HERCCULES
full CCUS chain demonstration

CCUS ZEN

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Tallinn, Estonia. 13/06/2024

Technical modelling of the Baltic CCUS ZEN Scenario (Denmark, Sweden & Germany)

Leandro-Henrique Sousa / Ramboll

Carbon capture, utilisation & storage

"

With more than 50 experts and project managers and more than 100 successfully completed assignments within CCUS over the last 3-4 years, Ramboll is a leading CCUS advisor.

We have a deep understanding of the industry, the technologies and their application and so we can help clients navigate the challenges and pitfalls that projects in this market entail.

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We have comprehensive, multidisciplinary expertise across the CCUS value chain

Non-exhaustive list of potentials for utilisation

1 Carbon capture

CO_2 capture can take place directly from an industrial source or through direct air capture.

2 Transportation

CO_2 can be transported in large volumes via pipelines, road, rail and/or ships to the storage or utilisation location.

3 Utilisation

Captured CO_2 can be used as input for production of e.g., fertiliser, polymer or in Power-to-X processes.

4 Storage

CO_2 can be permanently stored onshore, nearshore or offshore in deep geological formations.

Our CCUS advisory covers both the public and private sectors.
We continuously advise policymakers and industrial clients in all stages of the CCUS value chain.

We provide technical, commercial and environmental insights into all phases of capturing, transporting, and utilising and/or storing CO_2.

1. We offer clients the **full range of project lifecycle services** for the planning, construction and operation of CO_2 capture facilities. Our technical and commercial expertise draws on extensive project experience.
2. Transportation of captured CO_2 is a key step in the CCUS value chain. Our experience across **all key carbon transport modalities** allows us to recommend the most technically and economically feasible setups.
3. We have a comprehensive understanding of **possibilities for CO_2 utilisation** (CCU), demonstrated through our **world-class experience in Power-to-X** across all technologies, resource inputs and offtake potentials.
4. In addition to utilisation, our extensive experience with **assessing storage possibilities for captured CO_2** (CCS) provides the client with a fully integrated overview of all potentials.

