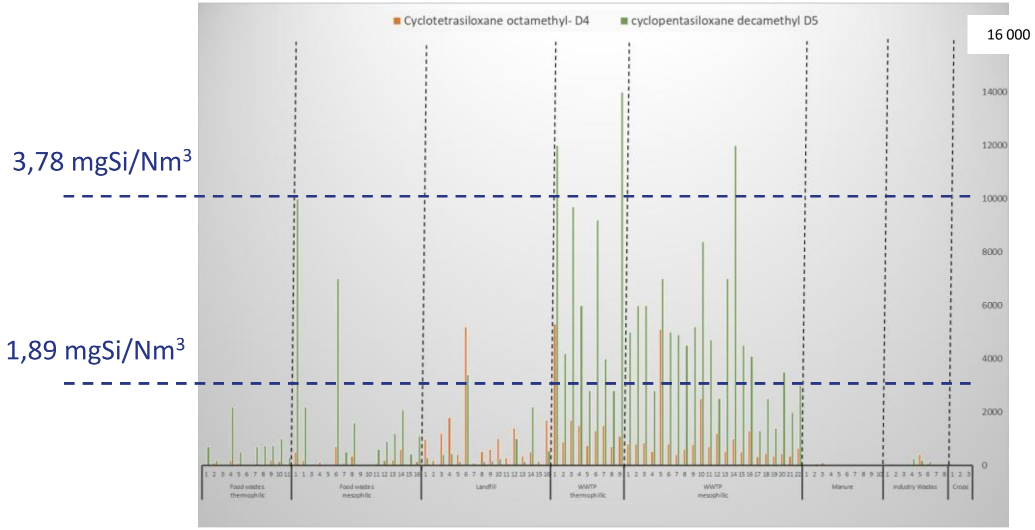
As expected : the lower the siloxane concentration, the lower the silica depositions

→ Cleaning of the boiler along normal maintenance protocol allowed for recovering initial performances

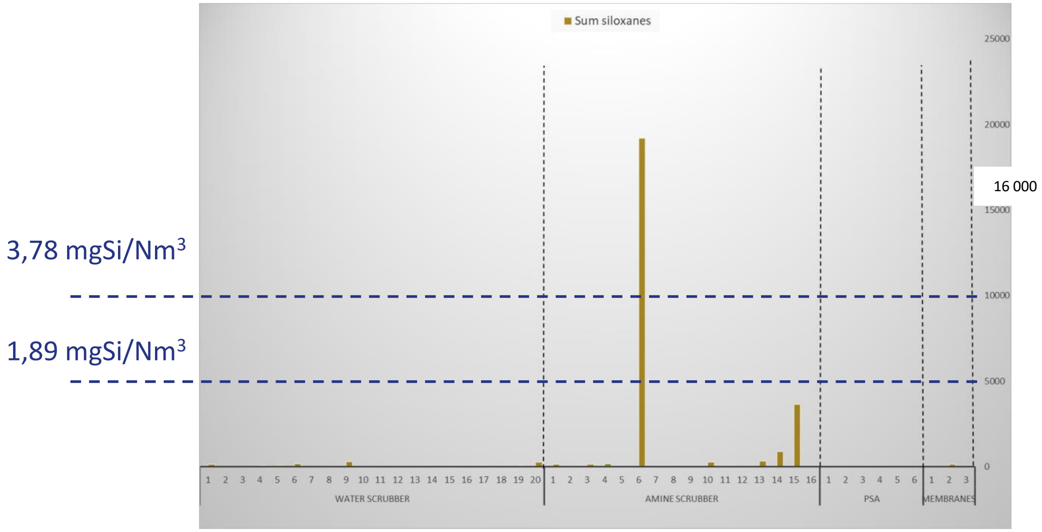
WP 5 Improving biomethane knowledge-Task1 : Biomethane data Sweden → concrete usage

Concentration of siloxane D4 and D5 (90% of all siloxane encountered)

Biogas



Biomethane



- Siloxane are mostly encountered in biogas from WasteWater Treatment (WWTP)Plants
  - (for ref : 10 000 µg siloxane/m^3 = 3,78 mgSi/Nm^3)
- **Biogas upgrading is very efficient to reduce siloxane concentration in biomethane.** Spot measurement (1/ 45 measurements) on amine scrubbing technologies however show strong concentration which can be attributed to the fact that the gas was wet. Those siloxane would probably be removed by dryer.

→ All other measurement show siloxane concentration below 1,5mg Si/Nm^3 → setting up a limit of siloxane at 2mgSi/Nm^3 is not too restrictive for biomethane producer while ensuring acceptable performances of industrial boilers between 2 maintenance procedure

WP2 : siloxane impact on industiral boilers

Considering the current scenarios of low WWTP shares and low siloxane concentrations present in biogas, overall impact on industrial boilers of realistic siloxane concentration in biomethane is limited.
Based on results and extrapolation, **2mgSi/Nm3 appears to be a reasonable value to be implemented in EN 16723 standard revision**

2 mgSi/Nm3	**100% bioCH4**	**50% bioCH4**	**10% bioCH4**
Expected burner performances loss over 12 months period considering siloxane present all over the gas network	9.15%	4.58%	0.92%
Expected burner performances loss over 12 months period considering siloxane only present on WWTP (1/10 of biomethane plants in Europe)	0.91%	0.46%	0.09%

Work Package 4 Status

Impact of oxygen and corrosives

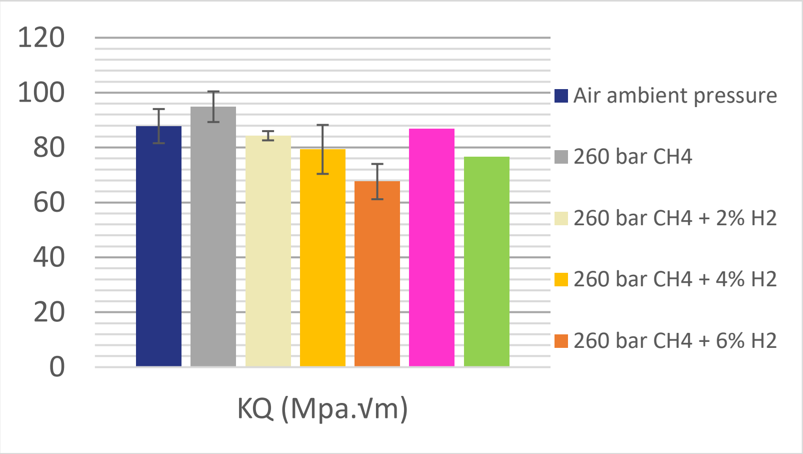
Objective and structure of the WP

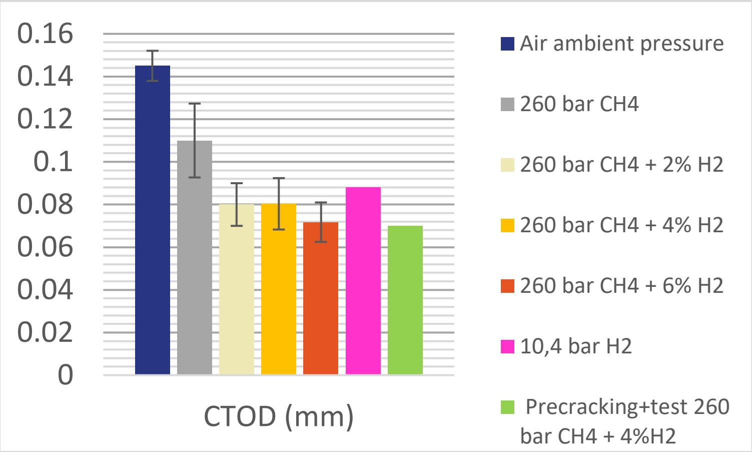
- Task 1 : Impact of oxygen on Underground Gas Storage
  - Structure of the task1 : Lead by DNV UK / GLIS
    - Formation Damage Evaluation
    - Microbial Population Identification
    - Elemental Sulfur Generation
    - Surface process equipment impacts
- Task 2 : Corrosion tests
  - Lead by KIWA and GRT Gaz
  - Samples would be placed in each autoclave with at least one sample in the liquid phase, one sample in the gas phase and one sample at the interface
- Task 3 : Impact of H2 on CNG type 1 steel tanks → **focus of today**
  - Objective : Getting better insights on the suitability of CNG type 1 steel tanks with H2
  - Structure of the task 2 :
    - Tests carried out by P' institute (University of Poitiers) as a subcontractor of ENGIE
    - 2 kinds of tests planned : fracture toughness tests and crack growth rate tests - both with 34CrNiMo6 steel

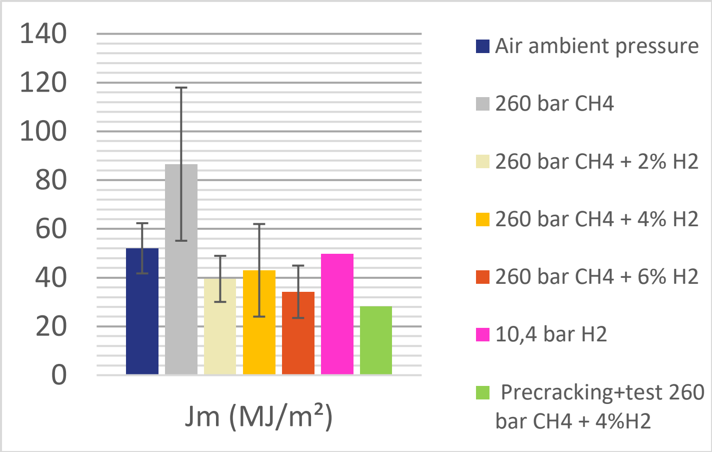
WP4 : Impact of oxygen and corrosives compounds- task 3 H2 impacts

Fracture toughness tests aim to provide information on the stress that a structure with a crack of a certain length can withstand without it propagating.

Current limit at 2% H_2







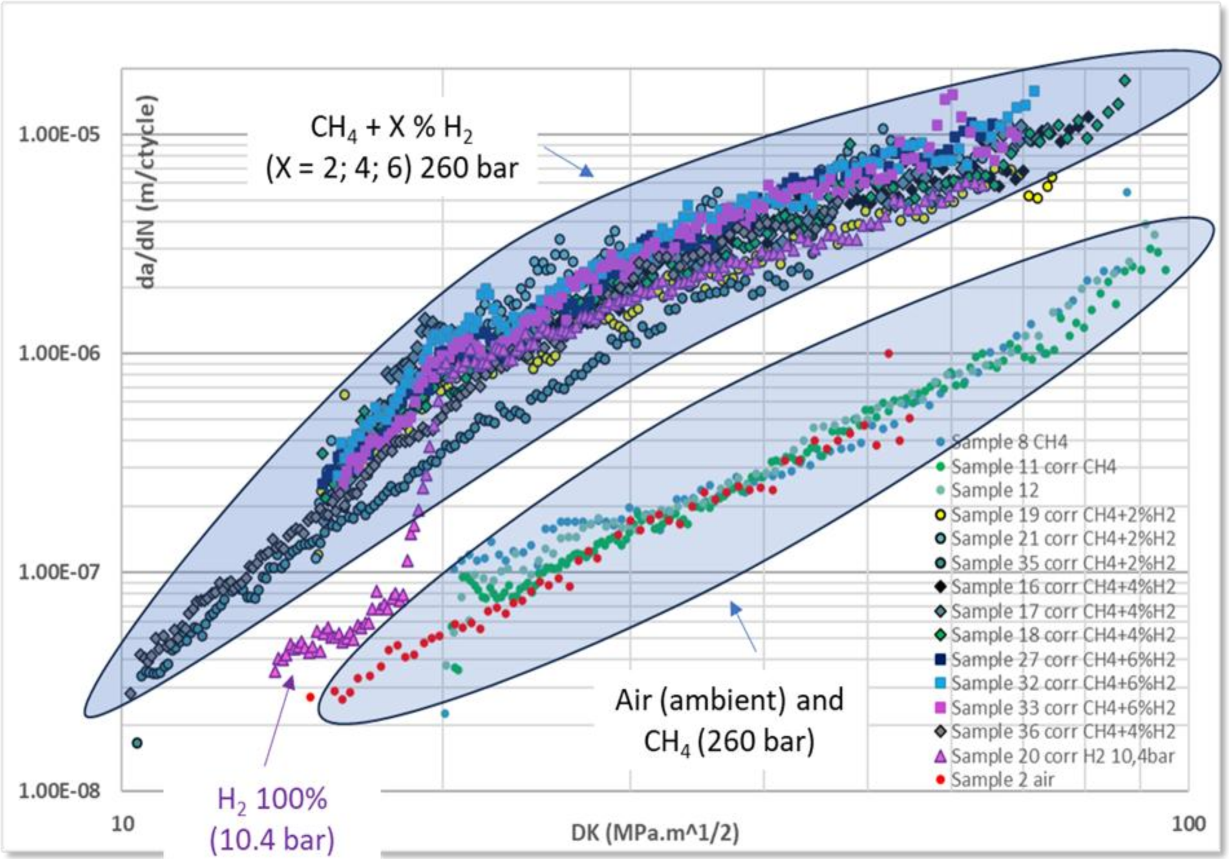
- Tests conducted in air at atmospheric pressure and under 260 bar CH4 show similar KQ mean values around 90 MPa×√m. The same observations can be made with the 2% H2 mixture but with a slight decrease compared to the mean value KQ in air
- Significant **reduction is noticed on the KQ value, with over 17 MPa×√m in difference between the 2% H2 mixture and the 6% H2 one**
- All samples in a blend with the presence of hydrogen (H2) yield similar results, regardless of the hydrogen percentage. These blended samples show a significantly reduced CTOD mean value, close to 0.08 mm
- **The mean Jm values for samples tested under 2%, 4%, and 6% H2 are remarkably similar**

KQ ($Mpa.m^{1/2}$) = stress intensity factor : capacity of a material to resist to crack propagation at a given force
Jm ($MJ:m^2$): minimal variation of potential energy due to crack propagation
CTOD (mm) : Crack Tip Opening Displacement

WP4 : Impact of oxygen and corrosives compounds- task 3 H2 impacts

Current limit at 2% H_2

Fatigue crack propagation tests aim to assess the lifespan in the presence of a crack-like defect on the inner surface of the tank.



- Adding hydrogen in the gas mixture drastically increase crack propagation rate (approximately an order of magnitude compared to no H2), corroborating findings in existing literature
- Increasing H_2 above 2% (current maximum concentration in both standard EN 16723 and R110 regulation), only show limited effect on the crack propagation over repeated fatigue cycles
- The results seems to indicate that an increase of the allowable maximum H_2% to 4% would be acceptable
- Dedicated analysis on other materials in presence of H2 (engine, pressure regulators, sensors..) would bring a more definitive picture for assesing the impact of an increase of H_2 on gas vehicle lifetime

CONCLUSIONS

CONCLUSIONS

Impact of siloxane on industrial boiler : *current limit at 1 mgSi/Nm^3*

- test realization on 4 siloxanes concentrations show that silica deposit can reduce burner yield
  - **A concentration of 2mgSi/Nm^3 is recommended for the revision of EN 16723 Standard** for ensuring sufficient performances between 2 maintenance periods (12/15 months)

Impact of H2 on CNG vehicle tanks

- Adding H_2 in biomethane have an impact on Type I reservoir mechanical properties
  - 2% in already accepted in standards and regulation (R110)
- Further adding H_2 (4% and 6%) does not lead to further reducing mechanical properties of Type I tank material
- Further test on other gas vehicle material are needed to the full picture on H_2 impact (needed for R110 revision) but a **4% H_2 seems to be acceptable for the revision of EN 16723 standard**

Improving Biomethane knowledge

- Biogas and biomethane database was realized on 70 plant in Sweden
- The database help to better understand where does biogas and biomethane stand compared to current standard
  - The database enable to show that Highest concentration of VOC in biogases was produced from food wastes feedstock
  - The database was used to better rationalized the results obtained on siloxane testing

➢ **Further study regarding the impact of corrosive compounds or the impact of O_2 are currently ongoing and should help to better adapt the standard revision on biomethane production reality considering both the upgrading constraint and the need for performance on end user appliances**

Project updates: Biostar2c - Gerg (www.gerg.eu/biostar2c/)

GERG

THE EUROPEAN GAS RESEARCH GROUP

Thank you for your attention!

alexandra.kostereva@gerg.eu
robertjudd@gerg.eu

Francegaz
ENSEMBLE, TRANSFORMONS L'ÉNERGIE

BioStAR2c

Funded by the European Union

The Biostar2C project has received funding from the Horizon Europe Programme under Grant Agreement No 101112475.

ENERGINET

HYDROGEN FROM BIOMETHANE AND E-METHANE

How to find the right implementation of limits

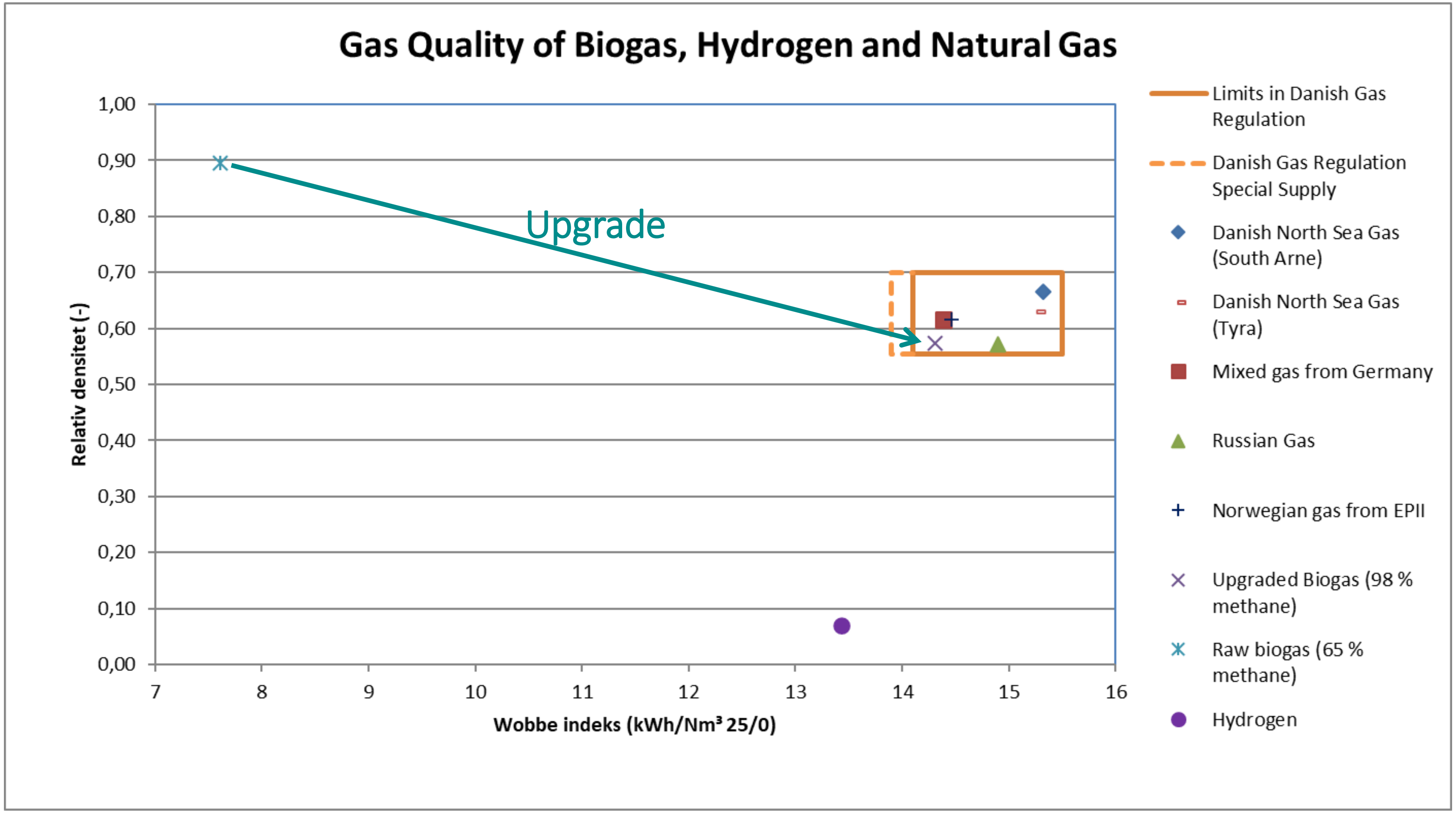
Jesper Bruun Munkegaard Hvid, Energinet

CONTENT

- Regulation of hydrogen in methane in Denmark
- Paths to hydrogen in the methane network
- Hydrogen in biomethane
- E-methane
- Measurement of hydrogen in methane
- Dialogue with neighbours
- International aspects
- Summary

GAS QUALITY OF GREEN GASES

ENERGINET



Source: 20/09059-9

ENERGINET

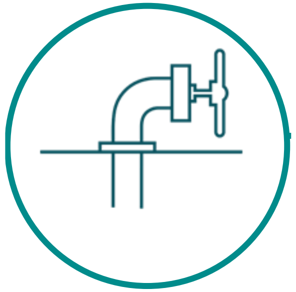
REGULATION OF HYDROGEN IN THE METHANE NETWORK IN DENMARK

The regulations do not (directly) account for the presence of hydrogen in bio-methane. E-methane is not (yet?) defined separately in existing regulations.

In the background;
...EU's gas package...

SIKKERHEDSSTYRELSEN	ENERGINET	evida	evida
BEK 230 OF 21/03/2018 ON GAS QUALITY	ENERGINET'S CONDITIONS FOR GAS TRANSPORT	RULES FOR BIOMETHANE	CONNECTION AGREEMENT

PATHS TO HYDROGEN IN THE METHANE SYSTEM

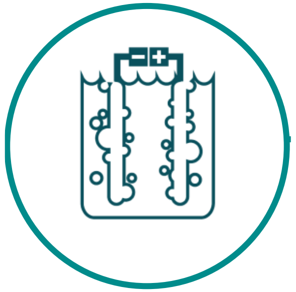


HYDROGEN SLIP FROM BIOMETHANE

- Approximately 40% of Danish consumption is currently covered by biomethane
- Driven by increased production and decreased consumption.
- Several new impurities and trace elements have been introduced.
- A recent realization is that biomethane can contain hydrogen!

HYDROGEN SLIP DURING METHANATION

- There is potential to increase methane production by 40-50% from upgrading plants.
- Depending on the methanation technology, there can be up to 4% hydrogen slip.
- Hydrogen is the result of an incomplete reaction between CO2 and hydrogen.
- Common hydrogen limits at the connection point.



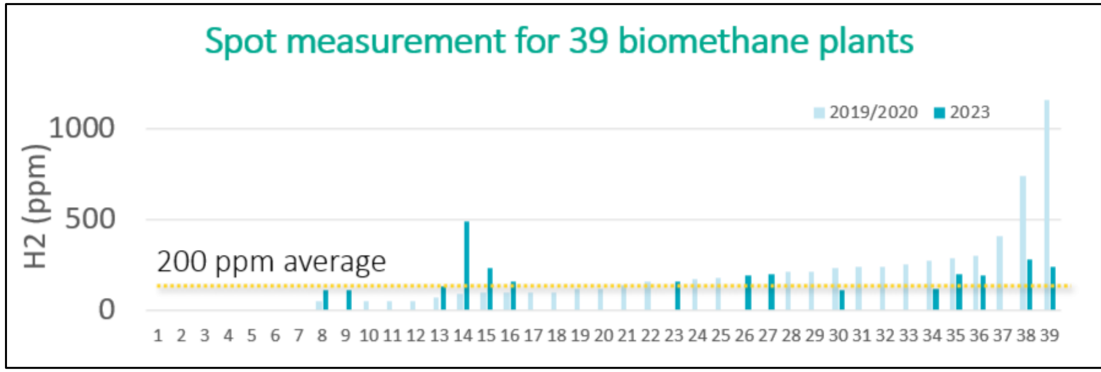
DIRECT INJECTION OF HYDROGEN INTO THE GAS SYSTEM

- There are requirements for controlling supply facilities to prevent excessively high hydrogen concentrations.
- Equal access to hydrogen injection capacity for actors.
- "Contamination" of a high-value product.
- Very small green contribution to the system.
- It is not considered relevant in the Danish context.

ENERGINET

HYDROGEN IN BIOMETHANE

Biomethane contains trace amounts of hydrogen



It was recently found, that most biomethane injected into the natural gas system contains small amounts of hydrogen.

This means that hydrogen is already present in the gas

DGC has made measurements of approx. 40 biogas facilities.

- Average hydrogen content: 200 ppm (0,02 %).
- Peak values up to 1200 ppm (0,12 %).
- <10 facilities below detection limit.

HYDROGEN FROM E-METHANE (1)

E-methane has the potential to significantly increase the overall production of green gas

E-methane is methane produced through the reaction between hydrogen and carbon dioxide. Hydrogen is, in a Danish context, assumed to form from electrolysis.

Risk of hydrogen ”carry over” in the methanated gas due to an incomplete reaction.

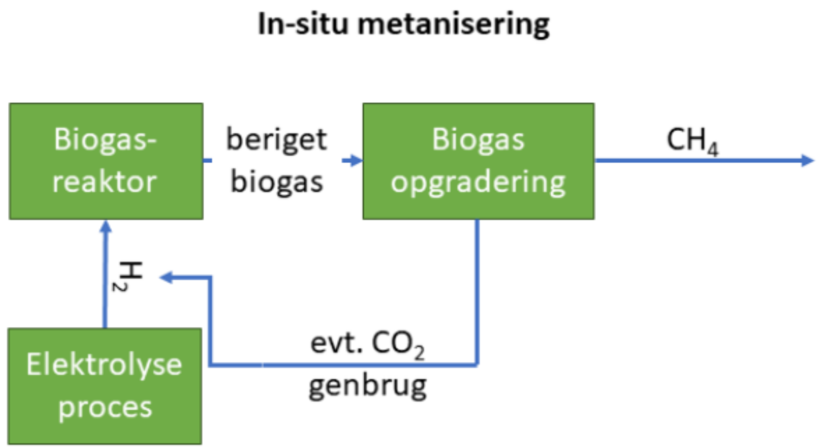
Stakeholders are looking into the possibility of utilizing surplus CO_2 from raw biogas to produce e-methane.

The stakeholders would prefer to be allowed to inject 1-2 % hydrogen into the distribution/transmission grid.

Especially the start-up of biological methanation is difficult as surplus of hydrogen is needed to “wake-up” the microorganisms.

