Detailed development plans of two selected CCUS Value Chains for the Baltic and Mediterranean Sea Regions

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Agenda

- CCUS ZEN Project Introduction
- CCUS Value Chain Mediterranean Sea Region Detailed Plan
- Project risk assessment highlights
- CCUS Value Chain Baltic Sea Region Detailed Plan
- Business models definition highlights
- Conclusions

CCUS ZEN - main objective is to facilitate CCUS uptake in the industry

HORIZON EUROPE

- CSA – Coordination and Support Action
- September 2022 – January 2025 https://www.ccuszen.eu/

Objectives

- Enable faster development of CCUS projects in industrial clusters across two EU regions: Baltic Sea and Mediterranean Sea regions
- Identify potential new Project of Common Interest projects for transport and storage
- Contribute to knowledge sharing on key issues relevant to industrial deployment of CCUS

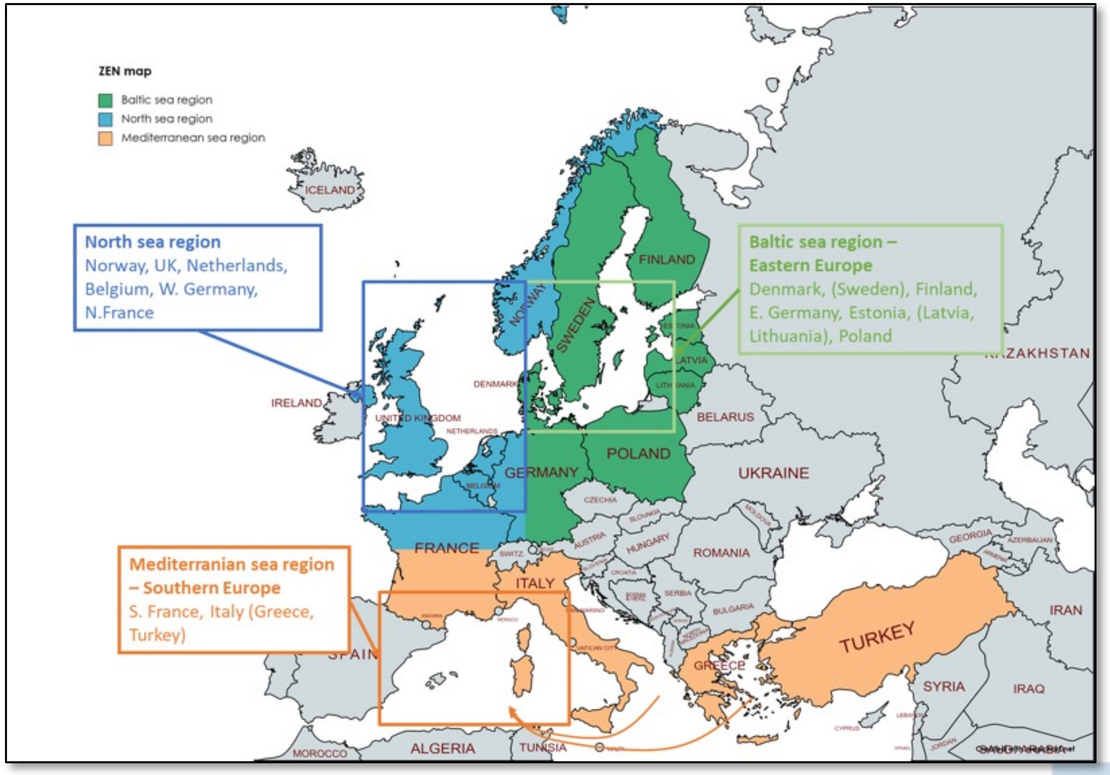
Disclaimer: Scenarios presented in CCUS ZEN, while based on an industrial reality on the ground, are forward-looking scenarios and are subject to further research and input data validation. However, they provide an initial framework for such developments using preliminary available information accessible to the Consortium to-date.

CCUS ZEN - Focusing on the Baltic Sea and Mediterranean Sea regions

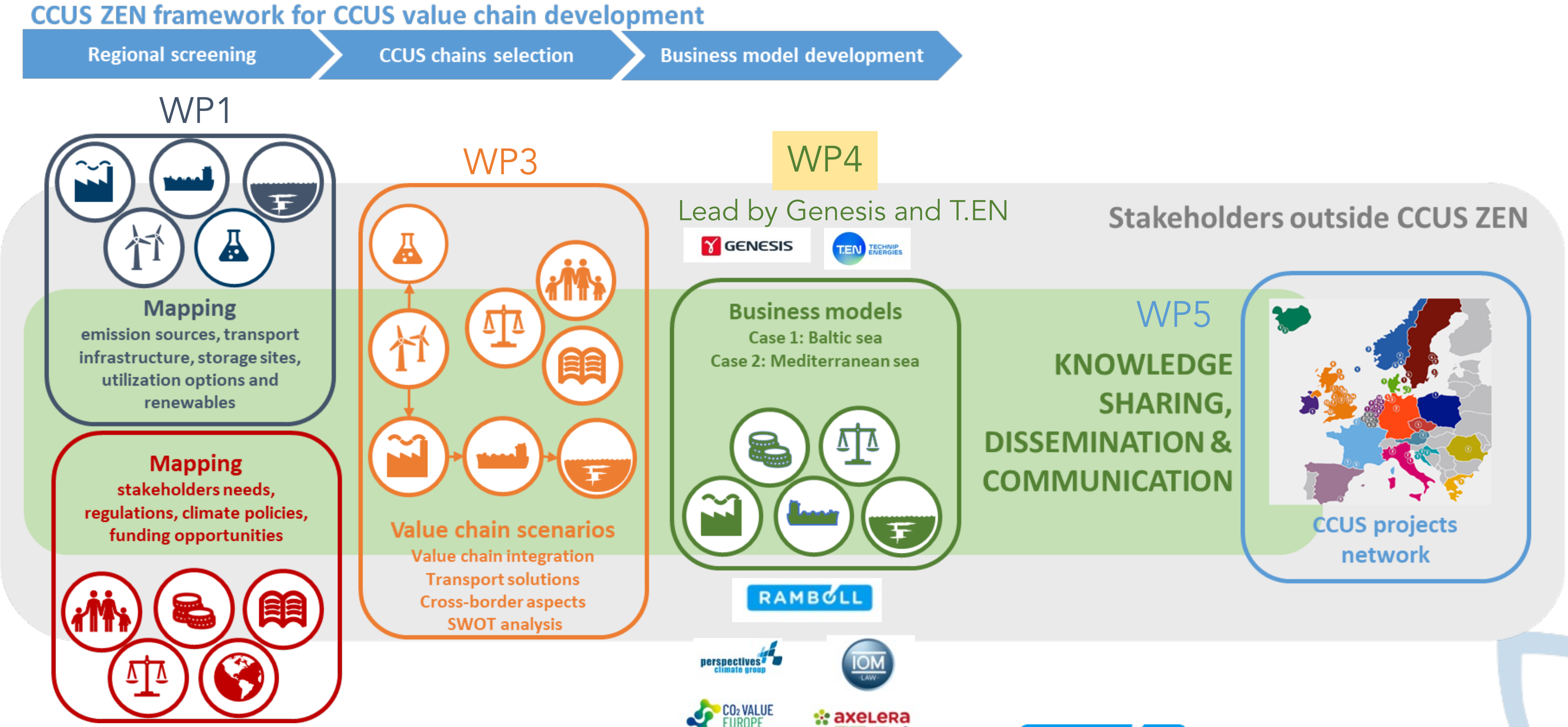
CCUS ZEN REGIONS

- **Greater Baltic Sea region** covering Denmark including its inland waters and the easternmost North Sea*, Sweden, Finland, Germany, Estonia, Latvia, Lithuania, Poland and the Baltic Sea.
- **Mediterranean Sea region** covering France, Turkey, Spain, Italy and Greece.

***North Sea region** primarily for experience/knowledge sharing

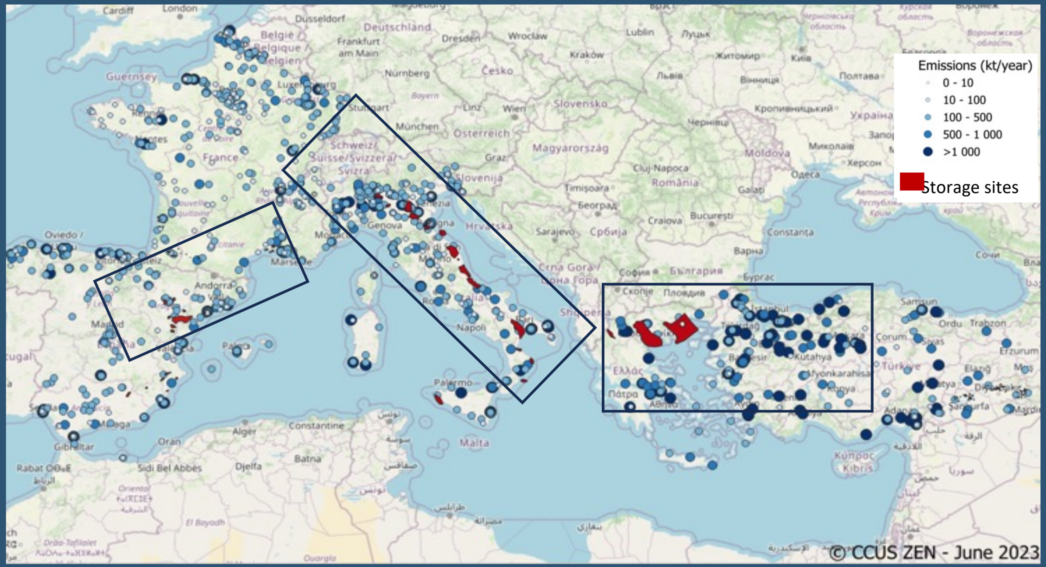


CCUS ZEN – Scope of Work



Identifying CCUS value chains in the Mediterranean Sea region

Emission Sources Mapping



Available Storage Sites and envisaged value chains

Nontechnical / Technical Mapping

- Emission sources
- Storage sites
- Transport infrastructure
- Utilization options