Agenda

1 _ Introduction

2 _ Emission sources

3 _ Storage sites

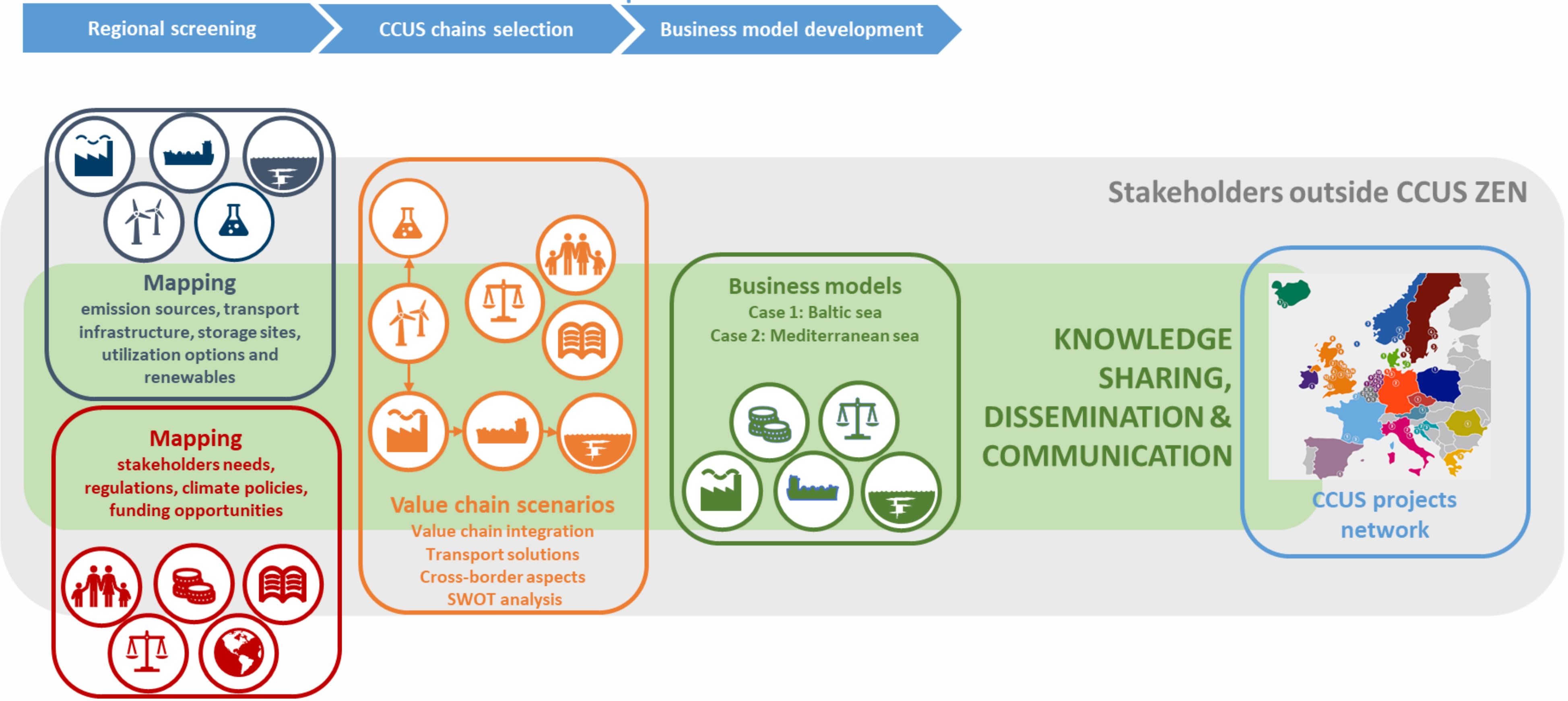
4 _ Utilisation projects

5 _ Transport infrastructure

6 _ Scenario selection and final remarks

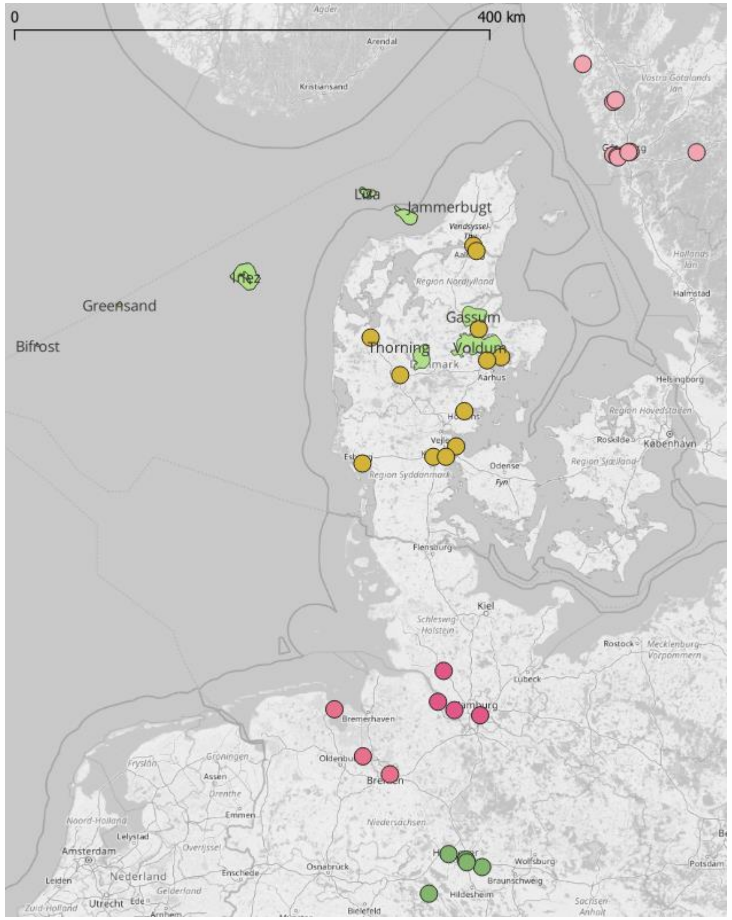
7 _ Q&A

CCUS ZEN framework for CCUS value chain development



Setting forth a large scale, cross-border CCUS initiative

- 3 countries
- Up to 33 emitters
- Up to 20 MTPA of captured CO_2
- 8 geological storage locations
- More than 928 million tonnes of mean storage capacity
- 15.1 MTPA injection volume
- 6 MTPA for 15 CCU installations



