



THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of the Environment,
Climate and Biodiversity



THE GOVERNMENT
OF THE GRAND DUCHY OF LUXEMBOURG
Ministry of the Economy

Comparative assessment of multi-modal CO₂ transport concepts

Presentation

AFRY MANAGEMENT CONSULTING – JUNE 2026

BACKGROUND TO THE STUDY

This study investigates and evaluates different options to transport CO₂ captured in LUX to final storage / utilization sites

BACKGROUND TO THE STUDY

- As part of its 2050 climate neutrality target, the government of Luxembourg has approved its first framework for CCUS and CDR deployment, identifying seven strategic measures and emphasizing cross-border infrastructure.
- Since both CCS and CCU involve the transportation of CO₂, managing CO₂ transport logistics is a critical factor.
- Luxembourg's Ministries of Economics and Environment are actively seeking to investigate and evaluate the different options to transport CO₂ from Luxembourg to a final storage / utilisation site.
- The study investigates multiple angles of the CO₂ transport challenge from Luxembourg's perspective:
 - Identifying suitable technical solutions for CO₂ transport from Luxembourg to permanent destinations
 - Identification of potential destinations for the CO₂
 - Assessment of lacking regulations to enable CO₂ transport
 - Development of dynamic calculation to identify optimal multi-model transport setup until 2050