4 CCUS Value chain scenarios

- Value chain integration
- Transport solutions
- Cross-border aspects

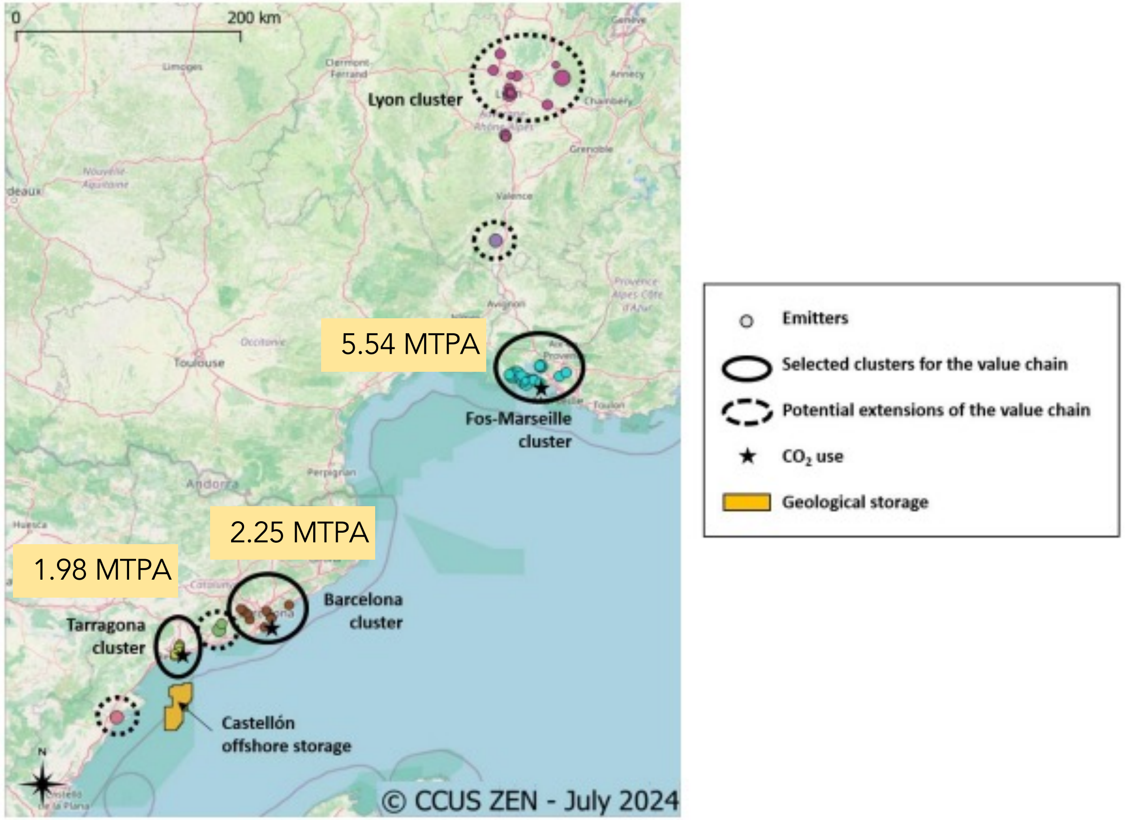
Selection of Favored CCUS Value Chain

- Med-2 between France and Spain

The selected Mediterranean Value chain allows to decarbonise several clusters through one storage site

- **Cross-border project** (France, Spain)
- **32** potential emitters in three clusters: Tarragona, Barcelona, Fos-Marseille
- **9.8[1] MTPA** of captured CO_2 with associated transport & storage chain

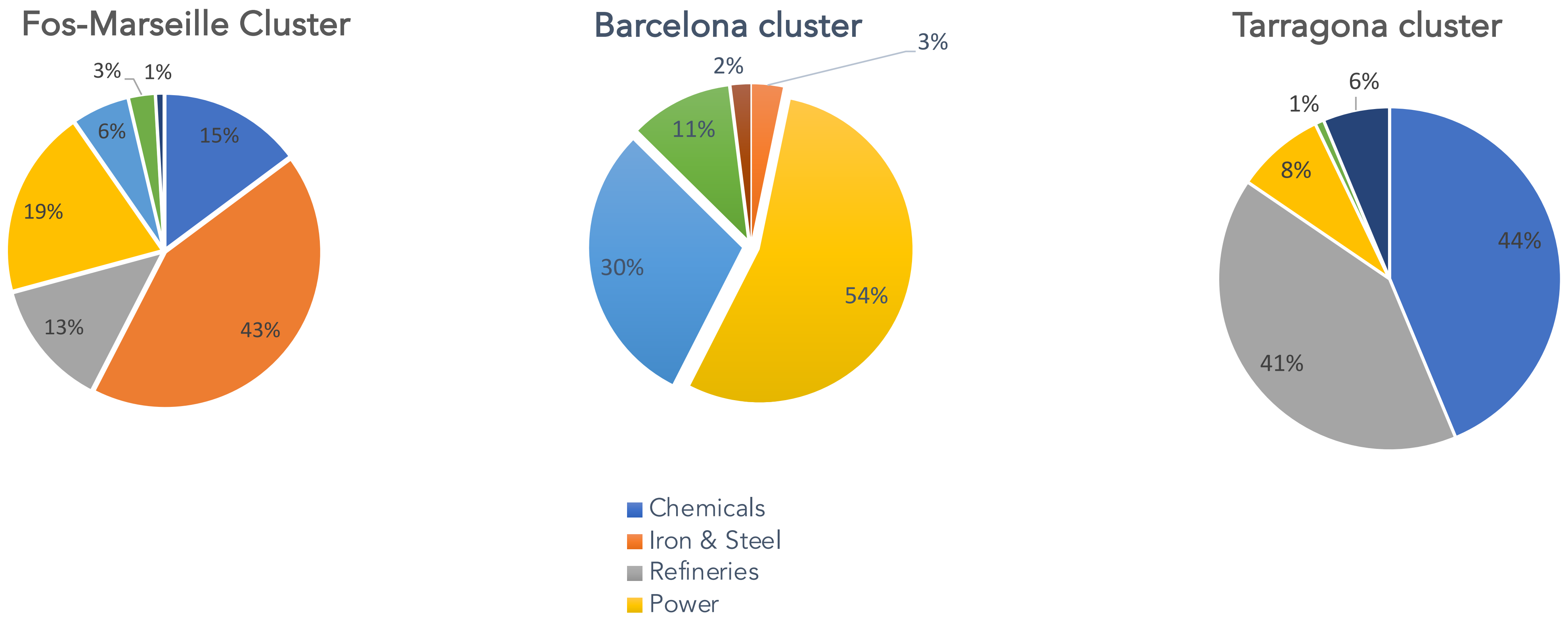
  Possible additional CO_2 volumes from Lyon area (not considered yet)
- Geological storage site **offshore Tarragona** (Ebro Basin) – exploration permit application ongoing
- **CO_2 Utilisation opportunities (to e-fuels) located at each cluster** depending on the CO_2 source and availability of green hydrogen



Note

1- Captured CO_2 volumes are estimated based on 2022 data and are assuming a potential percentage of CCUS implementation among other decarbonisation solutions per sector and a 95% of capture efficiency

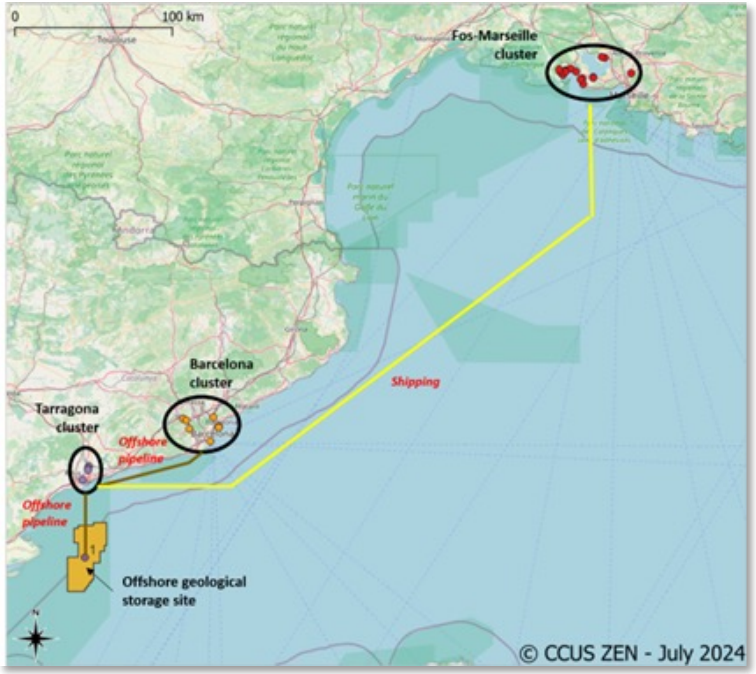
Local Emitters' specificities show a wide range of industry sectors, different for each cluster