A collaborative effort to achieve a common goal

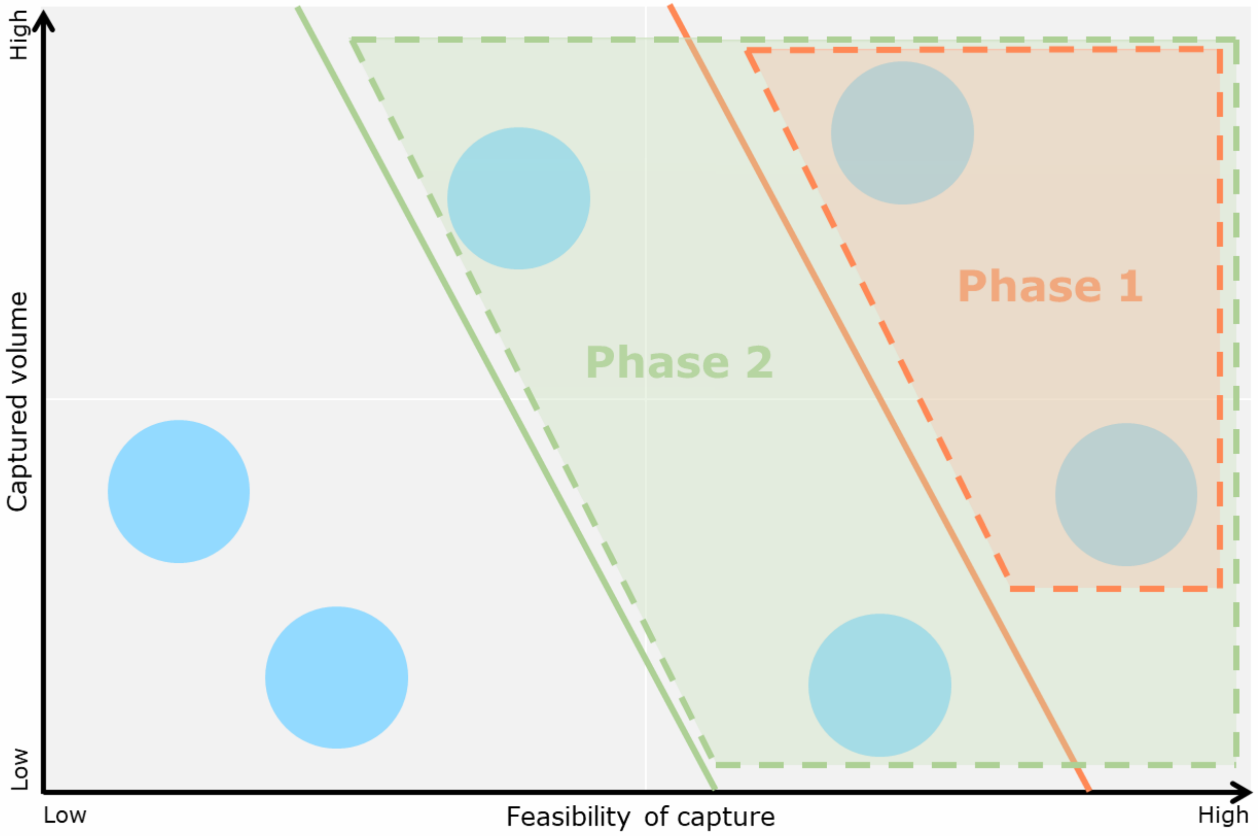
Technical scope

Technical scope	
Emission sources	RAMBOLL
Storage sites	GEUS – De Nationale Geologiske Undersøgelser for Danmark og Grønland
Utilisation options	axelera – Ensemble, catalysons les réussites – Auvergne Rhône-Alpes; CO2 VALUE EUROPE
Transportation infrastructure	RAMBOLL

The emitters were analysed and filtered through the "value-effort" matrix prioritisation technique

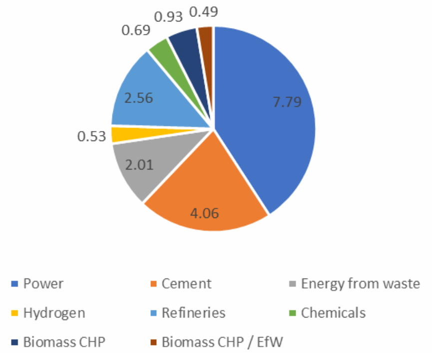
- 56 emitters analysed and 33 selected
- Filtering of emitters selected in WP1 according to:
  - Captured volume (quantitative variable)
  - Feasibility of capture (qualitative assessment mainly based on existing decarbonisation, retrofitting or out phasing plans)

- Phases 1 and 2 represent potential first line and followers, respectively for a CCUS decarbonisation solution.

