TECHNO-ECONOMIC CCUS MODELLING

for the Baltic Offshore Cross-Border Scenario Using Direct Injection from Ships

UPDATED

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CTS

https://www.cts-cetp.net

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NORCE

NEMO MARITIME

Technology partners:

OMV

TotalEnergies

BREVIK engineering

slb OneSubsea

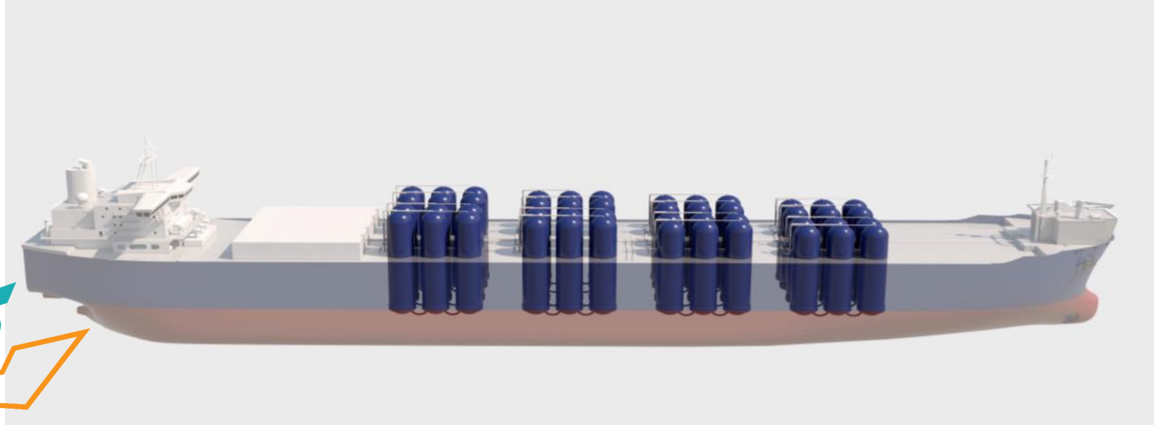
GAME-CHANGING CCUS TECHNOLOGY

Nemo Concept: One-step transportation solution with a ship equipped for direct injection

The CTS project assesses the feasibility of utilising ships for CO_2 transport and storage across various geographical regions, with a focus on developing flexible and cost-effective offshore storage solutions.

Advantages:

- ✓ Low-cost transportation solution
- ✓ Lower CAPEX expenditure than alternatives, making it ideal for initial phase developments and small to medium-scale applications
- ✓ Flexible and scalable capacity, adaptable to market needs
- ✓ Independent of location and water depth, the global application
- ✓ Very high regularity