Metanisering:

$$CO_2 + 4H_2 \leftrightarrows CH_4 + 2H_2O$$ (+ varme)



Schematic of the in-situ methanation process.

HYDROGEN FROM E-METHANE (2)

E-methane has the potential to significantly increase the overall production of green gas

The first methanation plant was commissioned in November 2023.

Attention to hydrogen slip due to an incomplete methanation reaction has led to:

- A working group between the Danish Safety Technology Authority, Evida, Energinet, and DGC, which should assess which hydrogen concentrations can be recommended and handled in the gas system.
- Gas Storage Denmark was also involved as part of a larger working group.
- There is a request for a hydrogen limit of 1-2% from producers.
- The group assessed the need for a limit as close to 0% as possible.
- Initially, only individual case processing of the first plant.

Methanation:

$CO_2 + 4H_2 \leftrightarrows CH_4 + 2H_2O$ (+ heat)

Risk of hydrogen in methane due to an incomplete reaction

FORMULATED LIMIT VALUES

Energinet, DGC, Evida, and the Danish Safety Technology Authority, has made a joint proposal for rules for hydrogen in the biomethane and e-methane added to the gas network.

The limits are designed so that they:

- Do not affect the operation of existing or upcoming upgrading plants (considering that these are biological processes that can fluctuate).
- Do not discriminate between biomethane and e-methane plants.
- Consider neighboring systems and measurement accuracies.
- The limits have been added to Energinet's terms in the transmission network from 1/10-2024 for transparency.

Hydrogen limit values:

- Normal operation: 500 ppm at the connection point.
- Exceptions:
  - Up to 8 hours ≤1000 ppm.
  - Up to 1 hour <2000 ppm.
- Exceeding these limits will result in a temporary shut-of from the natural gas network.

SYSTEMATIC MEASUREMENT ERRORS

The measurement system cannot measure hydrogen - yet...

Hydrogen that is not measured is implicitly considered methane due to the way the equipment measures. This means:

- An artificially elevated calorific value from biomethane (primary error, depending on hydrogen content).
- Errors in conversion to reference volume (secondary, depending on pressure/temperature and hydrogen content).
- Measurement equipment at BMR stations can be more easily converted to also measure hydrogen.
- This is also possible at the transmission level, but it is neither easy, cheap, nor quick.

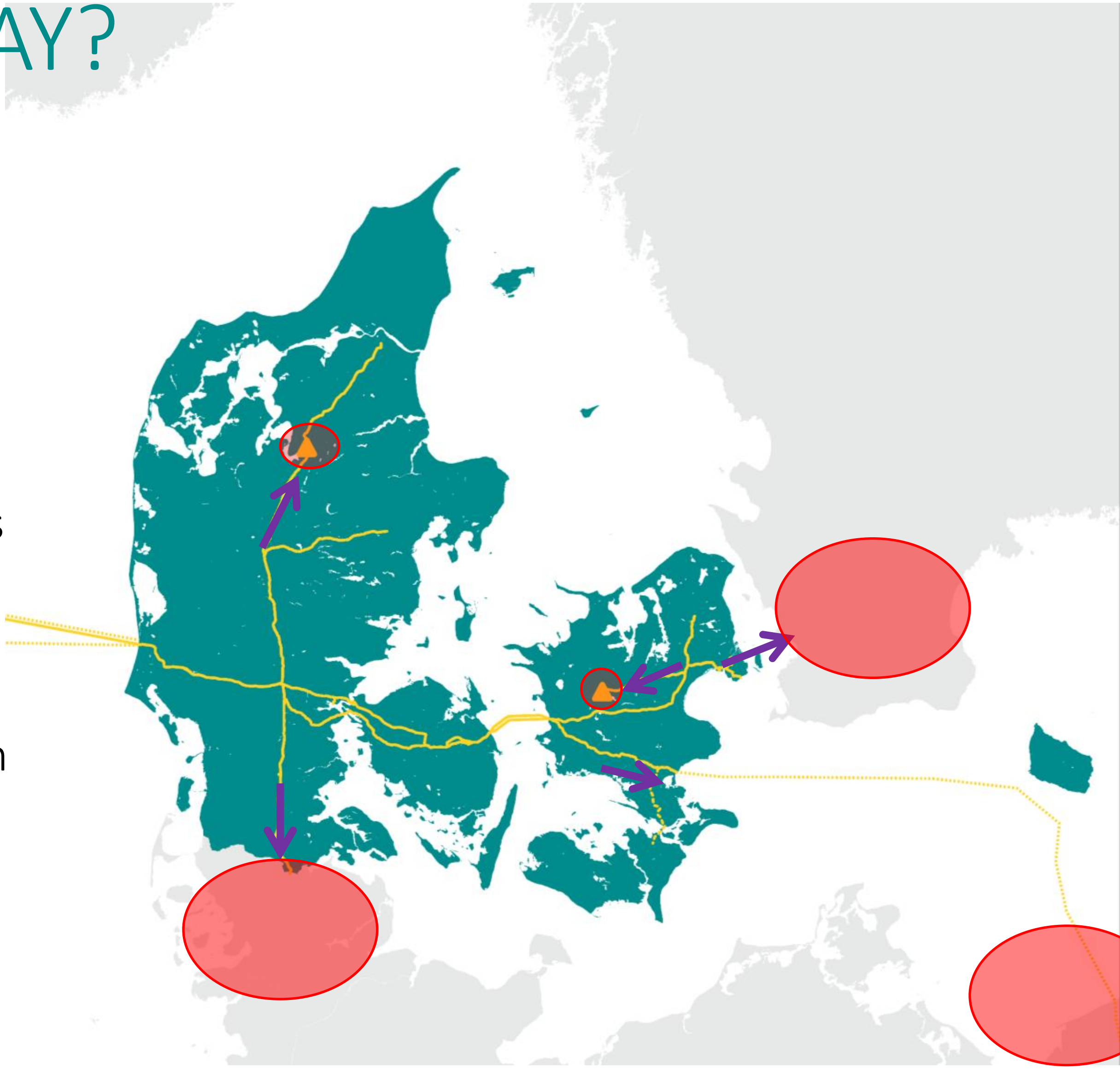
WHAT DO OUR NEIGHBORS SAY?

Hydrogen can pose a barrier to physical flow across system boundaries.

Hydrogen is not mentioned in our neighboring systems' quality specifications and is, in principle, not allowed.

Feedback from neighboring systems on limit values:

- Gas storage: Wants the lowest possible limit but accepts the proposal, desire for a plan for measurement/operational strategy.
- German colleagues: Interested, does not receive biomethane from DK (and thus hydrogen) due to oxygen requirements.
- Swedish colleagues: Interested, but no major concern.
- Polish colleagues: No major concern. Recommendation for annual measurement, e.g., at the border station.



INTERNATIONAL ASPECTS

The EU's hydrogen and gas package sets frameworks for hydrogen content in natural gas across borders.

My interpretation: Implicit goal of 2% hydrogen in the network. Transmission system operators (TSOs) must justify deviation from the requirement upon specific request from a neighboring system (only IPs).

However, there is great uncertainty about how this will be interpreted in practice.

Gas quality standard EN 16726 also points to 2% hydrogen in the methane system.

Consideration for sensitive installations is recognized.

The process for assessment is not yet described.

ENERGINET

SUMMARY - WHAT IS ENERGINET DOING NOW?

INTERNAL CLARIFICATION PROCESS

It is crucial to assess the possibilities, added value, consequences, and costs of different approaches, including permissible hydrogen content.

PREPARATION OF THE MEASUREMENT SYSTEM

"Pilot project" for measuring hydrogen in the methane network decided.

To be carried out in 2025.

Goal is the establishment of hydrogen measurement at 3 locations and gain knowledge.

DIALOGUE WITH NEIGHBORS AND OTHERS

Sweden, Germany, Poland, Gas Storage Denmark, EVIDA, Authorities, Other stakeholders

QUESTIONS

Jesper Bruun Munkegaard Hvid, Energinet - jbr@energinet.dk

Hydrogen network – purity levels and impurities in hydrogen

(Pre-) ennoh

Hydrogen Network – Purity levels and Impurities in Hydrogen

ENTSOG Gas Quality Workshop

27 November, Brussels

ENNOH Foundational Process

- ENNOH – European Network of Network Operators for Hydrogen
  - entity to be established according to the EU H_2 and Decarbonised Gas Market
- Submission of Statutory documents to ACER and DG ENER on the 30th of August.

Q4 2024 – Q4 2025:

- Gas/H_2 Regulation EU/2024/1788 imposes a number of tasks and deliverables for 2025 and 2026, which require preparatory work in 2024/2025 to meet the given deadlines.
- Some tasks have a significant impact on the future development of the hydrogen market
- There are additional tasks/activities following the Energy Infrastructure Forum, and others related to the establishment of ENNOH in Q3 2024.
- Pre-ENNOH to be set up until ENNOH is fully legally operational (around Q4 2025)

Hydrogen Quality in the Regulatory Framework

- **“Hydrogen quality”** means hydrogen purity and contaminants in line with applicable hydrogen quality standards for the hydrogen system *[Article 2, Directive 1789/2024]*

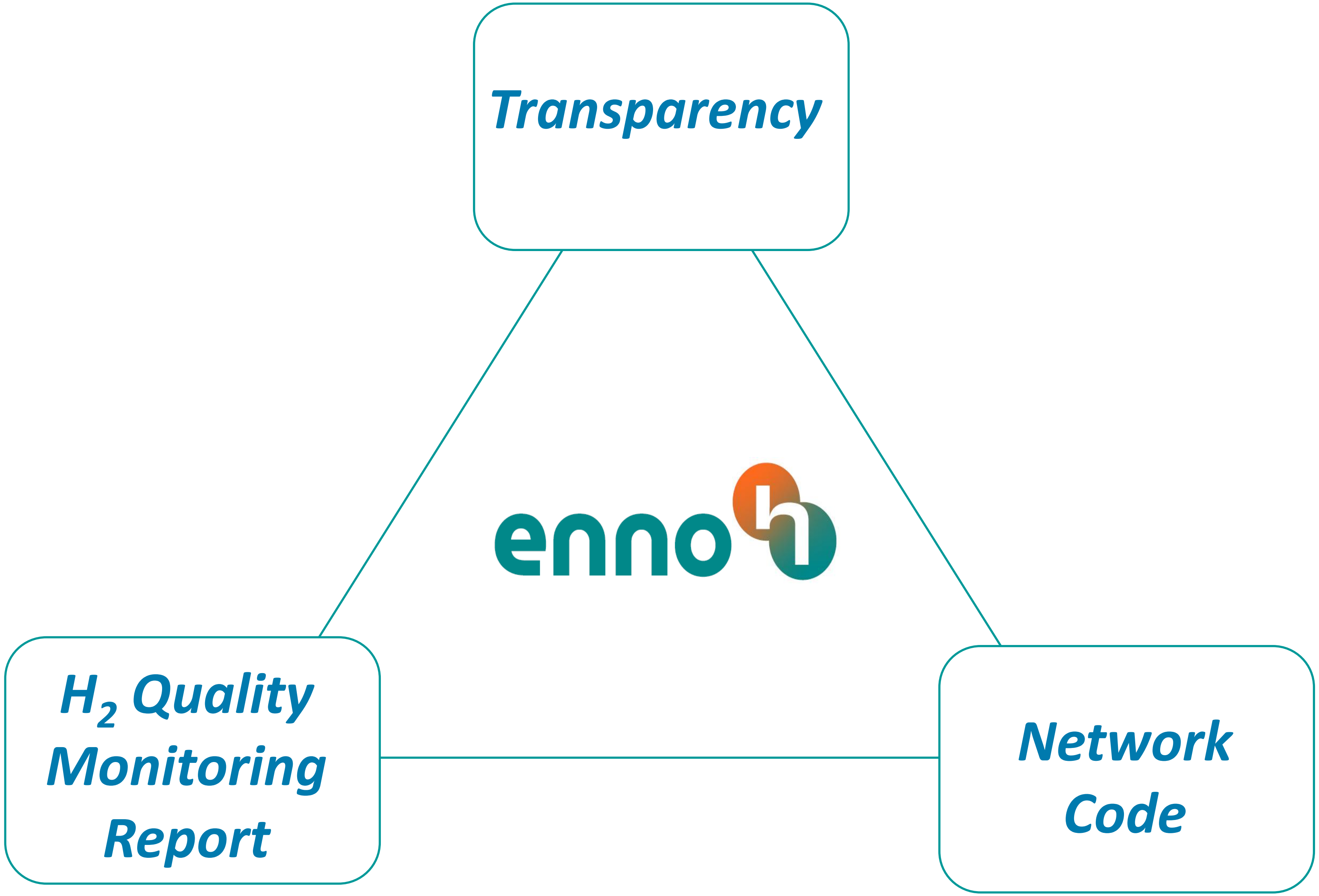
- The **quality of hydrogen transported** and consumed in the Union can vary depending on its production technology and transport specificities. Therefore, **a harmonised approach at Union level to hydrogen quality management** at cross-border interconnectors should lead to the cross-border flow of hydrogen and to market integration *[Recital 90]*

- Where the regulatory authority considers it to be necessary, **HTNOs could become responsible for managing hydrogen quality in their networks**, within the framework of applicable hydrogen quality standards *[Recital 91]*

- A **strong cross-border coordination and dispute settlement process between HTNOs is essential** to facilitate the transport of hydrogen across hydrogen transmission networks within the Union *[Recital 92]*
  - According to *[Article 55],*
    - HTNOs shall cooperate to avoid restrictions to cross-border flows of hydrogen due to the hydrogen quality differences
    - Where restriction cannot be avoided, then the HTNOs, Regulatory Authorities, and ACER will work as described in Article 55 of the Regulation.

- **Technical specifications and standards for the quality of hydrogen** in the hydrogen network should **take into account already existing standards** setting such end-user requirements, for example, the standard EN 17124. *[Recital 99]*

The role of ENNOH in H_2 Quality



Transparency

- Enhanced transparency requirements on hydrogen quality parameters and on their development over time combined with monitoring and reporting obligations should contribute to the proper functioning of an open and efficient internal market for hydrogen. *[Recital 92]*

- The hydrogen network operators **shall make public detailed information regarding the quality of hydrogen** transported in their networks, which might affect network users. *[Article 66]*

- Hydrogen network operators shall publish
  - if relevant for access to the network, for all relevant points, a specification of **relevant hydrogen quality parameters** and the liability or **costs of conversion for network users** where hydrogen is outside those specifications *[Annex 1, point 4.2]*

  - measured values of the **hydrogen purity and contaminants** at all relevant points, on a daily basis. Preliminary figures shall be published at the latest within three days. Final figures shall be published within three months after the end of the respective month *[Annex 1, point 4.3]*

→ These **data on H_2 purity and contaminants** shall be made **available from 1 October 2026** on one Union-wide **central platform, established by the ENNOH** on a cost-efficient basis. *[Annex 1, point 4.1]*

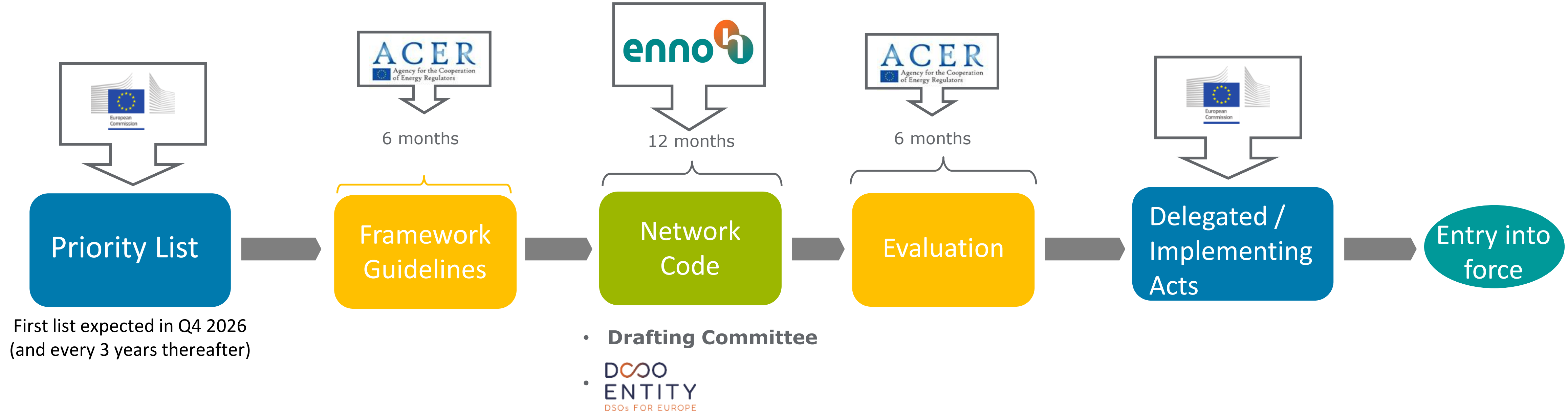
Network Code on Hydrogen Interoperability

[Article 66] The **Network Code on Interoperability** will address:

- **interconnection agreements**:
  - units
  - data exchange
  - transparency
  - communication
  - information provision and
  - cooperation among relevant market participants
- **hydrogen quality**:
  - common specifications at interconnection points and standardisation,
  - odorisation,
  - cost benefit analyses for removing cross-border flow restrictions due to hydrogen quality differences
  - reporting on hydrogen quality

The ENNOH shall monitor and analyse the implementation of the Network Codes. ENNOH will report to ACER.

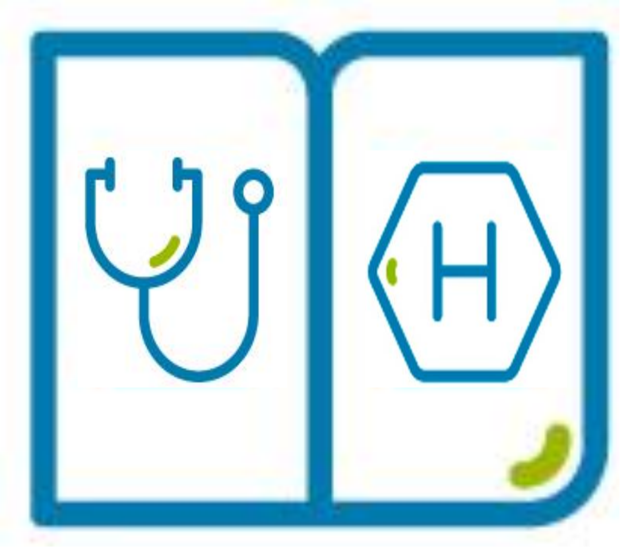
Network Code Development Process



Drafting Committee: it will include representatives from ACER, ENTSOG, ENTSOE, if appropriate the EU DSO Entity, and a limited number of affected stakeholders

Hydrogen Quality Monitoring Report

- **ENNOH will adopt a** Hydrogen Quality Monitoring Report **by 15 May 2026** and every two years thereafter. *[Article 59]*
  This report will include:
  - developments and forecasts for the expected developments of hydrogen quality parameters,
  - information on cases related to differences in hydrogen quality specifications and how such cases were settled



The **EU DSO entity shall provide input to the ENNOH for the Hydrogen Quality Monitoring Report** with regard to the hydrogen distribution networks where hydrogen distribution network operators are responsible for hydrogen quality management *[Article 41]*

(Pre-) ennoh

Hydrogen Network – Purity levels and Impurities in Hydrogen

ENTSOG Gas Quality Workshop

27 November, Brussels

WHEN TRUST MATTERS

DG ENER: Technical Assistance on Hydrogen Quality Standardization

Gas Quality Workshop - 27 November 2024

Johan.Knijp@dnv.com - DNV Technology Centre Groningen

Towards harmonized standards and certification processes

To stimulate traceability, transparency and market access across the hydrogen value chain

- Production and use of **renewable hydrogen** and its derivatives is a means to achieve climate neutrality

- The EU has **set the rules** for domestic and imported hydrogen in Europe through the Delegated Acts and REDII

- Standards are the **silent foundations of a single market**
  - **Ensure trust:** crucial element in establishing a liquid hydrogen market
  - **Promote trade:** (cross border, global) - interoperability
  - **Uniformity**: Provide common reference points for all firms along the value chain
  - **Conformity** in product use for off-takers

Hydrogen Commoditization

Connecting markets, regions and stakeholders along the value chain

- **Unified Metrics**:
  - mass (kg), energy (kWh) or volume (m^3) ?
- **Proof of Sustainability:**
  - grey, blue, green ?
- **Product Quality specification**:
  - 98%, 99,5% or 99,97% purity?
  - Allowable trace components?

Hydrogen Quality Standardisation challenge

How to specify hydrogen quality?

Minimum hydrogen purity level (example)

- Production
- End-users 1
- Infrastructure
- Storage
- End-users 2

Other product characteristics to agree on:

- Wobbe number
- Impurities
- Pressure
- Temperature

Projects leading the way

Finished

- **European Clean Hydrogen Alliance - Roadmap on hydrogen standardization**
  - Delivered March 2023 - Link

Execution

- **DG ENER (C2I2023-397) - Technical assistance on hydrogen quality standardisation request**
  - Contractors: LBST, DNV, DBI GUT and Trinomics
  - Execution April 2024 – March 2025
- **EASEE-gas: “Optimal hydrogen purity for the European market"**
  - Contractors: DNV/ KIWA
  - Startied October 2024

Starting

- **DG ENER: HyQual Net**
  - contractors: DVGW, DIN and Danish Standards
  - Start November 2024, duration of 12 months

DNV

Technical assistance on hydrogen quality standardization in the EU

DG ENER (C2I2023-397) - Project summary

EU Context:

- Harmonisation of hydrogen gas quality by standardisation is a pivotal element in **creating a common gas market** in the European Union.
  - cross-border traded
  - dedicated hydrogen infrastructure
  - along the whole hydrogen supply chain.
- Commission aims to support the ongoing standardisation activities on national, European, and international level
- **Standardisation request:** DG ENER is preparing a proposal to CEN/CENELEC to develop standards for the quality of gaseous hydrogen in the hydrogen network

Project status:

- Execution April 2024 – March 2025
- Phase 1: Existing data en information base
- Phase 2: Stakeholder consultation
- Phase 3: Techno-economic analyses

LBST DNV DBI GUT Gas- und Umwelttechnik GmbH

Phase 1: Existing data en information base

1. **98 mol-% H_2**

   DIN CEN/TS 17977

   EASEE-gas Common Business practice

   ISO/DIS 14687 Grade A

2. **99.5 mol.-% H_2**

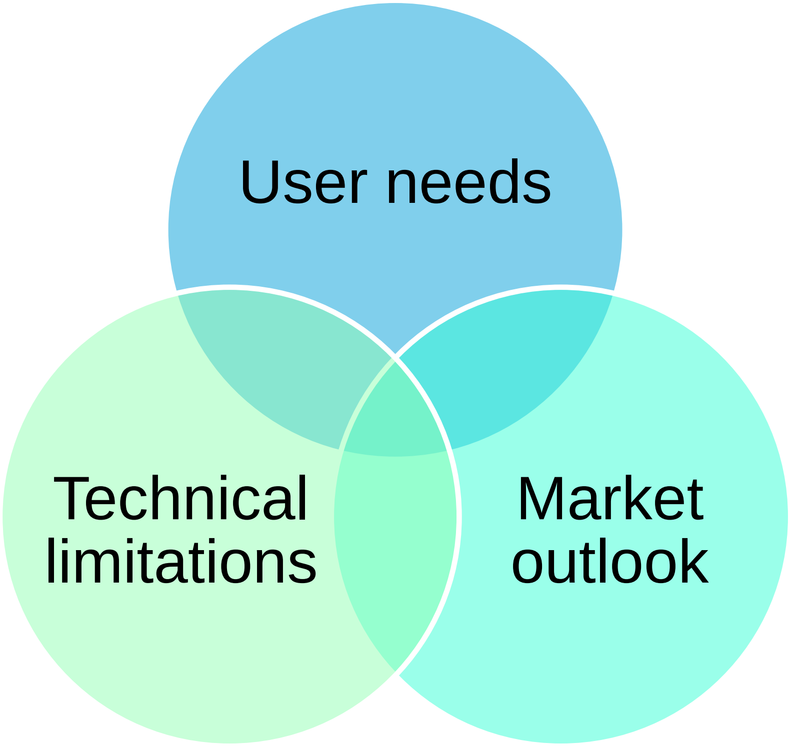
   Indicative quality specification Hydrogen Network Netherlands

3. **99.97 mol.-% H_2**

   ISO/DIS 14687 Grade D

Phase 2: Stakeholder consultation

- Intensive stakeholder consultation to create a broad perspective
  - 50+ reactions – ongoing
  - Divided into six stakeholder groups
    - ➢ End-use, Production, Storage, Transmission
    - ➢ Associations, Standardization bodies
  - Proactive involvement
  - Detailed answers



Thanks for your attention

Johan.Knijp@dnv.com
+31 6 50 26 24 10

www.dnv.com

DNV

EISMEA H2Qual Net

in the context of EISMEA call SMP-STAND-2024-ESOS-01-IBA Topic 10 Hydrogen quality in dedicated gaseous grids, May 2024/approved July 2024

Joint project of DIN and Danish Standards (DS)

EISMEA H2Qual Net – Hydrogen quality in dedicated gaseous grids – **Topics and objectives**

Hydrogen quality topics in the project:	Objectives

(1) Leakage detection and monitoring
   (1) with and without odorisation for safety
   (2) for emission reduction

(2) Odorants without sulfur

(3) Safety protocols and technical leakage and explosion prevention, measurement and management procedures

(4) Purification

(5) Hydrogen quality parameters*

Objectives

– Facilitating and speeding up the CEN standardisation on the project topics by PNR and technical preparations

– Identifying all relevant stakeholders

– Promoting their participation in the following standardisation process.

*overlap with the current EC project on H2 quality standardisation, in process with Ludwig-Bölkow-Systemtechnik (LBST), DNV, DBI GUT and Trinomics and ending in May 2025. The project partners are in exchange to benefit from each other and come to most efficient results.

EISMEA H2Qual Net – Hydrogen quality in dedicated gaseous grids - **The Tasks and procedures**

a. Elaboration of a **standardisation landscape and needs**

b. Analysis of research, laboratory results and real experiences with focus on relevance for the standardisation

c. Drafting of **detailed scopes and technical specifications** as basis for the further standardisation in CEN-CENELEC

d. Organisation of **two Workshops** (one at the beginning and one towards the end of the project) to involve all relevant stakeholder in the process and motivate them to join the further standardisation process.