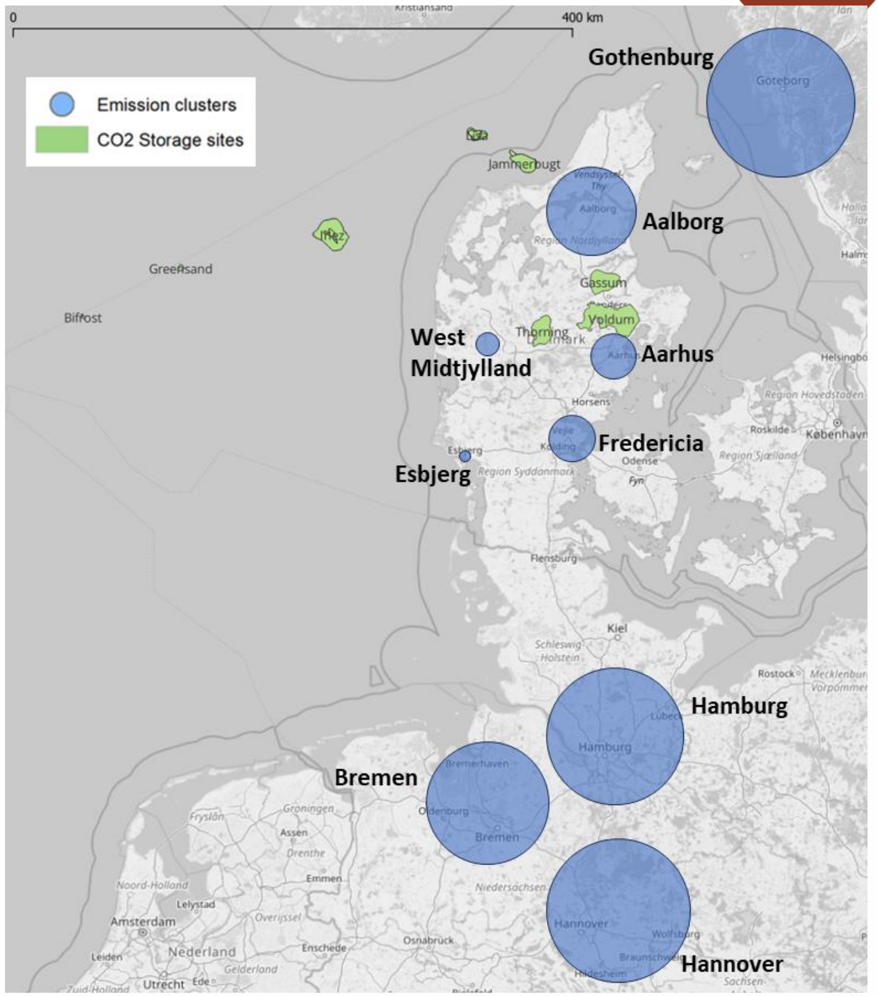


Nine clusters were defined with an assumed capture rate of 95%, resulting in 20 million tonnes per year of CO_2

Country	Cluster	CO_2 emissions [Mton/yr]	CO_2 captured [Mton/yr]	Captured biogenic CO_2 [Mton/yr]	Number of emitters
Germany	Bremen Cluster	2.78 - 3.43	2.64 - 3.26	2.64	2 - 3
	Hannover Cluster	3.12 - 3.99	2.96 - 3.79	1.73 - 1.81	4 - 5
	Hamburg Cluster	1.05 - 3.80	1.00 - 3.61	0.00 - 1.14	1 - 4
Sweden	Gothenburg Cluster	3.12 - 4.12	2.96 – 3.92	0.34 - 0.65	5 - 9
Denmark	Aalborg Cluster	2.48 - 2.48	2.36 - 2.36	0.13	2 - 2
	Aarhus Cluster	0.82 - 2.72	0.78 - 1.16	0.25 - 0.55	2 - 3
	West Midtjylland Cluster	0.00 - 0.62	0.00 - 0.59	0.00 - 0.34	0 - 2
	Fredericia Cluster	0.85 - 1.28	0.81 - 1.21	0.67	3 - 4
	Esbjerg Emitter	0.22	0.21	0.12	1
Total (Phase 2)		14.44 - 22.66	13.71 – 20.10	5.90 – 8.05	20 - 33



- Captured CO_2 in million tonnes per year.
- The power sector emitters were selected due to their plans to retrofit to biofuels. 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.



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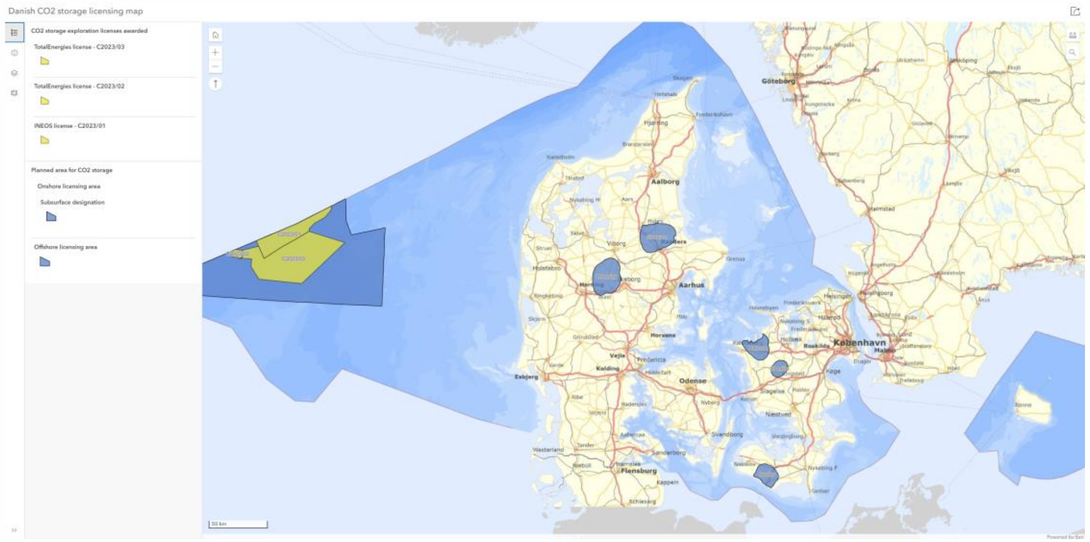
Eight storage sites located in Denmark, providing approximately 928 million tonnes of storage

Storage case	Site name	Type	Location	Mean capacity [Mton]	Injectivity [MTPA]
1	Gassum	Deep Saline Aquifer	Onshore	146	3.0
2	Voldum	Deep Saline Aquifer	Onshore	213	3.0
3	Jammerbugt	Deep Saline Aquifer	Nearshore	100	3.0
4	Inez	Deep Saline Aquifer	Offshore	178	3.0
5	Bifrost	Depleted O&G field	Offshore	Min. 60	0.8
6	Greensand	Depleted O&G field	Offshore	Min. 128	1.5
7	Lisa	Deep Saline Aquifer	Offshore	29	0.5
8	Thorning	Deep Saline Aquifer	Onshore	74	0.3



- The network considers a mix of onshore, nearshore and offshore storage sites.
- The two commercial and licensed projects (Bifrost and Greensand) have limited published information but include predicted injection rate when in operation.
- A round for CO_2 storage licensing was launched for multiple onshore sites which include Gassum and Thorning.