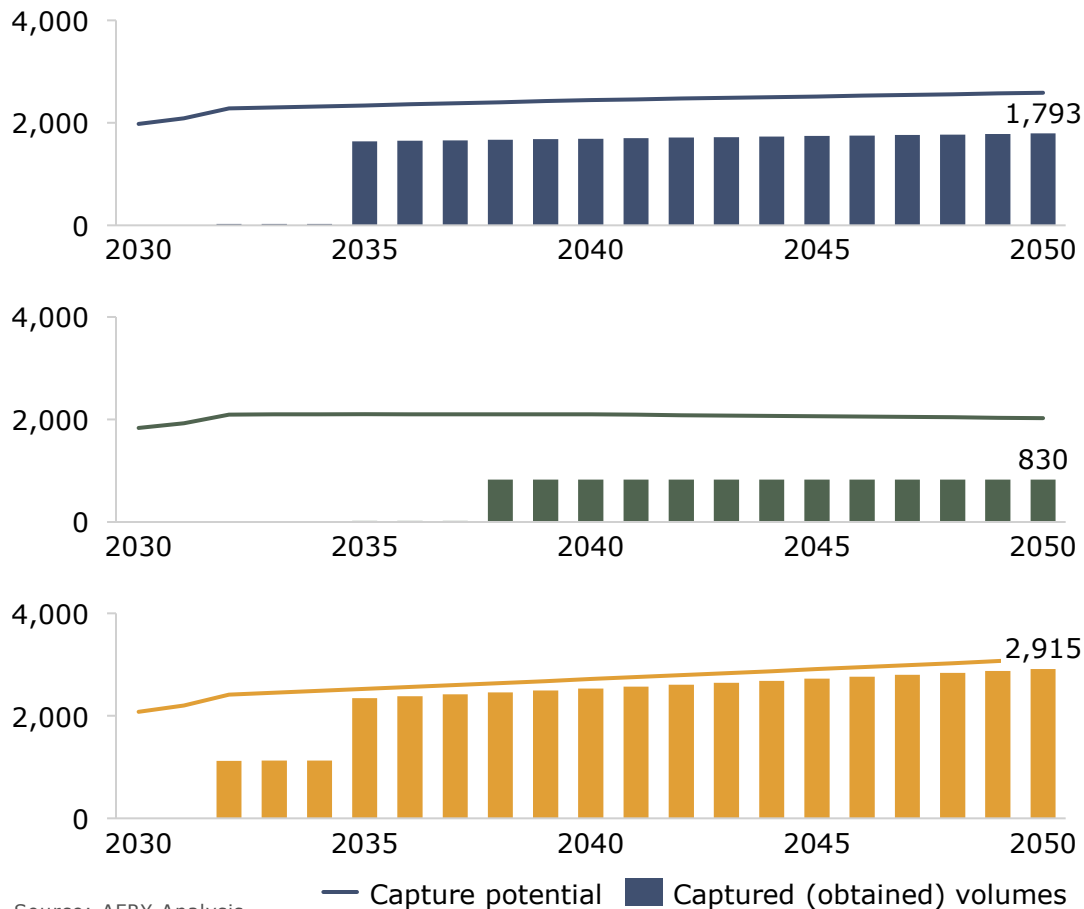
KEY OBJECTIVES OF THIS STUDY



- Understanding available options for CO₂ transport considering economic, technological, and environmental factors
- Determination of the most effective multimodal transport concepts for inland and cross-border CO₂ transport in Luxembourg
- Understanding of regulatory frameworks in neighbouring countries to ensure smooth cross-border transport
- **Overall target: Overall evaluation of most suitable transport concepts for the LUX context under consideration of economic, social, technical, legal and operational aspects.**

EXECUTIVE SUMMARY

Projected total volumes for 2050 are estimated to range between 0.8 and 2.9 Mtpa, based on a variety of economic and regulatory premisses

ESTIMATED CAPTURED CO₂ VOLUMES IN LUXEMBOURG [ktpa]

Source: AFRY Analysis

