



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 CO<sub>2</sub> transport concepts

Presentation

AFRY MANAGEMENT CONSULTING – JUNE 2026

## BACKGROUND TO THE STUDY

# This study investigates and evaluates different options to transport CO<sub>2</sub> 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 CO<sub>2</sub>, managing CO<sub>2</sub> 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 CO<sub>2</sub> from Luxembourg to a final storage / utilisation site.
- The study investigates multiple angles of the CO<sub>2</sub> transport challenge from Luxembourg's perspective:
  - Identifying suitable technical solutions for CO<sub>2</sub> transport from Luxembourg to permanent destinations
  - Identification of potential destinations for the CO<sub>2</sub>
  - Assessment of lacking regulations to enable CO<sub>2</sub> transport
  - Development of dynamic calculation to identify optimal multi-model transport setup until 2050

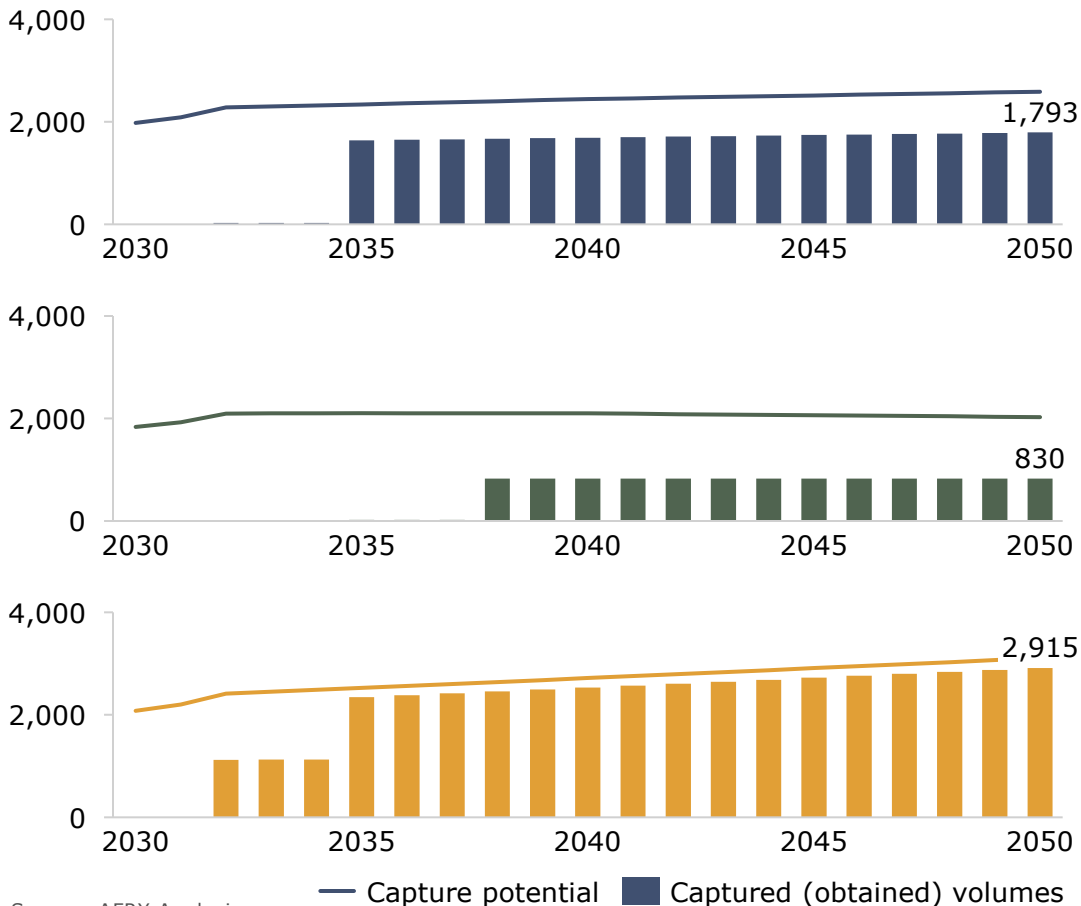
## KEY OBJECTIVES OF THIS STUDY



- Understanding available options for CO<sub>2</sub> transport considering economic, technological, and environmental factors
- Determination of the most effective multimodal transport concepts for inland and cross-border CO<sub>2</sub> 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 CO<sub>2</sub> VOLUMES IN LUXEMBOURG [ktpa]