Current CO2 Emission distribution per sector and cluster

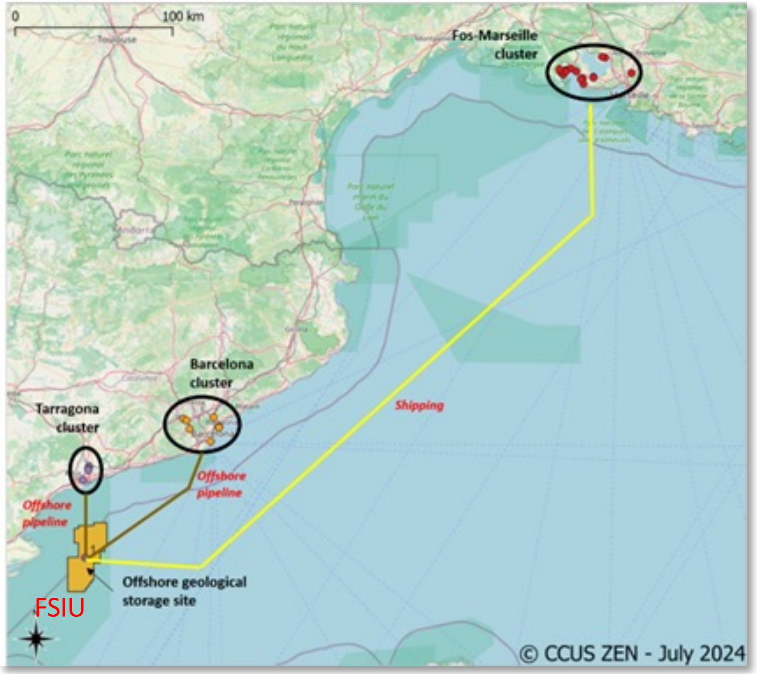
Two Transport and Storage Value Chains could be envisaged

- Reference Case:
  Onshore Collection Hub



Injection through a single offshore pipeline from Tarragona

- Alternative Case:
  Offshore Collection Hub

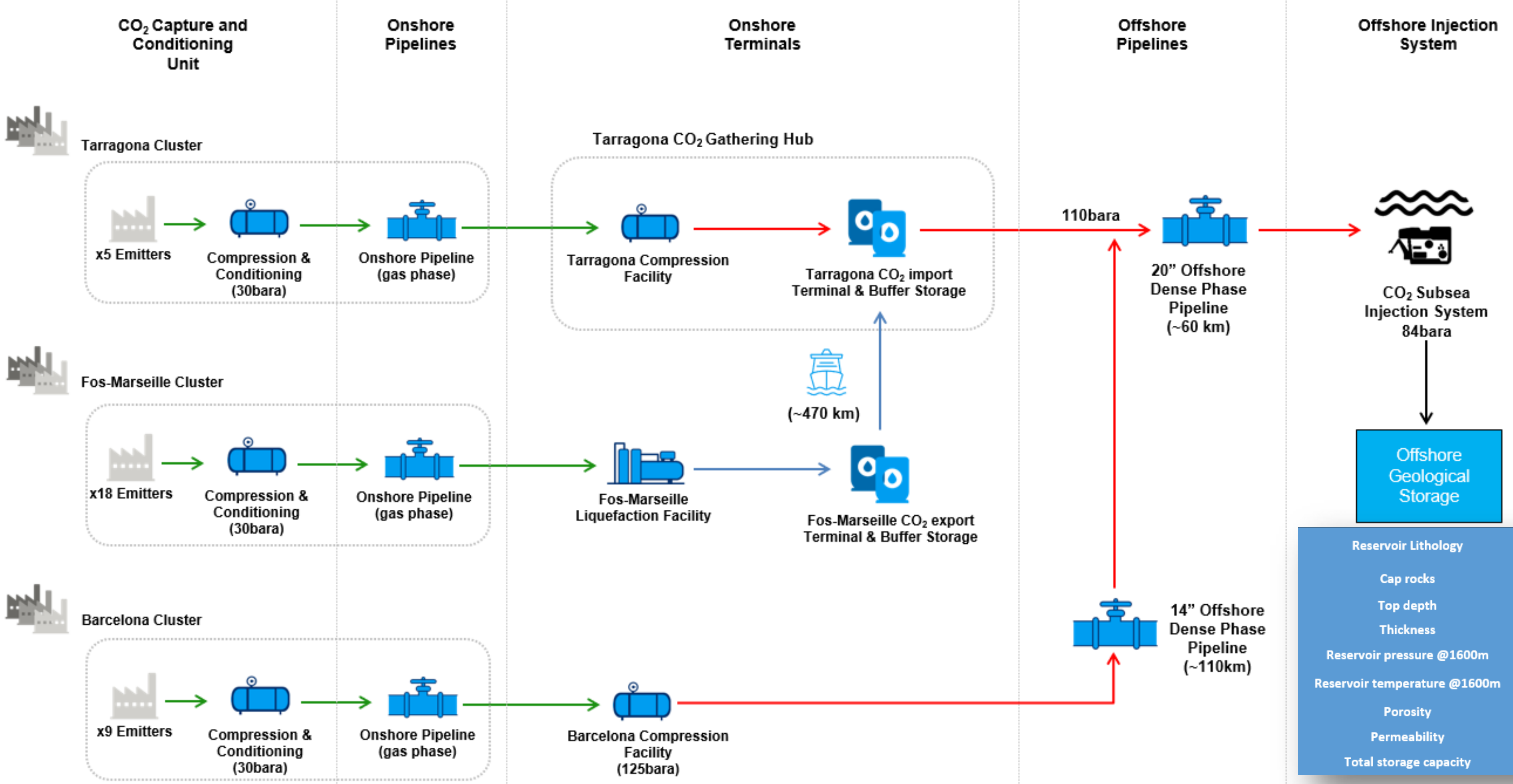


Floating Storage and Injection Unit (FSIU) and direct injection from Clusters

Overall Principles

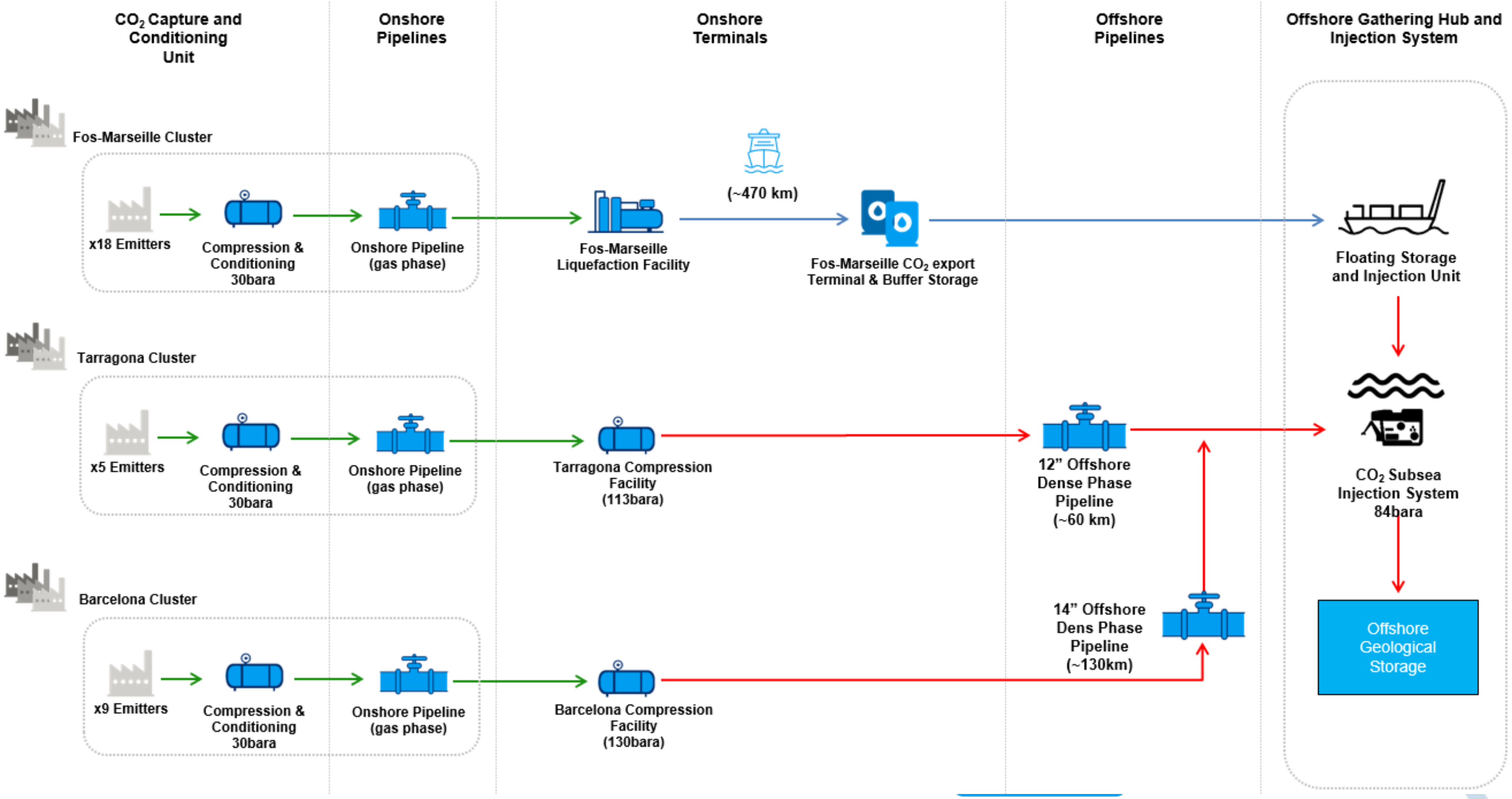
- Capture at each emitter
- Common CO_2 Gathering network at each cluster
- Medium Pressure Shipping
- Dense phase offshore export pipelines
- Ebro Basin reservoir (200 Mt)

Reference Case based on an Onshore Collection Hub, a similar concept as existing developments



Reservoir Lithology		Upper Miocene Castellon Sandstone
Cap rocks		Ebro Shales
Top depth	m	1600
Thickness	m	300-600
Reservoir pressure @1600m	MPa	16
Reservoir temperature @1600m	°C	74
Porosity	%	14-20
Permeability	mD	10-500
Total storage capacity	Mt	200