DESCRIPTION OF PREMISES FOR SCENARIOS

Central

CO₂ capturing is done as last resort by fossil emitters and as upside by part of biogenic emitters

- Best view on economic and industrial developments (following public and industrial strategies)
- CCUS last option, after efficiency measures, electrification and H₂
- Value of biogenic CO₂ sufficient, capturing viable for large players

Min

CO₂ capturing stays very expensive and is only done in cases where there is absolutely no alternative to reach net zero

- Slowed economic growth (-1% p.a. compared to Central) and stagnating industry
- Only hard-to-abate fossil emissions considered, biogenic CO₂ has no business case

Max

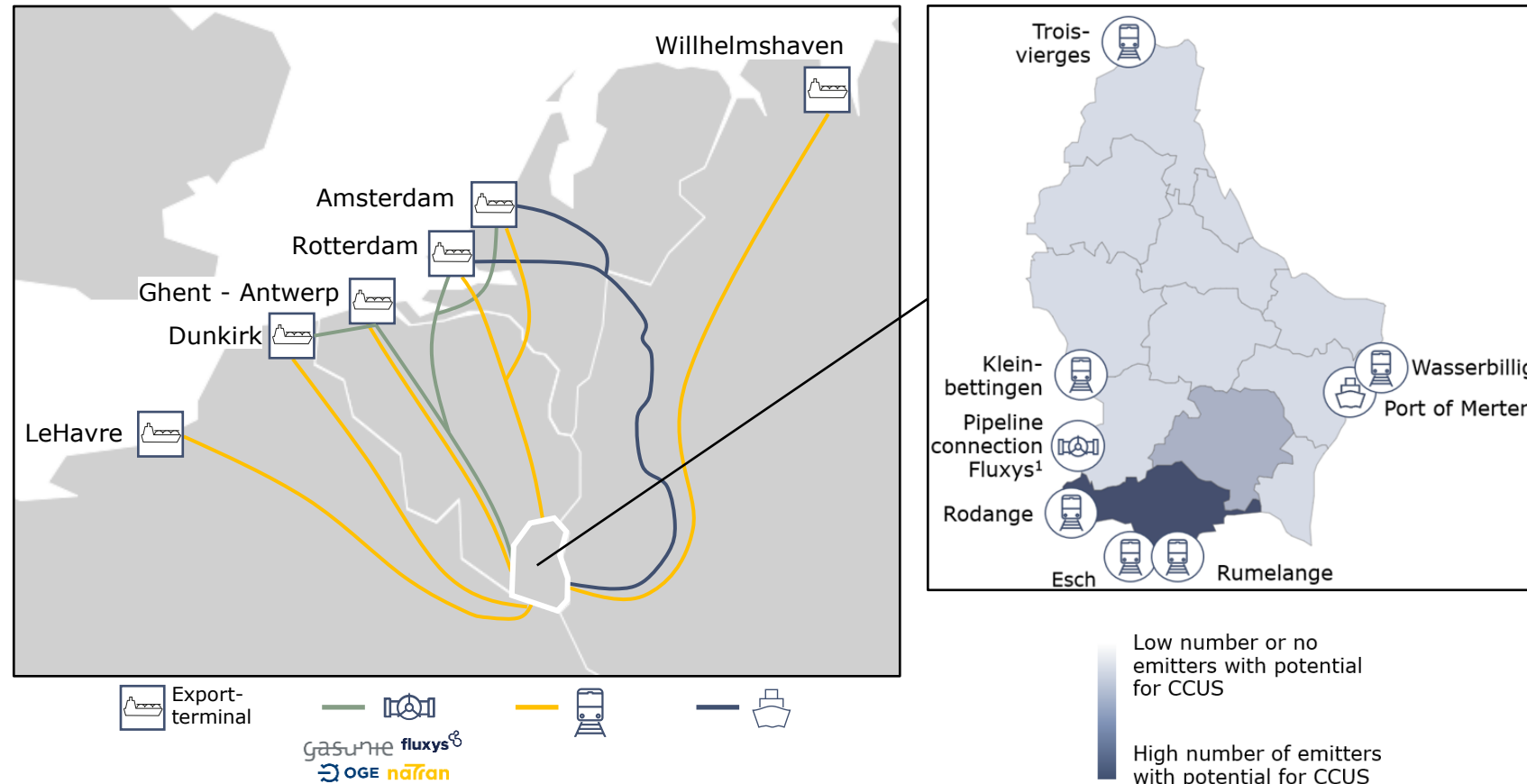
CO₂ capturing becomes widely viable, with high valuation of biogenic CO₂ so that all biogenic CO₂ is captured as well