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At least 30% of the captured CO_2 is dedicated to CCU and 70% to CCS, aligned with the Impact Assessment of the EU 2040 climate targets communication

Option 1 – CCU near emitters

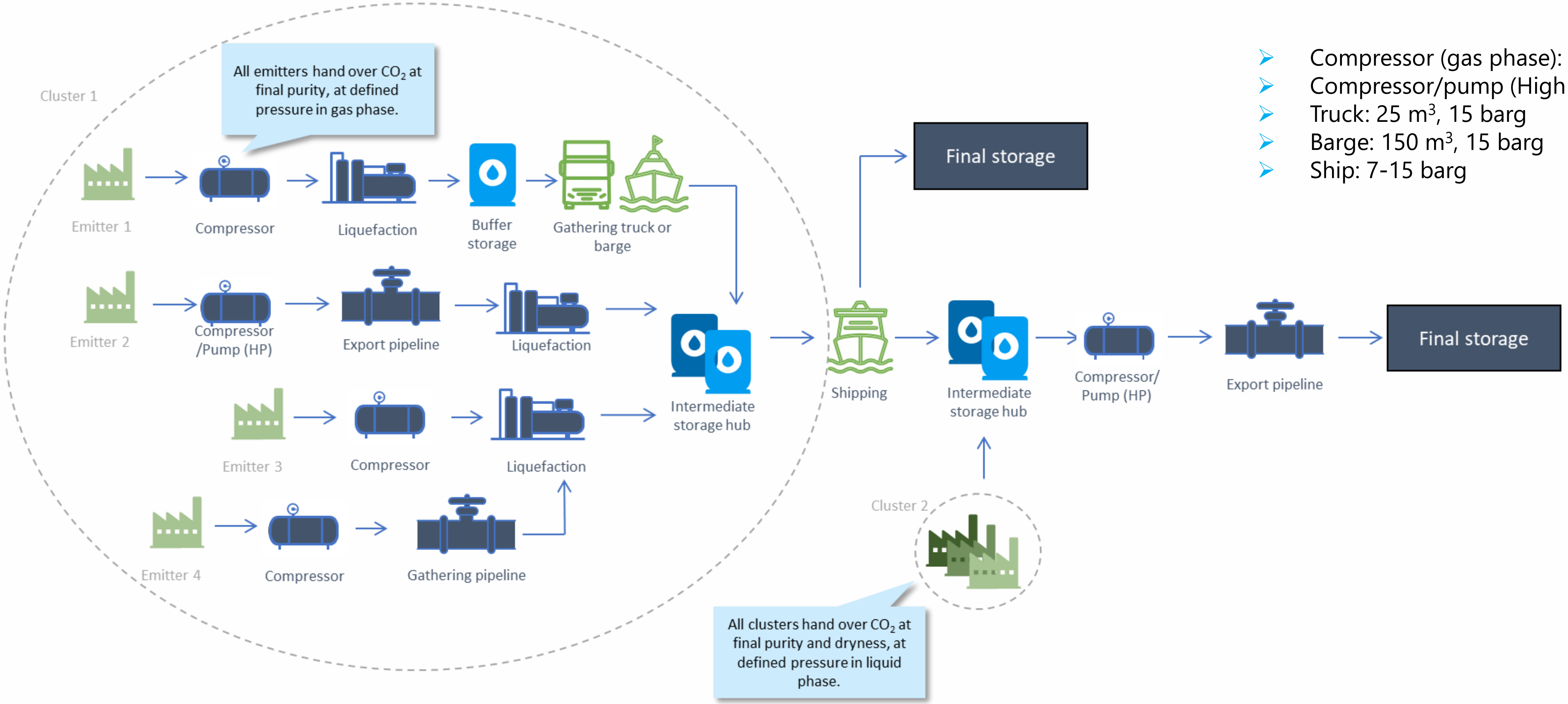
Country	Cluster	Captured CO_2 from Phase 1 emitters (Biogenic fraction) (Mtpa)	Captured CO_2 from Phase 1 emitters for CCU (Mtpa)	Number of CCU installations close to Phase 1 emitters	Average capture capacity of CCU installation (ktpa)	Average product capacity of CCU installation (ktpa)
Germany	-	6.61 (4.98)	1.98	7	280	190 (for methanol) 85 (for synthetic jet fuel)
Denmark	-	4.16 (1.17)	1.25	8	156	109 (for methanol) 47 (for synthetic jet fuel)
Sweden	-	2.95 (0.34)	0.89	5	178	125 (for methanol) 53 (for synthetic jet fuel)