Alternative Case based on an Offshore Collection Hub minimizes onshore impacts

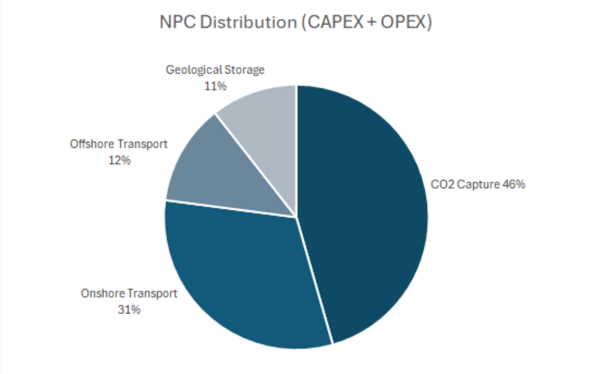


Preliminary Economic evaluation provides first insights on the investments required

- Preliminary economic analysis (of the CCS chain) shows a Levelized cost (LC) of around **130[1] EUR/t of CO_2** injected over 20 years
  - Similar Results for both Transport and Storage options
  - Split between 45% Capture and 55% T&S
  - Economic viability relies on the capacity to amortize fixed investments costs over the largest volume of CO_2 possible
- CO_2 Utilization opportunities at cluster level depending on CO_2 type
  - Potential additional volumes of CO_2 to transit on common T&S infrastructure with CCS value chain
  - Viability of utilization project, notably e-fuels, relies on the grid capacity to allow green hydrogen production and local availability of captured biogenic CO_2 (currently estimated at around 0.4 Mtpa)

	Reference Case	Alternative Case
CAPEX[1] [MEUR]	8 050	8 186
OPEX [MEUR/y]	343	344
NPC[2 3] [MEUR]	8 557	8 665
LC [EUR/tCO_2]	128	130

Reference Case - Key Numbers



Notes

1- Cost estimate accuracy based on AACE Class 5 definition, 3rd Quarter 2023 cost baseline. Cost estimates includes 30% of Unallocated Provision.

Estimates exclude CO2 utilisation plants, Modularisation & transportation to site, Route survey, land acquisition and right of way, Major harbour changes, Grid expansion, Decommissioning and removal/relocation of equipment at brownfield sites, Customs duties and local taxes, Owner's costs, Escalation costs., Client's Authorization for Expenditure (AFE) Contingency.

2 - Project development starts in 2030 with operations starting in 2035 for 20 years (until 2045). NPC = Net Present Cost (including CAPEX + OPEX) = present value of cash outflows, using a discount rate of 8% (real pre-tax).

3 - Assume 8% discount rate and no inflation considered

Project Risk Assessment Methodology developed to ensure a collaborative and systematic assessment

Categorisation

Identify risks for better analysis

- Categorize risks into key topics:
  - Environmental and Social Risks
  - Safety and Security Risks
  - Technical Aspects and Design Risks
  - Financial Aspects (Cost & Contract)
  - Partners, Business Model & Economic Risks
  - Legal and Regulatory Risks

Risk Score = Likelihood X Severity

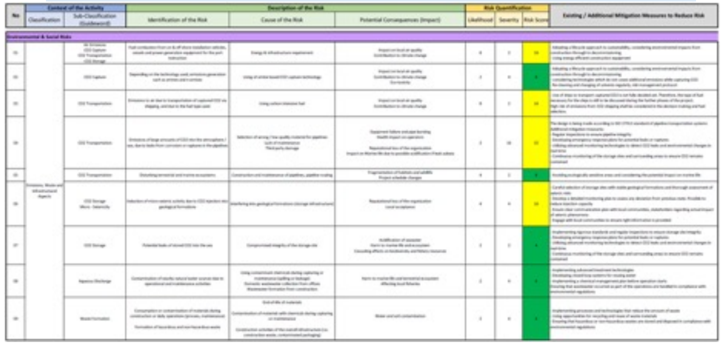
	1 - Very Unlikely	2 - Unlikely	4 - Possible	8 - Likely	16 - Very Likely
16 - Critical	16	32	64	128	256
8 - Substantial	8	16	32	64	128
4 - Significant	4	8	16	32	64
2 - Minor	2	4	8	16	32
1 - Negligible	1	2	4	8	16

Class 1 (Green) – Acceptable risk level
Class 2 (Yellow) – Long-term control measures to be addressed to keep risk at an acceptable level
Class 3 (Red) – Immediate mitigation measures to be taken

Workshop

Conduct a collaborative risk assessment

- Organize a one-day workshop with relevant project partners
- Systematic identification of risks, causes and consequences
- Quantify likelihood and severity impacts of each risk to define its acceptability level
- Formulate clear mitigation



Actions

Enhance risk management strategies

- Analyze grouped risks to identify priority areas
- Identify existing or required mitigation measures to be implemented in the next project phase
- Highlight potential opportunities

Key risks and associated Mitigation Measures, similar for both regions, are identified for future implementation at later phase

	Risks	Mitigation Measures
Non-technical Risks	• Environmental impact and leakage risks • Public perception and acceptance • Regulations and government support uncertainty • Permitting processes • Revenue mechanisms uncertainties • Business viability	• Detailed environmental impact assessments • Definition of effective leak detection systems and safety measures. • Stakeholders' engagement (e.g. public, industries, developers, regulators, governments, local authorities) • Clarification of regulations and ensuring predictable revenue mechanisms to secure economic feasibility • Definition of clear business models and contracting strategies between stakeholders
Technical Risks	• Different readiness levels of the CCUS blocks along the value chain • Technical Risks associated to uncertainties on technical input: o Projected CO_2 captured volumes and Transportation schemes definition o Low maturity of the geological storage sites o CO_2 Utilisation feasibility (i.e. access to renewable electricity, biogenic CO_2, cost…)	• Engagement with local emitters to confirm CO_2 volumes and assumed input data • Further engagement with storage site owners and operators to confirm site selection • De-risk technical challenges with sequenced engineering assessment in line with project phase on the full value chain (capture, transport, storage and utilization)

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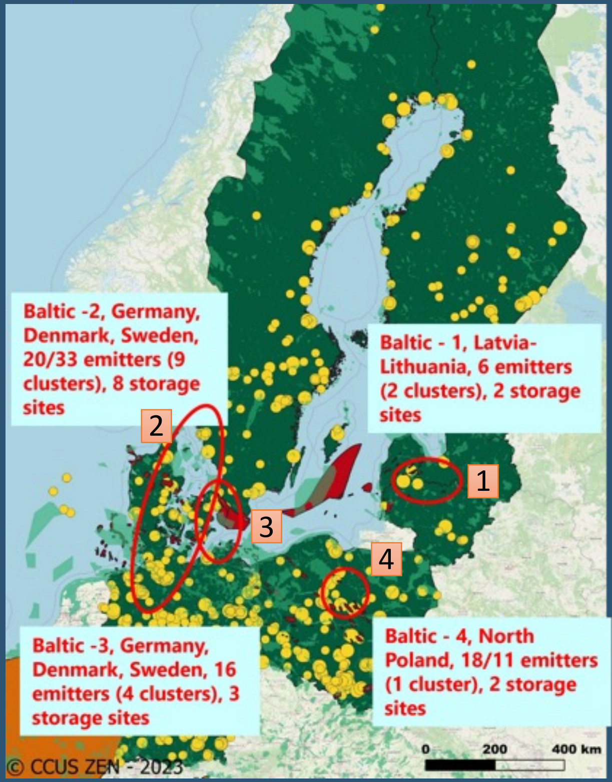
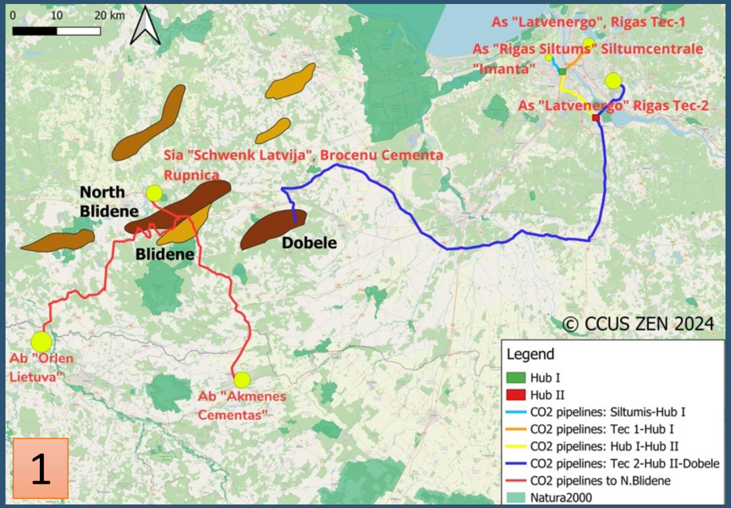
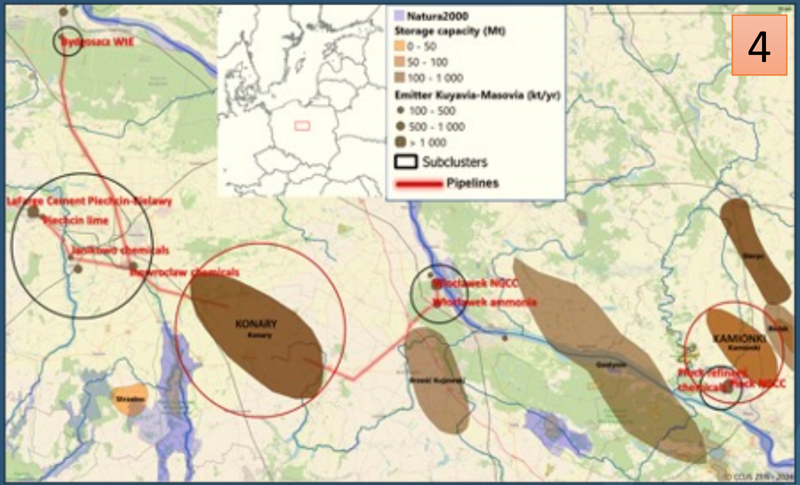
Identifying CCUS value chains in the Baltic Sea region