- Strong economic growth (+1% p.a. compared to Central) and expanding manufacturing industry
- Favourable conditions for CCUS with high application rate including by all biogenic emitters

EXECUTIVE SUMMARY

Luxembourg's location enables CO₂ transport to all nearby export terminals
– with access to relevant transport infrastructure and different routes

INFRASTRUCTURE TO NORTH SEA EXPORT HUBS

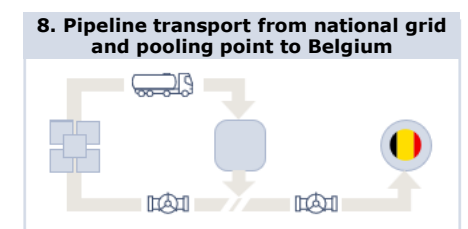
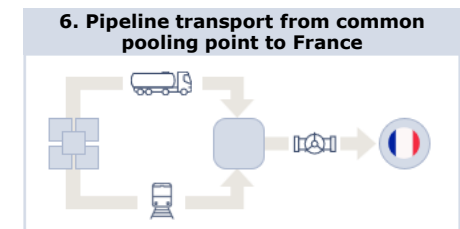
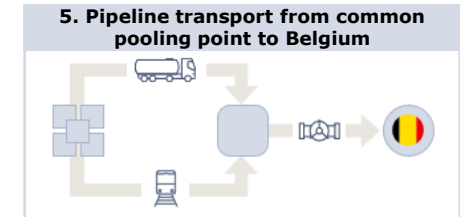
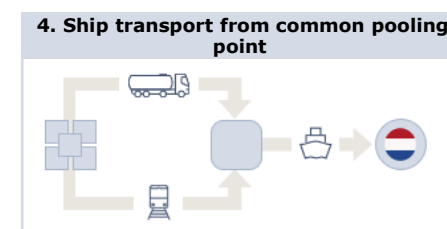
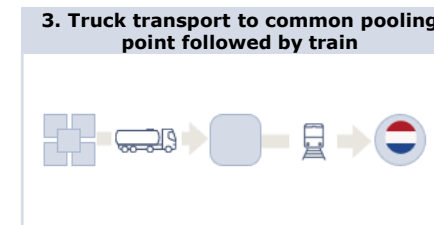
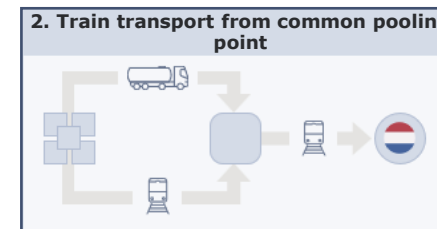
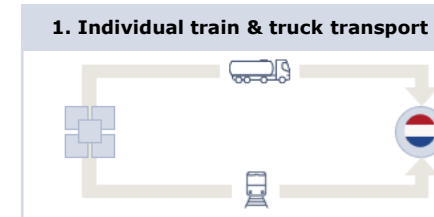
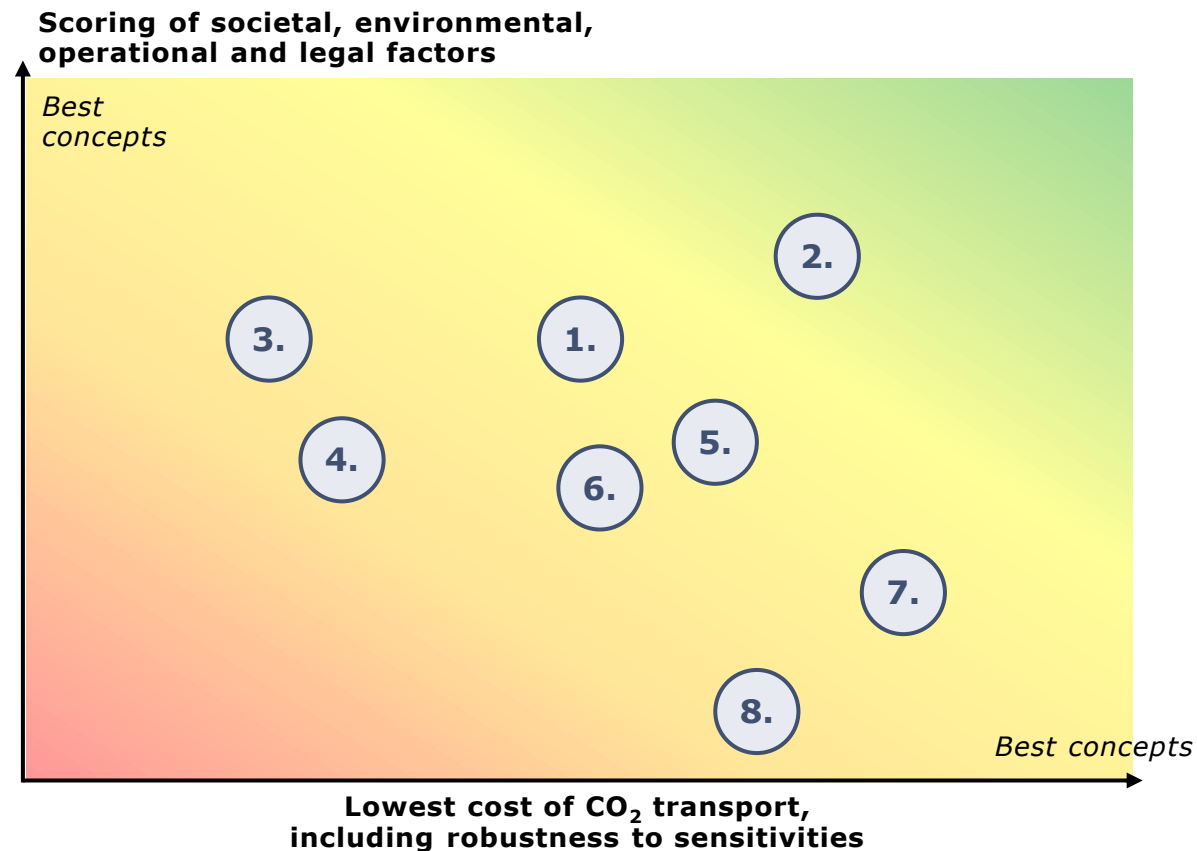


- North Sea ports accessible by different modes
- Train with high flexibility regarding destination
- Large pipeline grid planned in region
- Various potential export points from Luxembourg by train – especially in region of high CCUS potential
- Potential pipeline connection to Belgium in Southwestern part
- Potential export via ship from Port of Mertert