Source: AFRY Analysis

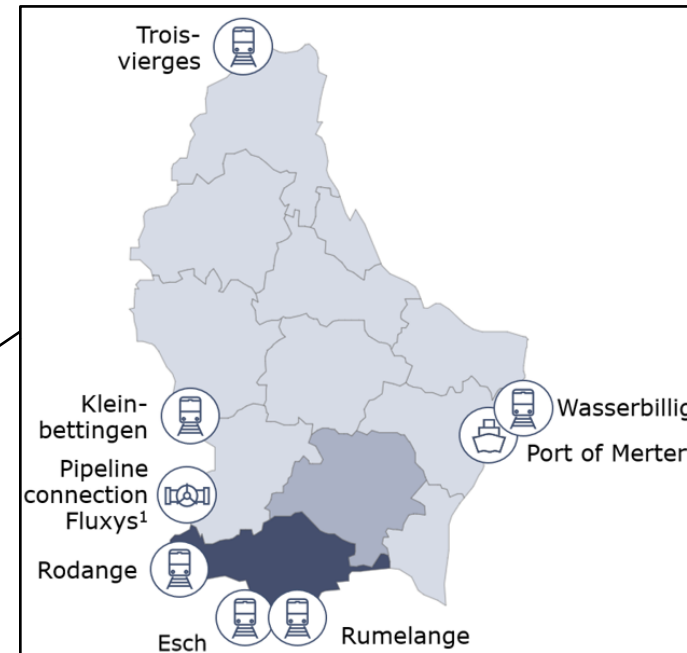
## DESCRIPTION OF PREMISSES FOR SCENARIOS

- Central**
- CO<sub>2</sub> 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 H<sub>2</sub>
  - Value of biogenic CO<sub>2</sub> sufficient, capturing viable for large players
- Min**
- CO<sub>2</sub> 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 CO<sub>2</sub> has no business case
- Max**
- CO<sub>2</sub> capturing becomes widely viable, with high valuation of biogenic CO<sub>2</sub> so that all biogenic CO<sub>2</sub> 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 CO<sub>2</sub> transport to all nearby export terminals – with access to relevant transport infrastructure and different routes