Nontechnical / Technical Mapping

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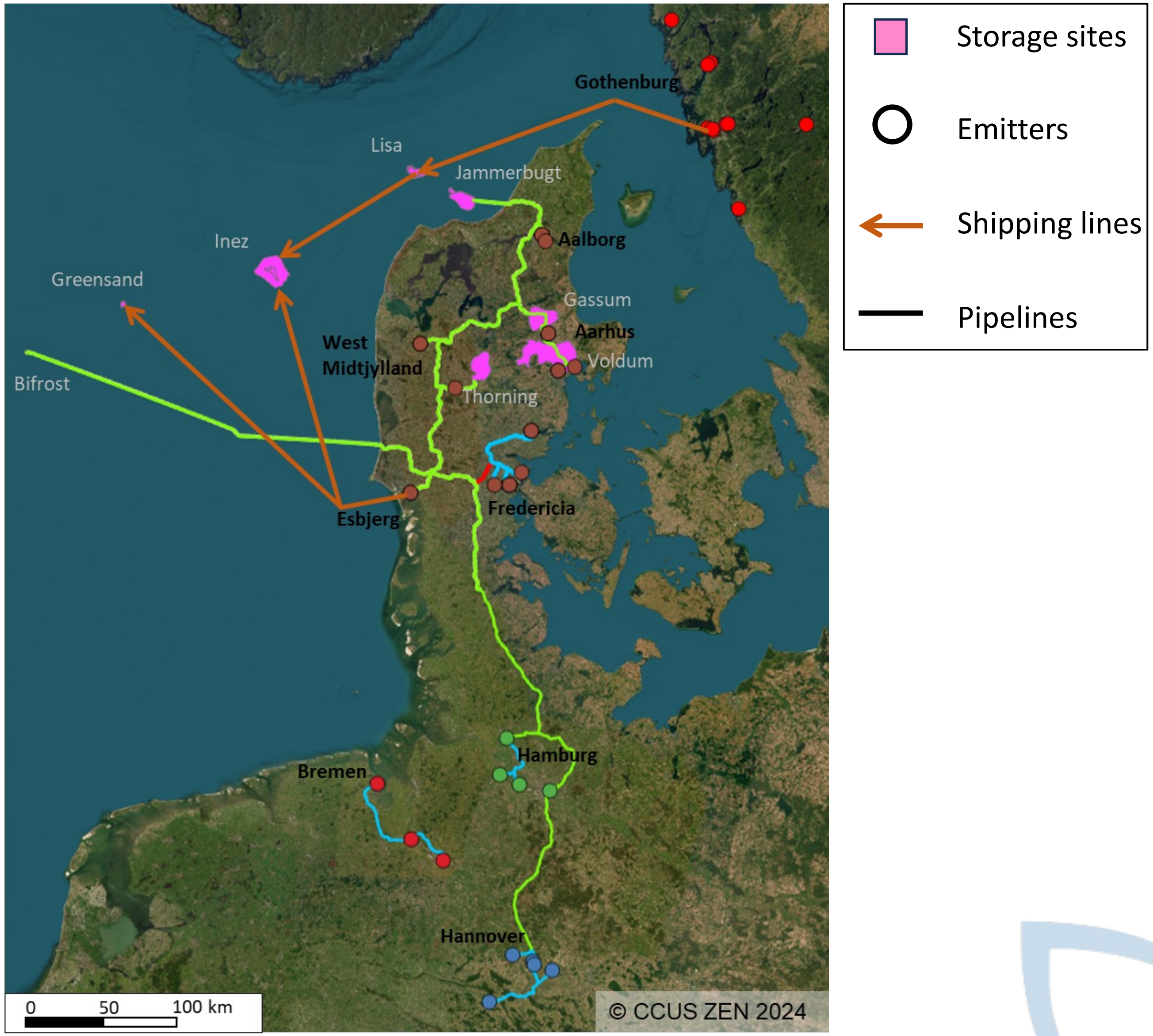
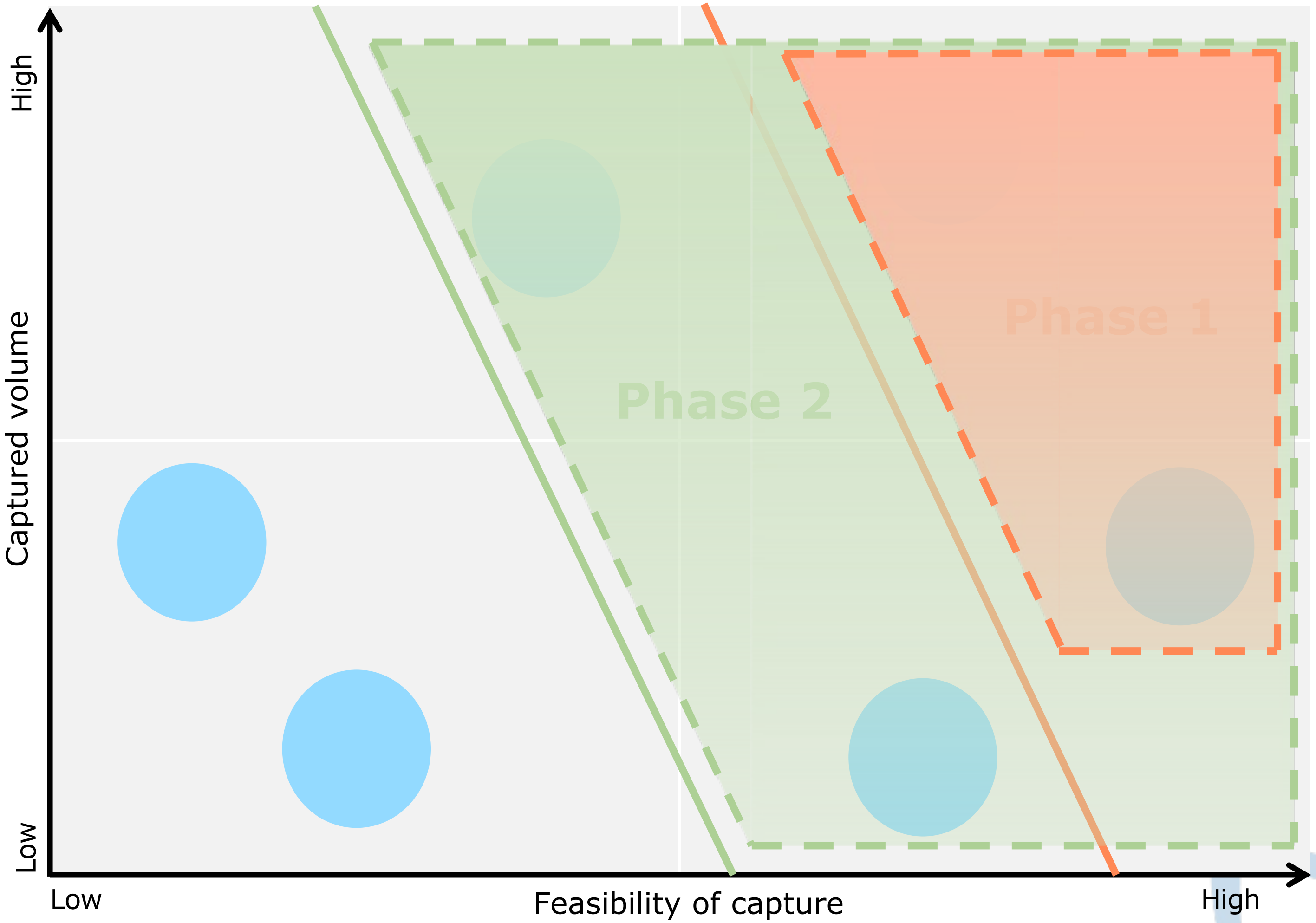
Setting forth a large scale, cross-border CCUS initiative

- 3 countries: Germany, Denmark and Sweden
- 33 emitters
- 20 Mt/y of captured CO_2
- 8 geological storage locations
- More than 928 million tonnes of theoretical mean storage capacity
- 15.1 Mt/y injection volume
- 6 Mt/y for 15 CCU installations



The emitters were analysed and filtered through a “value-effort” matrix prioritisation technique