Source: TSO data, public data on CO₂ hubs, AFRY analysis | Note: (1) Pipeline connections are indicative and their exact location have yet to be determined

EXECUTIVE SUMMARY

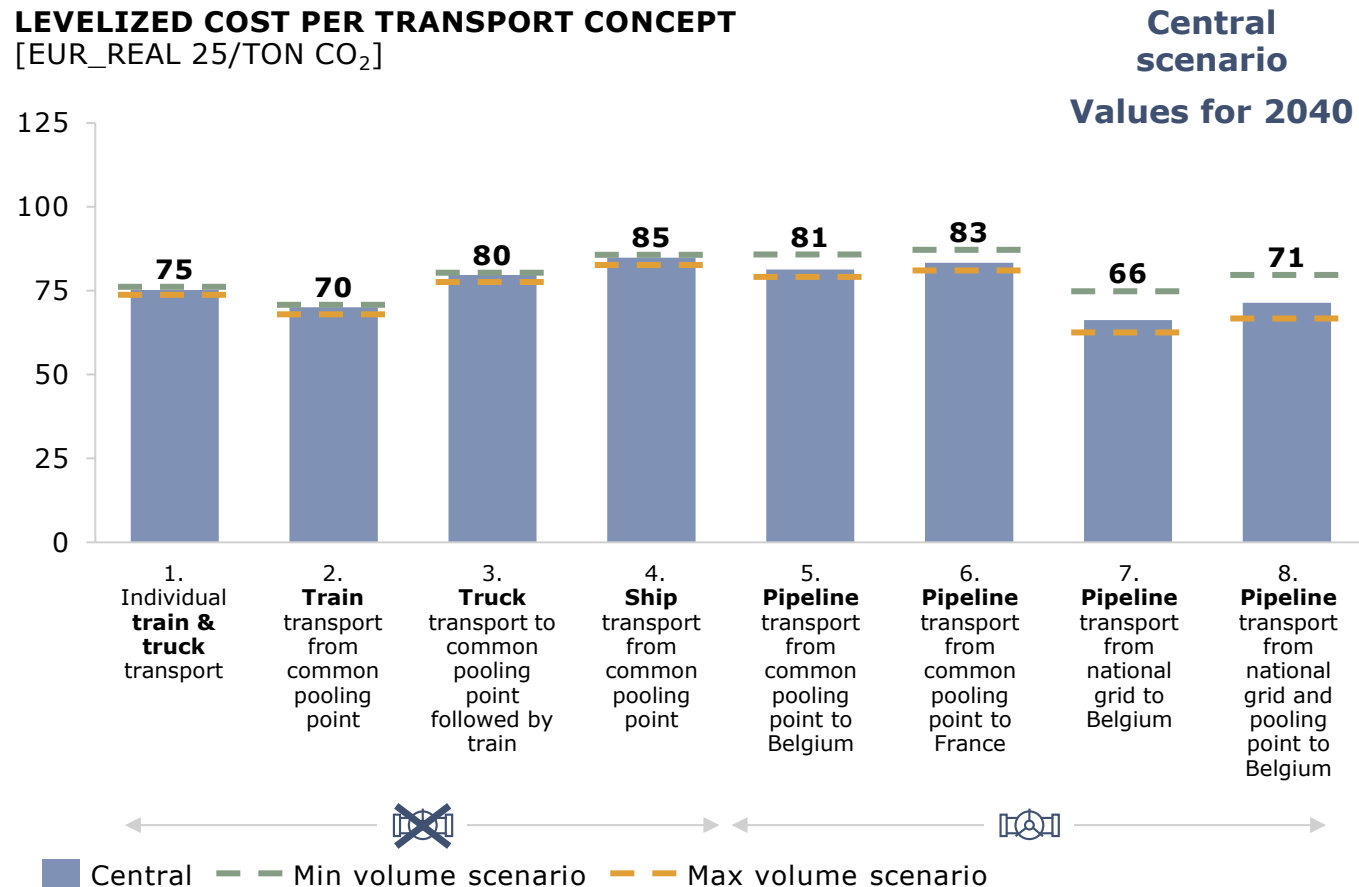
A train-based transport concept is expected to be the best compromise of costs, societal, environmental, operational & legal factors