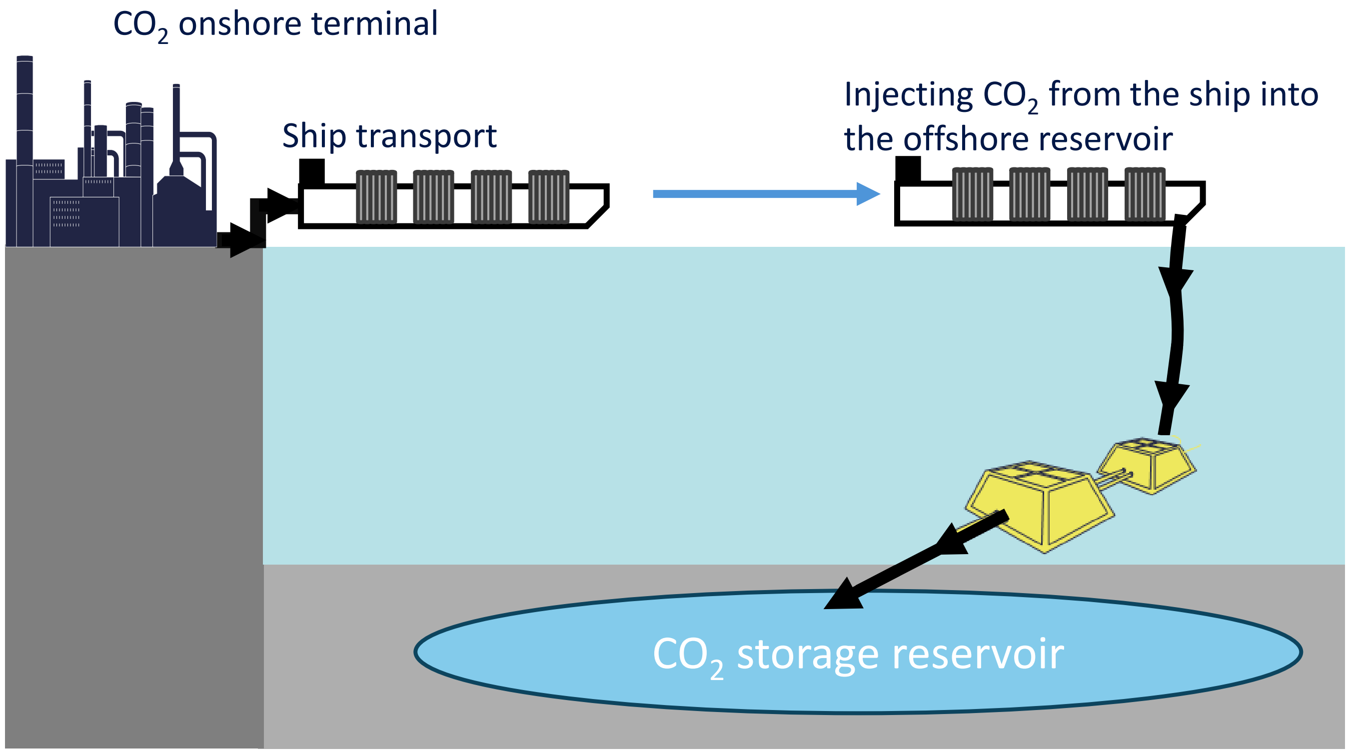


GAME-CHANGING CCUS TECHNOLOGY

Nemo Technical Design Elements - Pilot

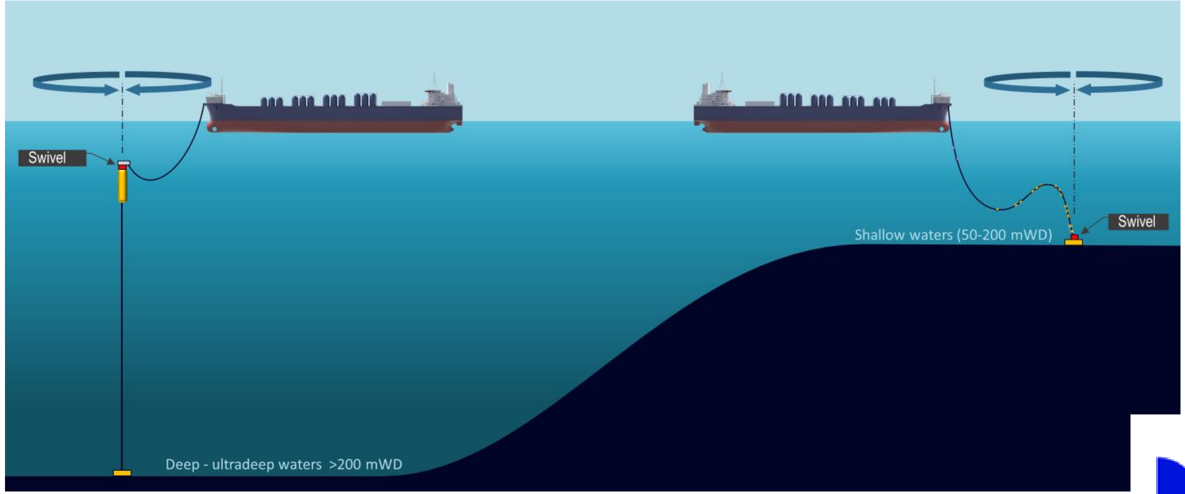
The Nemo concept

- ✓ **Ship equipped for CO_2 transportation with onboard process unit for CO_2 conditioning and injection pumps**
- ✓ **Connection to an offloading system connected to an injection well**
- ✓ **On board well control**
- ✓ **CO_2 is stored onboard ships in large tanks**
- ✓ **Medium pressure (15 bar, -28°C)**
- ✓ **Transport capacity up to 100,000+ tons**
- ✓ **Yearly capacity 1–5 million tons CO_2**
- ✓ **Equipped with a CO_2 process unit**
- ✓ **Specially designed CO_2 pumps**
- ✓ **Flexibility on location and water depth**
- ✓ **Low investments, no intermediate storage or pipelines**
- ✓ **Fast-track start-up by 2028–2029**
- ✓ **Global application**

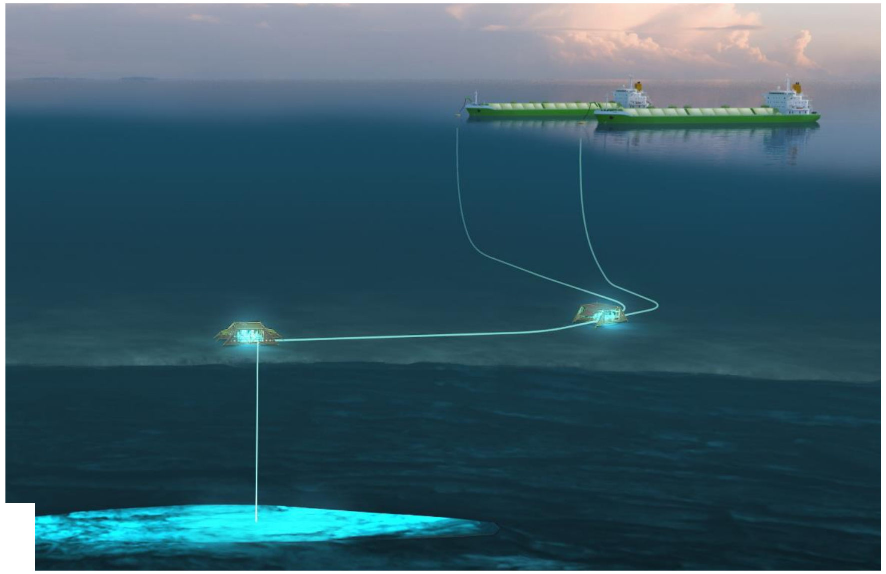


GAME-CHANGING CCUS TECHNOLOGY

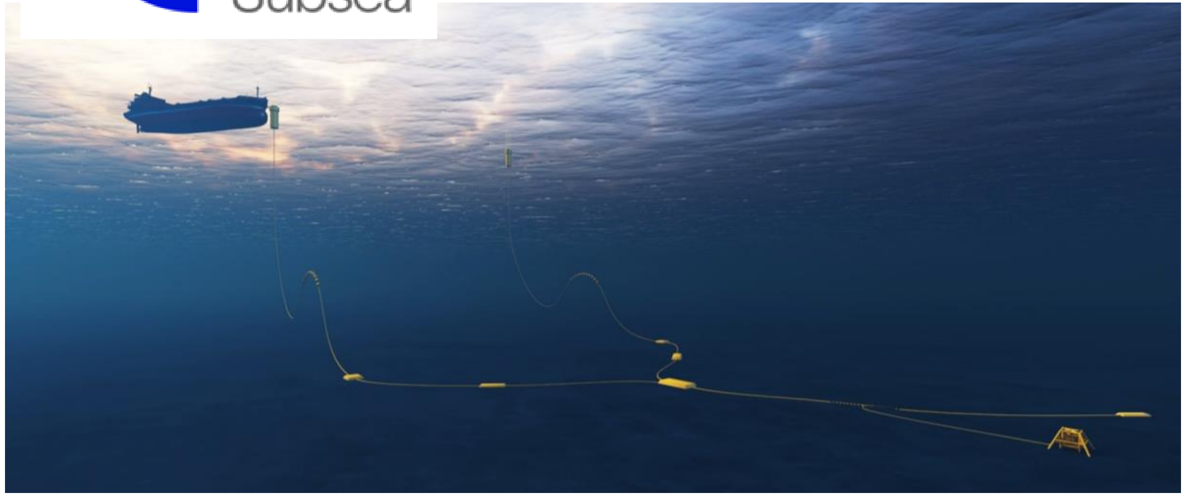
Current project phase: Offloading system for direct injection



Submerged
Loading
System
Applications



slb One Subsea



Project partners :