## INFRASTRUCTURE TO NORTH SEA EXPORT HUBS

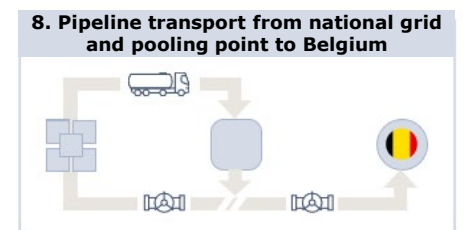
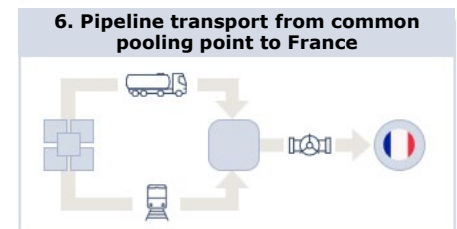
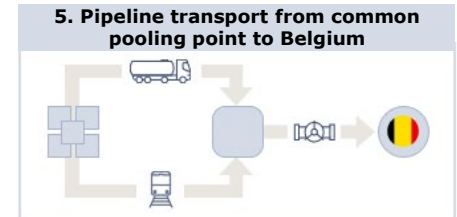
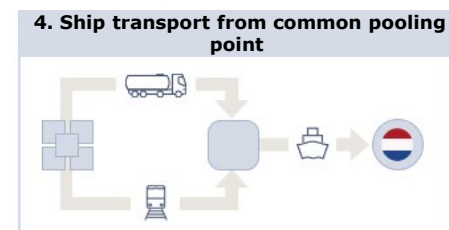
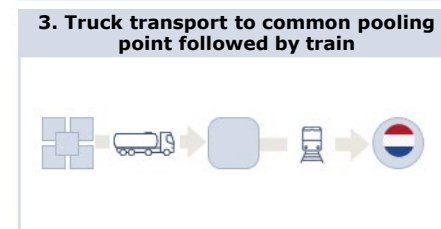
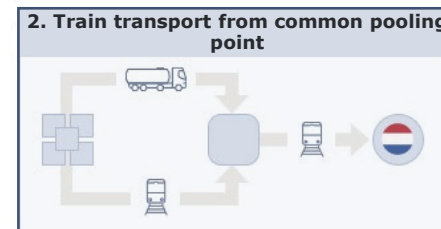
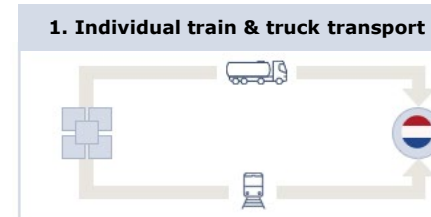
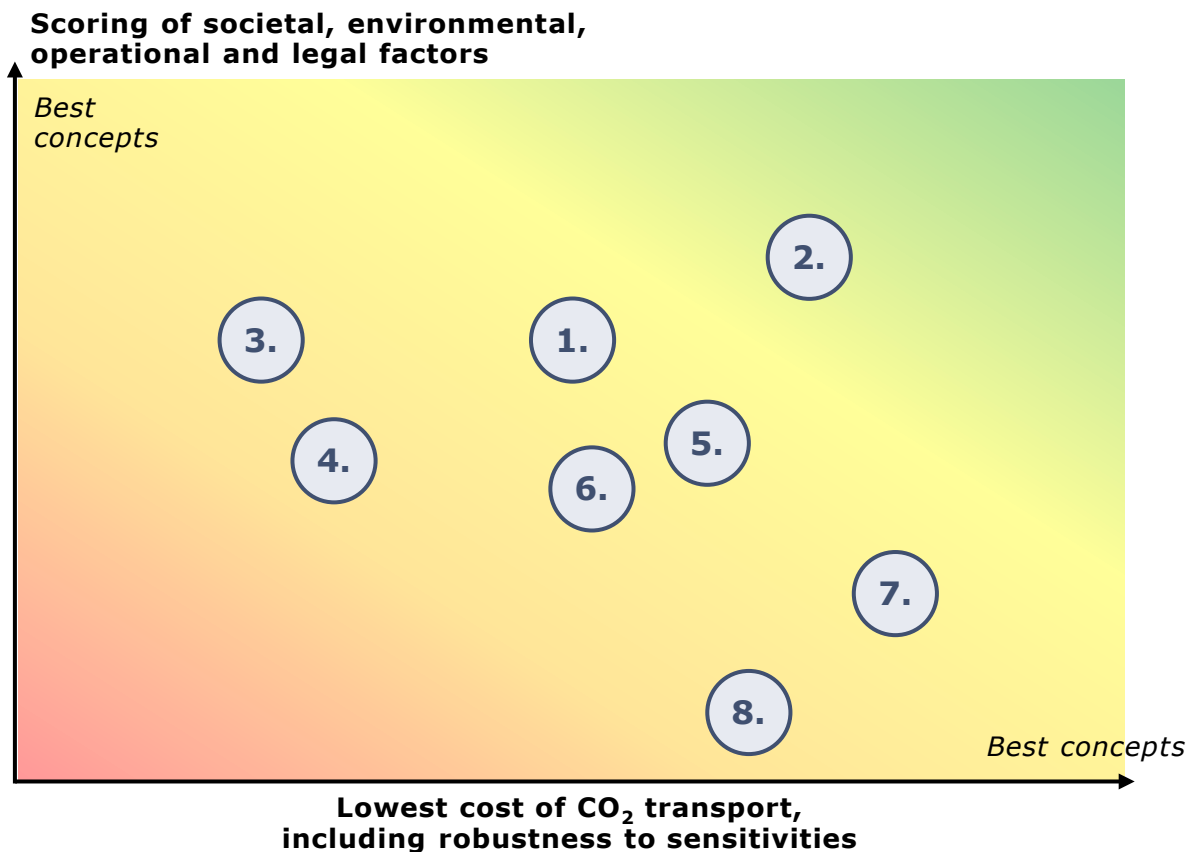