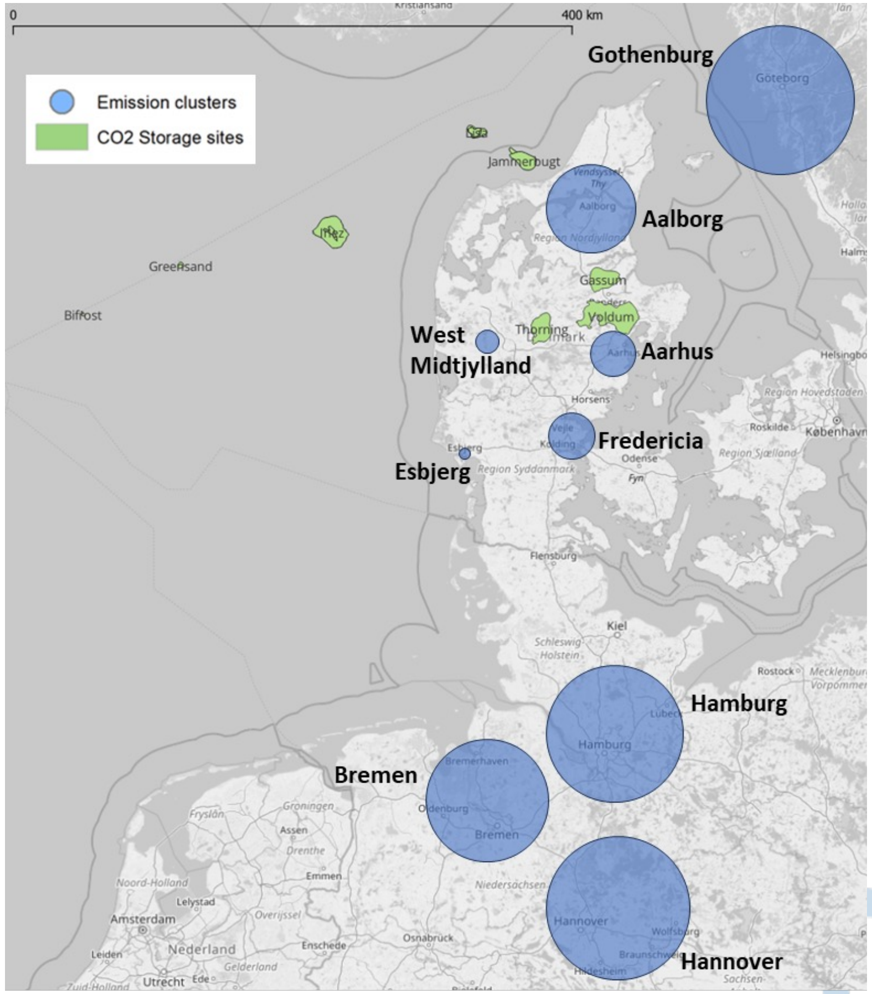
- 56 emitters analysed and 33 selected
- Filtering of emitters according to:
  - Captured volume (quantitative variable)
  - Feasibility of capture (qualitative assessment mainly based on existing decarbonisation, retrofitting or out phasing plans)
- Phases 1 and 2 represent potential first line and followers, respectively for a CCUS decarbonisation solution.



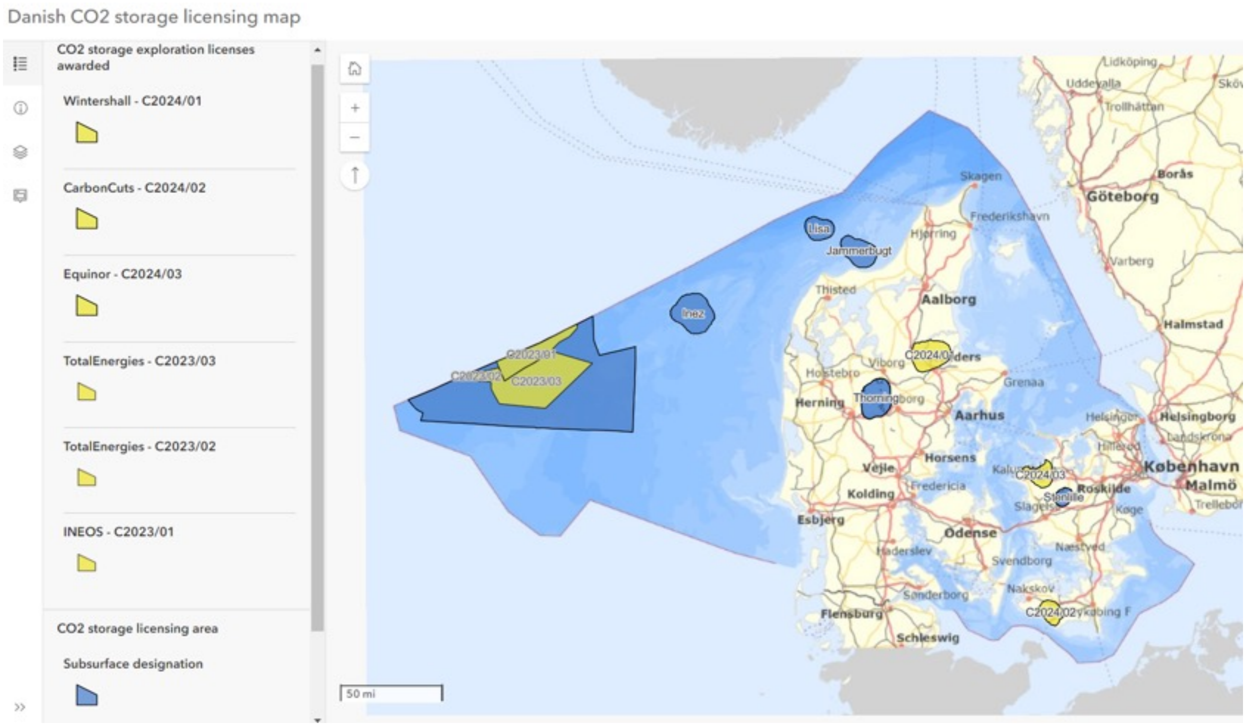
Nine clusters were defined with an assumed capture rate of 95%, resulting in 20 million tonnes per year of CO_2

Country	Cluster	CO_2 emissions [Mton/yr]	CO_2 captured [Mton/yr]	Captured biogenic CO_2 [Mton/yr]	Number of emitters
Germany	Bremen Cluster	3.43	3.26	2.64	3
	Hannover Cluster	3.99	3.79	1.81	5
	Hamburg Cluster	3.80	3.61	1.14	4
Sweden	Gothenburg Cluster	4.12	3.92	0.65	9
Denmark	Aalborg Cluster	2.48	2.36	0.13	2
	Aarhus Cluster	2.72	1.16	0.55	3
	West Midtjylland Cluster	0.62	0.59	0.34	2
	Fredericia Cluster	1.28	1.21	0.67	4
	Esbjerg Emitter	0.22	0.21	0.12	1
Total (Phase 2)		22.66	20.10	8.05	33

- Selected power sector assumed to retrofit to biofuels, due to communicated plans. The resulting emissions are assumed to be similar as before retrofit.
- Multiple emitter sectors result in a diverse impurity mix. T&S infrastructure may be affected.



Utilisation and storage ensure the material balance



[Danish CO_2 storage licensing map]()

Site name	Onshore / offshore	Mean capacity [Mt]	Storage site area [km²]	Max. annual CO_2 injection volume [Mt/y]	No of injection wells	No of monitoring wells
Gassum	Onshore	146	233	3.0	7	4
Voldum	Onshore	213	560	3.0	7	4
Jammerbugt	Offshore (nearshore)	100	140	3.0	7	0
Inez	Offshore (nearshore)	178	250	3.0	7	0
Bifrost	Offshore	min. 60	16	0.8	4	0
Greensand	Offshore	min. 128	16	1.5	4	0
Lisa	Offshore (nearshore)	29	70	0.5	2	0
Thorning	Onshore	74	210	0.3	3	2

Cluster acting as CCU hub with 5 installations each	Captured CO_2 from all emitters for CCU [Mt/y]	Average capture capacity of CCU installation [kt/y]	Average product capacity of CCU installation [kt/y]
Bremen	3.20	640	450 (for methanol) 192 (for synthetic jet fuel)
Aalborg	1.66	332	232 (for methanol) 100 (for synthetic jet fuel)
Gothenburg	1.19	238	167 (for methanol 72 (for synthetic jet fuel)