slb One Subsea

BREVIK engineering
Naval design

TotalEnergies

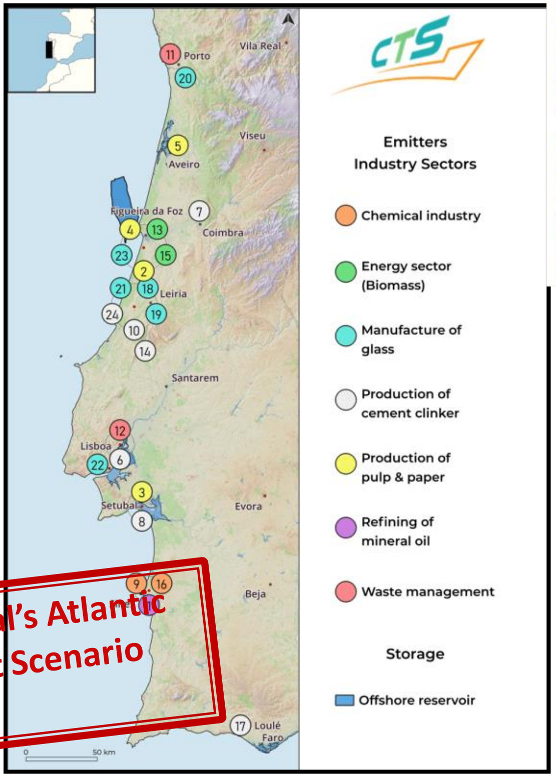
OMV
Reservoir partner

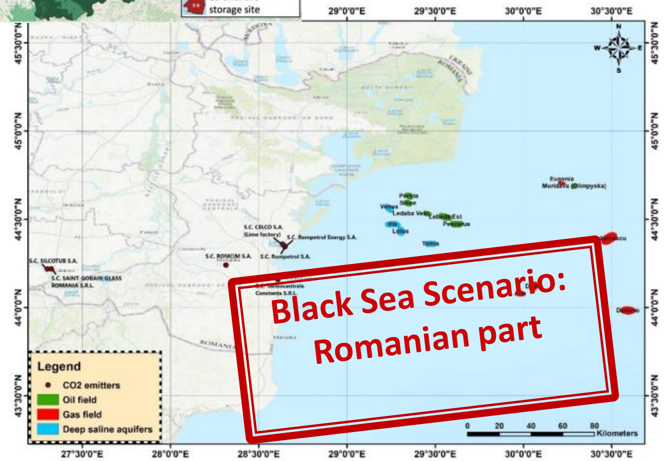
Funding support: CLIMIT

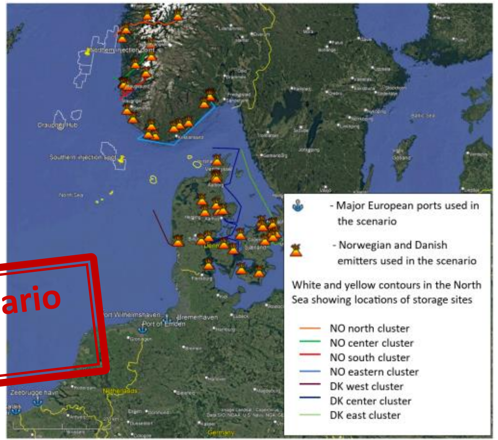
GAME-CHANGING CCUS TECH Y

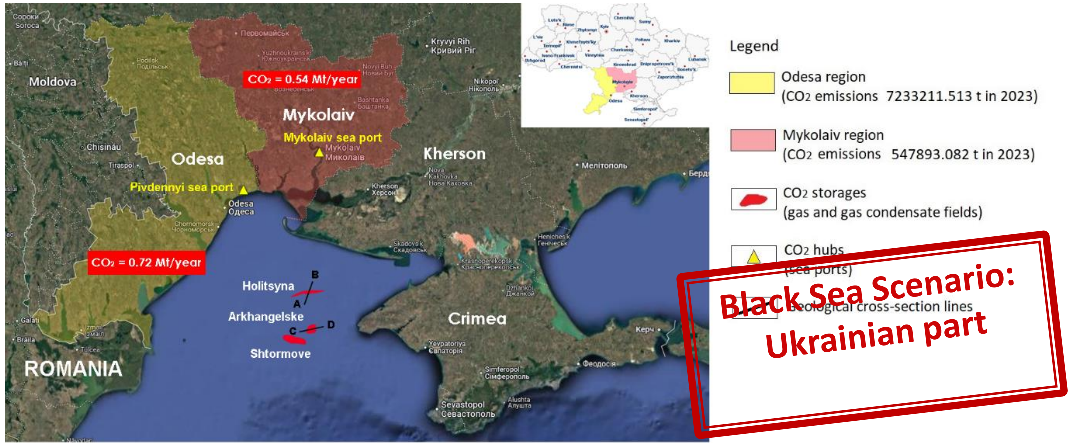
Objective

The primary objective of the CTS project is to thoroughly investigate the feasibility of utilising ships as injection vessels to store CO_2 (CGS) permanently. The CTS project will evaluate the new technology on CCS scenarios in four sea regions (North Sea, Baltic Sea, Black Sea and the Portuguese Atlantic Coast) and compare different scenarios within one region using the CTS technology and traditional CCS methods (ships and pipelines)









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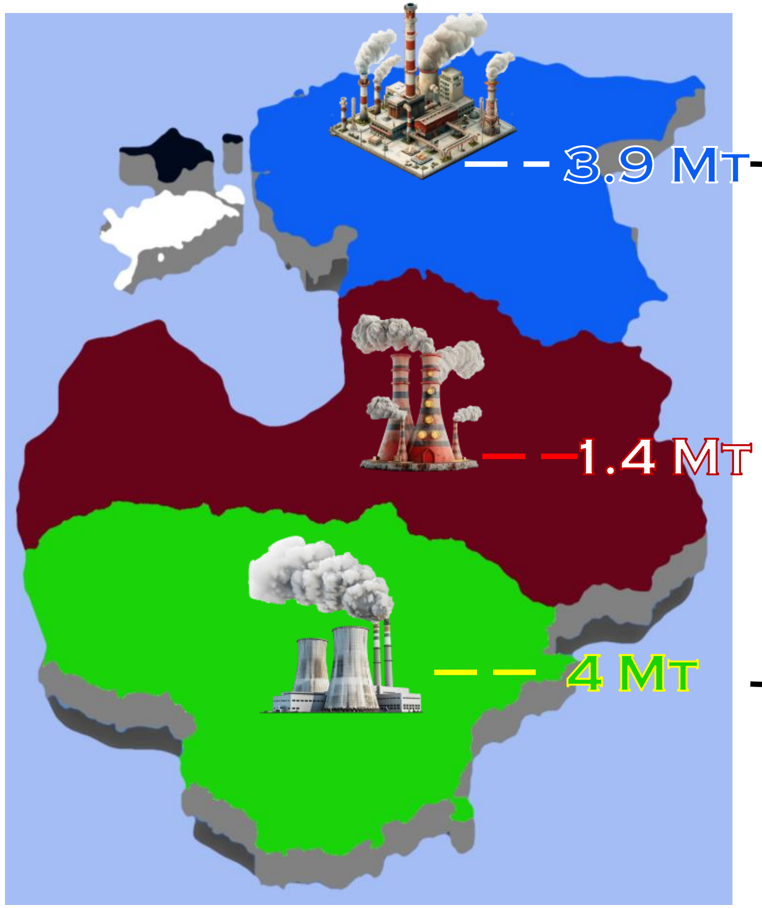
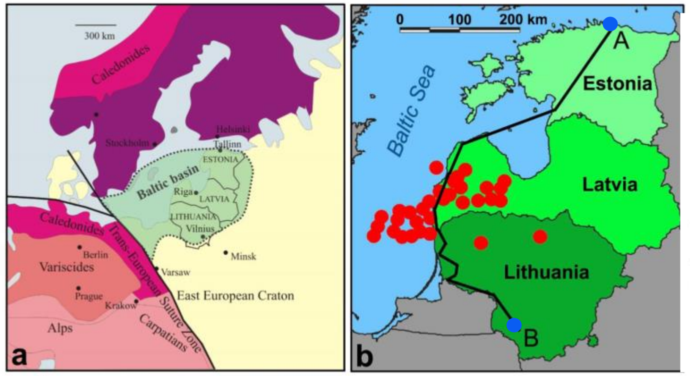
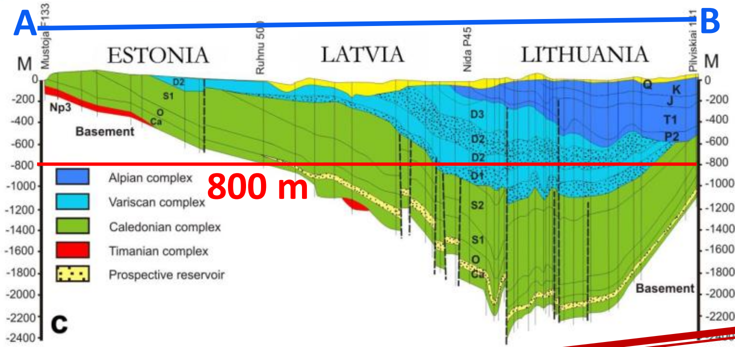
DIRECT INJECTION FROM A SHIP IN THE BALTIC SEA