COMPARISON OF ALL INVESTIGATED CO₂ TRANSPORT CONCEPTS

EXECUTIVE SUMMARY

Minimum transport costs are achieved using a mainly train-based or a mainly pipeline-based transport concept

LEVELIZED COST PER TRANSPORT CONCEPT [EUR_REAL 25/TON CO₂]



COMMENTS

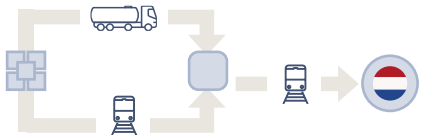
- All shown **transport concepts incl. ship transport** to offshore storage point in Denmark
- Transport **concept 7 (pipeline)** with the **overall lowest cost** in 2040 in central scenario
- Transport **concept 2** is the **most cost-effective non-pipeline** option and remains competitively close to transport concept 7
- Concepts 5 and 6 involve two liquefaction processes (i.e., one additional liquefaction process compared to other concepts), leading to substantially higher electricity costs compared to other options
- Several concepts around 70 EUR/ton range, which could lead to **non-cost relevant factors being the deciding factor** for most optimal CO₂ transport concept

Note: Shown costs include only transport cost (incl. auxiliary costs like liquefaction, regasification, (un-)loading & intermediate storage). Volumes remain consistent across all transport concepts and are only effected by years and scenario. Volumes are expected to be captured in a baseload profile.

EXECUTIVE SUMMARY

Pipeline concept has advantage in levelized cost and environmental impact – train concepts have lower stranded asset risk and lower societal impact

COMPARISON BETWEEN BEST EVALUATED CO₂ TRANSPORT CONCEPTS

	 2. Train transport from common pooling point 	1. Individual train & truck transport 	7. Pipeline transport from national grid to Belgium  <i>Very small emitter <20 ktpa via truck</i>
Cost	– Moderate levelized cost – Moderate investment need – Modular concept, low volume sensitivity	– Higher levelized cost due to truck use – Lowest investment cost of all concepts – Modular concept, low volume sensitivity	– Lowest levelized cost of all concepts – Highest investment cost of all concepts – Strong economies of scale
Societal and economic impacts	– Higher social acceptance – Low need for new infrastructure – Low stranded asset risk	– Lowered social acceptance: traffic, noise, safety concerns – Moderate local value creation – Low stranded asset risk	– High NIMBY potential during planning/construction – Strong stranded asset risk
Operational complexity	– Some logistical complexity due to rail operation and pooling of volumes – Low permitting and cross-border dependencies expected	– Moderate logistical complexity in rail operation	– Low technical-operational complexity – Strong dependence on cross-border collaboration with authorities and TSO
Environmental impact	– Environmental impact of truck/train slightly higher than pipeline concept 7 in all categories	– Environmental impact was not analysed but similar impact to concept 2 can be expected	– Lowest environmental impact of assessed concepts

Worse evaluation
than other concepts

Mixed evaluation

Better evaluation
than other concepts

INTERNAL

CO₂ TRANSPORT – REAL WORLD PRECEDENTS

Cement industry has shown high willingness to pursue train-based solutions for CCS instead of waiting for development of national infrastructure in GER

Examples for planned CO₂ transport concepts

Project name: CO₂LLECT
 Emitter: CEMEX (cement industry)
 Location: Rüdersdorf, Germany
 Captured volumes: 1.3 mtpa
 Planned COD: 2030
 # trains per day: 4