- North Sea ports accessible by different modes
- Train with high flexibility regarding destination
- Large pipeline grid planned in region
- Various potential export points from Luxembourg by train – especially in region of high CCUS potential
- Potential pipeline connection to Belgium in Southwestern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

Source: TSO data, public data on CO<sub>2</sub> hubs, AFRY analysis | Note: (1) Pipeline connections are indicative and their exact location have yet to be determined

## EXECUTIVE SUMMARY

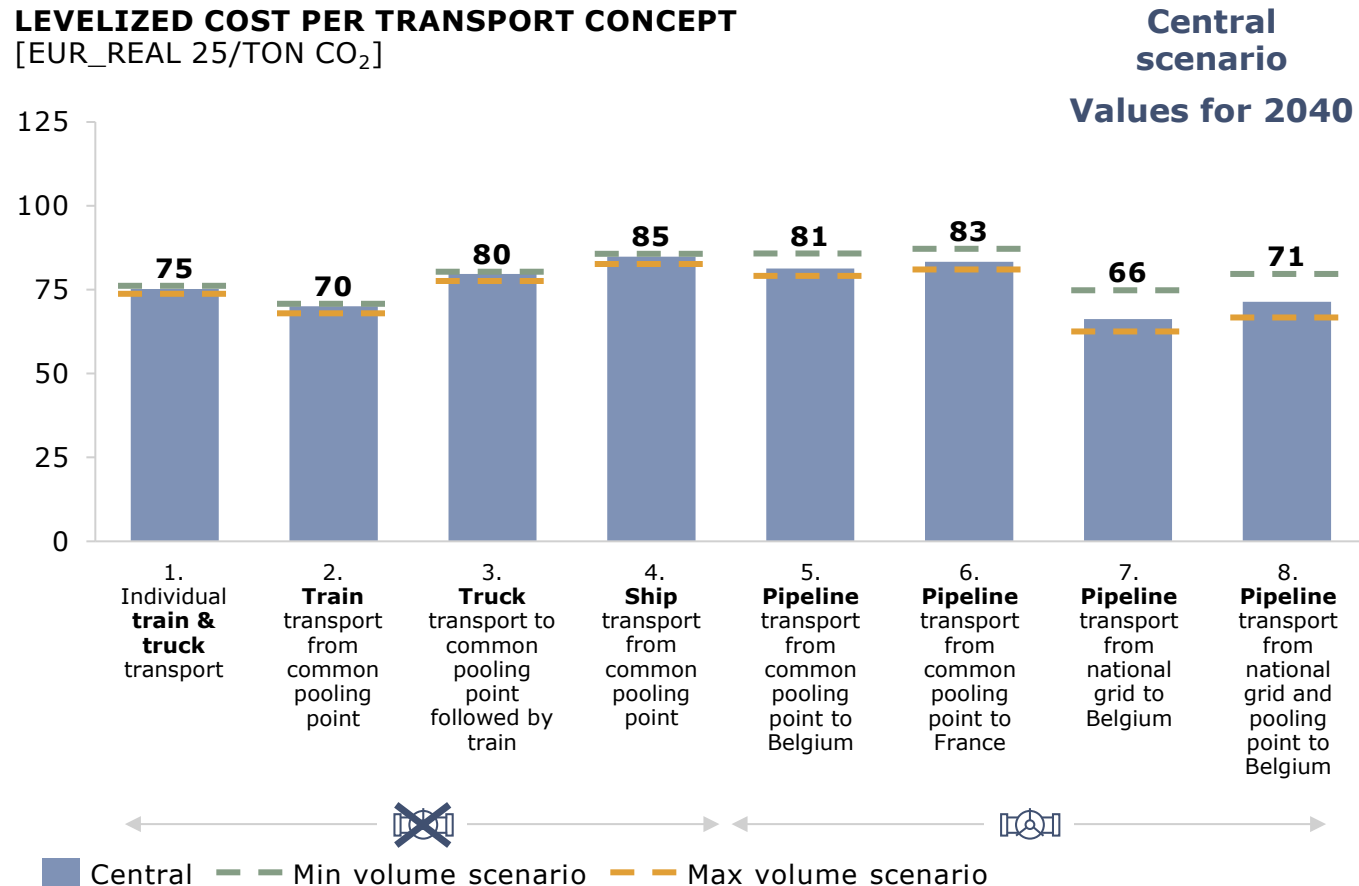
A train-based transport concept is expected to be the best compromise of costs, societal, environmental, operational & legal factors