9.3 Mt [2023]*

0.9 Mt
Bio-CO_2
EMISSIONS





ESTONIA
CO_2 storage

NO GEOLOGICAL CONDITIONS

LATVIA
CO_2 storage

CCUS is permitted on 9th October 2025

LITHUANIA
CO_2 storage

BANNED

*Large emitters (>100 kt CO_2/y) were selected

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GEOLOGICAL BACKGROUND OF THE BALTIC OFFSHORE STRUCTURE

CO₂ STORAGE CAPACITY, MT

SALDUS F. OIL RESERVOIR

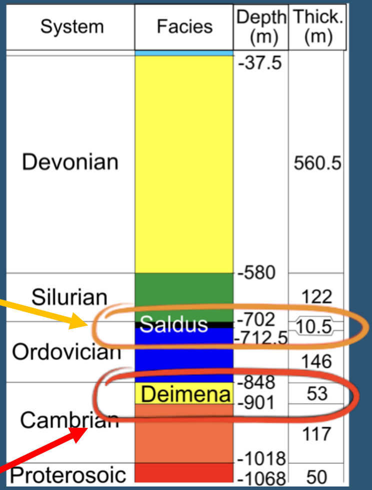
- **E6**: 65–144 (mean 110)
- **E6-A**: 60–133 (mean 100)
- **E6-B**: 5-11 (mean 10)

DAIMENA F. CGS RESERVOIR

- **E6**: Optimistic: 251–602 (mean 377); Conservative: 101–243 (mean 152)
- **E6-A**: Optimistic: 243–582 (mean 365); Conservative: 97–233 (mean 146)
- **E6-B**: Optimistic: 8–20 (mean 12); Conservative: 4–10 (mean 6)

DAIMENA F. + SALDUS F.

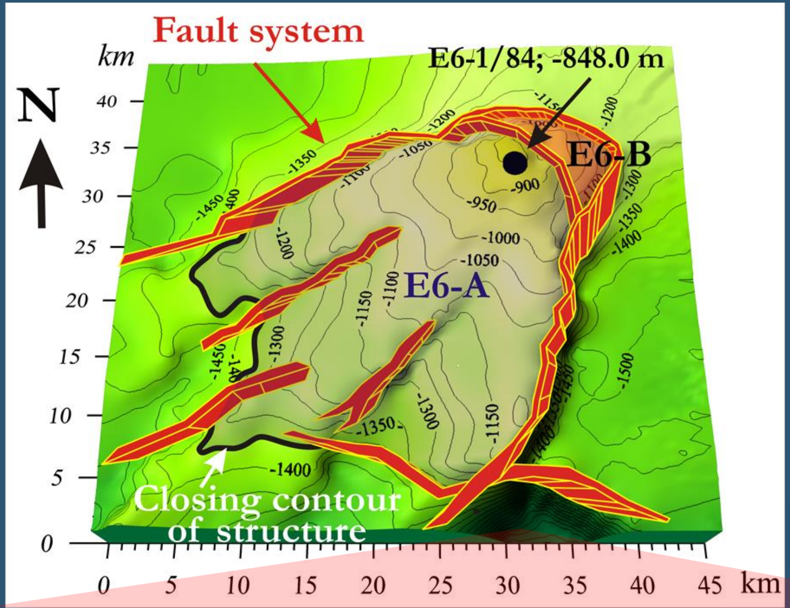
- **E6**: Optimistic: 320–745 (mean 490); Conservative: 170–385 (mean 265)
- **E6-A**: Optimistic: 305–715 (mean 470); Conservative: 160–365 (mean 250)
- **E6-B**: Optimistic: 15–30 (mean 20); Conservative: 10–20 (mean 15)



References:
Shogenov et. al, 2013a, b
Shogenov et. al, 2015
Shogenov et. al, 2016
Shogenov & Shogenova, 2021
Shogenov & Shogenova, 2023
Shogenova et. al, 2023
Shogenov & Shogenova, 2024