- **for b (Analysis) and partly c (purification, odorants, safety protocols …) calls for tender are** foreseen (preferably) before end of 2024;

- **Evaluation Committee will decide on the tender applications.**

EISMEA H2Qual Net – Hydrogen quality in dedicated gaseous grids - **The expected results**

a. Documentation of **Standardisation landscape and standardisation needs**

b. **Technical reports on each topic** as basis for the elaboration of draft scopes and technical specifications and for further CEN standardisation

c. **Draft scopes and draft technical specifications** as basis for further CEN standardisation

d. **Network building and preparation of the further CEN standardisation** in the Workshops

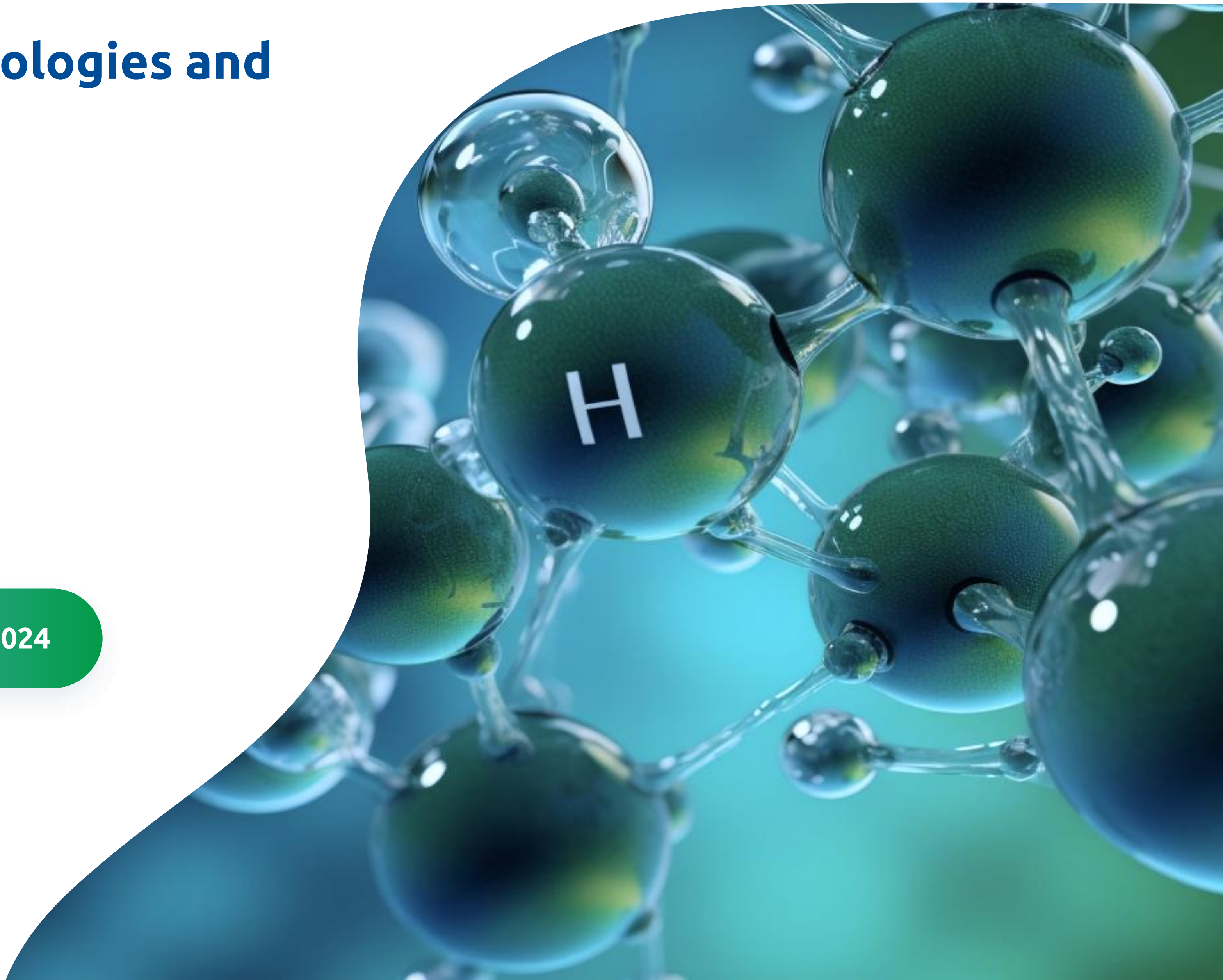
Potential responsible CEN/CENELEC Technical Committees should be involved in the project.

Contact

Hiltrud Schülken
DIN NAGas
hiltrud.schuelken@dvgw.de
Mobil: + 49 172 7852138
Festnetz: + 228 9188 905

Hydrogen impurities

according to production technologies and prioritization of their analysis



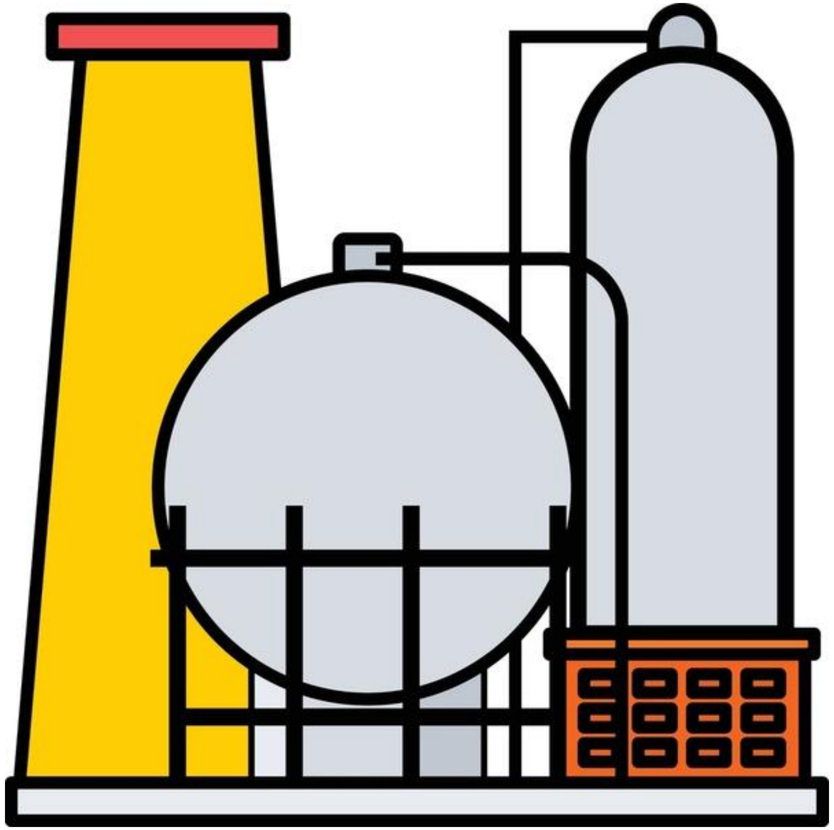
Alejandra Casola

ENTSOG Gas Quality Workshop - 27 Novembre 2024

Specifications EN TS 17977

Parameter	Unit	Value	Reference standards for test methods (informative)
Hydrogen	mol-%	≥ 98	DIN 51894
Wobbe Index	MJ/m^3 (15 °C/15 °C)	42,0 – 46,0	
The content and composition of the further quality parameter (e.g. sum of inerts) shall satisfy the Wobbe Index value above.			
Water	mg/m^3	≤ 200 ≤ 50[a]	ISO 21087
Hydrocarbon dew point (HCDP)[b]	°C	< −2 °C at 1 < p < 70 bar	ISO 21087
Sum of inerts (N_2, He, Ar)	mol-%	≤ 2	ISO 21087
Gaseous hydrocarbons[b]	mol-%	≤ 2	ISO 21087
Oxygen (O_2)[c]	mol-% µmol/mol	≤ 0,1[d] ≤ 10	ISO 21087
Carbon monoxide	µmol/mol	≤ 20	ISO 21087
Carbon dioxide	µmol/mol	≤ 20	ISO 21087
Total sulfur[b]	mg/m^3	≤ 10[e]	ISO 21087
Ammonia	mg/m^3	≤ 10	ISO 21087
Halogenated compounds	mg/m^3	≤ 0,08	ISO 21087

Steam Reforming (SRM)

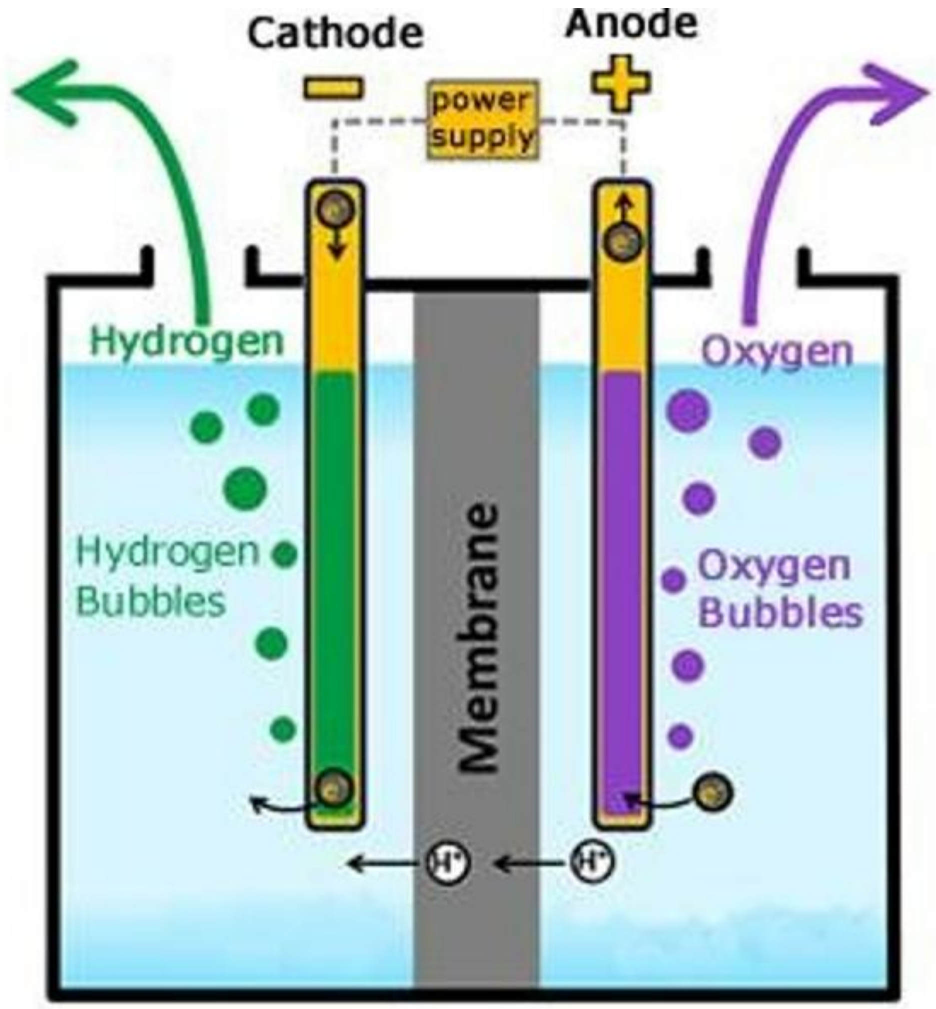


Possible impurities:

- **Carbon monoxide:** in the syngas produced in the process
- **Nitrogen:** from the raw material (natural gas)
- **Argon:** from the raw material (natural gas)
- **Methane:** from the raw material (natural gas)
- **Ammonia:** reforming reaction itself
- **Water:** could be present in the syngas
- **Carbon dioxide:** in the reforming and gas shift reaction
- **Sulfur compounds:** from the raw material (natural gas)
- **Halogenated compounds:** possibly present in the raw material
- **Hydrocarbons (C>2):** possible present as trace amount from raw material
- **Oxygen, helium:** not present in the raw material

Water PEM electrolysis

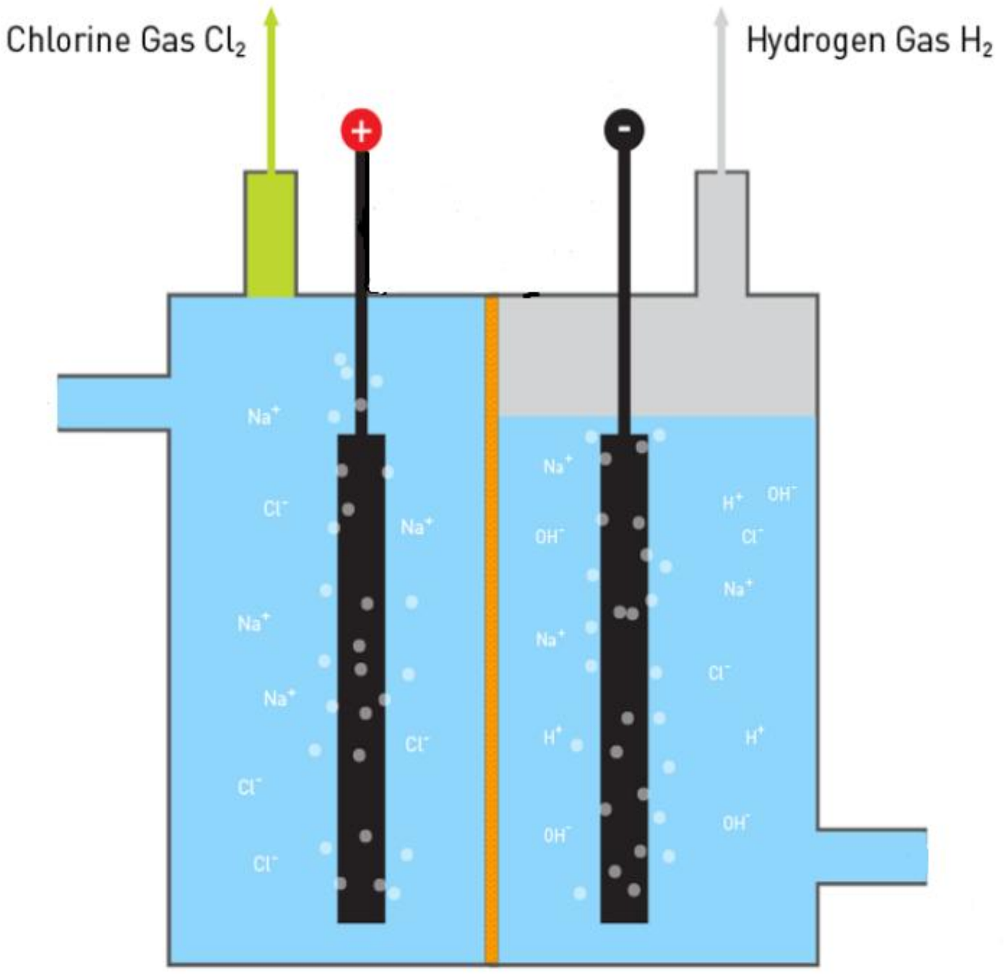
energy
to inspire the world



Possible impurities:

- **Nitrogen:** air intake and use as purging/inerting/actuating gas
- **Water:** reactant in the electrolysis process
- **Oxygen:** generation at the anodic side of the cell stack
- **Carbon dioxide:** tap water or air in the pure water tank
- **Ammonia:** from tap water used at the anodic side
- **Halogenated compounds:** tap water
- **Sulfur compounds:** potential release from material gaskets
- **Helium, CO, hydrocarbons):** completely absent in the production process

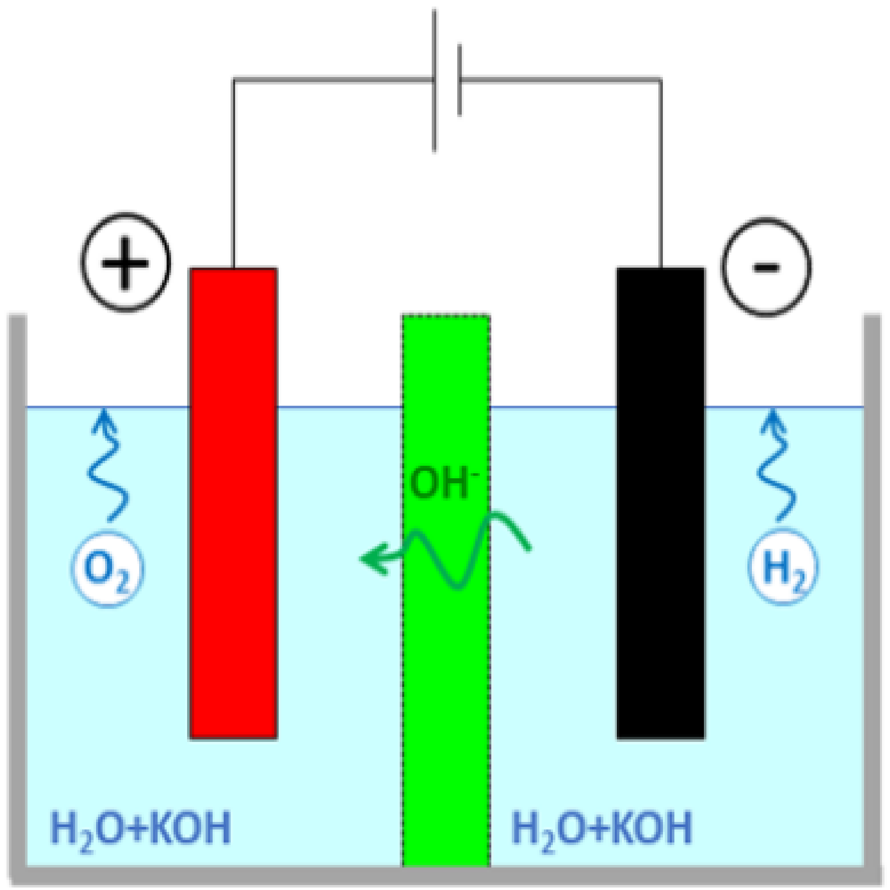
Chloro-alkali membrane electrolysis



Possible impurities:

- **Oxygen:** can be present in the process
- **Water:** reactant present in the process
- **Nitrogen:** used for safety in the process (to avoid air in the system)
- **Carbon dioxide:** could be formed from oxidation of organic matter in the brine
- **Argon:** contaminant in nitrogen used for purging
- **Halogenated compounds**: presence of chlorine
- **Helium, CO, sulfur compounds, ammonia, hydrocarbons):** completely absent of the production process

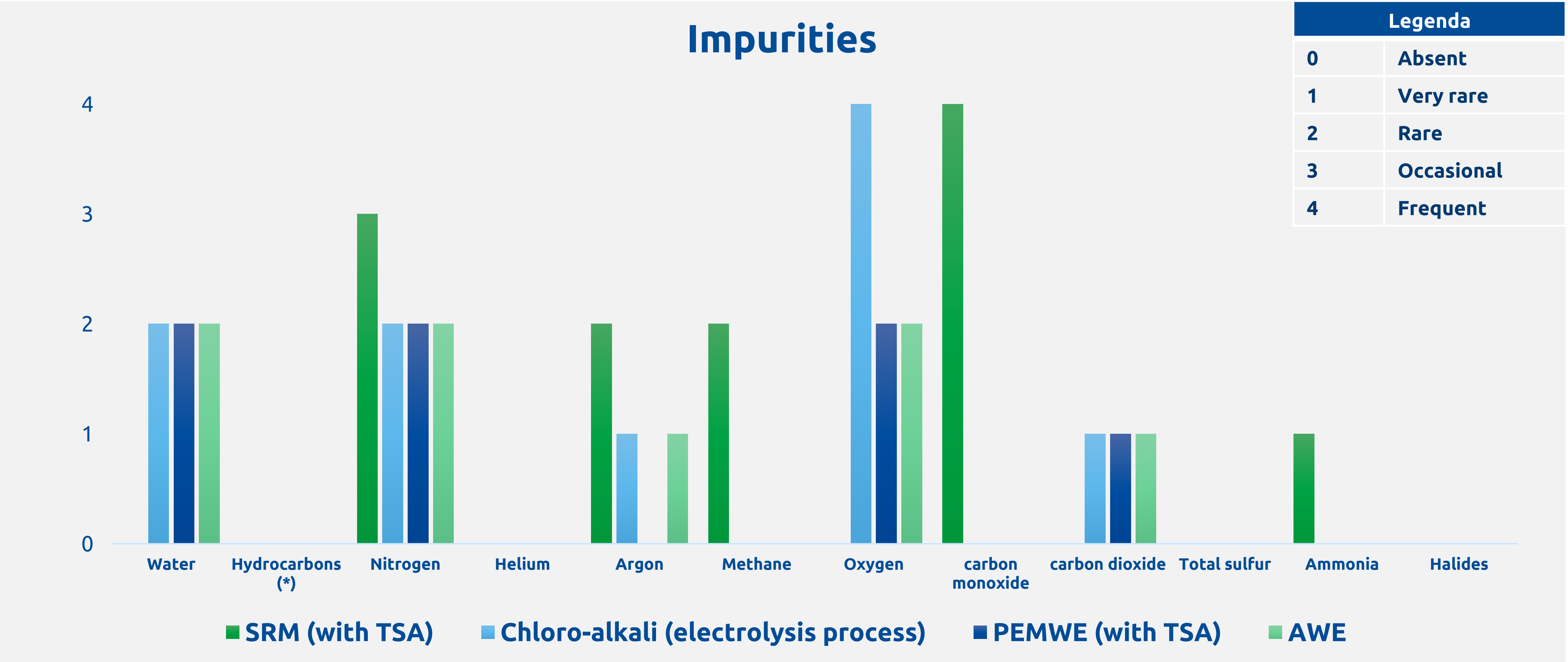
Alkaline electrolysis



Possible impurities:

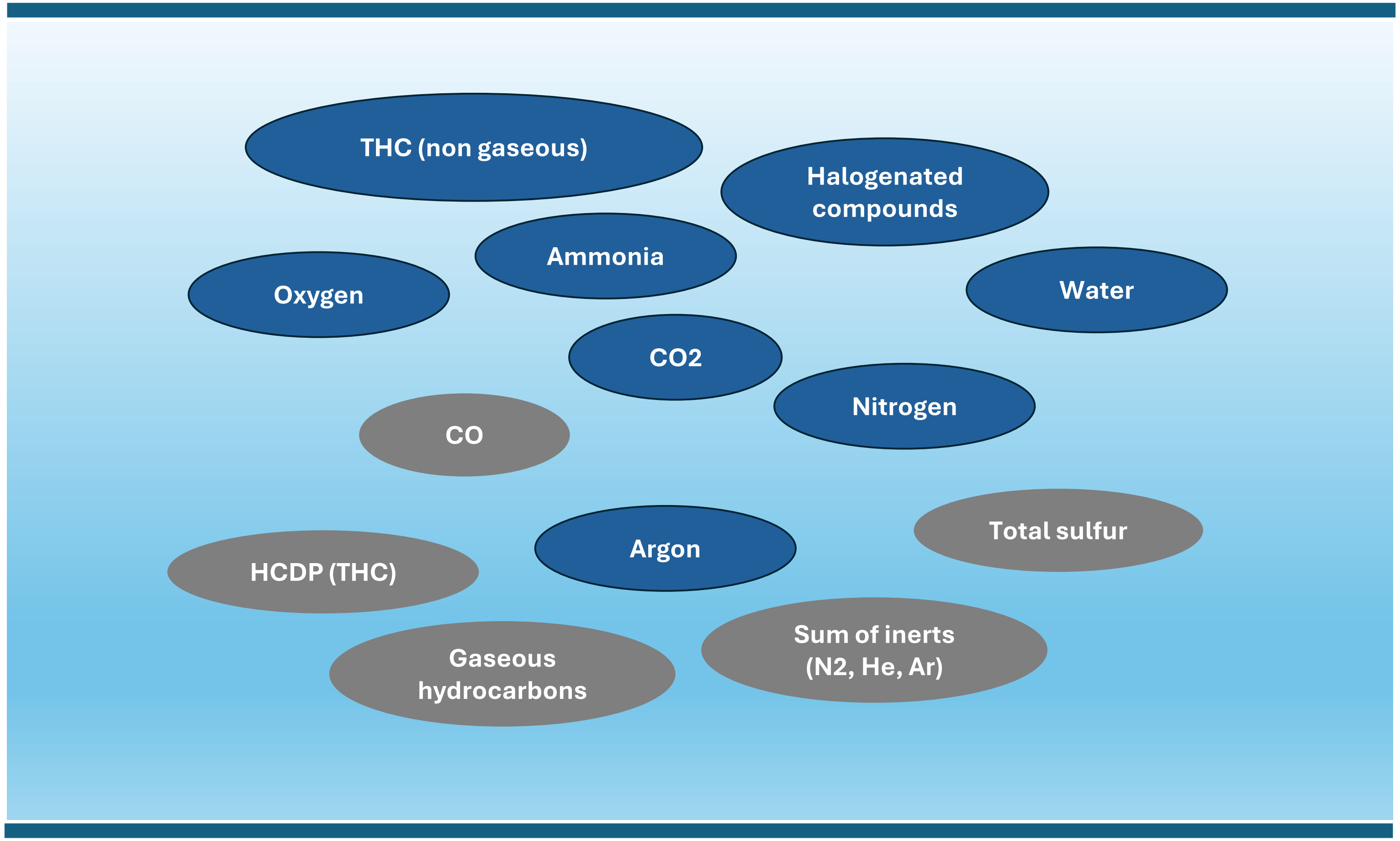
- **Nitrogen:** purge gas, from insufficient purging after shutdown
- **Oxygen:** generation at the anodic side of the cell stack
- **Water:** reactant in the electrolysis process
- **K+, Na+:** KOH, NaOH are electrolytes commonly used
- **Argon:** contaminant in nitrogen used for purging