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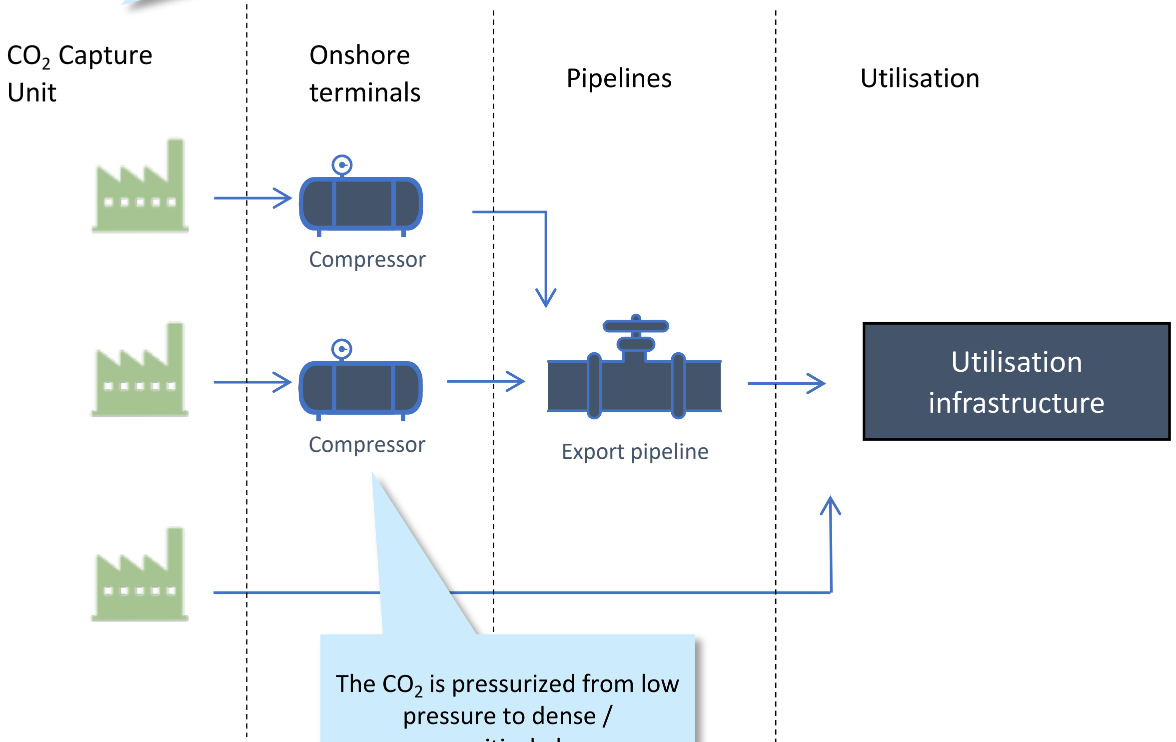
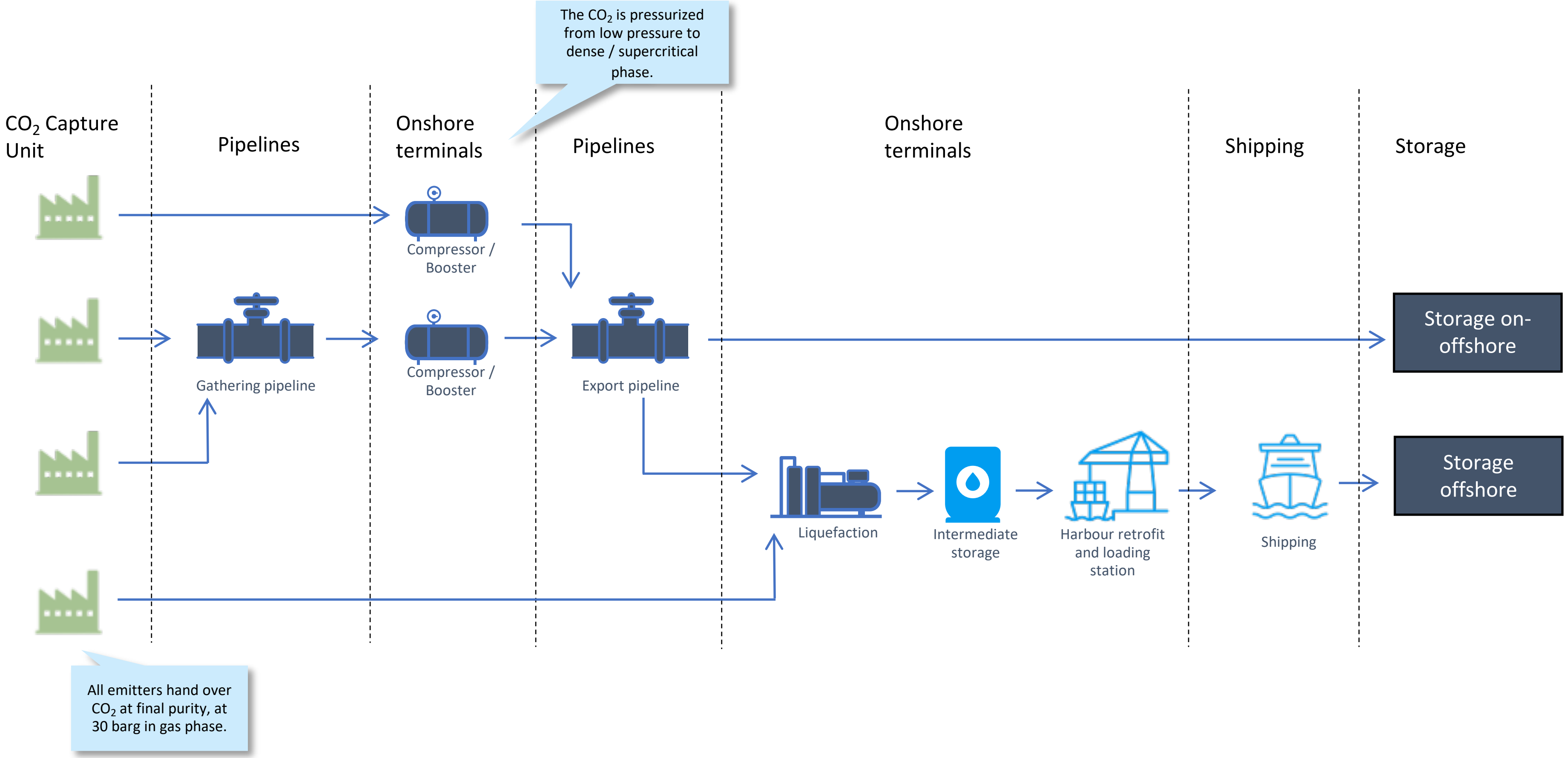
A single dense phase CO_2 pipeline in Bremen simplifies the transportation network

All emitters hand over CO_2 at final purity, at 30 barg in gas phase.

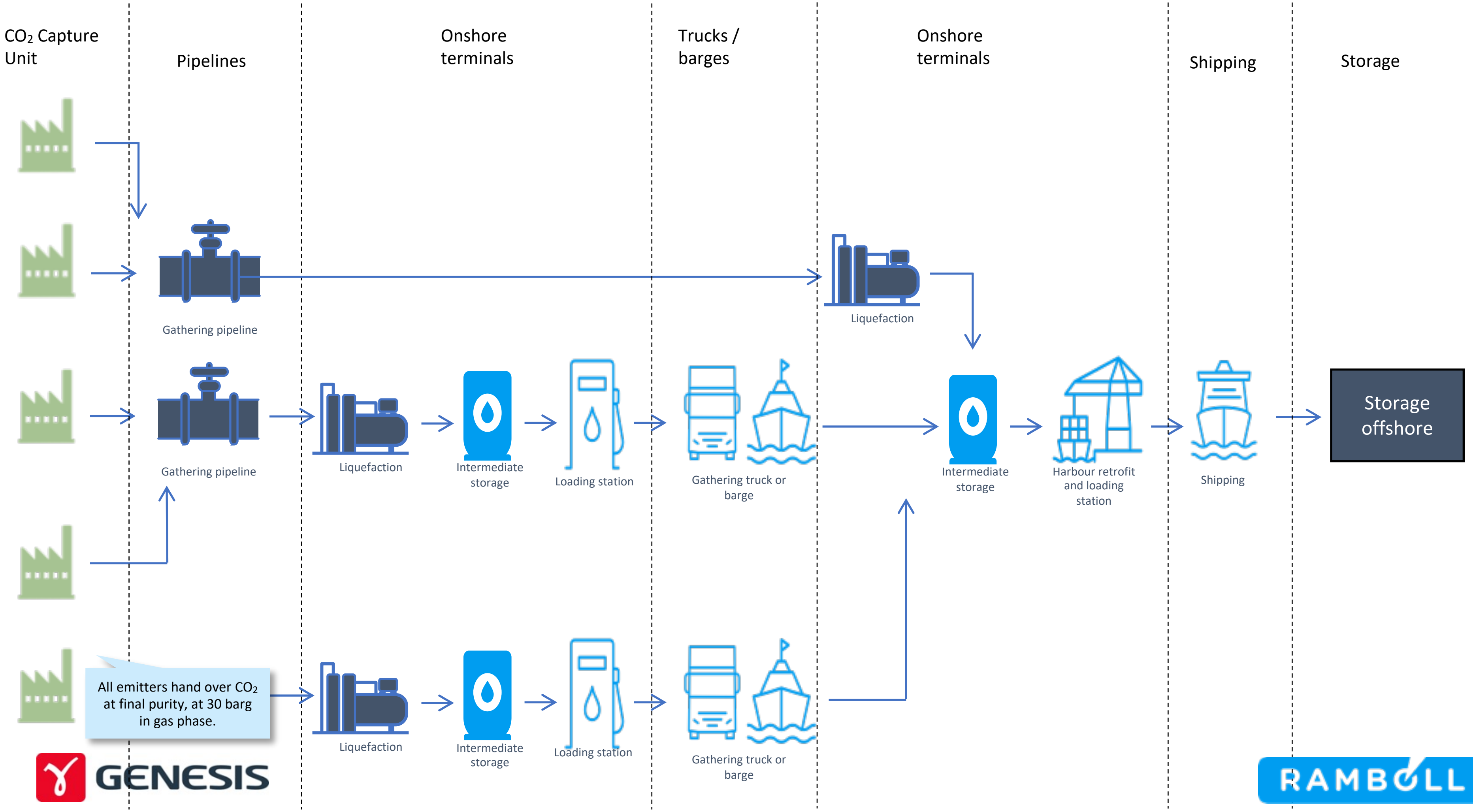


The CO_2 is pressurized from low pressure to dense / supercritical phase.

Complexity is introduced with batch transportation methods

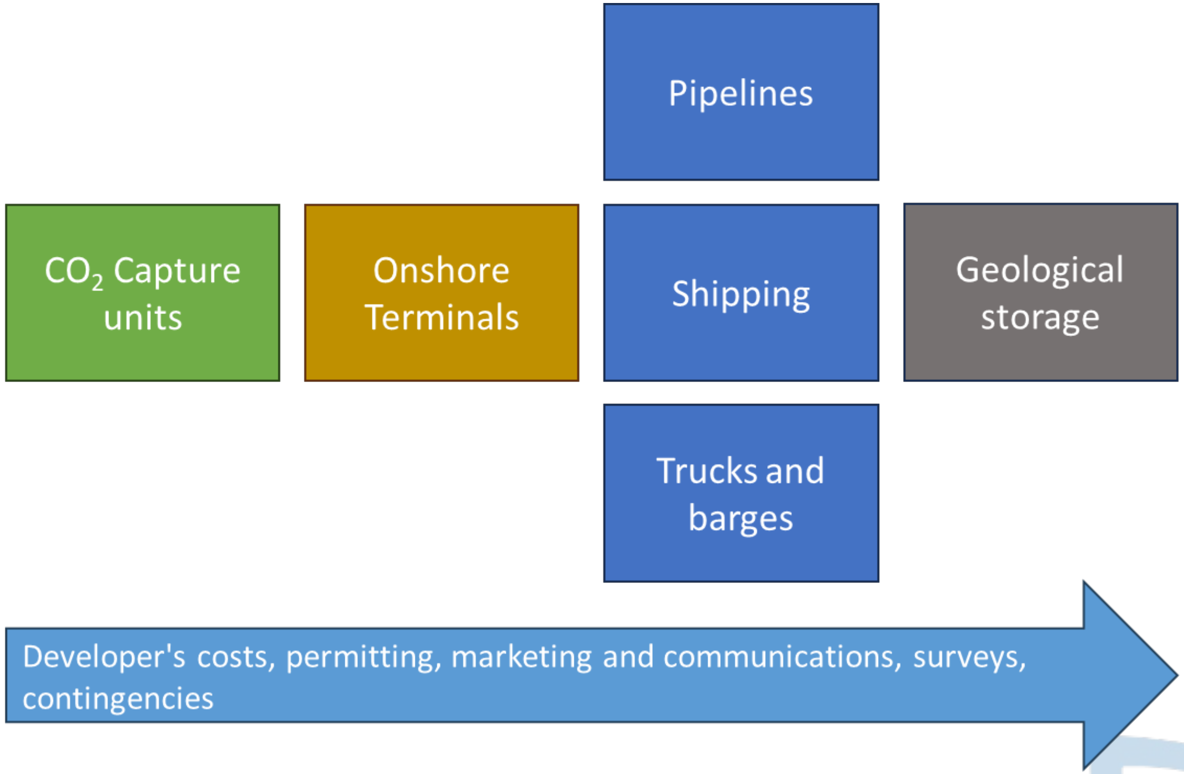


Difficult access to the Gothenburg Port requires the utilisation of trucks/barges