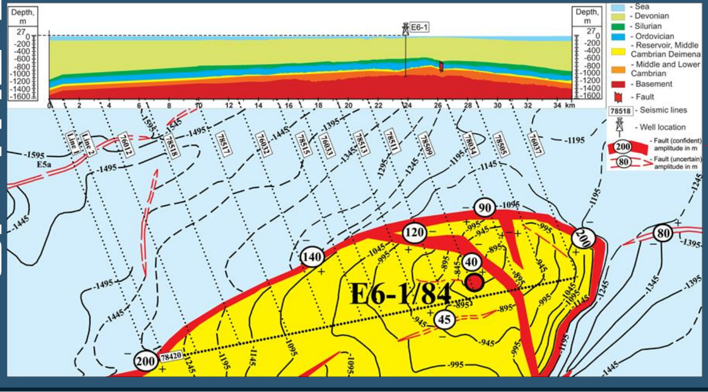
E6 PROPERTIES

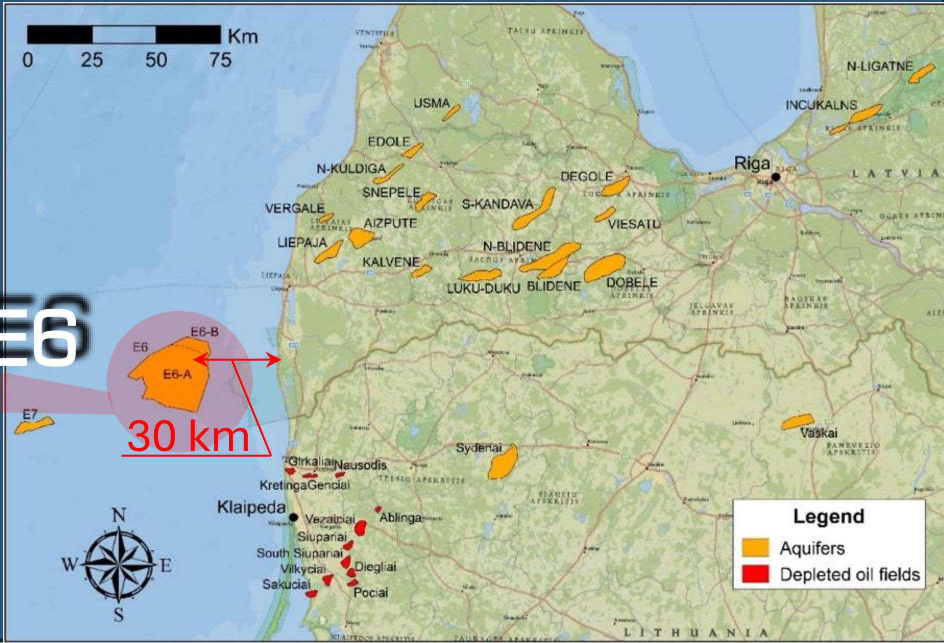
Salinity: 99 g/l
Thickness: 53 m
Density of CO_2 in situ: 658 (kg/m³)
Net Gross ratio of aquifer: 0.90
Reservoir temperature in situ: 36°C
Reservoir pressure in situ: 9.3 mPa
Area E6: 600 (km²)
E6-A: 553 km²
E6-B: 47 km²
Porosity: 21%
Permeability: 170 mD



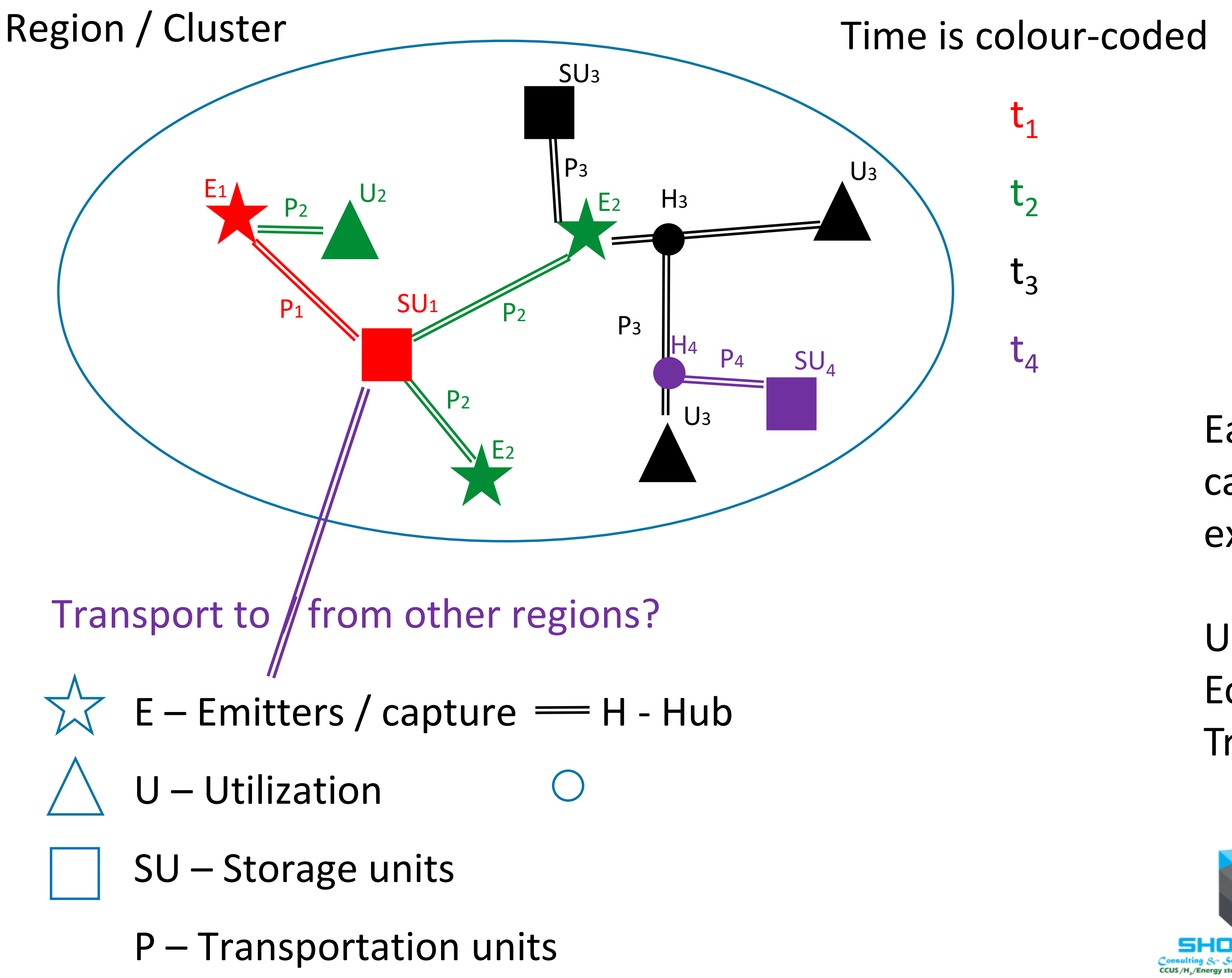
Reservoir quality: ‘good’
Application for CGS: ‘appropriate’
(average porosity 21%;
permeability 170 mD)

Shogenov et. al., 2013 a, b, 2015, 2022, 2023





TEA ASSESSMENT METHODOLOGY-STRATEGY CCUS TOOL



Output on **Scenario Scale**:

- Unit, type and total costs?
- How much is stored, used, leaked?
- Value created by downstream industries using CO_2 as a key input factor?
- How much energy is required, and what are the associated emissions?
- Etc.