Probability of occurrence of impurities



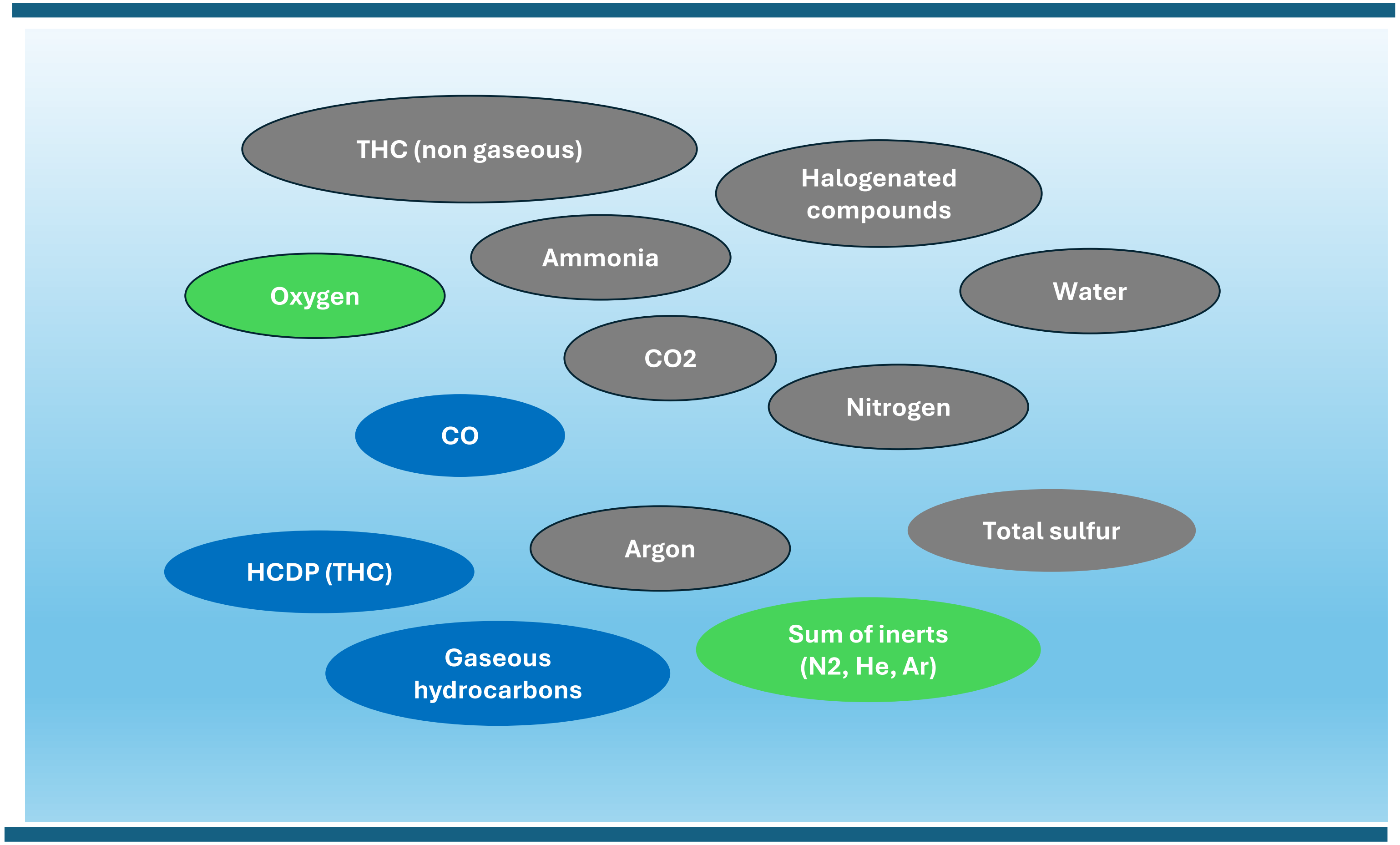
Legenda	
0	Absent
1	Very rare
2	Rare
3	Occasional
4	Frequent

Analytical technique



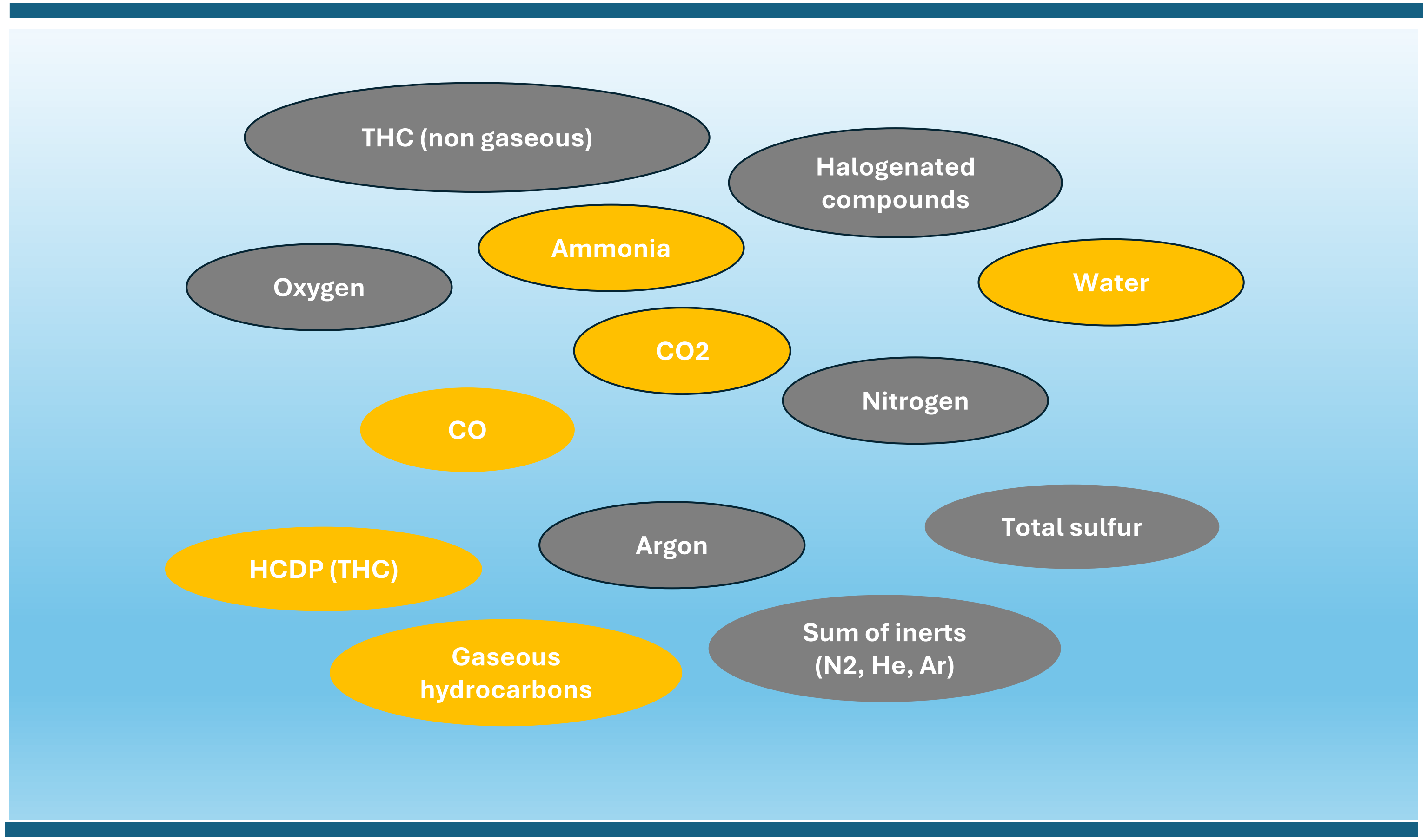
GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Analytical technique



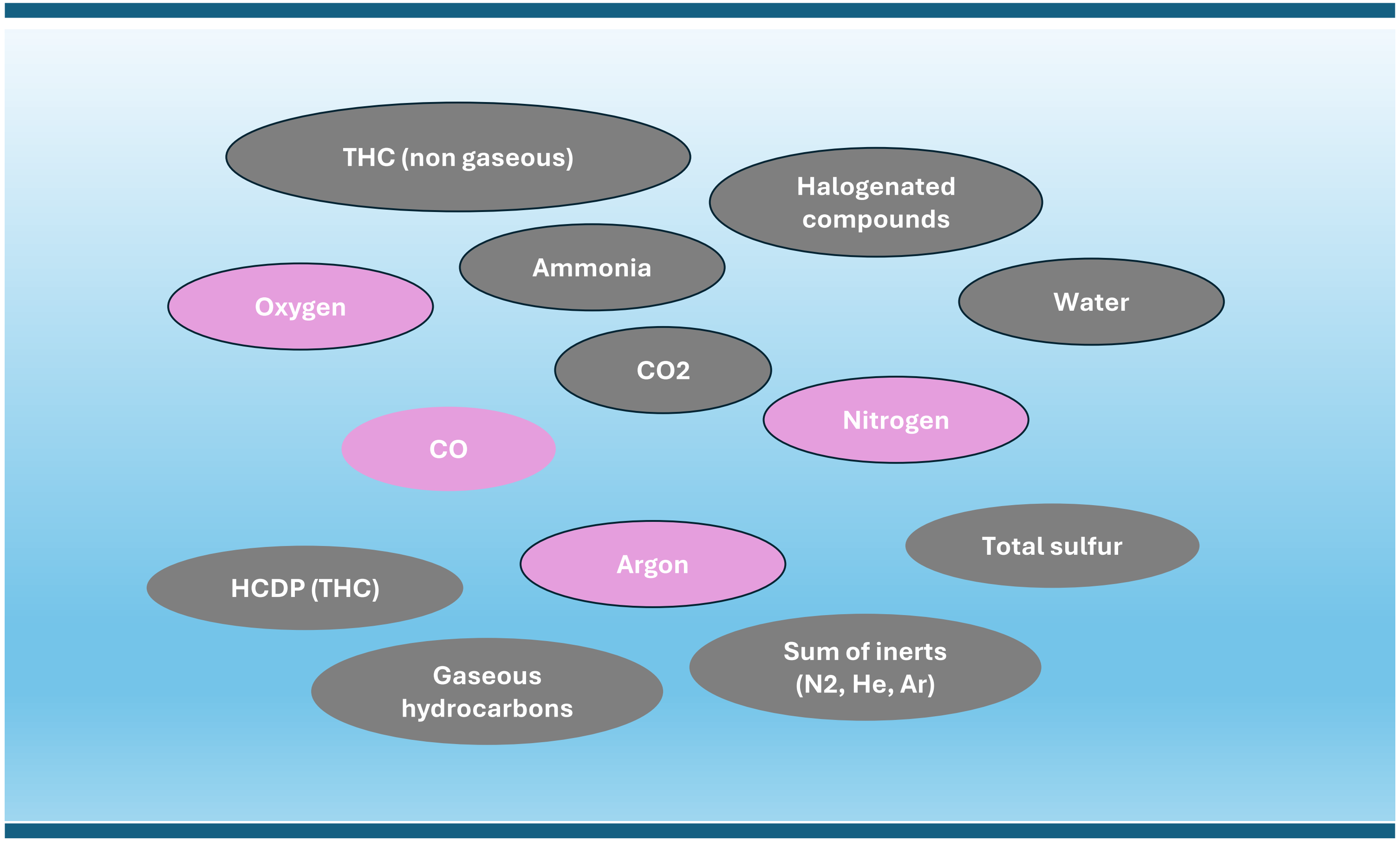
GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Analytical technique



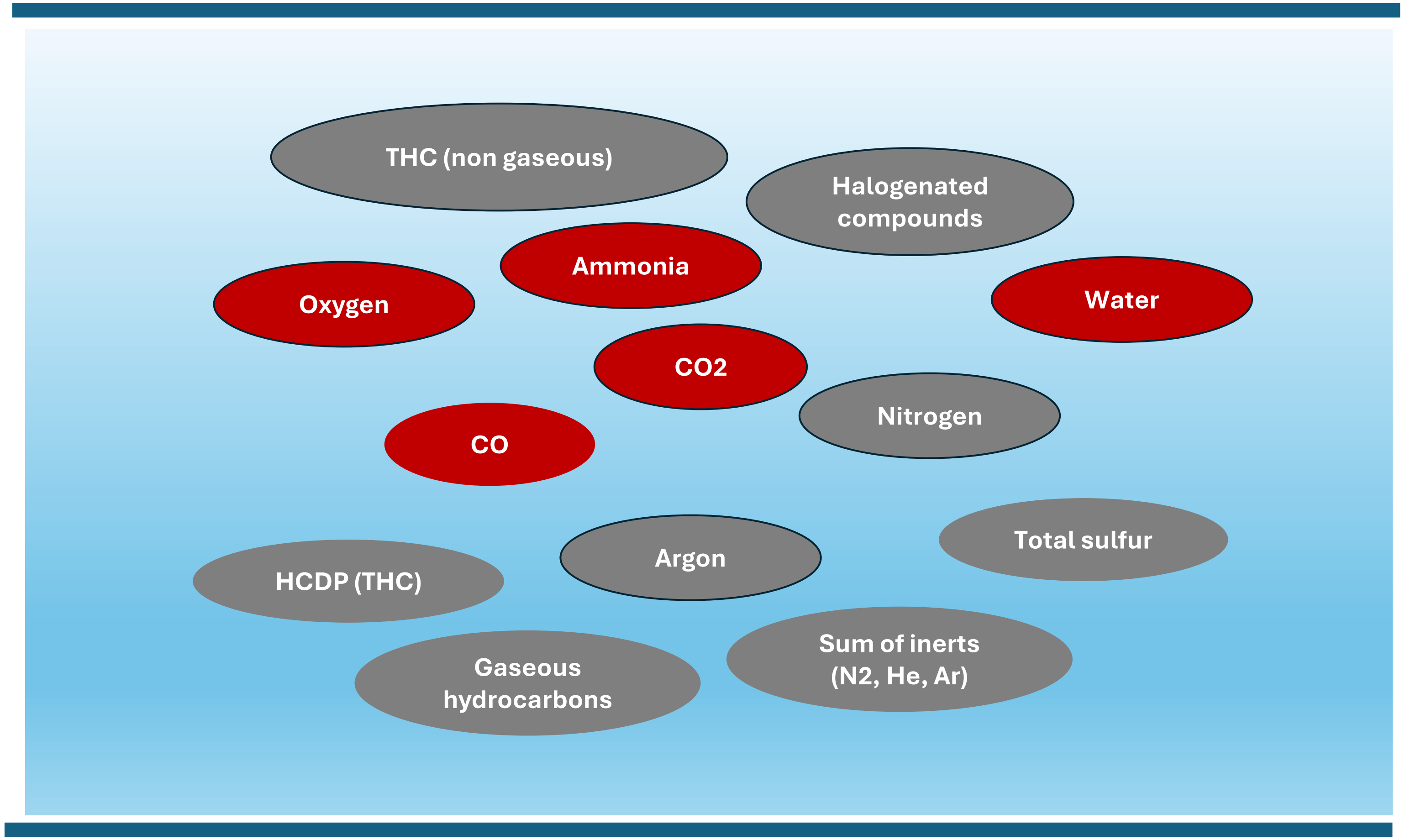
GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Analytical technique



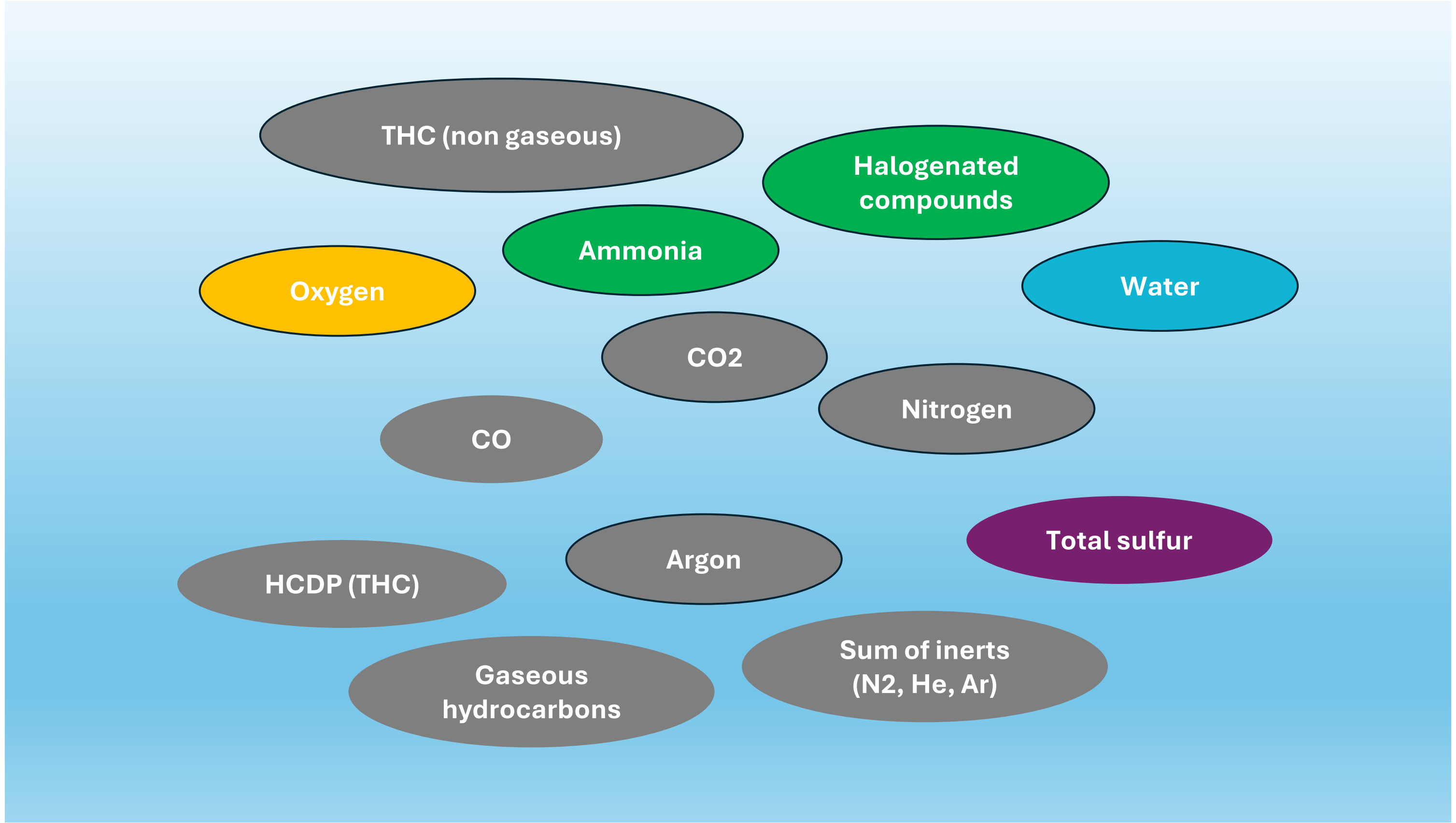
GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Analytical technique



GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Analytical technique



GC/MS (with jet pulse injection/preconcentrator)
GC/FID (with /without methanizer)
GC/TCD
FTIR
GC/PDHID (Pulse discharge helium ionization detector)
CRDS (cavity ring down spectroscopy)
Electrochemical sensor
Chilled mirror hygrometer
Quartz crystal microbalance
Capacitance
IC (with or without impinger sampling device)
GC/PFPD (with preconcentrator)
GC/SCD (with preconcentrator)

Conclusions

Conclusions

- ❑ Impurities present in the hydrogen depend on the production technology and on the purification step.
- ❑ The probability of contaminant presence, based on risk assessment, will provide a first approach to develop an analysis plan for the monitoring

Bibliography

- ❑ Probability of occurrence of ISO 14687-2 contaminants in hydrogen (International Journal of hydrogen energy 43 (2018) 11872-11883)
- ❑ CEN TS 17977
- ❑ EN 17124
- ❑ ISO 21087

Thank you for your attention

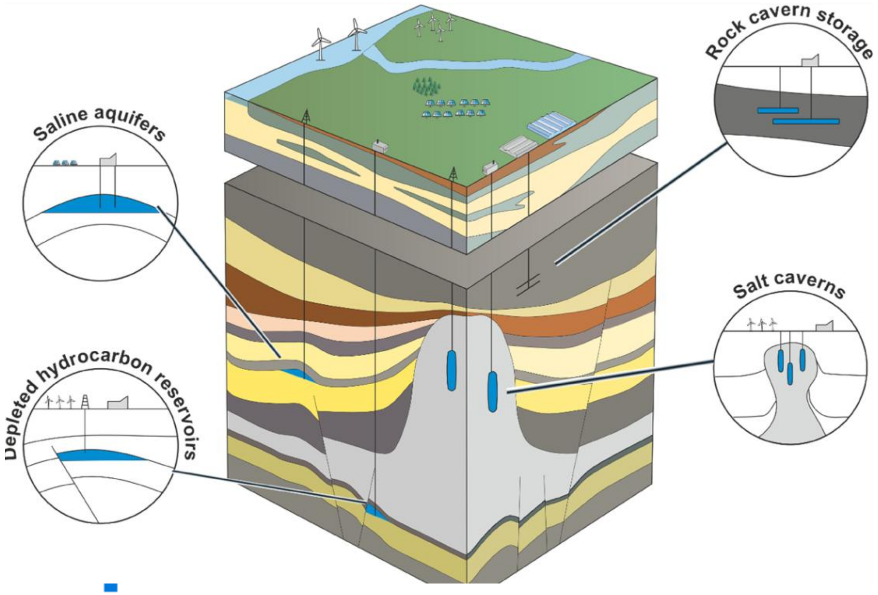
Alejandra Casola
alejandra.casolalopez@snam.it

Hydrogen Purity Requirements
The SSO Perspective
ENTSOG Workshop, Brussels Nov. 27th. 2024

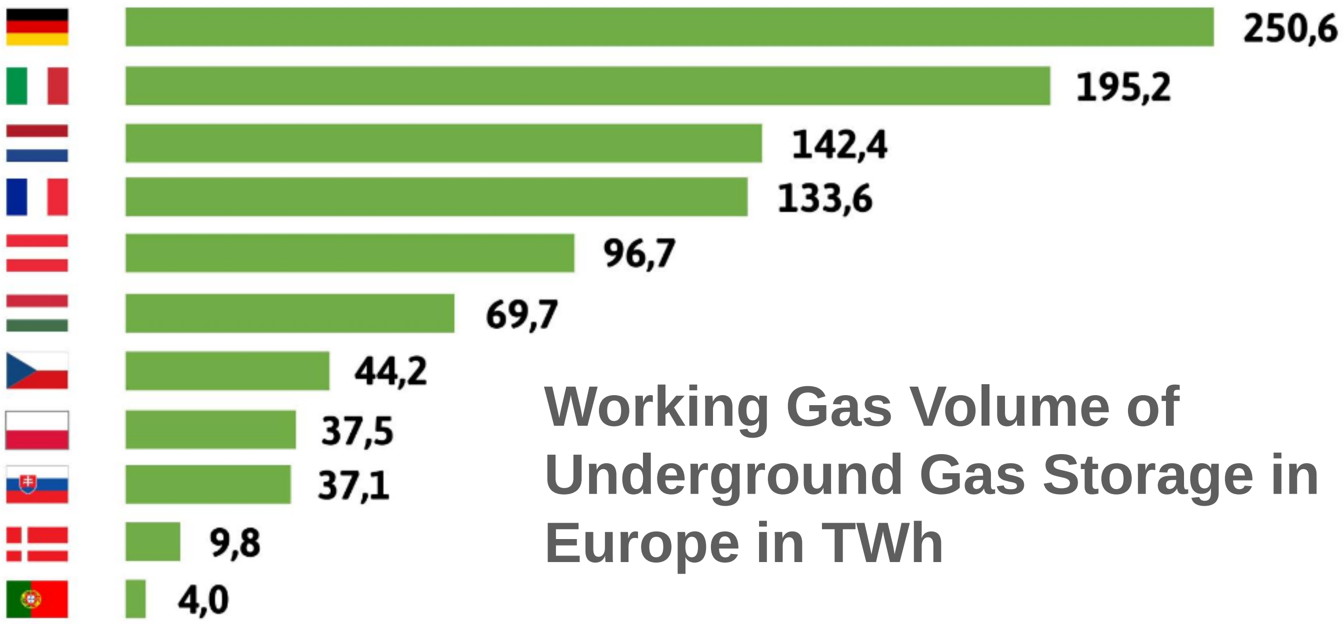
Dr. Ulrich Duda, Uniper Energy Storage

25% of EU`s Gas demand can be stored in Underground gas Storage facilities in Europe

- > 30 Underground Gas Storage Operators (SSOs) operate Underground Gas Storage sites in 19 countries in Europe with a total WGV of > 1100 TWh
- 175 TWh (ca 15 %) of the gas storage capacity are cavern storage facilities



Source: adapted from Griffioen *et al.* (2014).