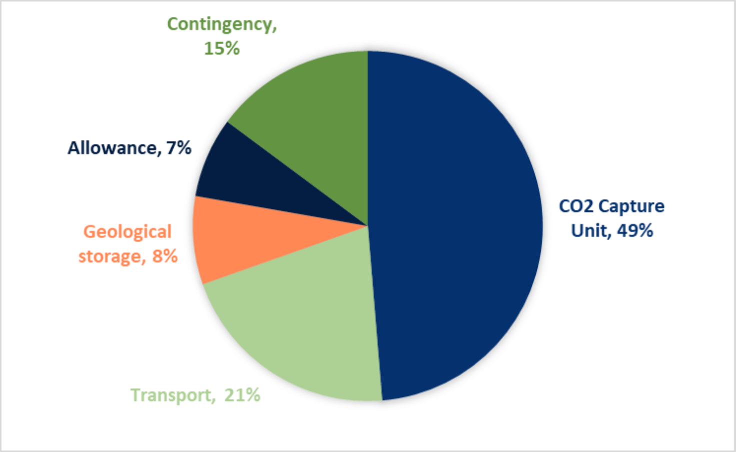
CAPEX/OPEX were estimated considering the early maturation level of the project definition

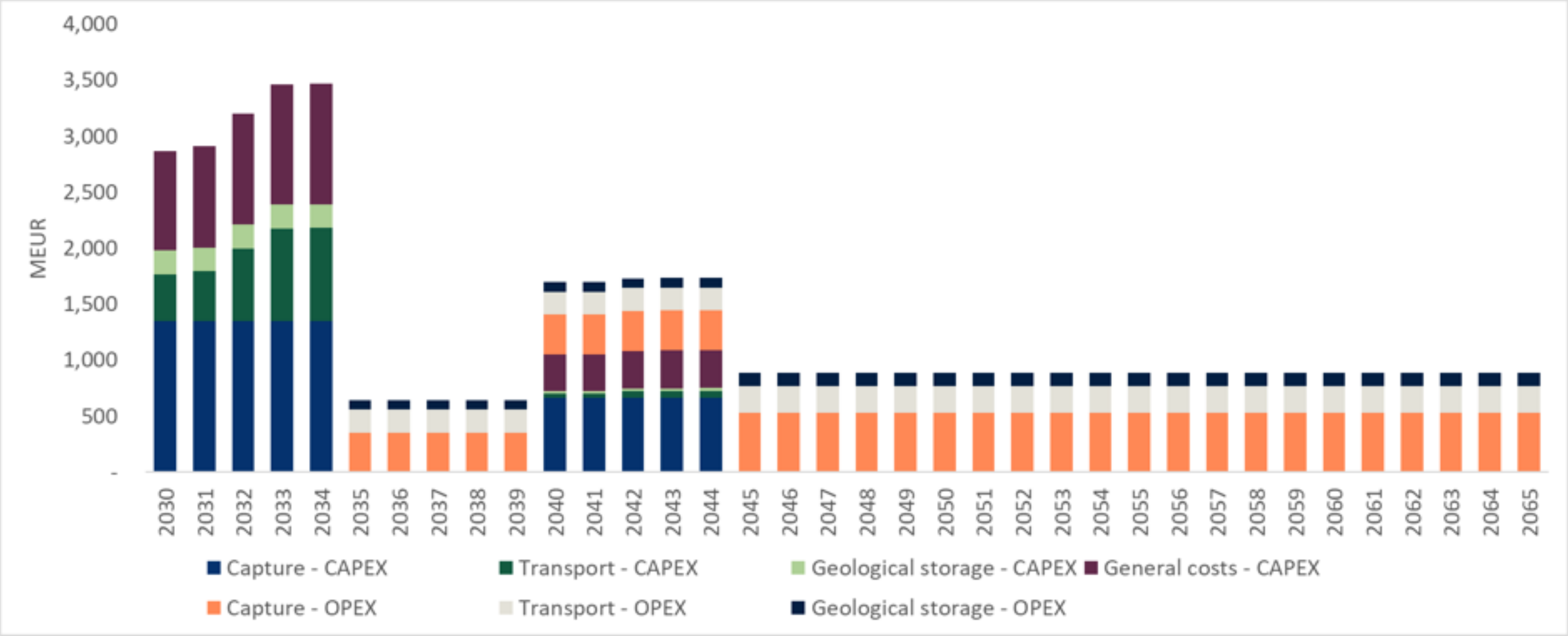
- Utilisation plant costs are excluded from the cost scope. Only the respective CO_2 transportation up to the utilisation hubs is included.
- Land acquisition and right of way.
- Requirements for grid expansion.
- Heat and fuels for Carbon Capture plants.
- Electricity consumption for ID cooling tower, other utilities, heat pumps and purification.
- Flue and exhaust gas pre-treatment.
- Fuels and chemicals for Onshore Terminals.
- Waste treatment and disposal.
- Major harbour changes, such as dredging, or reclaiming land.
- Offshore accommodation.
- Decommissioning and removal/relocation of equipment.
- Customs duties and local taxes.
- Escalation costs.
- Insurance.



A large CCS infrastructure mutualises several costs that benefit from economy of scale

CAPEX [MEUR]	21,266
OPEX [MEUR/y]	889
NPC [MEUR]	12,809
LC [EUR/tCO_2]	168





The economic analysis also introduces two main definitions: Net Present Costs (NPC) and Levelised Costs (LC).
NPC represents the present value of cash outflows, using a discount rate of 8% (real pre-tax).
Levelised Cost is often used to compare the cost-effectiveness of different decarbonisation technologies and the ETS carbon priced. It allows policymakers and investors to evaluate the cost competitiveness of various decarbonisation methods on a consistent basis.
The levelised cost and NPC obtained do not consider CO_2 utilisation costs or any revenue.

Both value chains could be better represented by a single/multi-hub integration model

Full chain model	• Integrated service provider • Covers all sections of the value chain
Self-capture	• Emitters own and operate the capture plant • CO_2 offtake by third party
Capture as a service	• Emitters hire third party specialised operator specialised in capture technologies • Third party operator may offer services for multiple emitters
T&S as a service	• T&S operator offtakes CO_2 from the emitter • Pipeline systems or fixed infrastructure may lead to monopolies requiring government involvement

Applicable to single and multi hub integration model

Engagement of a wide range of stakeholders is a requirement

Project developers and partners: can be divided in emitters, aggregators and T&S operators. Partners include supporting functions to the project development, such as consultancy and research.

Regulatory authorities: nature considerations, such as Natura 2000 and Annex IV species, and the water framework directive, cultural heritage, safety issues, and citizen's health. The regulatory aspect also covers municipalities and local planning as fundamental to realise the project.

Non-governmental Organisations: promote the development of CCUS and highlight the challenges or possibilities. Engage with the developers and authorities for better informed decisions.

Financial Institutions: provide financial support, managed at both national and EU levels.

Ensuring a predictable revenue stream is essential for the business case success

- Revenue generation mechanisms
  - Utilisation of CO_2
  - Carbon markets
    - Voluntary Carbon markets
    - Compliancy markets (ETS)
  - Technology Licensing
  - Low-carbon premium
  - Tax credits / Avoided Tax
  - Government support
  - Other services
    - District heating (using waste heat)
    - Consultancy and research
    - MRV activities

Conclusions

- The Baltic and Mediterranean Sea Regions value chains propose to be a comprehensive suggestion for the definition of an **integrated CCUS infrastructure** and to identify potential paths for a viable business plan.
- The results obtained rely on very **early premises** that are subject to potential risks or opportunities that could shift the project layout. Additionally, the project scope was purposely limited to fit to specific CCUS ZEN requirements, (i.e geographical restriction to the Baltic and Mediterranean regions), therefore, the study must be understood as a potential path for a full CCUS network development.
- Main drivers to ensure a successful deployment
  - **De-risk** technical challenges with sequenced engineering assessment in line with project phase (feasibility, PreFeed, FEED, FID)
  - Find mechanisms to guarantee **early stakeholders' engagements** (industries, governments, local authorities, public…)
  - Secure **long term and clear policy supports** including notably fiscal incentives, carbon pricing mechanisms, or direct subsidies to make projects financially viable.

- Deliverables will be issued on https://www.ccuszen.eu/.
- Subscribe to CCUS ZEN Newsletter or Follow us on LinkedIn an

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