Each unit (capture / transport/utilization/ storage) can be evaluated by the tool or integrated from external evaluations

Updated after Nermoen et.al. 2022 "A Techno-Economic Analysis Tool for Regional CO2 Capture, Transport, Use and Storage Scenarios"

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STRATEGY CCUS A viable solution for a sustainable future

METHODOLOGY AND ASSUMPTIONS

- We are estimating technical costs, contractual, operational and capital costs at a high level, based on the published estimates available and CO_2 emissions produced by plants in 2023
- No risk premiums
- Total CO_2 emissions – The **gross amount of CO_2 physically captured at the point of capture** (e.g., at the plant's capture unit) that is then handed off for transport and storage. This is the headline "tonnes captured" number (IPCC Report, 2005)
- Operational/process emissions associated with CCUS - The additional CO_2 (and other GHGs) emitted during the CCUS chain: energy used for capture (heat, electricity), emissions from compressors, transport (fuel for ships/trucks/pipelines), injection operations, and any fugitive/leakage during handling. These are emissions produced by the CCUS activity itself, not the original source emissions (ICAP Carbon Action, 2023)
- CO_2 Emissions Avoided - The amount of CO_2 that is prevented from entering the atmosphere thanks to the CCUS activity, relative to a defined baseline (what would have been emitted without the project).
- CO_2 Emissions Abated - The amount of CO_2 Avoided, together with captured and stored Bio-CO_2
- Bio-CO_2 - refers to CO_2 originating from biomass. When bio-CO_2 is captured and permanently stored (e.g., BECCS), the resulting **Avoided bio-CO_2** contributes to **negative or very low net emissions**, because the CO_2 removed from the atmosphere via biomass is not released back into it.

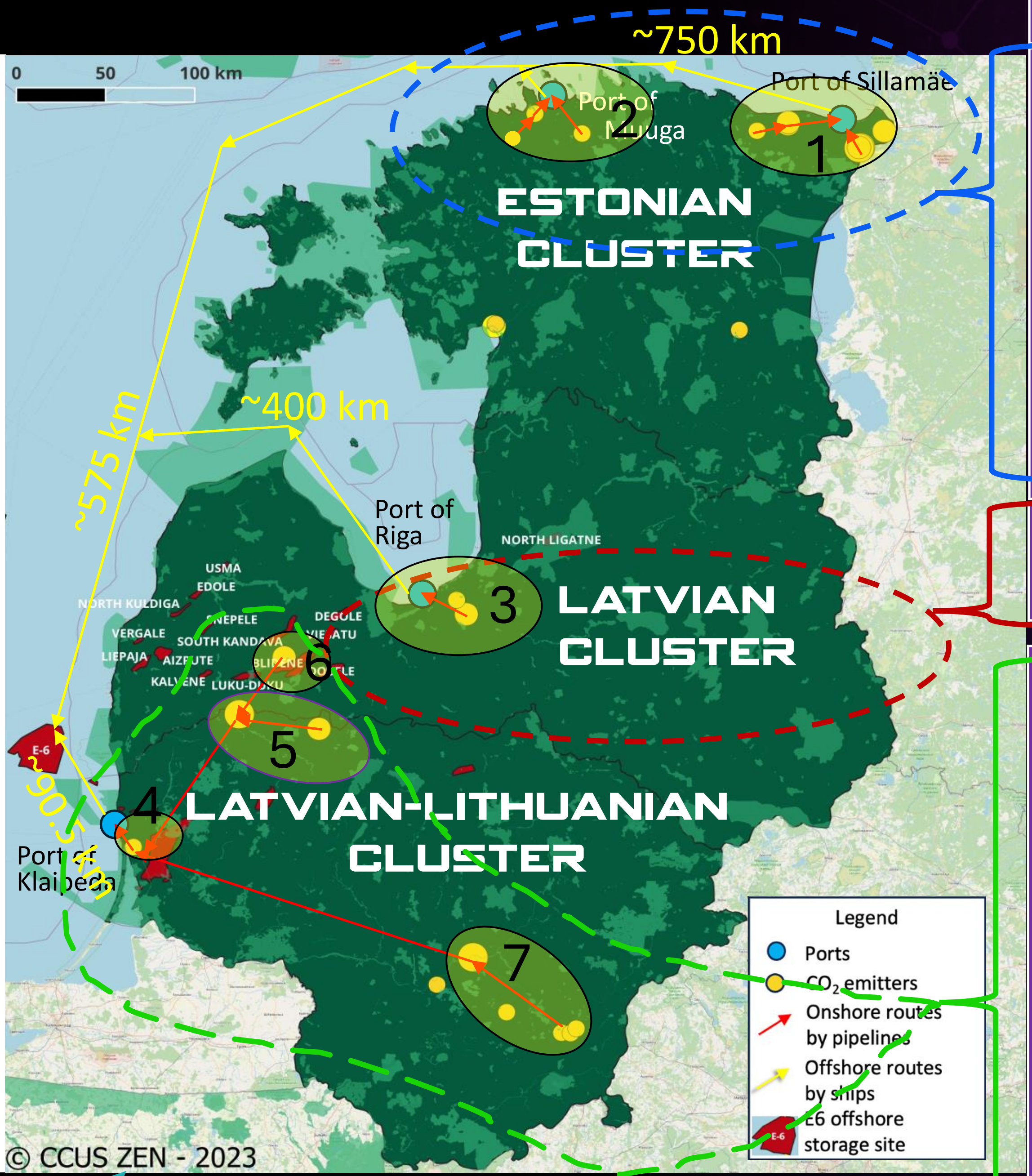
Avoided CO_2 = Gross CO_2 captured at source – CCUS chain emissions (capture + transport + storage + technical losses during operations)

Abated CO_2 = Avoided CO_2 + Negative Bio-CO_2

Key consequence: Abated CO_2 (as well as **Avoided CO_2**) is normally lower than gross CO_2 captured. That is expected — capture systems and logistics consume energy and produce emissions, so the net climate benefit equals captured minus those additional emissions.

- Inflation is 4% per year, and the social discount rate is 5% per year
- Electricity price is 87 €/MWh

BALTIC SCENARIO



NEE - North-Eastern Estonia, K-J – Kohtla-Järve city, Kiv-Kiviõli town, PP - Power Plant, SOP - shale oil plants, WtE - Waste to Energy Plant, TP - Thermal Power Plant, t – tonnes

Cluster	Sub-cluster	N	Plant Name	Region	Sector	CO_2 produced in 2023, t/y: Fossil CO_2	CO_2 produced in 2023, t/y: Bio-CO_2	Total CO_2, t
ESTONIAN CLUSTER	IDA-VIRU (NE) CLUSTER TO SILLAMÄE PORT (1)	1	Auvere PP	Auvere	Power	681,162	256,035	937,197
		2	Auvere SOP	Auvere	SOP	975,506	-	975,506
		3	VKG SOP	NEE/K-J	SOP	721,077	-	721,077
		4	VKG Energia North TP	NEE/K-J	Power	619,974	-	619,974
		5	Kiviõli Chemical Plant	NEE/ Kiv	SOP	231,536	-	231,536
	TALLINN-HARJU CLUSTER TO MUUGA PORT (2)	6	Horizon Paper Factory	Kehra	Paper	4030	121,311	125,341
		7	Utilitas Tallinn PP	Tallinn	Power	49	156,170	156,219
		8	Iru WtE	Iru	WtE	1835	149,941	151,776
			Total CO_2 produced in Estonian clusters					3,918,626
LATVIAN CLUSTER (RIGA PORT)	(3)	1	Latvenergo Tec-2	Salapils	Power	546,285		546,285
		2	Latvenergo Tec-1	Riga	Power	154,079		154,079
			Total CO_2 produced in Latvian clusters			700,364		700,364
LATVIAN-LITHUANIAN CLUSTER (KLAIPEDA PORT)	WEST LITHUANIAN SUB-CLUSTER (4)	1	Gren Klaipeda WtE	Klaipeda	WtE	100,151		100,151
	NORTH LITHUANIAN SUB-CLUSTER (5)	2	Orlen Lietuva	Telšiai	Refinieries	1,664,257		1,664,257
		3	Akmenės Cement	Kaunas	Cement	783,849		783,849
	LATVIAN SUB-CLUSTER (6)	4	Schwenk Latvia	Saldus/ Broceni	Cement	744,135		744,135
	KAUNAS SUB-CLUSTER (7)	5	AB Achema	Jonavos Region	Ammonia	1,363,39 8		1,363,398
		6	UAB Kauno WtEP	Vilnius	WtE	119,661		119,661
			Total CO_2 produced in Latvian-Lithuanian Cluster					4,775,451

