

Supporting Document

“Joining the CCS Club! The Economics of CO₂ Pipeline Projects”

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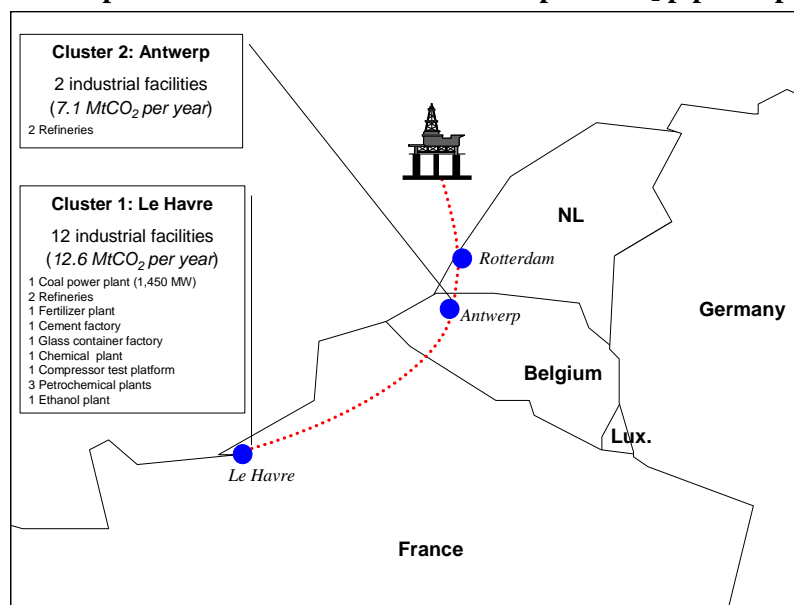
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This document clarifies the assumptions used to evaluate the long-run total cost of a CO₂ trunkline system. Our approach has its roots in Chenery (1949) and stems on the engineering process model detailed in McCoy (2009).

The long-run total cost function, an engineering model

From a technological perspective, the CO₂ trunkline at hand (cf., Figure 1 for an illustration) can be decomposed into two subsystems: a first pipeline system connects Le Havre to Antwerp (distance 427 kilometers) and a second pipeline system connects Antwerp to the Rotterdam area (distance 164 kilometers).

Figure 1. A picture of the North-Western European CO₂ pipeline project



Each of these two subsystems can have a specific design (pipeline diameter; operating pressures). For each subsystem, our cost estimates are based on the following hypotheses:

- there are negligible differences in elevation along the projected routes;
- the pipeline's lifetime is 30 years;
- the real interest rate used in the analyses is 8.00%;¹
- the exchange rate used in the analysis is 1.30 USD = 1.00 Euro;
- the future hourly flow rates of CO₂ that will be transported during the plant's lifetime are known ex ante;
- a one-year periodicity is assumed for these hourly flow rates so that the design of the infrastructure can be chosen so as to minimize the annual equivalent cost to transport the flows of CO₂ observed during a typical year;
- the terminal pressure at the delivery point is equal to those measured at the inlet of the system;
- several compression stations can possibly be installed along the pipe. In that case, we follow the rule of thumb detailed in Chapon (1990) and implicitly used in McCoy (2009, chapter 2)² and assume: (i) that there is a unique pipe-diameter for each subsystem; (ii) that these compression stations are regularly spaced along the pipeline; and (iii) that all these compression stations are operated at the same regime so that a unique compression ratio is used for all the compressors installed along the pipeline.³
- the size of the compressor equipments is imposed by the peak hourly flow rate, but on a given hour, their rate of use (and thus, the variable cost of the energy required to power these equipments during that hour) is imposed by that hour's output. The amount of energy required for compression purposes is obtained using the engineering relations detailed in McCoy (2009, subsection 2.1.3 and Appendix A).

These hypotheses together with the engineering process model detailed in McCoy (2009) allows us to compute, for any vector of future hourly flow rates of CO₂, the long-run cost-minimizing design of a point-to-point CO₂ pipeline infrastructure (i.e., the optimal value of the pipeline diameter, the number and the size of the compressor stations, the amount of energy used for compression purposes).

References

André, J., & Bonnans J.F. (2011). Optimal structure of gas transmission trunklines. *Optimization and Engineering*, 12(1-2), 175–198.

¹ To our knowledge, there is no foolproof way of choosing this rate. This figure is coherent with those typically used in Northwestern Europe for natural gas pipelines.

² A pipeline expert might argue that some of these hypotheses could be relaxed to obtain a slightly lower cost (e.g., the assumption of equally spaced stations as in André and Bonnans, 2011). Nevertheless, we proceed assuming that this engineering-based model conveys a sufficient level of sophistication to capture the essential features of the technology of a CO₂ trunkline system.

³ Thus, the whole subsystem can be described as a sequence of identical elementary modules (each module includes a compressor station and a pipeline segment) that are serially connected one to the other.

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Chenery, H.B. (1949). Engineering production functions. *The Quarterly Journal of Economics*, 63(4), 507–531.

McCoy, S.T. (2009). *The Economics of CO₂ Transport by Pipeline and Storage in Saline Aquifers and Oil Reservoirs*. PhD Dissertation. Pittsburgh (PA): Carnegie Mellon University.