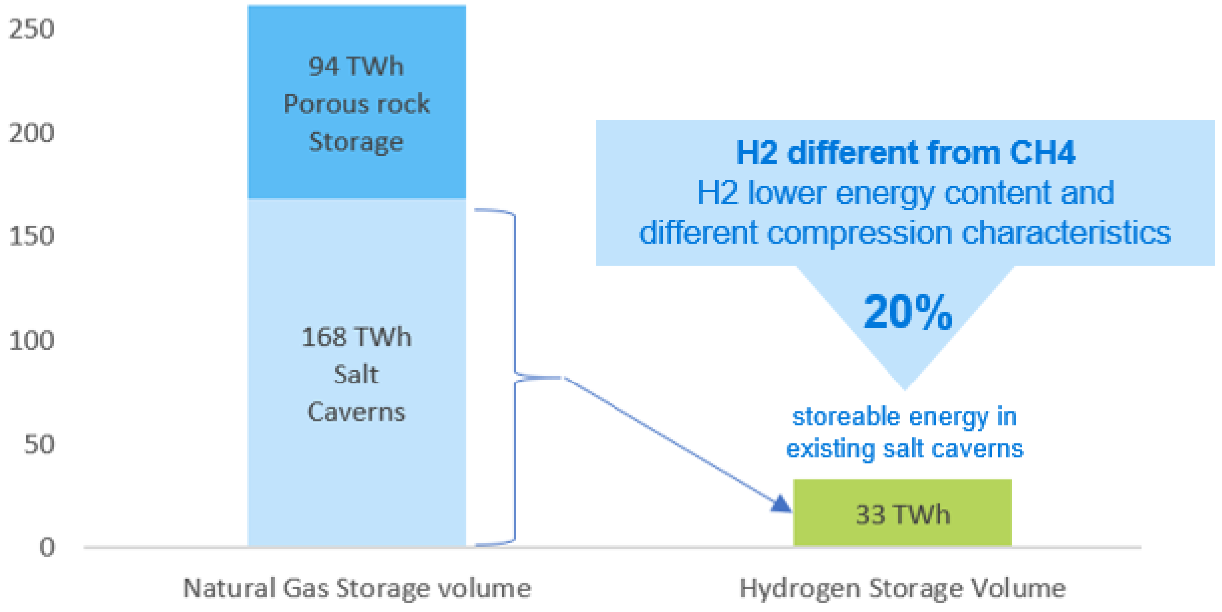


Source: GIE AGSI+,

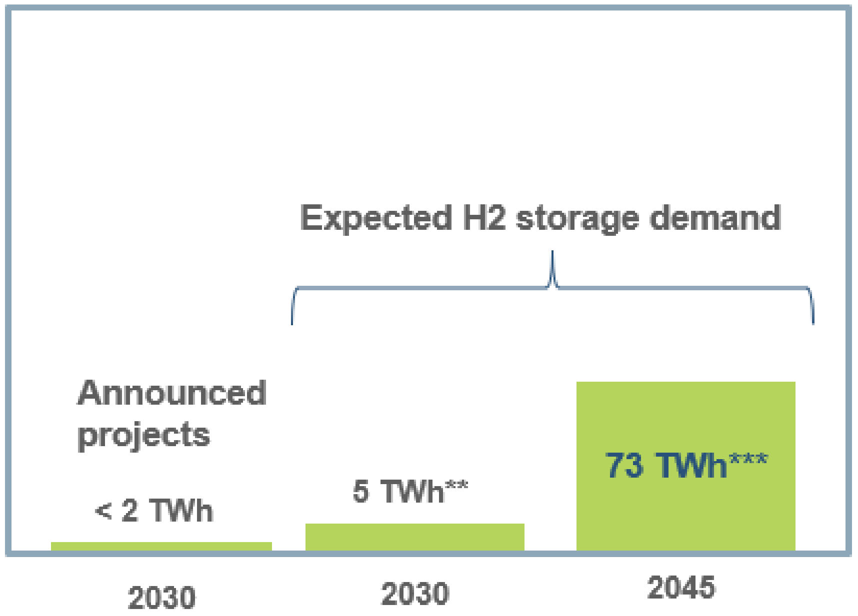
Working Gas Volume of Underground Gas Storage in Europe in TWh

Hydrogen storage demand to exceed available capacity

Suitable H2 storage volume in existing German sites*



Announced H2 storage projects and H2 storage demand in Germany



Source: BMWK Long Term Scenarios

Trajectory of underground hydrogen storage developments: 2030 and beyond

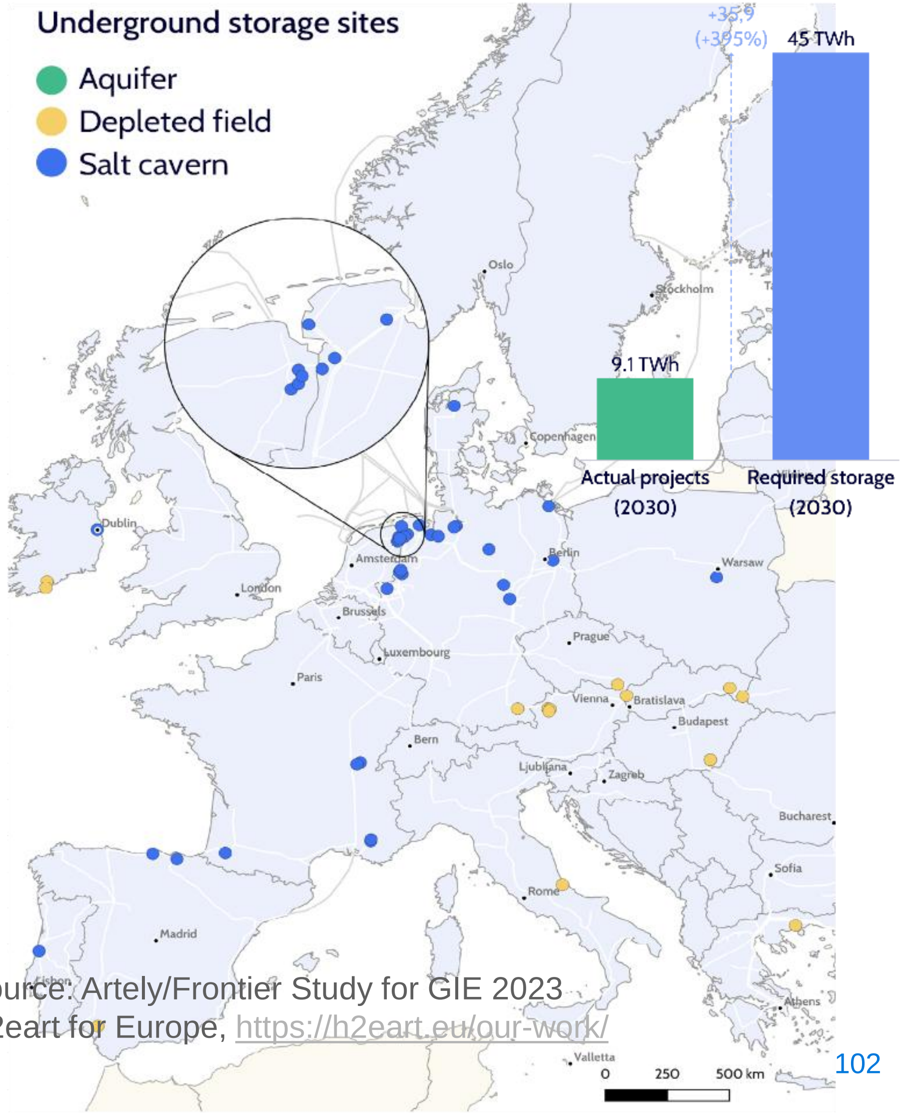
» Storage projects are already being developed across Europe with **9.1 TWh of pure-hydrogen storage capacity** in the pipeline **for 2030.**

» Around **45 TWh** of storage would be **required** to tap into the benefits for the energy system, resulting in a **gap of 36 TWh in 2030 - 2035?**

» **Conversion and extension** of existing salt cavern storage sites **is unavoidable in a first step.**

» **Expansion of surface installations** is locally **hardly limited by legal/environmental requirements** and requires legal prioritisations and exemptions.

» **New build and conversion of porous rock/aquifer will be needed in addition in the long term** (especially in Europe without suitable salt formations).



Source: Artely/Frontier Study for GIE 2023
H2eart for Europe, https://h2eart.eu/our-work/

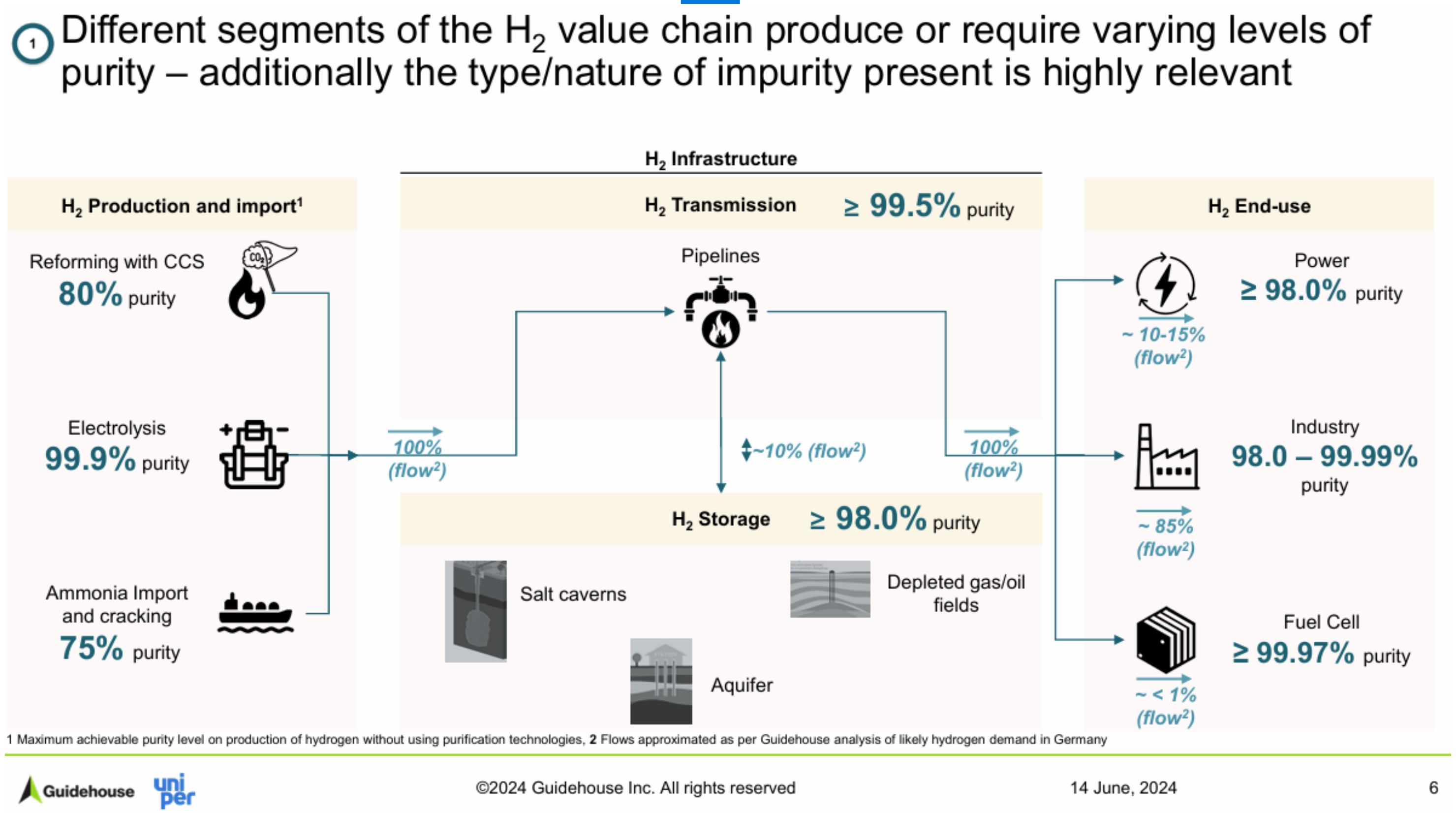
Main H2 Purity Challenges at Converted Gas Storages

- Hydrocarbons (short chain):
  - Complex and space and energy consuming treatment technology required; lossy process and tail gas implications.
  - Legal permission require exemptions, prioritisations and legal/regulatory adjustments.
  - Required surface areal extensions often limited or impossible at existing sites.
- Sulphur: H_2S due to microbiological activities (mainly in porous rock facilities)
- High purity requirements (>98%) cannot be achieved with current knowledge by the storage facilities (large-scale) according to current knowledge

uniper

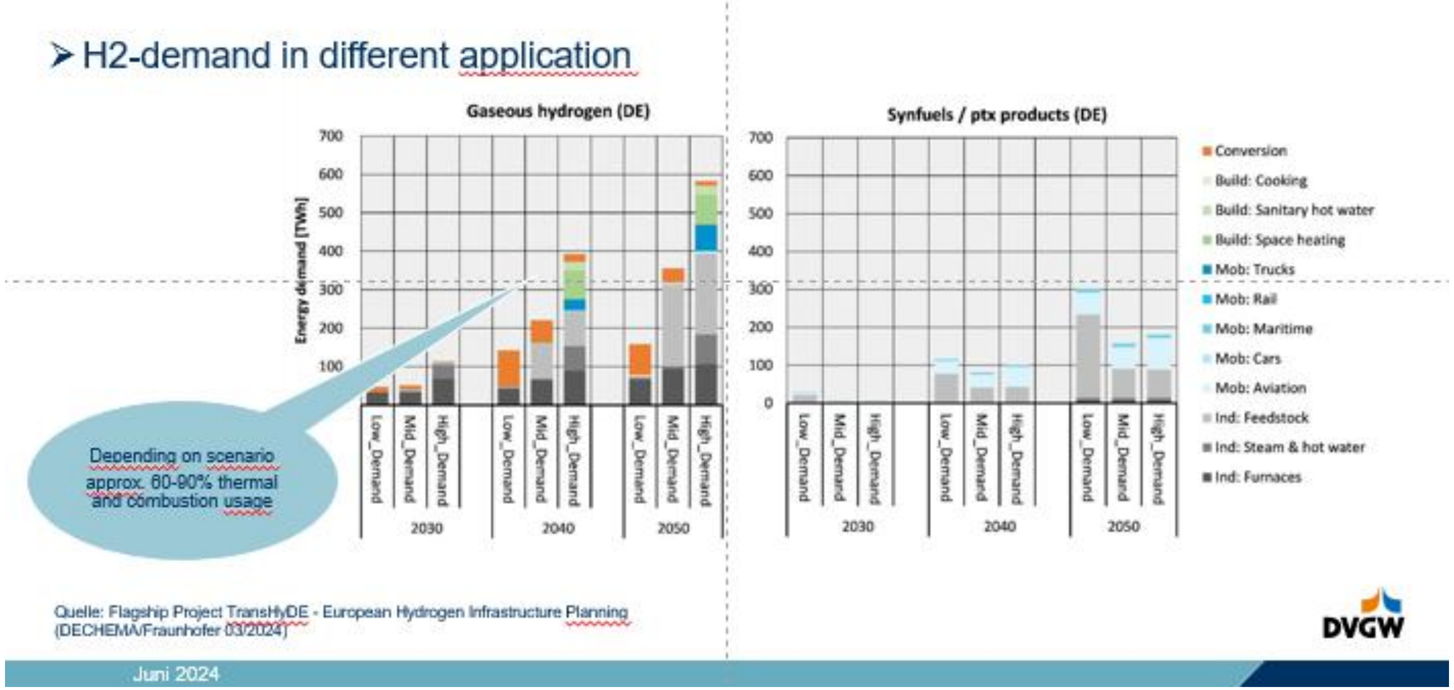
Challenge: efficient transition from CH4 to H2 storage

- H2 Storage are expected to churn ~10% of annual demand
- Converted storage sites require new purification plants to achieve ~99,5%
- Purifcation at this level stays challenging and costly: Limited areal space; legal environmental obligations; technical constraints; high energy consuming and related emissions



Which H2 quality is needed in which quantity?

- H2 quality needs vary depending on scenarios and timeframes
- Cost efficient purifcation need to be analysed for the whole value chain in terms of economical impact, locations, quantity, technical parameter and further limiting aspects
- Question: maximum purity or limitation of critical components?



EASEE-gas

Optimum hydrogen purity in Europe

Peter van Wesenbeeck (N.V. Nederlandse Gasunie)
Chair EASEE-gas Gas Quality Harmonisation Working Group (GQHWG)

EASEE-gas
European Association for the Streamlining of Energy Exchange – gas

Organisation

- Founded in 2002
- 80 companies in EU gas market

Three working groups

- Technology Standards
- Message & Workflow Design
- Gas Quality Harmonisation

Solutions

- Edig@s
- Gas Role Model
- Security Certificates
- Common Business Practices (CBP’s)

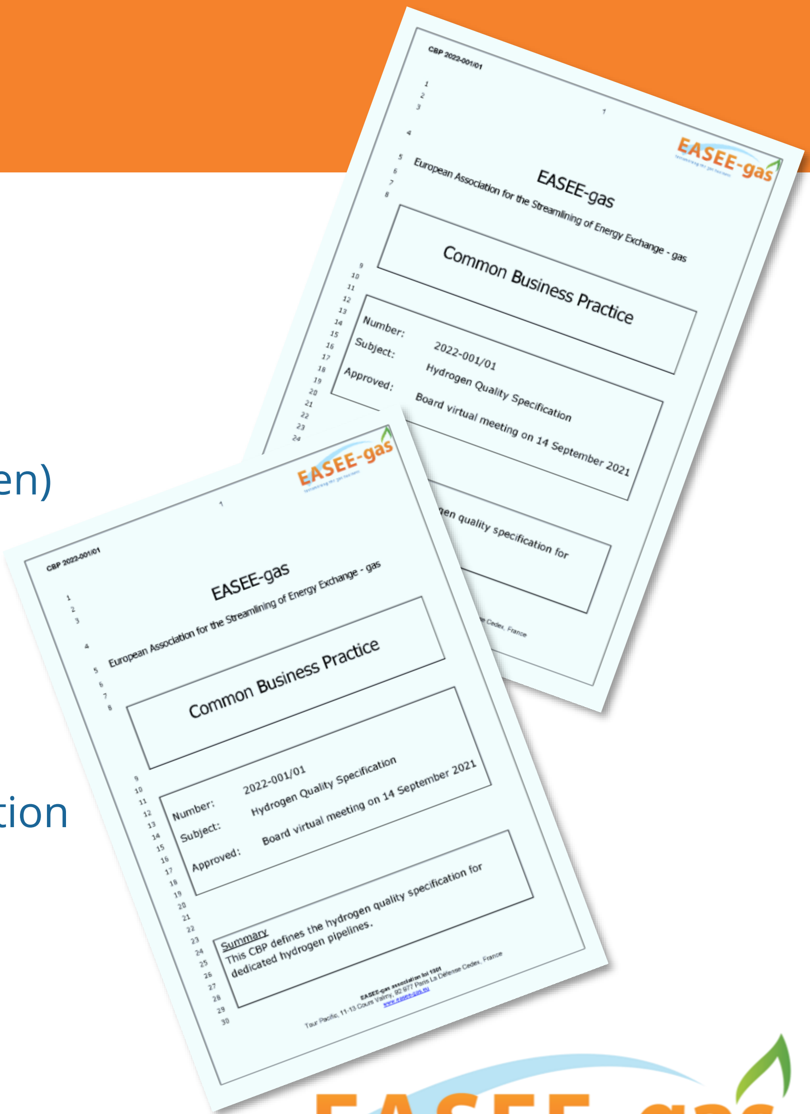
EASEE-gas

EASEE-gas hydrogen activities

EASEE-gas Common Business Practices

- [CBP 2022-001/01 - Hydrogen Quality Specification]
  - Quality specification for hydrogen flowing through dedicated systems
  - Networks previously used for natural gas transmission (suited for hydrogen)
  - Newly built hydrogen pipeline systems
  - Entry and exit points

- [CBP 2023-001/01 - Hydrogen Units]
  - Units to be used in contracting, trading, nomination, balancing and allocation
  - Energy content only based on hydrogen share



Hydrogen properties in messages framework

Hydrogen quality specifications

Existing (draft) hydrogen quality specifications

- ISO 14687 “*Hydrogen fuel quality - Product specification*”
- CEN TS 17977 “*Gas infrastructure - Quality of gas - Hydrogen used in rededicated gas systems*”
- (Proposals for) national hydrogen specifications (BE, DE, DK, NL, UK …)

Under development

- EC standardization request to CEN/CENELEC to develop (a) standard(s) for gaseous hydrogen quality in (dedicated) hydrogen networks

Observation

- Different limit values for minimum hydrogen purity (50 – 98 – 99,995 mol-% H_2)

EASEE-gas

Optimum hydrogen purity in Europe
Background

No hydrogen purity fulfills all stakeholders' requirements

- Producers – No additional purification required
- End-users – No additional purification required
- Storage operators – Usage of converted natural gas storages for hydrogen
- Transmission system operator – Usage of rededicated gas pipelines

Determining the optimum hydrogen purity

- Minimisation of the total purification costs in the total value chain
- Approach used from the study on hydrogen purity in the Netherlands

EASEE-gas

Optimum hydrogen purity in Europe
Way of working

EASEE-gas contribution

- Study sponsored from a number of companies within EASEE-gas
- Core team from the EASEE-gas GQHWG is accompanying the study

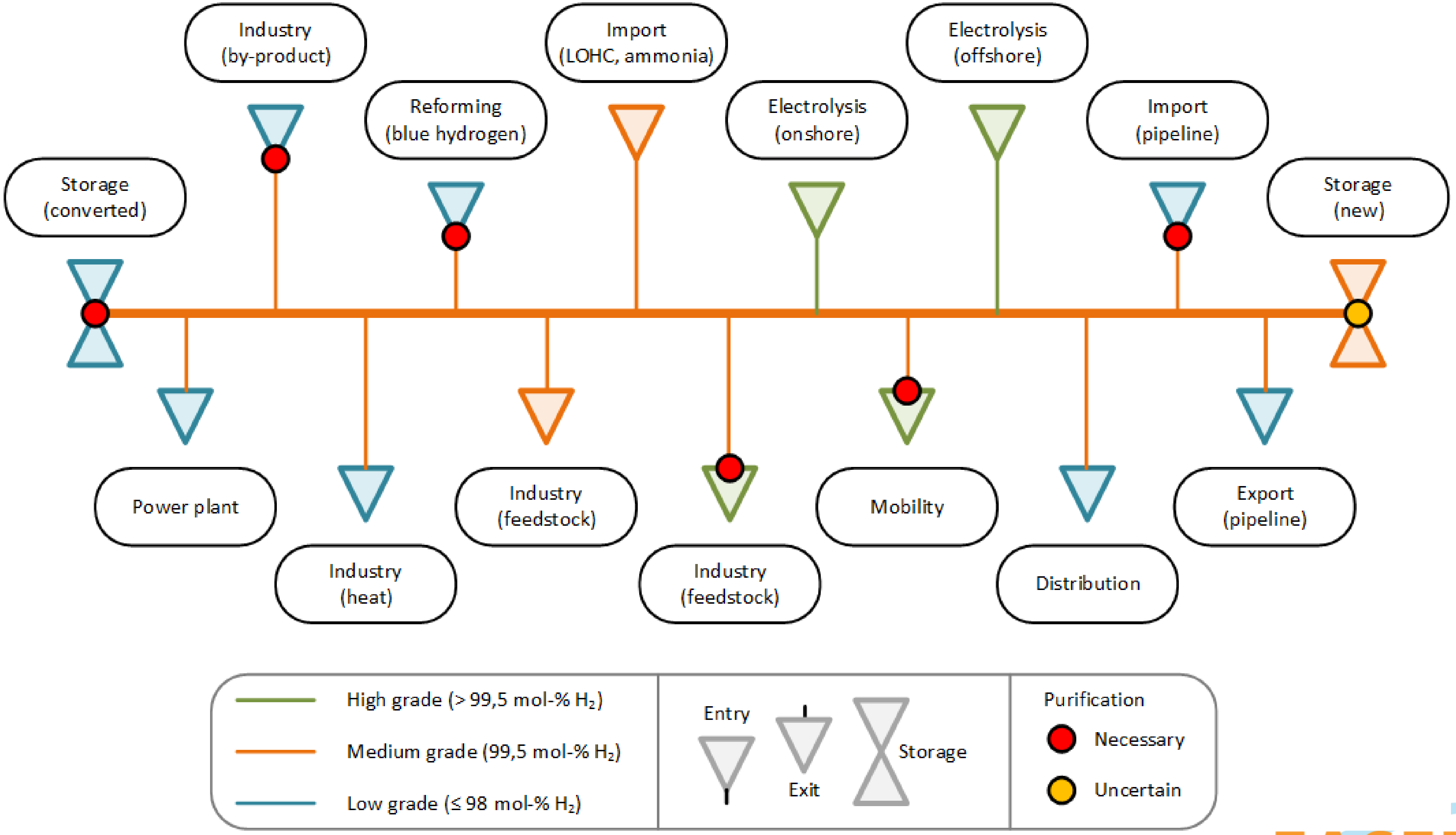
By analogy with Dutch DNV KIWA study

- A number of supply / demand scenarios for the whole of Europe, categorised by type
- Purification will take place by Pressure Swing Adsorption (PSA)
- Focussing only on the optimum hydrogen concentration, not on trace components

Different approach to Dutch DNV KIWA study

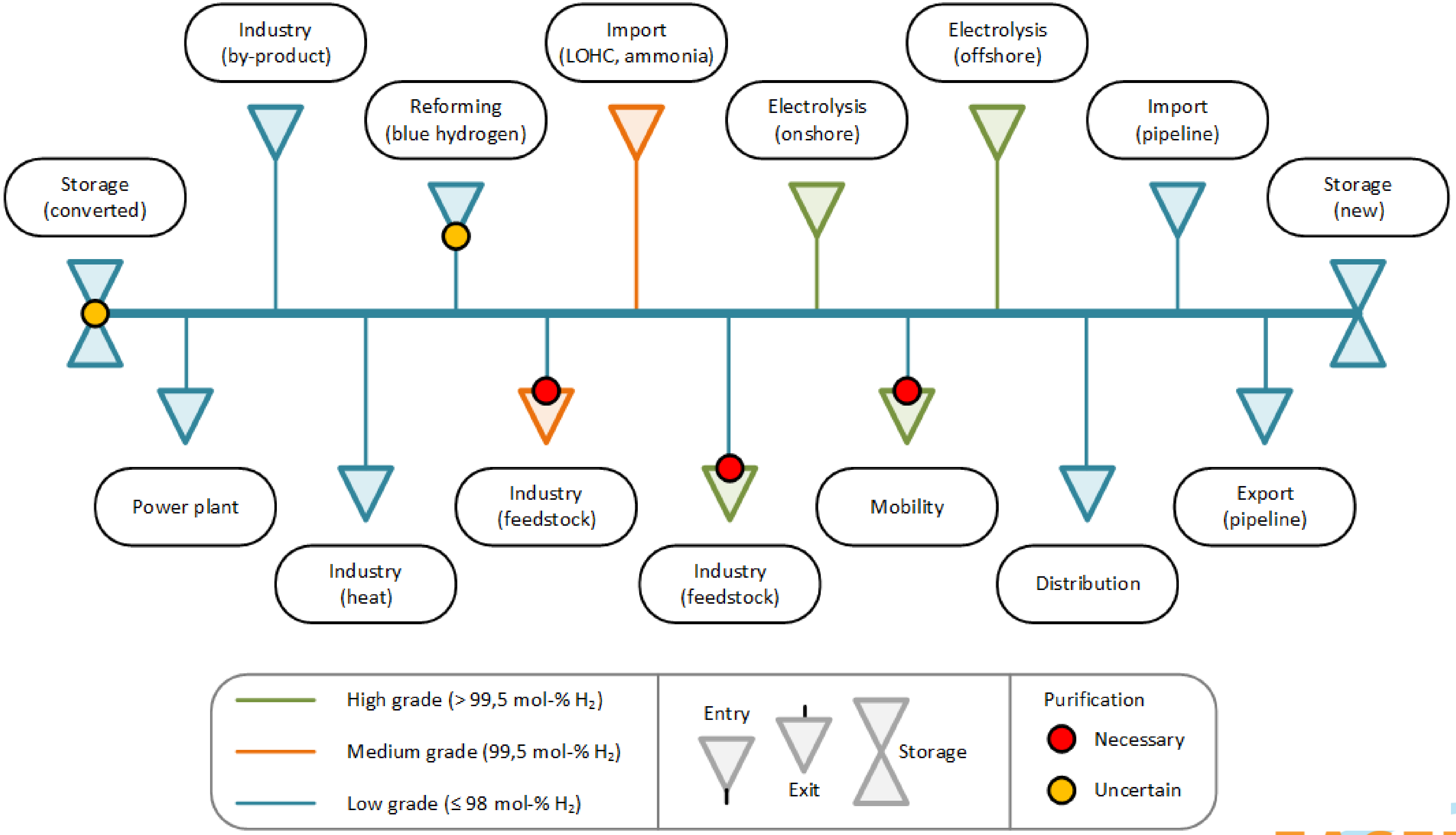
- Way the storage facilities are modelled

Model example “high purity grid”



EASEE-gas

Model example “low purity grid”



Optimum hydrogen purity in Europe
Outlook

Planning

- Study started on 21 October 2024
- First results expected before the end of this year
- Final report available at the beginning of next year

Publication

- Results of the study will made available publicly through the EASEE-gas website

Developments on CCUS and CO2 quality

Update on the work at
EU Industrial Carbon Management Forum: Working Group CO_2 standards
at ENTSOG Gas Quality Workshop

Michael Drescher, 27.11.2024

Agenda

- Background & Objective
- Scope
    - Current status
    - Future CO_2 networks in EEA
    - Future standardization needs
- Current situation and initial main messages
- Way forward

Background & Objective

ICM Forum (formerly CCUS Forum)

The Industrial Carbon Management Forum (ICM Forum) is a robust stakeholder consultation platform established by the Commission in 2021, initially under the name CCUS Forum.