Option 2 - CCU near hubs

Country	Cluster acting as collection hub	Captured CO_2 from all emitters (Biogenic fraction) (Mtpa)	Captured CO_2 from all emitters for CCU (Mtpa)	Number of CCU installations close to the collection hub	Average capture capacity of CCU installation (ktpa)	Average product capacity of CCU installation (ktpa)
Germany	Bremen	10.66 (5.59)	3.20	5	640	450 (for methanol) 192 (for synthetic jet fuel)
Denmark	Aalborg	5.53 (1.82)	1.66	5	332	232 (for methanol) 100 (for synthetic jet fuel)
Sweden	Gothenburg	3.95 (0.65)	1.19	5	238	167 (for methanol 72 (for synthetic jet fuel)

- Option 2 has in general considered a larger average capacity because it reflects a concept where CO_2 volumes have been centralised, hence the facilities may accommodate larger volumes.
- Option 1 shows more risk, as the utilisation plants are dependable of their respective emitter
- Option 2 was selected for further stages

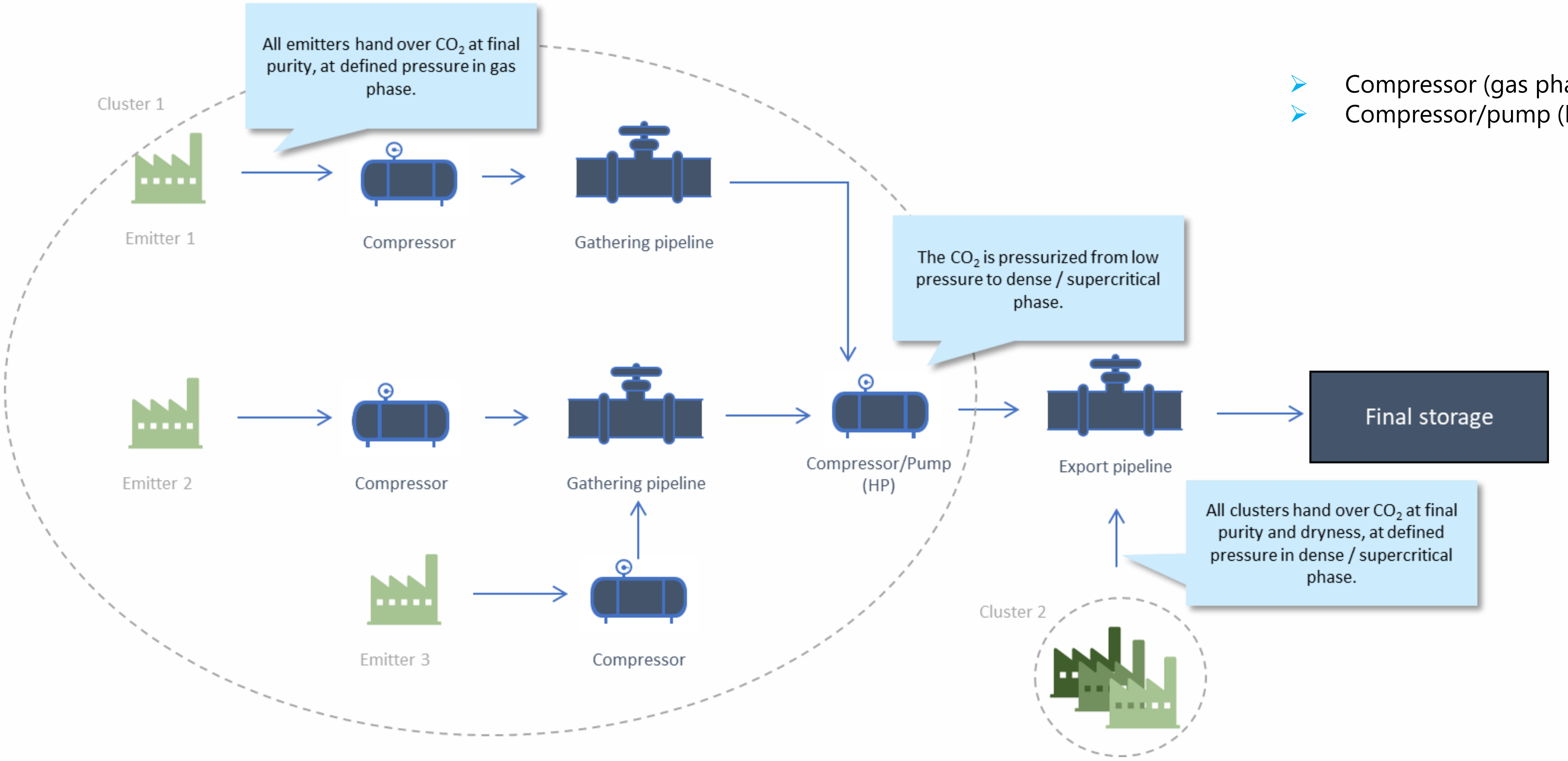
CO_2 transported through a batch method requires a high complexity value chain