16 EMITTERS IN 3 BALTIC COUNTRIES LOCATED NEAR PORTS PRODUCED 9,376,441 T OF CO_2 IN 2023

CO_2 SOURCES

Enefit Power As	Enefit Power As	VKG Oil As	VKG Energia Oü	Kiviõli Keemiatööstus e OÜ	Horizon Tselluloosi Ja Paberi As	Utilitas Tallinna Elektrijaam Oü	Enefit Power As	Sia "Schwenk Latvija"	As “Latvenergo”	As “Latvenergo”	Ab "Achema"	UAB Gren Klaipėda	UAB Kauno kogeneracine jegaine	Ab "Orlen Lietuva"	Ab "Akmenės Cementas"
Auvere Power Plant	Auvere Shale Oil Plant	VKG Shale Oil Plant	VKG Energia North Thermal Power Plant	Kiviõli Chemical Plant	Horizon Paper Factory	Utilitas Tallinn Power Plant	Iru Waste to Energy Plant	Schwenk Latvia	Latvenergo Tec-2	Latvenergo Tec-1	Achema	Gren Klaipeda WtEP	UAB Kauno WtEP	Orlen Lietuva	Akmenės Cement

Capture starts in 2031 at Akmenės Cement and Schwenk Latvia, with the vast majority of emitters joining in 2035. Horizon Paper Factory, Iru Waste to Energy Plant, Gren Klaipeda WtEP, and UAB Kauno WtEP are expected to join in 2040.

Capture facilities are designed «oversized», allowing for capturing associated emissions with a high efficiency of 95%

The total Baltic Scenario captures 353 $MtCO_2$ (280 $MtCO_2$ abated) over its operational period of 2031–2065

Technical costs of capture per ton vary significantly from 55€ for waste incinerators, to 120–156 € for some of the power-producing facilities.

Total (and discounted) capture costs for a ton of CO_2 are

CO_2 captured, €/ton abated	Corrected for inflation	Discounted
Total	177	71
CAPEX	15	13
OPEX	162	58

CO_2 CAPTURE DETAILS

Unit name	Start Year	€/ton CO_2 captured	Total CO_2 captured, Mt	Capture Technology
Auvere Power Plant	2035	78.5	31	Co-generation post combustion
Auvere Shale oil	2035	112	39,4	Refinery post combustion
VKG Shale oil	2035	120	29,1	Refinery post combustion
VKG Energi North Terminal	2035	74	25	Coal post combustion
Kiviõli Chemical Plant	2035	156	9,4	Chemical
Horizon Paper Factory	2040	118	4,3	Pulp and paper
Utilitas Tallinn Power	2035	93	5,2	Co-generation
Iru waste to Energy	2040	54	4,9	Incinerator
Schwenk Latvia	2031	78	29,7	Cement post combustion capture
Latvenergo Tec-2	2035	75	18,1	Natural Gas PP
Latvenergo Tec-1	2035	93	5,1	Natural Gas PP
Achema	2035	124	47,4	Chemical
Gren Klaipeda WtEP	2040	57	3,2	Incinerator
UAB Kauno WtEP	2040	55	3,8	Incinerator
Orlen Lietuva	2035	90	66,5	Refinery
Akmenes Cement	2031	78	31,3	Cement post combustion capture

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TRANSPORT

Transport consists of 16 pipelines connecting emitters to 4 ports (total length 730km) and 4 shipping routes (total length 1820km).

Shipping routes can be further optimised:

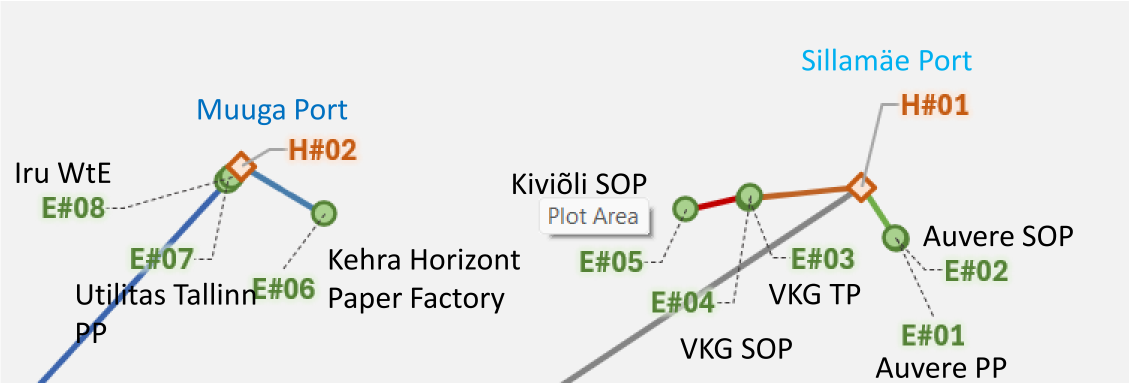
ships from Sillamäe pass by Muuga port

The route from Klaipeda (being the shortest) is the least efficient

CO_2 transported, €/ton abated	Corrected for inflation	Discounted
Total	58	25
CAPEX	8	7
OPEX	50	18

TRANSPORT
Estonian pipeline system

Connection ID	Start ID	End ID	Pipeline length (km)	Total cost (M€)
P01	E#01	E#02	1,3	4,3
P02	E#02	H#01	25,2	30,2
P03	E#05	E#04	19,8	8,1
P04	E#04	E#03	1	4,0
P05	E#03	H#01	37,3	40,4
P06	E#07	E#08	3,7	3,0
P07	E#06	H#02	32,7	10,8
P08	E#08	H#02	9,6	4,7



Total CAPEX for pipelines **for the whole scenario**: **416M€**
Total OPEX: **495M€**
Total costs **for the whole scenario**: **911M€**