COMPARISON OF ALL INVESTIGATED CO<sub>2</sub> 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 CO<sub>2</sub>]

## COMMENTS


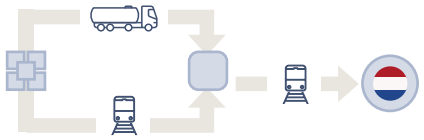


- All shown **transport concepts incl. ship transport** to offshore storage point in Denmark
- Transport **concept 7 (pipeline) with the overall lowest cost** in 2040 in central scenario
- Transport **concept 2** is the **most cost-effective non-pipeline** option and remains competitively close to transport 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 CO<sub>2</sub> 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 CO<sub>2</sub> TRANSPORT CONCEPTS

	 <b>2. Train transport from common pooling point</b> 		<b>1. Individual train &amp; truck transport</b> 		<b>7. Pipeline transport from national grid to Belgium</b>  <p><i>Very small emitter &lt;20 ktpa via truck</i></p>
<b>Cost</b>	<ul style="list-style-type: none"> <li>– Moderate levelized cost</li> <li>– Moderate investment need</li> <li>– Modular concept, low volume sensitivity</li> </ul>		<ul style="list-style-type: none"> <li>– Higher levelized cost due to truck use</li> <li>– Lowest investment cost of all concepts</li> <li>– Modular concept, low volume sensitivity</li> </ul>		<ul style="list-style-type: none"> <li>– Lowest levelized cost of all concepts</li> <li>– Highest investment cost of all concepts</li> <li>– Strong economies of scale</li> </ul>
<b>Societal and economic impacts</b>	<ul style="list-style-type: none"> <li>– Higher social acceptance</li> <li>– Low need for new infrastructure</li> <li>– Low stranded asset risk</li> </ul>		<ul style="list-style-type: none"> <li>– Lowered social acceptance: traffic, noise, safety concerns</li> <li>– Moderate local value creation</li> <li>– Low stranded asset risk</li> </ul>		<ul style="list-style-type: none"> <li>– High NIMBY potential during planning/construction</li> <li>– Strong stranded asset risk</li> </ul>
<b>Operational complexity</b>	<ul style="list-style-type: none"> <li>– Some logistical complexity due to rail operation and pooling of volumes</li> <li>– Low permitting and cross-border dependencies expected</li> </ul>		<ul style="list-style-type: none"> <li>– Moderate logistical complexity in rail operation</li> </ul>		<ul style="list-style-type: none"> <li>– Low technical-operational complexity</li> <li>– Strong dependence on cross-border collaboration with authorities and TSO</li> </ul>
<b>Environmental impact</b>	<ul style="list-style-type: none"> <li>– Environmental impact of truck/train slightly higher than pipeline concept 7 in all categories</li> </ul>		<ul style="list-style-type: none"> <li>– Environmental impact was not analysed but similar impact to concept 2 can be expected</li> </ul>		<ul style="list-style-type: none"> <li>– Lowest environmental impact of assessed concepts</li> </ul>