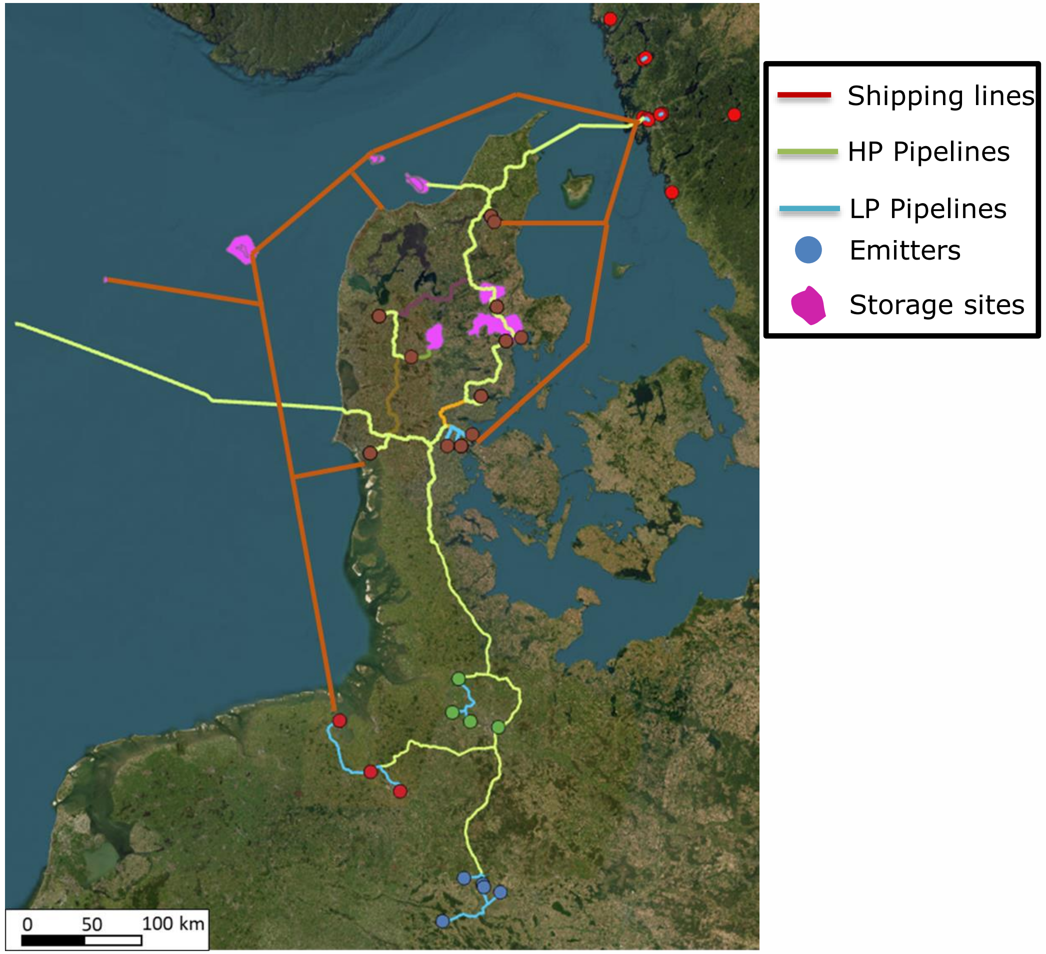
- Compressor (gas phase): 30 barg
- Compressor/pump (High Pressure): 120 barg
- Truck: 25 m^3, 15 barg
- Barge: 150 m^3, 15 barg
- Ship: 7-15 barg

Continuous transportation methods, although less flexible, can decrease complexity

- Compressor (gas phase): 30 barg
- Compressor/pump (High Pressure):120 barg



All scenarios for the Baltic case study in one figure



- The routes have prioritised information such as:
  - Areas of environmental and cultural importance
  - Existing and planned infrastructure
  - Technical feasibility (high-level)
  - Soil conditions

- An existing pipeline connection between South Arne (Syd-Arne) oil and gas field to the city of Nybro in Denmark to supply CO_2 to the Bifrost storage site

- The capacity of the medium pressure ships developed specifically for CCS applications is about 10,000 m^3 CO_2. Much larger capacities, up to 50,000 m^3 are expected to be achieved for low pressure variants. Constrained by the port capacity.