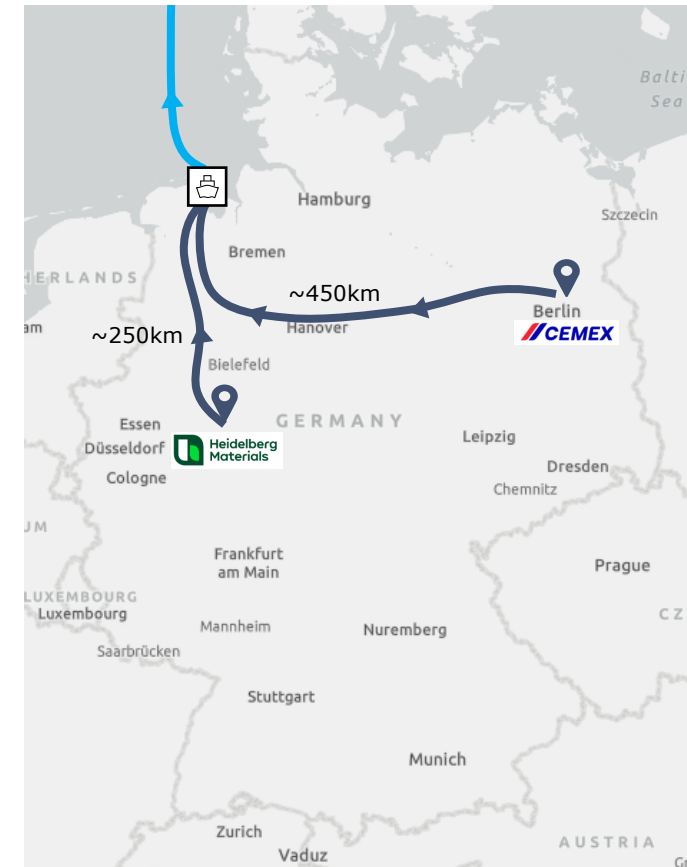
Project name: GeZero
 Emitter: Heidelberg Materials (cement industry)
 Location: Geseke, Germany
 Captured volumes: 0.7 mtpa
 Planned COD: 2029
 # trains per day: 2



Sources: European commission, CEMEX, Heidelberg Materials



Transport route



Indicative

EXECUTIVE SUMMARY

Overall, a train-based transport concept is the best compromise of cost, flexibility and resilience to evacuate CO₂ from LUX to permanent offtakers

Area	Key take aways	Meaning for Luxembourg
 CO₂ volumes	The overall CO₂ volume captured in LUX is expected to be in the range of 1-3 Mtpa by 2050, which is on the upper limit for train / Moselle vessel transport, and on the lower limit of a bespoke CO₂ pipeline.	– Overall, a train-based concept to transport the CO₂ from LUX to North Sea harbours shows the best overall compromise of flexibility, cost resilience, social acceptance and scalability¹.
 CO₂ destinations	Most of LUX' CO₂ will need to go to permanent storage sites around the North Sea, with Antwerp / Rotterdam being the most suitable evacuation vectors.	– To achieve CO₂ volumes suitable for large-scale injection contracts (typically >1 Mtpa), the CO₂ volumes should be pooled within Luxembourg to deliver full block trains to the hubs in BE / NL.
 Transport costs	Economically, a LUX-wide pipeline grid for CO₂ narrowly beats out a train-based solution – but at significantly increased sunk costs and downside risks from project delays.	– Beyond acceptance of the Amendment of the London Protocol and a national CO₂ transport regulation, no major regulatory steps need to be taken to enable the proposed CO₂ transport concept between Luxembourg and its neighbors.
 Societal impacts	From societal, operational / flexibility and resilience perspective, train-based concepts show the best compromise, avoiding the need for large-scale greenfield infrastructures and systemic bottlenecks.	– As immediate first steps, the LUX government could facilitate connections to the developers of the main large-scale CO₂ storage projects, as they will be the main bottleneck until at least 2035.
 EIA	From an environmental standpoint, pipeline-based concepts are the most favorable, having the highest emissions during manufacturing, but outperforming all other concepts significantly during the operations lifetime.	– In the longer term, a pipeline-based solution would deliver lowest costs per ton CO₂, but is conditioned to successful pipeline deployment in neighbouring countries and high local volumes committed to CCUS

1) Under the assumption, that the train infrastructure on-site at Luxembourg's main emitters permits the daily loading of rail carts with CO₂ – the general feasibility was verified with local experts, but direct discussions with the emitters were not held