It aims to bring together representatives of the EU institutions, EU and third countries, NGOs, business leaders and academia to facilitate the deployment of industrial carbon management technologies.

ICM Forum and its Working Groups >

©AdobeStock:BECCS Stockholm/K6 PROGRAM/SHARC

- ICM Forum and Working Groups

- Working Group (WG): CO2 infrastructure identified work related to CO2-specifications as important topic in 2023.
  - Towards a European cross-border CO2 transport and storage infrastructure
  - An Interoperable CO2 Transport Network – Towards Specifications for the Transport of Impure CO2
- WG: CO2 standards established for 2024
- Objective: Generate report on issues/challenges related to establishing CO2-specifications
- Bottom-up approach from the EU to get input into the topic from interested stakeholders (NGOs, industry, R&D institutes, etc.)
- Chairs of WG: Rob van der Meer (CEMBUREAU), Michael Drescher (Equinor), Filip Nele (TNO)

Scope of work

Current status

- Existing and proposed specifications (Europe, US, CA, other)
- Ongoing work on CO2 standards
  - CEN, DVGW, ISO groups, etc.
  - Operational experience
  - Insight into challenges (e.g. chemical reactions, mixing streams)
  - Existing technologies for composition measurement
- Discussion of differences
  - Drivers of differences between existing / proposed specifications
  - Emitters / capture systems involved
  - Storage vs use

Porthos
CO_2 TRANSPORT & STORAGE

CO_2 specifications

Component	Mole Base
CO_2	≥ 95%
H_2O	≤ 70 ppm
Sum [H_2+N_2+Ar+CH_4+CO+O_2]	≤ 4%
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_2S, SOx, Mercaptan)	≤ 20 ppm Of which H_2S ≤ 5 ppm
Total NOx	≤ 5 ppm
Total aliphatic hydrocarbons (C2 to C10)[i]	≤ 1200 ppm
Total aromatic hydrocarbons (C6 to C10, incl. BTEX)[i]	≤ 0.1 ppm
Total volatile organic compounds[ii] (excl. methane, total aliphatic HC (C2 to C10), 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[iii]	
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 CO_2 and other gases like i.e. H_2 and N_2 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

Title: Porthos CO_2 specifications
Date: 30 September 2021

Liquid CO_2 (LCO2) Quality Specifications

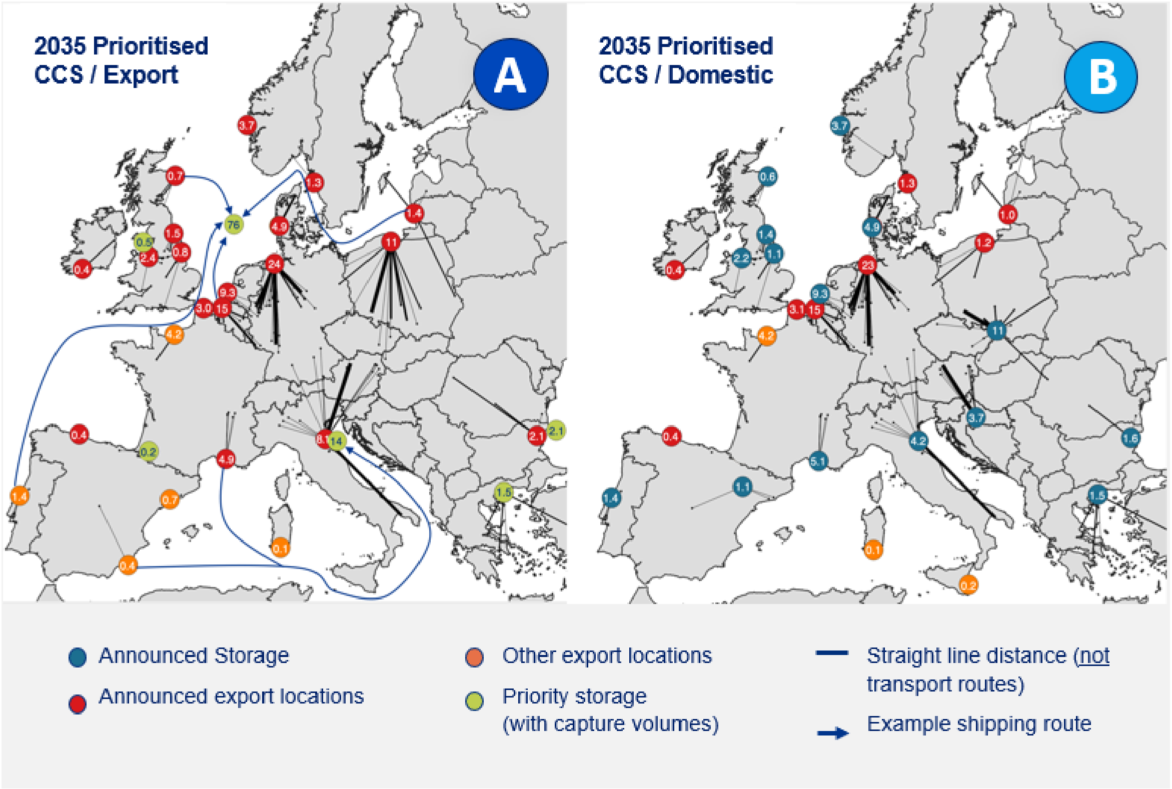
Component	Unit	Limit for CO_2 Cargo within Reference Conditions
Carbon Dioxide (CO_2)	mol-%	Balance (Minimum 99.81%)
Water (H_2O)	ppm-mol	≤ 30
Oxygen (O_2)	ppm-mol	≤ 10
Sulphur Oxides (SO_x)	ppm-mol	≤ 10
Nitrogen Oxides (NOx)	ppm-mol	≤ 1.5
Hydrogen Sulfide (H_2S)	ppm-mol	≤ 9
Amine	ppm-mol	≤ 10
Ammonia (NH_3)	ppm-mol	≤ 10
Formaldehyde (CH_2O)	ppm-mol	≤ 20
Acetaldehyde (CH_3CHO)	ppm-mol	≤ 20
Mercury (Hg)	ppm-mol	≤ 0.0003
Carbon Monoxide (CO)	ppm-mol	≤ 100
Hydrogen (H_2)	ppm-mol	≤ 50
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_3OH)	ppm-mol	≤ 30
Ethanol (C_2H_5OH)	ppm-mol	≤ 1
Total Volatile Organic Compounds (VOC)	ppm-mol	≤ 10
Mono-Ethylene Glycol (MEG)	ppm-mol	≤ 0.005
Tri-Ethylene Glycol (TEG)	ppm-mol	Not allowed
BTEX	ppm-mol	≤ 0.5
Ethylene (C_2H_4)	ppm-mol	≤ 0.5
Hydrogen Cyanide (HCN)	ppm-mol	≤ 100
Aliphatic Hydrocarbons (C_3+)	ppm-mol	≤ 1,100
Ethane (C_2H_6)	ppm-mol	≤ 75
Solids, particles, dust	Micro-meter (μm)	≤ 1

Northern Lights adheres to the CO_2 specification to ensure safety and technical integrity. While these components are specified, exception may be evaluated in close cooperation with the customer.

Scope of work

Future CO2 networks in EEA

- Transport networks in EEA (including growth scenarios)
    - Example: Northern Lights/Aramis
    - Example: Porthos/Aramis
    - Example: CO2 captured on-board ships
    - Expected modes of transport
    - Coastal vs landlocked emitters or clusters of emitters
- Expected forms of daisy chaining of transport modes
- Choice of location of purification facilities



Unlocking Europe's CO2 Storage Potential – Clean Air Task Force

Scope of work

Future standardization needs

- Long-term goals in Europe
- Interoperable networks and transport chains
- Access to affordable transport and storage for emitters throughout EU
- Drivers behind an EU-wide standard
- Impact of standards (and of evolution of standards) in growing networks
- Single vs multiple standards in the EEA
- Timing of standardization
- Challenges and opportunities in setting minimum quality standards
- Required composition measurement
- Multi-modal transport chains, cross-border networks
- Cost effectiveness, integrity, interoperability
- Discussion of cost impact and cost minimization

Main messages (preliminary)

- There are strong drivers on setting up common standards for CO_2-specifications to promote design certainty and future intermodal CO_2 exchange between projects.
- To establish CO_2 transport specifications, the full chain from source, transport and use has to be considered in order to find the optimum balance between CAPEX, OPEX and environmental impact with priority on safety.
- Open access CO_2 transport and storage introduces new risks which need to be properly managed.
- For avoiding too strict/conservative CO_2-specifications there is also the driver to acquire more knowledge on impurities and their interactions as well as operational experience before establishing common standards for CO_2-specifications.
- In addition, there is the dilemma between open access (anybody could join) vs. restricted access (limited CO_2 sources) where the CO_2-spec could be more optimized
- The work at ICM WG: CO_2 standards/CO_2 specifications discusses the current situation and dilemma. A standard for CO_2-specification will not be proposed as part of this work.

Way forward

- Presentation of report Mid-December
- Get input from stakeholders
- Finalize report in January

- Report will be published here:
  - ICM Forum and Working Groups

Acknowledgement

- Input from a lot of different stakeholders!
- Team work to get this report done!

- CEMBUREAU
- Clean Air Task Force
- CMA CGM
- Equinor
- Holcim
- IFE
- IOM Law
- NEL, TÜV SÜD
- Northern Lights
- OGE
- Ruhr-Universität Bochum
- Shell
- TNO
- Zero Emission Platform
- ++

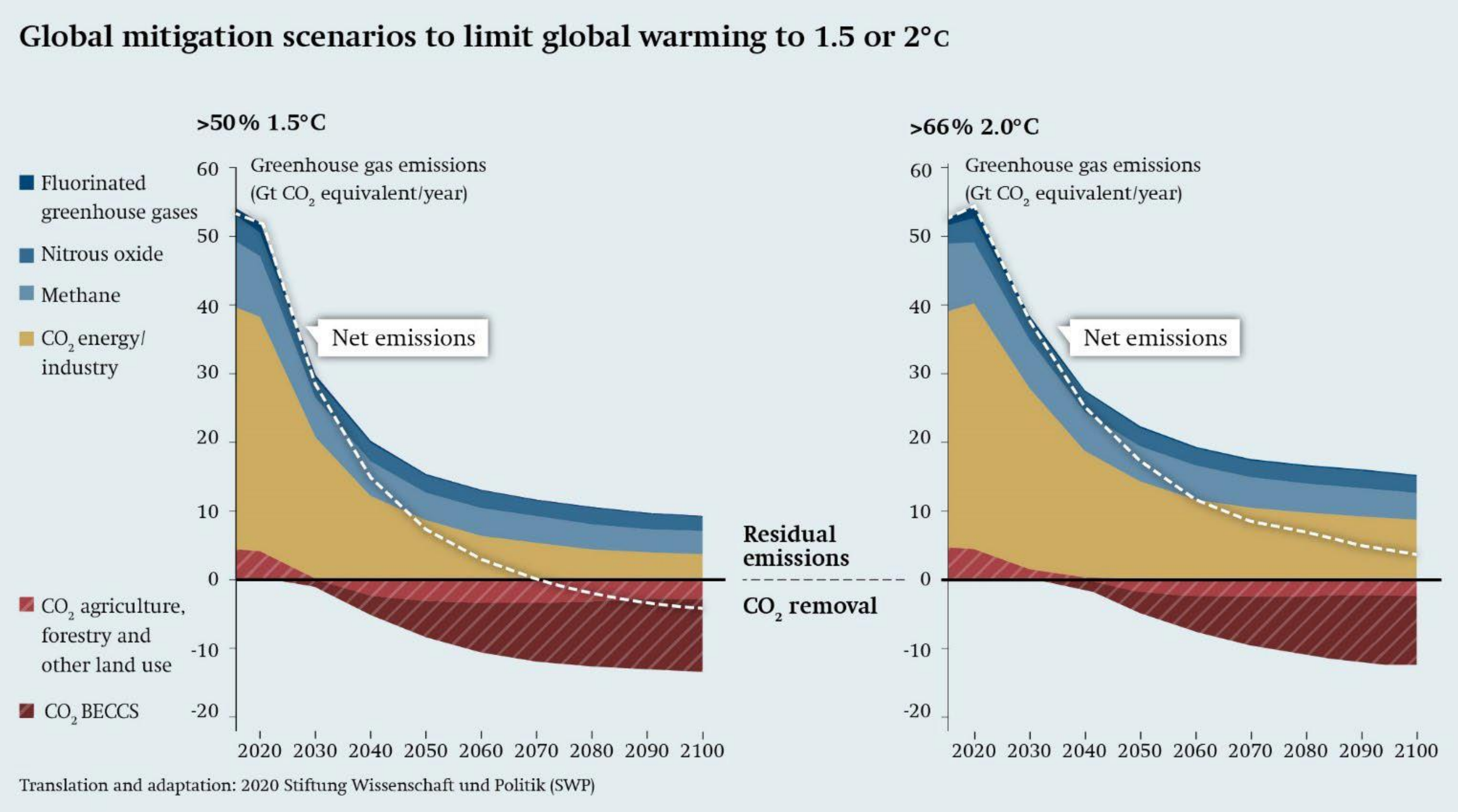
CO_2 quality in open-access pipelines – state of the art

Jens Erfurth

ENTSOG Gas Quality Workshop, 27.11.2024

OGE

Carbon management is necessary for climate neutrality



BECCS = Bio-Energy Carbon Capture and Storage (negative emission)

CO_2 quality for transport

- The definition of **limit values** for impurities is a prerequisite for any technical connection to CO_2 transport infrastructure.
- Current CO_2 specifications are generally **project-specific** and are also determined on the basis of the requirements of the respective storage site.
- European Commission (Industrial Carbon Management Strategy): Transport infrastructure should be

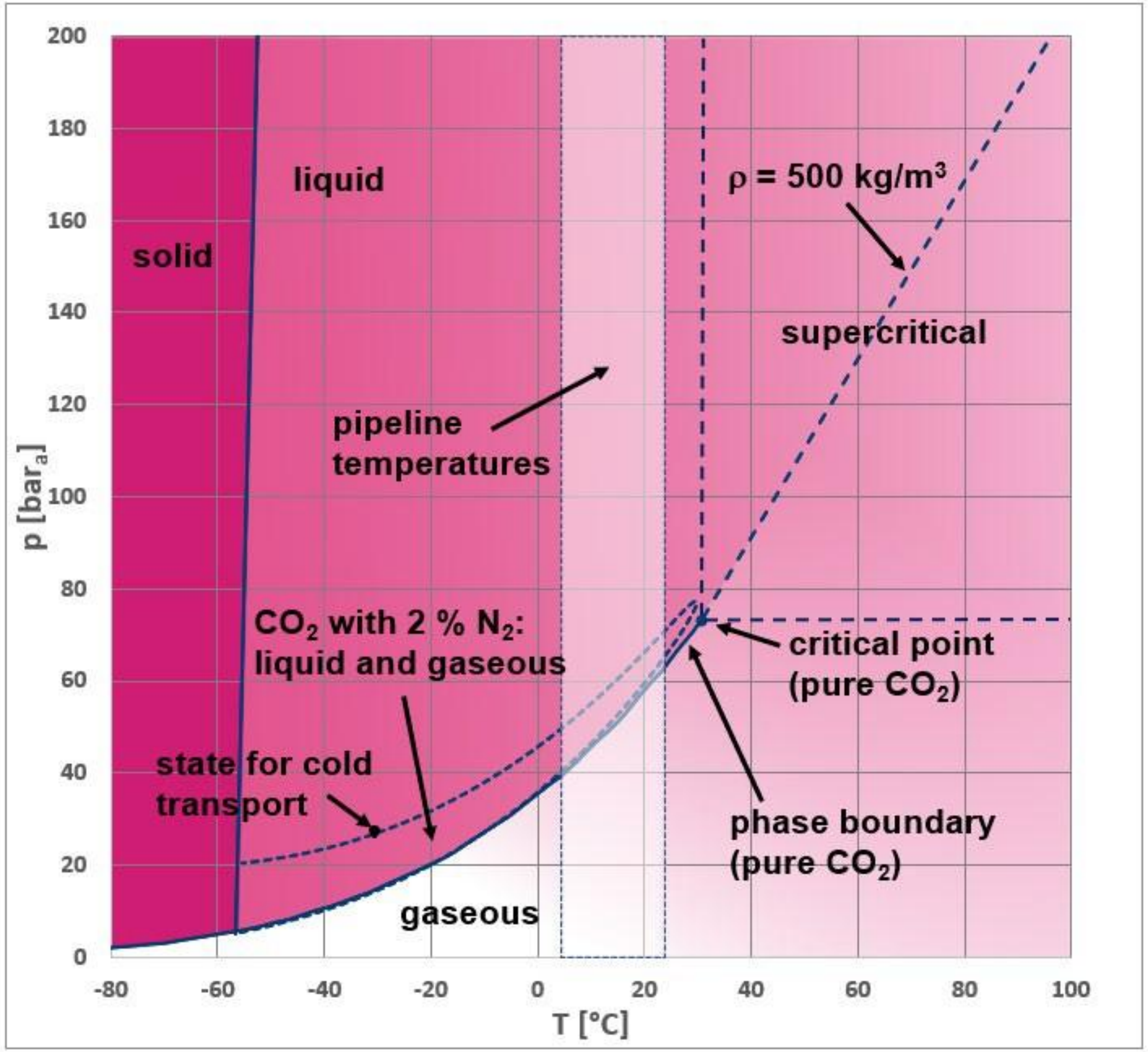
"multi-modal, reliable, robust, non-discriminatory, open-access, cross-border, fit-for-purpose, flexible, transparent, multi-origin"

The central motivation is market liquidity.

- Approach for European standardisation: minimum standard, no white list
- In the following, focus on a few limit values with integrity and cost relevance

Phase behaviour of CO_2

- CO_2 can be transported in pipelines either in gaseous form at low pressures or in dense phase.
- "Dense phase" is not a thermodynamic category, but refers to CO_2 that can be pumped instead of compressed.
    - A density of more than 500 kg/m³ is used as a criterion for this.
- Tank transport takes place at low temperatures due to the necessary high densities and low pressures.



Chapter 1: First CO_2 pipelines (since around 1980)

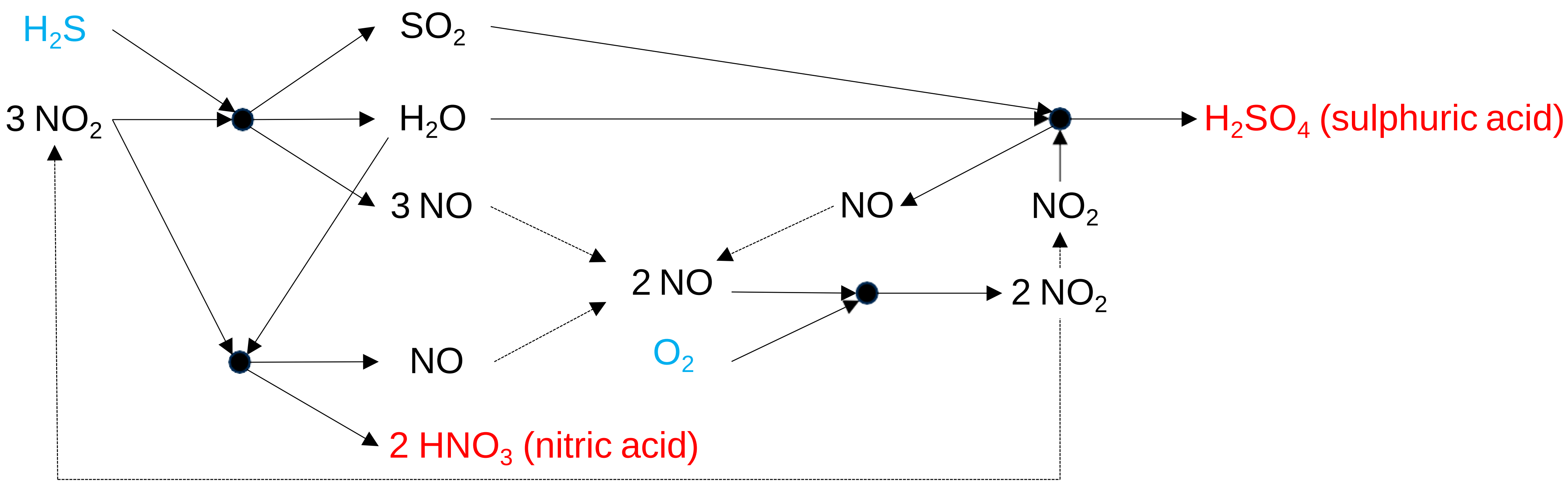
- In North America, CO_2 pipelines were put into service several decades ago and have been operated successfully ever since.
- The CO_2 comes from geological sources and is used for Enhanced Oil Recovery. It is transported in dense phase, often over hundreds of kilometres.
- Incentivised by the Inflation Reduction Act, CO_2 from industrial processes has only recently begun to be transported and stored. (5 %, and rising)

- Operating experience in Europe (OCAP, Netherlands) includes CO_2 from reforming processes, but not from combustion processes.

Chapter 2: Discovery of acid formation (since approx. 2010)

- CO_2 streams from **combustion processes** (e.g. cement, lime, thermal waste treatment) contain NO, NO_2, SO_2, H_2O, O_2, among others.
- CO_2 streams from **reforming processes** (e.g. H_2 production) contain, among other things, H_2S.

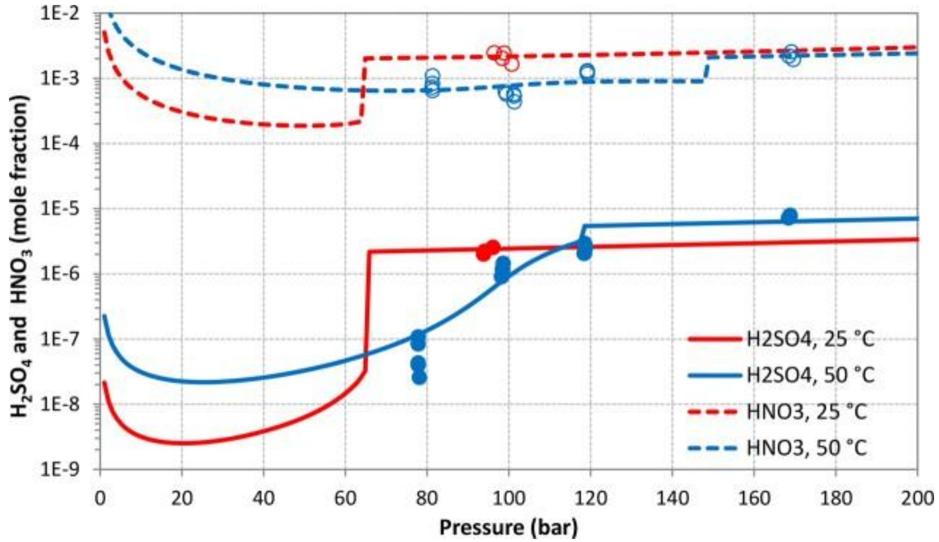
Simplified four-step reaction mechanism:



Chapter 3: Search for safe limits (2022)

[ppm-mol]	Safe Limit @ 100 bar, 25 °C
H_2O	200
SO_x	20
O_2	20
NO_x	10
H_2S	20
Source	[1]

- In 2022, Morland et al [1] for the first time publish limit values to prevent acid drop-out in pipelines. These limits can be complied with using state-of-the-art purification technology.
- A temperature of 25 °C is assumed.
- The formation of acid alone is not decisive for the integrity of the pipe. It only takes effect in a separate phase.



Source: Morland et al. 2019 [2]

Chapter 4: Temperature impact (end of 2022)

[ppm-mol]	Safe Limit @ 100 bar, 25 °C
H_2O	200
SO_x	20
O_2	20
NO_x	10
H_2S	20
Source	[1]

— 25 °C as the maximum pipeline temperature was considered a conservative assumption, as it was assumed that acid drop-out is kinetically limited.

— However, experiments have since shown that acid formation is always sufficiently fast and that acid precipitation instead depends on the phase equilibrium and thus the minimum temperature.

— In winter, German onshore pipelines are exposed to ground temperatures of only 5 °C. Under these conditions, pH values of 1 and corrosion rates of > 10 mm/a were measured.