Total costs **for the Estonian scenario**: **105.4M€**

Estonian clusters are app. 18% of the total length and **11.6%** of the total pipeline costs

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STORAGE
Traditional

Main costs (undiscounted) of storage are:

- Platform, drilling 8 wells, baseline monitoring – app. 680 M€
- Abandonment and post monitoring costs – app 75 M€
- Well maintenance, operational, monitoring costs – 31 M€/year
- Energy costs of app. 1.2 B€ - heating and injecting CO_2

CO_2 stored, €/ton abated	Corrected for inflation	Discounted
Total	23.4	9.85
CAPEX	3.4	2.4
OPEX	20	7.45

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OVERALL FOR BALTIC SCENARIO

Traditional

Strategy CCUS Region KPIs (Discounted)	
Analysis of the CCS system (€/tCO_2 abated)	
Total CCS value chain	
CCS value chain	106.2€
Total CAPEX	**22.84€**
Cost of Capture	13.4€
Cost of Transport	7€
Cost of Storage	2.4€
Total OPEX	**83.3€**
Cost of Capture	57.8€
Cost of Transport	18.1€
Cost of Storage	7.45€
Total CO_2 Captured	**353Mt**

Total CO_2 Captured, transported and stored (abated ~20% of captured) **280Mt**

Total cost of the project:

29.7 B€

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DIRECT SHIP INJECTION BENEFITS

- Flexibility in delivery and optimisation of routes will provide additional benefits

- Direct ships may be a way to reduce emission costs by being designed for less pure CO_2 (outside of the current project scope), and can utilise cleaner fuels or onboard capture systems

- No need for power production or electrification of the platform from onshore! While the energy requirement to heat and inject CO_2 is about the same, ship engines can be equipped with CO_2 capture or run on LNG/ammonia to reduce associated emissions of CO_2 from electricity production

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DIRECT SHIP INJECTION COST ESTIMATE

Numbers are preliminary, and further optimisation is ongoing

The injection equipment and crew are ship-based, as are heating and injection energy usage, thereby significantly reducing storage CAPEX and OPEX.

Total undiscounted savings are around 4.7B€, and discounted savings are 1.96B€

Traditional scenario		
CO_2 injected €/ton abated	Corrected for inflation	Discounted
Total	23.4	9.8
CAPEX	3.4	2.4
OPEX	20	7.4

VS

Direct ship injection		
CO_2 injected €/ton abated	Corrected for inflation	Discounted
Total	6.7	2.8 (savings 70%)
CAPEX	1.9	1
OPEX	4.8	1.8

DIRECT SHIP TRANSPORT COST ESTIMATE

Traditional scenario	
CO_2 transported, €/ton abated	Discounted
Total	25
OPEX	18
CAPEX	7

VS

Direct ship injection	
CO_2 transported, €/ton abated	Discounted
Total	29 (additional costs 16%)
OPEX	21
CAPEX	8

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DIRECT SHIP TRANSPORT + STORAGE COST ESTIMATE

Traditional scenario	
CO_2 transported and stored, €/ton abated	Discounted
Total	38
OPEX	23
CAPEX	15

VS

Direct ship injection	
CO_2 transported and stored, €/ton abated	Discounted
Total	35.5 (savings 6.5%)
OPEX	24.7
CAPEX	10.8

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DIRECT SHIP INJECTION COST ESTIMATE

Assuming app. 25% of energy coming from recuperation and 600€/ton diesel cost

Traditional

Total cost 29.7 B€

Analysis of the CCS system (€/tCO_2 *abated*)	
Total CCS value chain	
CCS value chain	106.2€
Total CAPEX	**22.84€**
Cost of Capture	13.4€
Cost of Transport	7€
Cost of Storage	2.4€
Total OPEX	**83.3€**
Cost of Capture	57.8€
Cost of Transport	18.1€
Cost of Storage	7.45€

VS

Ship Injection

Total cost 28.8 B€

Analysis of the CCS system (€/tCO_2 *abated*)		Change €
Total CCS value chain		
CCS value chain	**103€**	**-3.2**
Total CAPEX	**22.79€**	**-0.05**
Cost of Capture	13.4€	
Cost of Transport	8.4€	+1.4
Cost of Storage	**1€**	**-1.4**
Total OPEX	**80.2€**	**-3.1**
Cost of Capture	57.8€	
Cost of Transport	20.57€	+2.5
Cost of Storage	**1.82€**	**-5.6**

Benefit 896 M€

Total CO_2 abated: **280Mt**

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CONCLUSIONS 1

- In total, about 353 Mt CO_2 from 16 plants in 3 clusters will be shipped from 4 ports, covering **a total distance of 2550 km**
- **Estonia: 4.46** Mt/y from 5 plants in the Ida-Viru cluster via 84.6 km pipelines to NE Sillamäe Port, followed by a ship journey of 751 km to the E6.
0.58 Mt/y from 3 plants in the Tallinn-Harju cluster will go to the Muuga Port via 46 km pipelines and then 575 km by ship to the E6 structure
- **Latvia:** 0.77 Mt/y of CO_2 from 2 Latvenergo Natural Gas power plants will be conveyed 22.6 km pipelines to Riga and shipped 402 km to the E6 structure
- **Latvian-Lithuanian cluster:**
Two Schwenk cement plants will send 1.8 Mt/y of CO_2 starting from 2031, Achema and Orlen Lietuva 3.8 Mt/y of CO_2 from 2035 and two waste-to-energy plants (Lithuania) will send 0.28 Mt/y of CO_2 by pipelines to Klaipeda and then **90.5 km** by ship
In total, this cluster will transport 5.87 Mt/y of CO_2 from Klaipeda starting from 2040
- **Overall**, in total, 353 Mt CO_2 emissions captured, **transported and injected** into the underground geological structure **E6 in Latvia** at a depth exceeding 850 metres

CONCLUSIONS 2

- The total Baltic Scenario captures **353 Mt CO_2** over its operational period of **2031–2065**
- Total Baltic Scenario CO_2 abated is **280 Mt** over its operational period of **2031–2065**
- The technical costs of capture per ton vary significantly, from about **55€** for waste incineration plants, to **120–156€** for certain shale oil and chemical plants
- The total discounted capture cost per ton of CO_2 is estimated at **71€**
- The cost of one ton of CO_2 abated using:
  - traditional CCUS technologies: **106€/t CO_2 abated**
  - CTS technologies: **103€/t CO_2 abated**
- The total project cost amounts to:
  - **29.7 B€** when using traditional CCUS technologies
  - **28.8 B€** when using CTS technologies
- This results in a total benefit of approximately **900 M€**
- Furthermore, flexibility in delivery and optimisation of routes will provide additional benefits — not only financial ones (e.g. avoiding regulatory challenges with governments, environmental impacts, etc.)

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Thank You for your attention!

Kliimaministeerium

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