Port	Max draft [m]	Max beam [m]	Max LOA [m]	Max DWT [t]
Aalborg	9.4	40	250	102,000
Esbjerg	10.3	71	250	76,640
Hirtshals	9	-	150	-
Wilhelmshaven	20	52	430	260,000
Gothenburg	19	-	350	225,000

One possible solution for a CCUS value chain

- 33 emitters with 20 MTPA of captured CO_2
- CCU in Bremen: 3.2 MTPA
- CCU in Aalborg: 1.7 MTPA
- CCU in Gothenburg: 1.2 MTPA
- CCS: 14 MTPA (out of 15.1 MTPA estimated)

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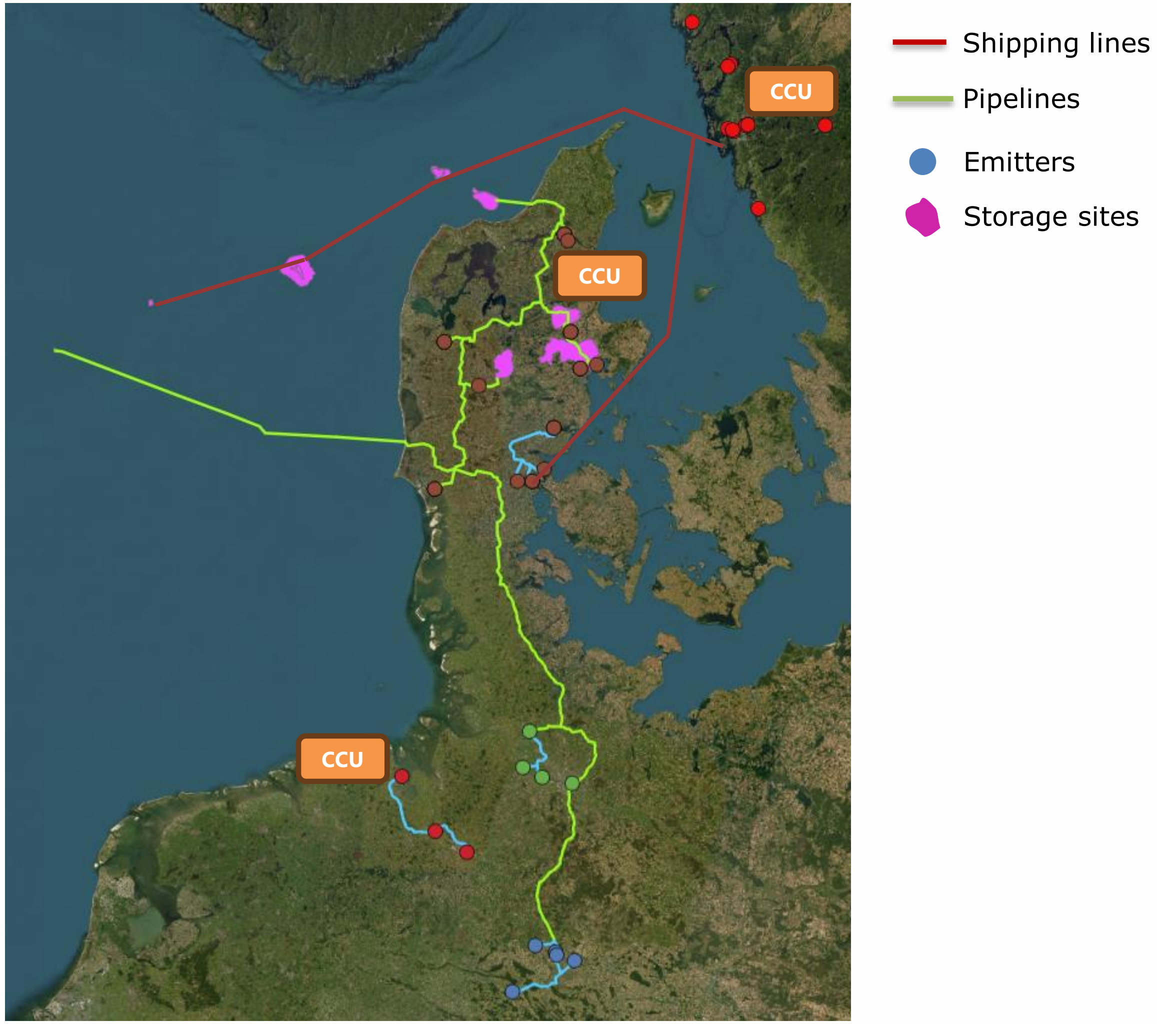
The study concludes with essential material for the economic assessment and development of a technical and business plan in WP4



- The use of large-scale transport infrastructure, including extensive pipeline networks involves multiple stakeholders that participate or are impacted by the project, resulting in cost and risk-related uncertainties.
- The significant CO_2 emissions of the German and Swedish economies, combined with Denmark's promising storage capacity, suggest a favourable balance for effective CCUS deployment of the Baltic project. The network could also account for expansion to other regions of Denmark, Sweden and Germany, and countries not analysed at this stage.
- The practical use of Danish storage facilities is paramount. This involves ensuring that logistical, institutional, and contractual factors support the timely implementation of storage solutions, which is essential for the CCUS deployment timeline. With close to 90% use of the Danish geological storage sites, this scenario is quite subject to the success of these infrastructure.

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> THANKS FOR YOUR ATTENTION