Chapter 5: The low-NO_x approach (March 2023)

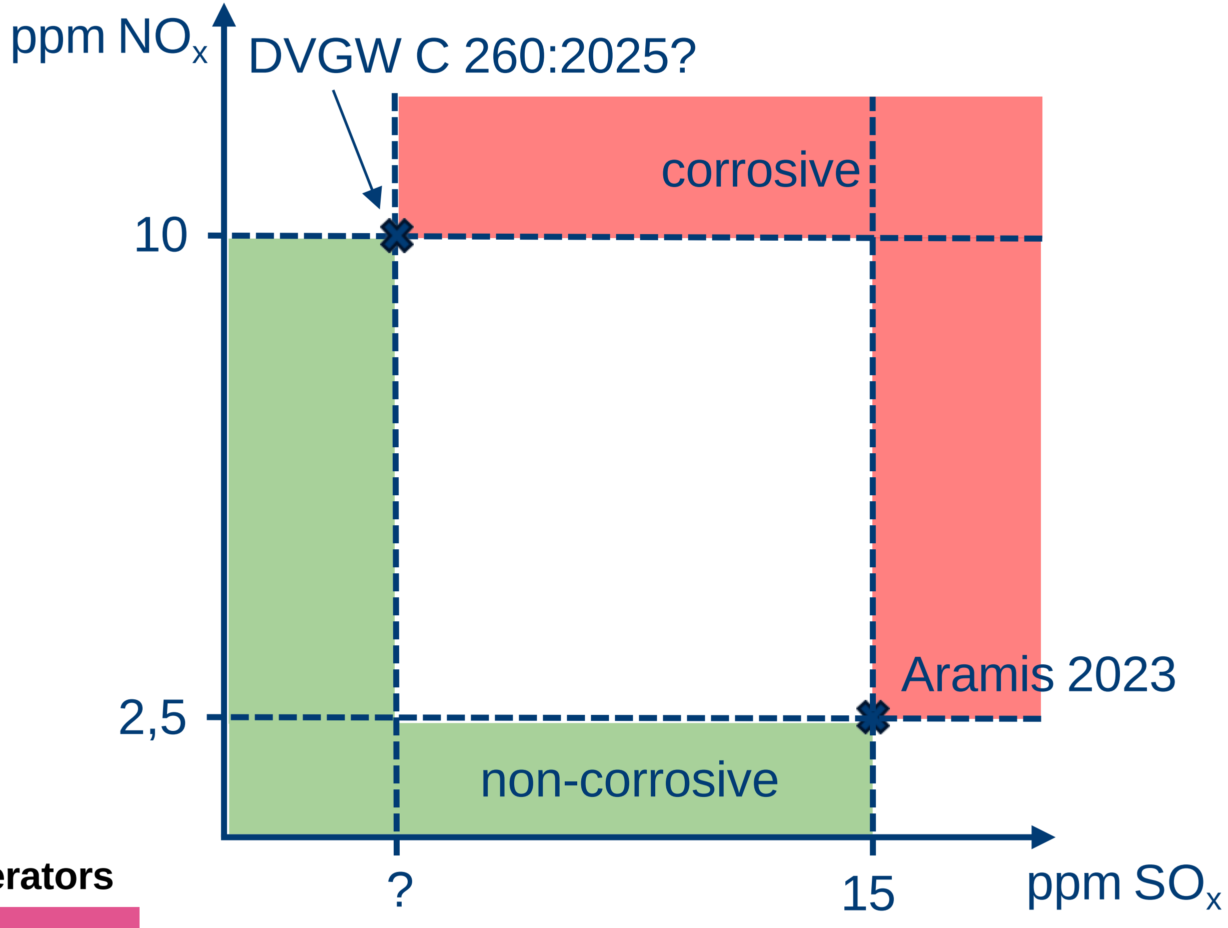
[ppm-mol]	Safe Limit @ 100 bar, 25 °C	Aramis (via Porthos Pipeline)	Aramis (ship)
H_2O	200	70	30
SO_x	20	15*	10
O_2	20	40	10
NO_x	10	2.5	1.5
H_2S	20	5	5
Source	[1]	[4]	[4]

- As a result, the limit value for NO_x was significantly re
  Aramis project.
- For transport by ship (temperatures of -30 °C), even stricter requirements apply than for pipeline
- However, these requirements (also adopted by North
  2024) pose problems for some emitters such as the
  steel industries. Here, the original limit value of 10 pp
  the state of the art in separation technology.

* Derived from total sulphur (20 ppm-mol) and limit value for H_2S

Chapter 6: The low-SO_x approach (2024)

- Since the precipitated acid is primarily sulphuric acid, a reduction of the more easily removed SO_x instead of NO_x also appears to be promising.
- This approach was developed during the current revision of DVGW C 260 and could be incorporated there.
- However, this first requires further experimental investigations.
- Sponsors:



Emitters

Association of the Cement Industry VdZ
Federal Lime/Lhoist Association
Heidelberg Materials

Network operators

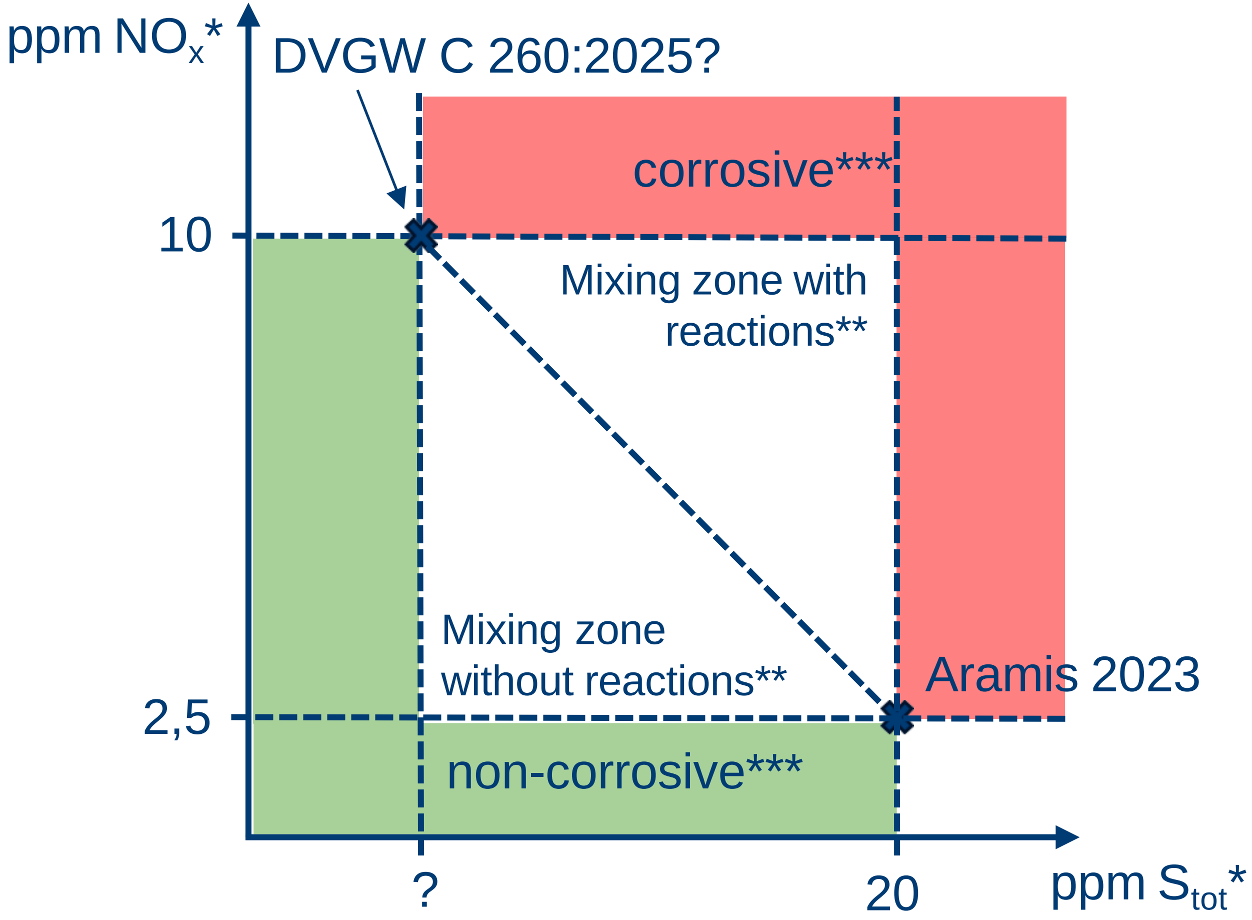
OGE (project lead)
VNG
Fluxys
Gasunie
Gassco
Evida

Storage operators

Wintershall Dea
Shell
Equinor

Chapter 7? The total sulphur/low-NO_x approach?

- H_2S is always converted very quickly to SO_2.
- H_2S and SO_2 will never occur simultaneously in unmixed CO_2 streams.
- Instead of individual limit values, a limit value for total sulphur can therefore be considered.
- This also raises the question whether acid drop-out can also be ruled out in arbitrary mixtures of the qualities.
- If this can be proven, emitters will have greater flexibility.
- The role of H_2O and O_2 must also be considered.



* Not to scale
** ...with product NO_x or SO_x
*** ...under pipeline conditions

Forums

- **ISO 27913:2024** (CO_2 Pipeline Transportation Systems) gives guiding principles for the definition of CO_2 quality but does not specify any.
- **DVGW C 260** was first published in April 2022 as the German standard for CO_2 quality in pipelines, but does not yet contain any limit values. A **revision** was therefore started in 2022 and is still ongoing.
- In February 2024, **CEN** was mandated by the European Commission in the Annual Union Work Programme for European standardisation with regard to transport and storage:

  "Develop new European standards for transporting carbon dioxide through pipelines, ships, trains, and trucks and for its permanent geological storage. The main objective is to ensure high interoperability of emerging carbon dioxide transport infrastructure and permanent storage capacities."

  The responsible TC 474 has started work.
- The **ICM (formerly CCUS) Forum** of the European Commission now has a regular working group on CO_2 standards. The aim is to coordinate technical standardisation at CEN and current legislative procedures.

Committee Members DVGW C 260:2025

Emitters

German Association of the Cement Industry VdZ
German Federal Lime Association BVK
German Thermal Waste Treatment Association ITAD
Heidelberg Materials
Energy from Waste
RWE

Transport System Operators

OGE
VNG
GRTgaz
Fluxys
Gasunie
Gassco
Evida

Storage Operators

German Federal Association for Natural Gas, Oil and Geoenergy BVEG
Wintershall Dea
Porthos/Aramis (via Gasunie/Shell)
Equinor

Research Institutions

Federal Institute of Materials Research and Testing BAM
University of Bochum, Chair of Thermodynamics
Engler-Bunte Institute
DBI Gas and Environment
IFE
Czech Academy of Sciences

Engineering/Technology Providers

Linde
Air Liquide
ete-a
TES
Dr Hilgenstock Consulting
Progressive Energy
Shell
Ramboll
Koole Terminals

Standardisation Bodies

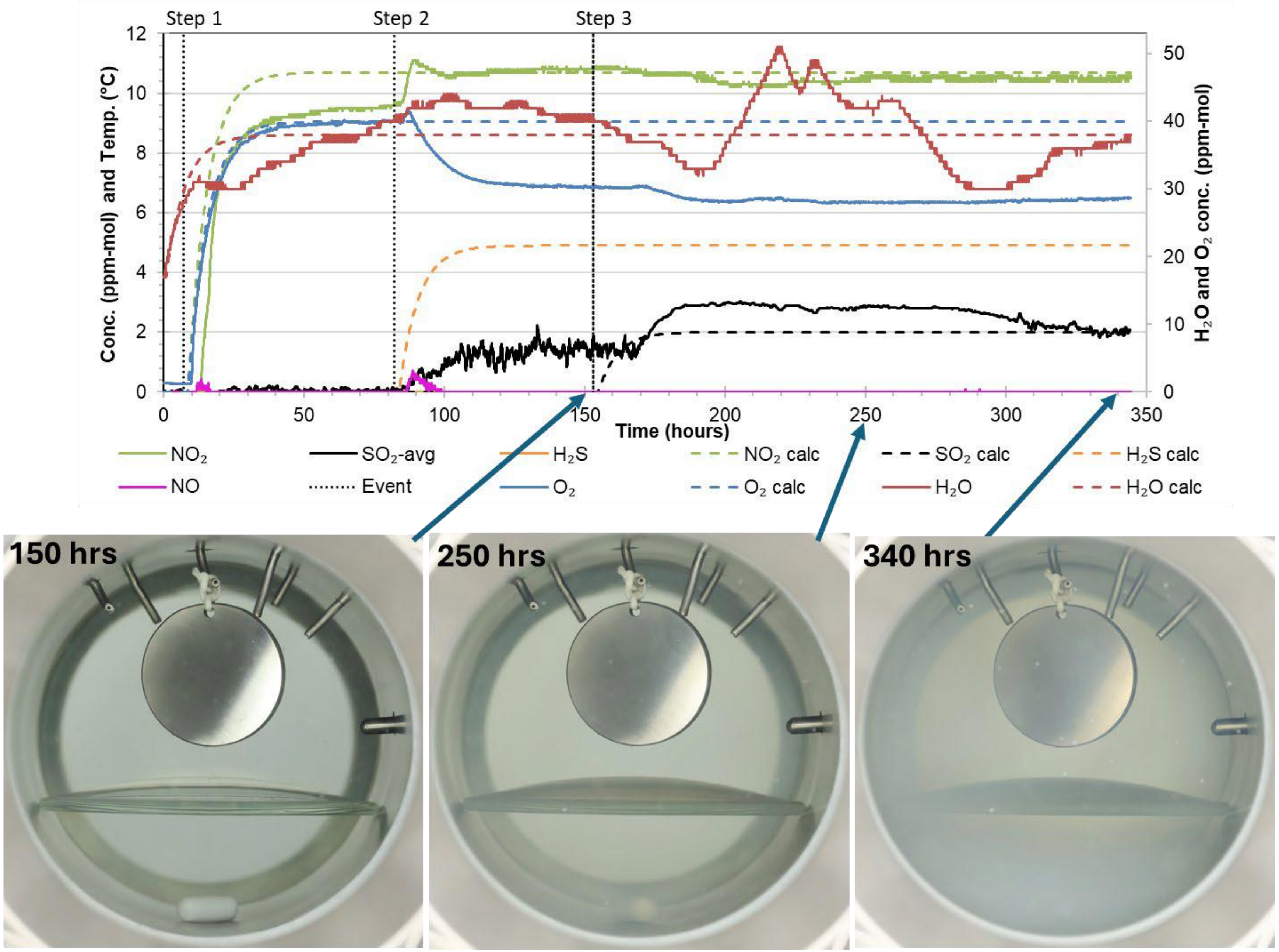
DVGW
ÖVGW
SVGW
Dansk Standard

Sponsors of Low-SO_x Tests

Emitters	TSOs	Storage Operators
German Association of the Cement Industry VdZ	OGE (Project Lead)	Wintershall Dea
German Federal Lime Association BVK/Lhoist	VNG	Shell
Heidelberg Materials	Fluxys	Equinor
	Gasunie	
	Gassco	
	Evida	

IFE

Draft results Experiment 1 – Visuals



Conclusions

- Only with a clearly specified CO_2 quality will it be possible for many emitters to make a reliable **cost calculation** for the first time.
  - Presumably establishment of separate CO_2 specifications for pipeline, medium-pressure and low-pressure tank transport.
- There is a consensus that the **integrity** of the transport system and storage facility must be guaranteed and costs must be minimised.
  - There also does not appear to be a fundamental conflict of interest between the stakeholders.
- **Corrosion phenomena** in industrial CO_2 have only been researched for a few years and are not fully understood.
  - Revisions to specifications have so far lowered the NO_x limit value to avoid acid drop-out. However, the removal of SOx appears to be more efficient for some emitters. Experimental confirmation is pending.

(Accelerated) standardisation work has begun at European level.

We bring the energy.

Contact:
Open Grid Europe
co2@oge.net

www.co2-netz.de
www.oge.net

OGE

Sources

1 B. H. Morland, A. Dugstad, G. Svenningsen, Experimental based CO_2 transport specification ensuring material integrity, International Journal of Greenhouse Gas Control, 119, (2022) p. 103697.

2 B.H. Morland, A. Tadesse, G. Svenningsen, R.D. Springer, A. Anderko, Nitric and sulfuric acid solubility in dense phase CO_2, Ind. Eng. Chem. Res., 58 (2019), pp. 22924-22933

3 Porthos project CO2 specification:
https://www.porthosco2.nl/wp-content/uploads/2021/09/CO2-specifications.pdf

4 Aramis project CO2 specification:
https://www.aramis-ccs.com/news/co2-specifications-for-aramis-transport-infrastructure

5 Liquid CO_2 Quality Specification:
NorthernLights-GS-co2-spec2024.pdf

ApolloCO2 – DESFA’s CCS PCI Project

ENTSOG Gas Quality Workshop

November 2024

AGENDA

About DESFA

Our CCS project – ApolloCO2

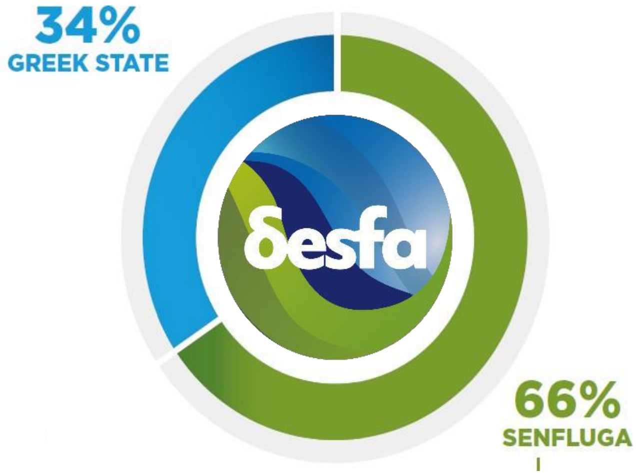
DESFA counts 17 years of successful operation post the liberalization of natural gas market in 2007

About DESFA

Key Points

- Established in **March 2007**, **DESFA owns & operates the Greek Natural Gas System (NNGS),** consisting of the **National Natural Gas Transmission System** & the **LNG Terminal in the islet of Revithoussa**
- DESFA has been certified as an **Ownership Unbundled Operator** under the **3rd EU Energy Package**, following the **completion of a privatization process on 20th December of 2018**
- **DESFA operates, maintains & develops the Greek Natural Gas System** in a **safe, reliable and economically efficient way**, offering:
  - **Regulated Third Party Access services** in a transparent and non-discriminatory way
  - **A range of non-regulated services** to a number of national & international clients
- DESFA has the **necessary know-how, highly trained staff and the proper equipment** to provide **high-level operation and maintenance services for LNG storage and gasification facilities**

Shareholders' Structure

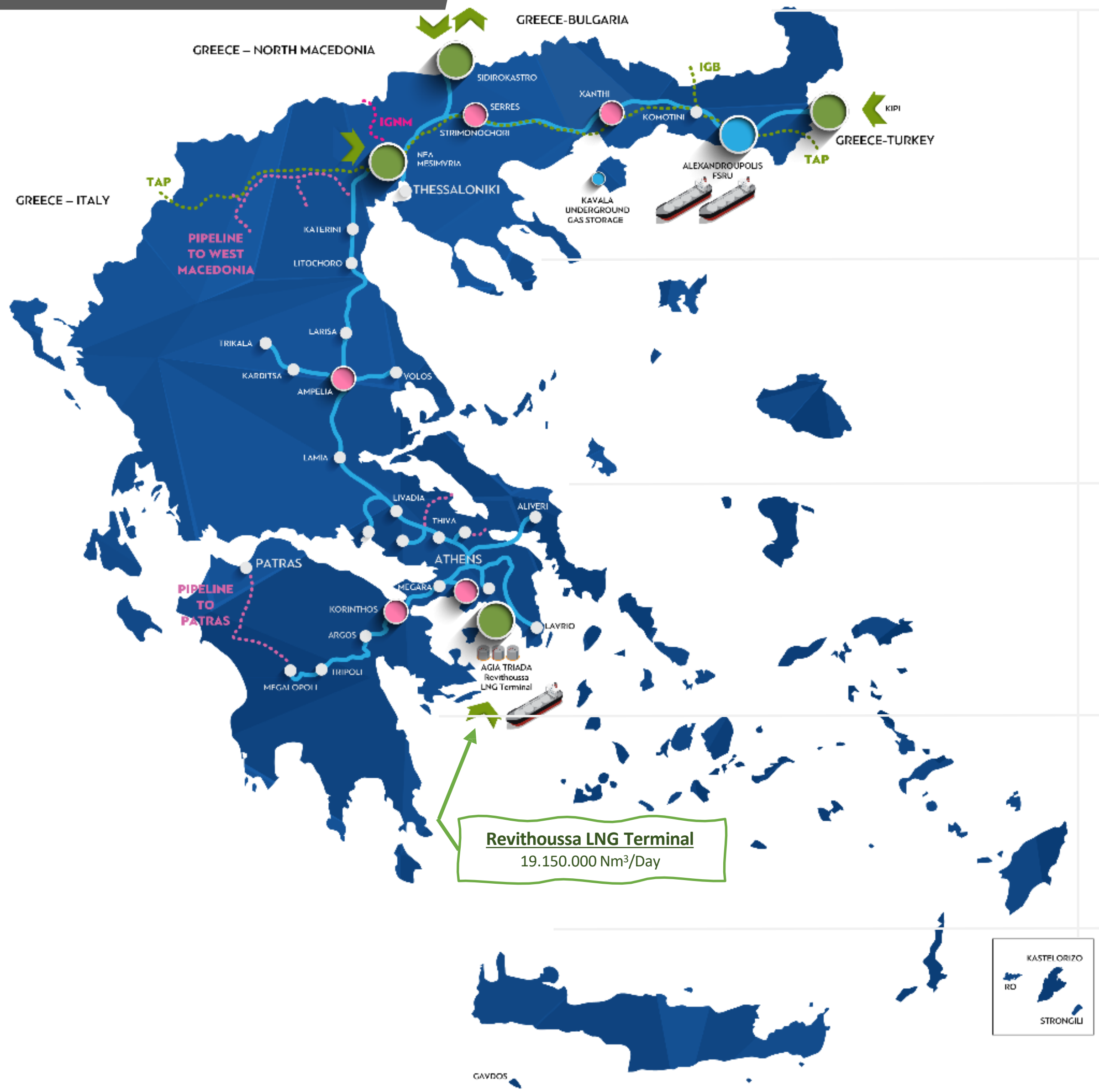


Key Milestones

2007	2014	2018
• Establishment of DESFA	• Certification of DESFA as Independent Transmission Operator under the 3rd EU Energy Package	• Completion of privatization process & certification as Ownership Unbundled Operator • Participation as a shareholder (7%) in the Hellenic Energy Exchange (HEnEx)

DESFA’s network at a glance

About DESFA



1,466 km
High Pressure Pipelines

6
Operation & Maintenance Centers

1
LNG Storage & Regasification Terminal Station in Revithoussa

25
Exit Points to Distribution Systems

4
Interconnection Points

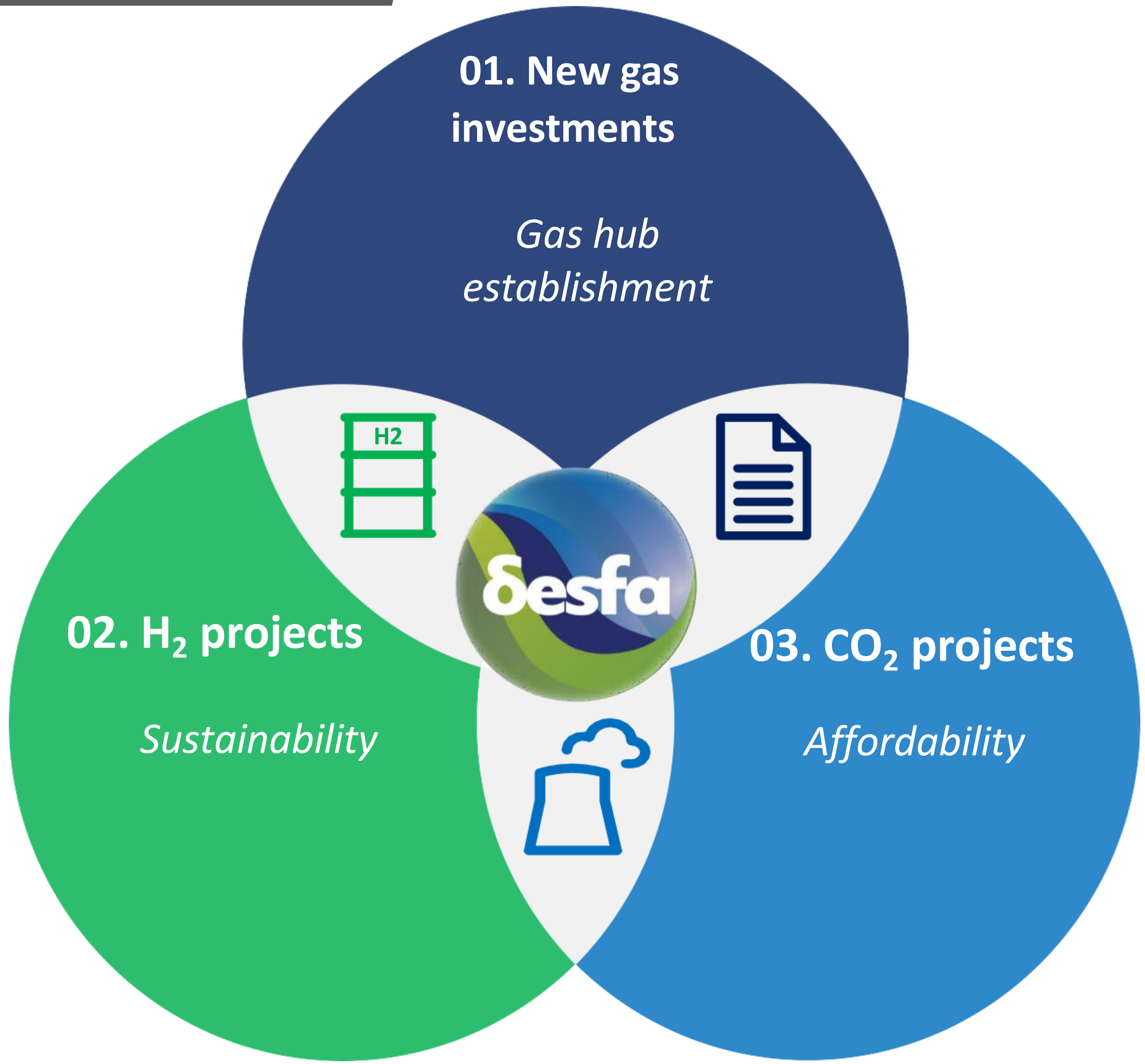
2
Dispatch Centers

53
Metering & Regulating Stations

1
Compression Station

DESFA's focuses on three main pillars to address the energy transition ambition as well as to support EU succeeding in its climate targets

About DESFA



01 Through **new (100% H_2 ready) gas investments** in Greek transmission system and in line with its **extroverted activity**, **DESFA secure the supply of NG in SEE and central EU**

02 Based on **EU targets**, the Greek TSO has set as one of its **main strategic goals** the **development of H2 sector in Greece** through the assessment of **Smart Gas Grid and H2 pipelines projects**