 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



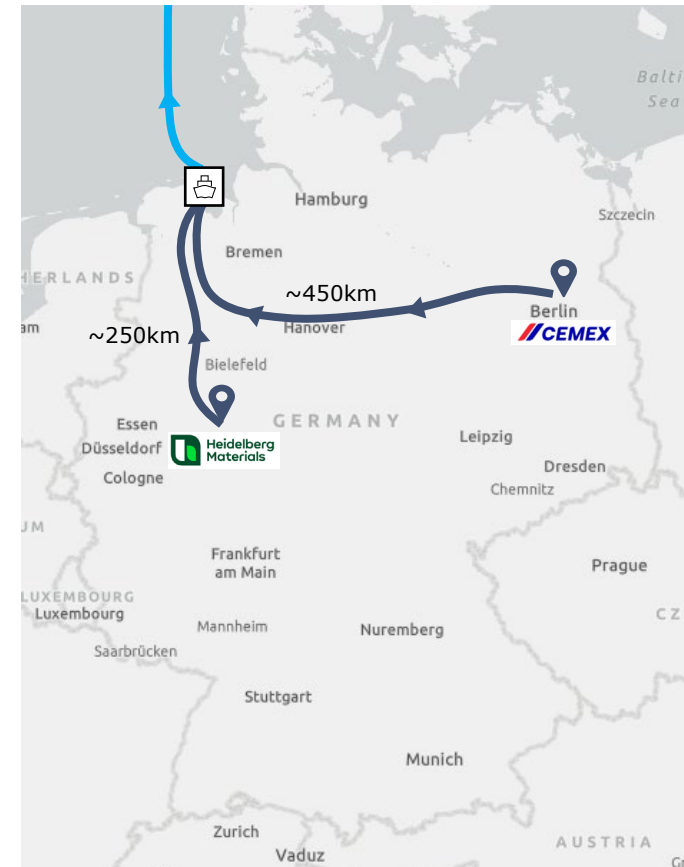
Project name: GeZero  
 Emitter: Heidelberg Materials (cement industry)  
 Location: Geseke, Germany  
 Captured volumes: 0.7 mtpa  
 Planned COD: 2029  
 # trains per day: 2



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 CO<sub>2</sub> from LUX to permanent offtakers

Area	Key take aways	Meaning for Luxembourg
 <b>CO<sub>2</sub> volumes</b>	<p>The overall CO<sub>2</sub> 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 CO<sub>2</sub> pipeline.</p>	<ul style="list-style-type: none"> <li>– <b>Overall, a train-based concept to transport the CO<sub>2</sub> from LUX to North Sea harbours</b> shows the best overall compromise of flexibility, cost resilience, social acceptance and scalability<sup>1</sup>.</li> <li>– To achieve CO<sub>2</sub> volumes suitable for large-scale injection contracts (typically &gt;1 Mtpa), the <b>CO<sub>2</sub> volumes should be pooled within Luxembourg to deliver full block trains</b> to the hubs in BE / NL.</li> <li>– Beyond acceptance of the <b>Amendment of the London Protocol and a national CO<sub>2</sub> transport regulation</b>, no major regulatory steps need to be taken to enable the proposed CO<sub>2</sub> transport concept between Luxembourg and its neighbors.</li> <li>– As immediate first steps, the <b>LUX government could facilitate connections to the developers of the main large-scale CO<sub>2</sub> storage projects</b>, as they will be the main bottleneck until at least 2035.</li> <li>– In the longer term, a <b>pipeline-based solution would deliver lowest costs per ton CO<sub>2</sub></b>, but is conditioned to successful pipeline deployment in neighbouring countries and high local volumes committed to CCUS</li> </ul>
 <b>CO<sub>2</sub> destinations</b>	<p>Most of LUX' CO<sub>2</sub> will need to go to permanent storage sites around the North Sea, with Antwerp / Rotterdam being the most suitable evacuation vectors.</p>	
 <b>Transport costs</b>	<p>Economically, a LUX-wide pipeline grid for CO<sub>2</sub> narrowly beats out a train-based solution – but at significantly increased sunk costs and downside risks from project delays.</p>	
 <b>Societal impacts</b>	<p>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.</p>	
 <b>EIA</b>	<p>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.</p>	

1) Under the assumption, that the train infrastructure on-site at Luxembourg's main emitters permits the daily loading of rail carts with CO<sub>2</sub> – the general feasibility was verified with local experts, but direct discussions with the emitters were not held