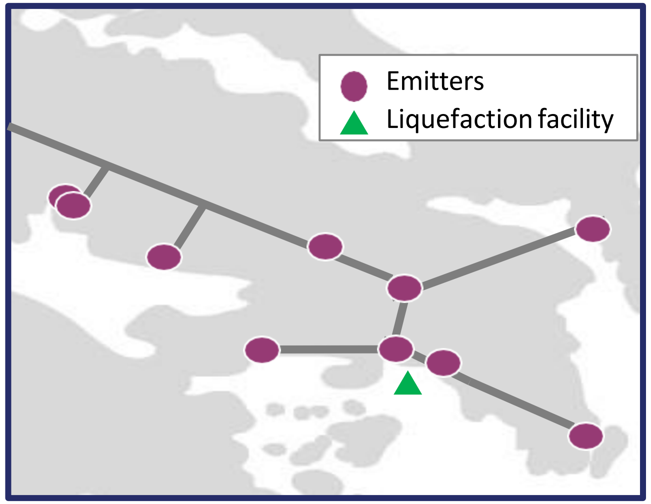
03 DESFA focuses on being **integral part** and constituting a **vital role in the CCUS business in Greece**, activated in the **midstream** part of the value chain

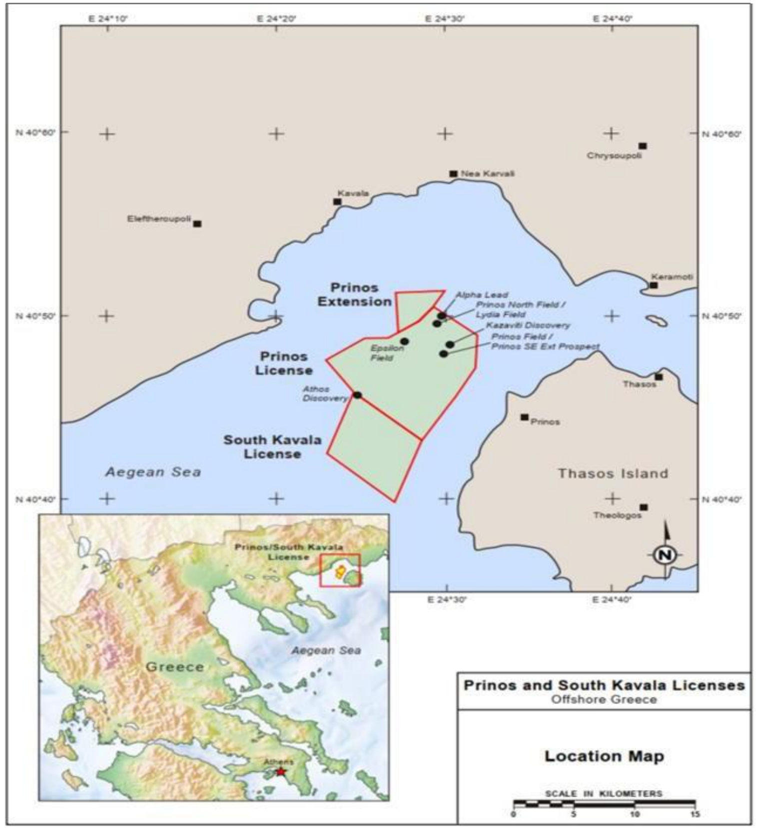
AGENDA

About DESFA

Our CCS project – ApolloCO2

Prinos CCS project developed by DESFA and Energean is part of the latest PCI list



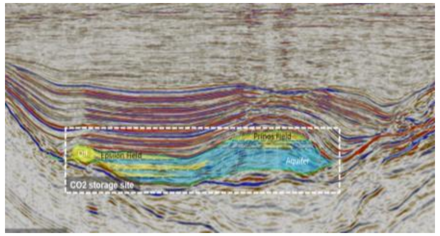


Key Highlights

The **"Prinos CO_2"** project submitted by Energean and DESFA has been included in the latest PCI list of EC

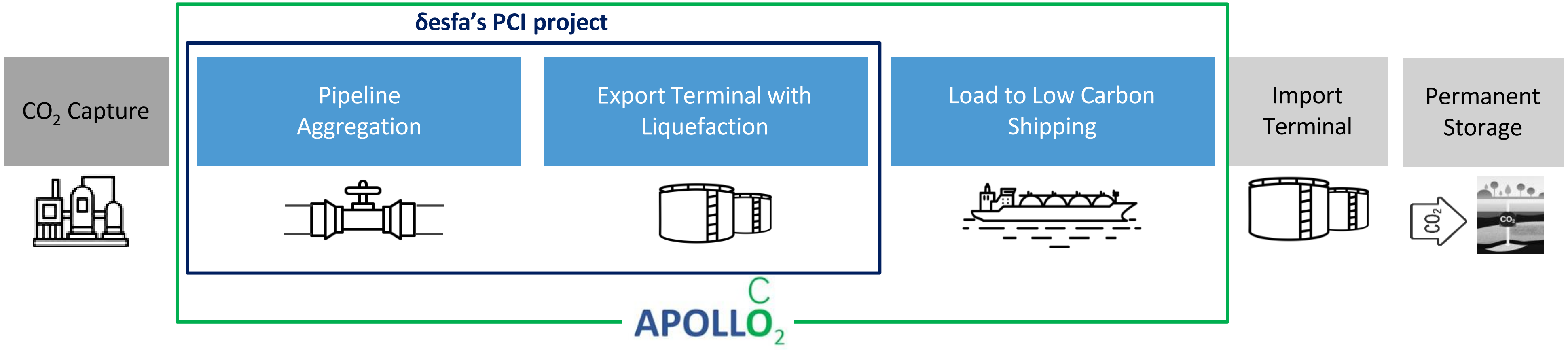
- ✓ **Energean's project** envisages Prinos CO_2 Storage Project to be among the **first CO_2 storage hubs at industrial/commercial scale in the Mediterranean**. **Prinos capacity** is expected to be deployed in Phases; **Phase 1** (2025-2028): **1 MTPA; Phase 2** (12/2027 – onwards): **3 MTPA**
- ✓ **DESFA's project** includes the construction of a **dedicated CO_2 pipeline** collecting CO_2 from emitters, a liquefaction terminal, from where the liquid **CO_2 will be temporarily stored in a dedicated facility** and then loaded to **CO_2 carriers that will transport it by sea** to Prinos Storage facility, **but also to future storage facilities to be developed in the wider European neighborhood**

Mapping of CO2 Storage Site

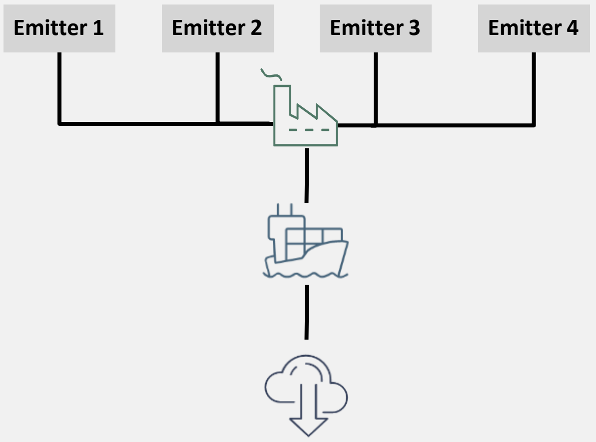


Existing On-Site Infrastructure

APOLLOCO$_2$ will cover the midstream part of the CCS system value chain



Key highlights



- Due to the benefits offered by **economies of scale**, DESFA proposes **an aggregated scenario** of a **single export facility** located barycentrically regarding industrial plants
- CCS Hub based on a scalable platform-as-a-service, with **an open-access system to add potential partners and technology** (e.g., smaller-scale emitters and cold energy usage)
- Accelerated licensing and permitting application and process

Main benefits from CCUS

- Strengthen the Energy Transition pathway, decarbonizing part of Greek industrial emission by 2030
- Development of a leading EU Infrastructure project
- Support Greek Industry to stay in country by enhancing competitiveness in Green Products
- Substantial Investment in Greek infrastructure for export terminal and pipeline
- Green Job Creation for construction, engineering and innovation with opportunity for Local Labour Upskilling
- Significant support for National Businesses during construction and operation, generating wider Economic Benefits

There is a potential of approximately 9 Mtpa CO2 in Central Greece and Attica region

CO2 market potential

Cluster Size

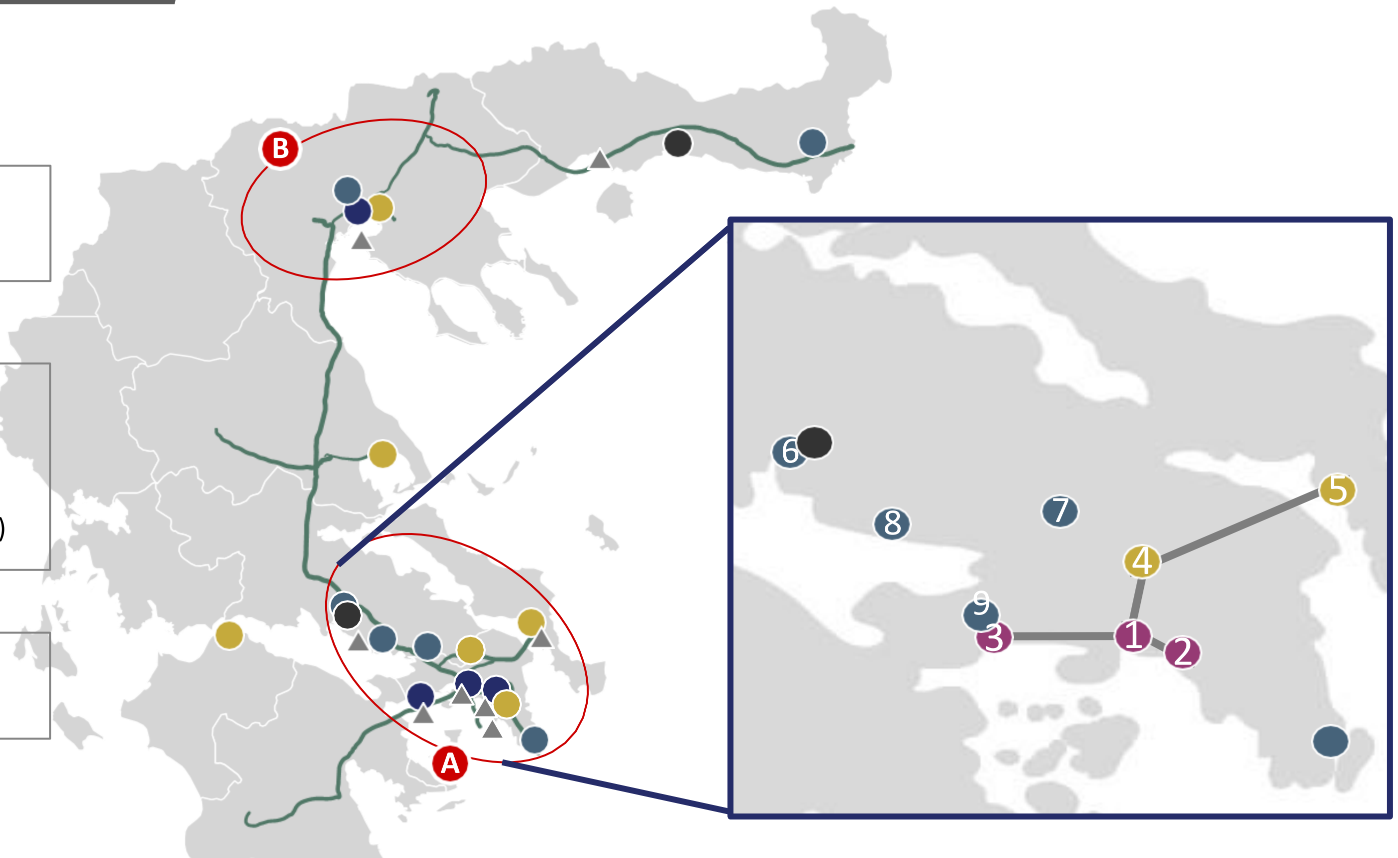
- A. Attica – 5-10 mtpa
- B. N. Greece – 1,5-2 mtpa

Industries

- Refining
- Cement
- Other industries (Metal)
- Power generation (CCGT)

Infrastructure

- Key ports
- Natural Gas Pipeline



Note: 3 4 5 are already eligible for Innovation Fund

South Greece potential in phases

Phase 1: EoI &NDA in place (4,1 mtpa)

Refining

1. **Refinery 1** (date tbc) -> **0,6 mtpa**
2. **Refinery 2** (date tbc) -> **tbd**
3. **Refinery 3** (2028) -> **0,5 mtpa**

Cement

4. **Cement 1** (2028-2029) -> **1,9 mtpa**
5. **Cement 2** (date tbc) -> **1,1 mtpa**

Phase 2: Future emitters (4,7 mtpa)

Power plants

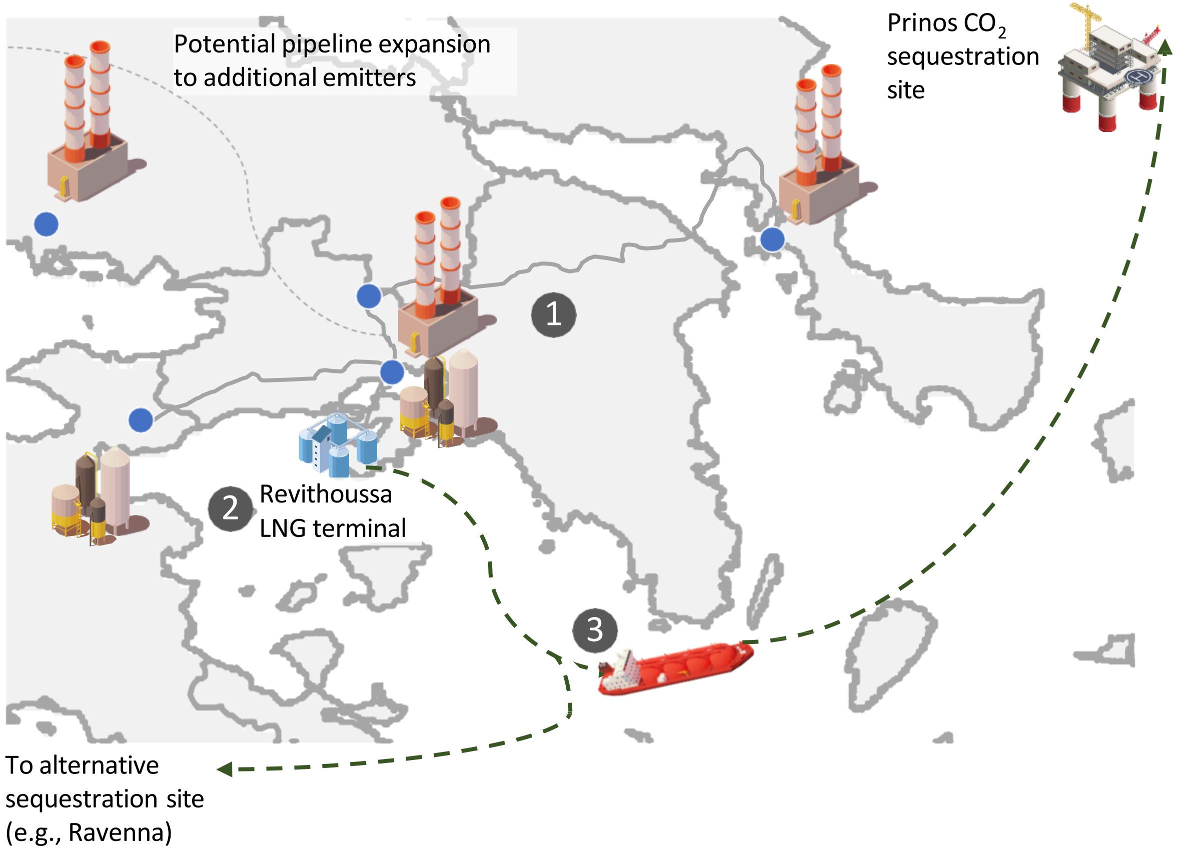
6. **Power producer 1** (date tbc) -> **2,3 mtpa**
7. **Power producer 2** (date tbc) -> **1,6 mtpa**
8. **Power producer 3** (date tbc) -> **0,4 mtpa**
9. **Power producer 4** (date tbc) -> **0,4 mtpa**

Total (Phase 1 & 2)≈ 9 mtpa

The design and techno-economic aspects of the APOLLOCO$_2$ CCS hub in a nutshell

● Industrial emitters — CO_2 pipeline -- Potential expansion: CO_2 pipeline → LCO_2 shipping

APOLLOCO$_2$ CCS hub schematic



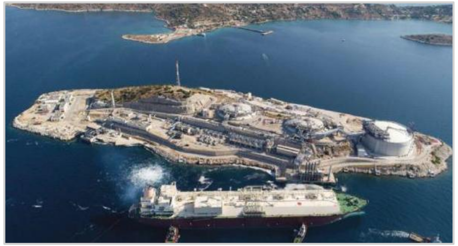
Details of core value-chain assets

1 | Pipeline network to integrate key emitters in South Greece

- Aggregates ~50% industrial emissions in Attica with expansion to Viotia
- Feasibility studies finalized, currently at the FEED stage

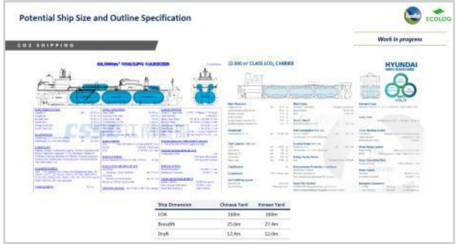
2 | CO_2 liquefaction facility with synergies with Revythoussa LNG terminal

- 5 MTPA capacity to accommodate several emitters (expandable to 10 MTPA)
- Cost efficient CO_2 liquefaction, leveraging cold energy with LNG (~65% opex savings)



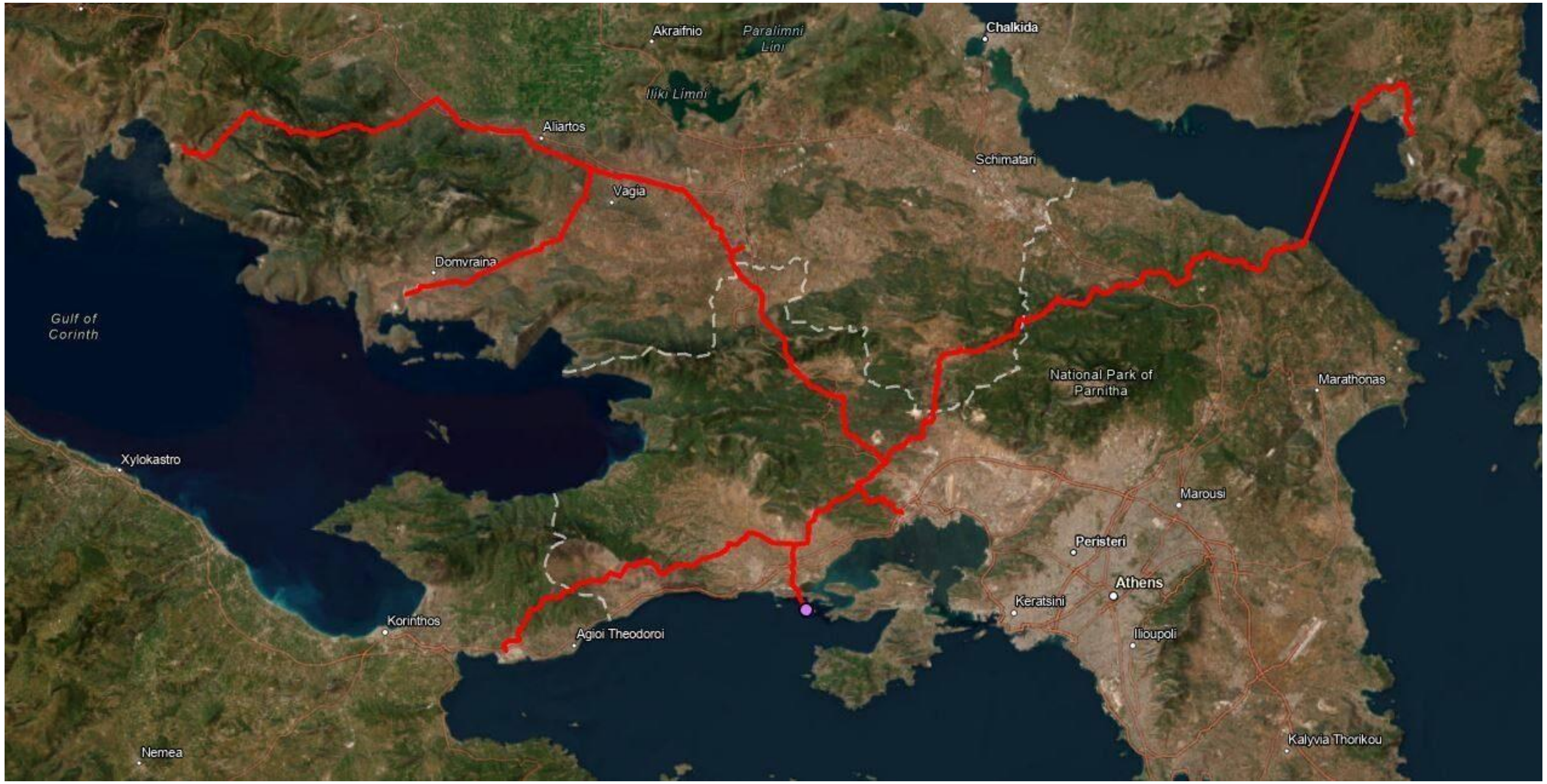
3 | Large-scale liquid CO_2 vessel (22-40k cbm)

- Optimised vessel size and routes, considering draft limitations around Attica
- Up to ~60% cost savings from scale and maximising utilisation



Feasibility study for CO2 Pipelines has been executed in 2 phases, resulting in a network of ~300km if all big emitters join ApolloCO2

CO2 pipelines



Pipeline dimensions	
Total length	275 km
Pipeline Diameter	20’’ – 24’’

Gas composition
Northern Lights specification

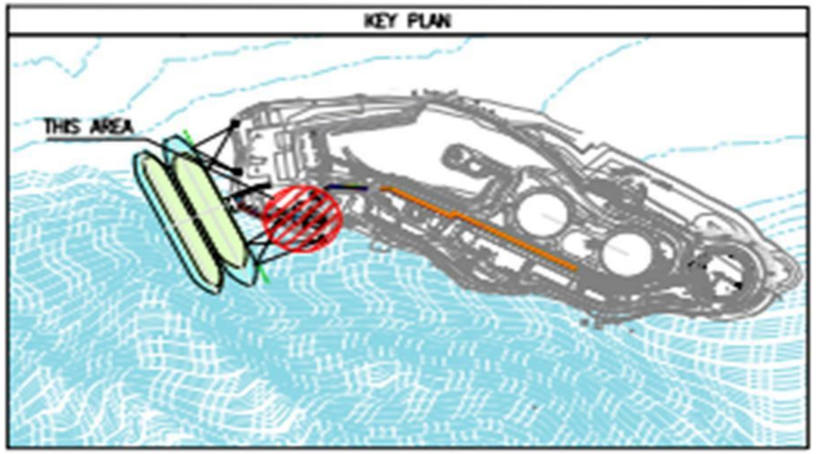
Gas conditions	
Upstream (Inlet of the CO2 pipelines)	
Temperature	40 oC
Maximum pressure	42 barg
Downstream (Inlet of Liquefaction Terminal)	
Delivery pressure	20 barg

Feasibility study for Liquefaction & Export Terminal has proven the benefits of proceeding with Revithoussa as the preferrable terminal location

Liquefaction Terminal

1 Technical solution

- ✓ Carbon dioxide **liquefaction facility located on Revithoussa Island** will comprise of both onshore and offshore parts
- ✓ Gas CO_2 will be delivered through pipelines in Revithoussa and **the cold energy exchange will take place on the island** (onshore part)
- ✓ Due to space constraints on the island, for **Storage, Backup liquefaction system** (in the case of LNG unavailability) **and Offloading** of LCO_2 an **FSU solution** was selected
- ✓ **FLSU Jetty linked** at south – west area of Revithoussa Island



2 Innovative characteristics of the proposal

Cold energy utilisation

Exploitation of the otherwise wasted **cold energy generated from LNG regasification processes** to significantly reduce the energy requirements for the CO_2 liquefaction and LNG regasification at the same time.

Low pressure solution

Implementation of a low pressure/gas phase system for the aggregation of CO_2, **providing scalability, safety in terminal's operation, mitigation of permitting hurdles & a cost-competitive advantage by minimising infrastructure & transportation expenses.**

Floating liquefaction & storage unit

Introduction of a FLSU as a **ground-breaking solution to geographical and physical constraints**, with a primary focus on temporary storage and secondary on liquefaction as a backup option. The depth of Revithoussa island enables the accommodation of larger vessels, which can cover greater distances and enable the feasibility of otherwise much more costly standalone CCS supply chains.

CO2 Sequestration Site Optionality

- APOLLOCO$_2$ through its partners is in advanced discussions with several sequestration providers in Europe, mitigating storage capacity and delay risks to customers
- By aggregating the volume and increasing the ship size, there are more storage options available for emitters with optimised costs

Potential Partner	Distance to Athens (Nm)	Note
ENERGEAN	250	▪ Nearest sequestration site / lowest transportation cost ▪ Limited sequestration capacity
eni	815	▪ Within Mediterranean ▪ Large sequestration capacity (c. 500mt) ▪ Significant emitter cluster in Northern Italy ▪ Restricted depth for shipping
NEPTUNE ENERGY	2,900	▪ Longer distances / higher transportation cost ▪ More mature compared to Med sequestration sites
STOREGGA	3,140	▪ Longer distance/ higher transportation cost / low sequestration cost ▪ More mature compared to Med sequestration sites ▪ Regulatory hurdle to sequestrate outside of EU
EnQuest	3,215	

APOLLOCO$_2$ Timeplan

Launch in Q1 2023

Pre-FEED + FEED + Permitting

FID

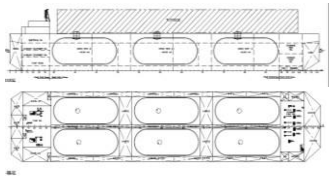
Construction

Operational Start

2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029

Pre-Feasibility Studies

Today



Thank you!

Giannis Stavrakopoulos

Energy Transition & Strategic Planning Specialist

i.stavrakopoulos@desfa.gr

Thank you for your participation!

Lorella Palluotto, Interoperability & Gas Quality & Hydrogen Adviser

Lorella.palluotto@entsog.eu

ENTSOG - European Network of Transmission System Operators for Gas
Avenue de Cortenbergh 100, 1000 Bruxelles

www.entsog.eu | info@entsog.eu