CO_2 Pipeline Cost Calculations, Based on Different Cost Models

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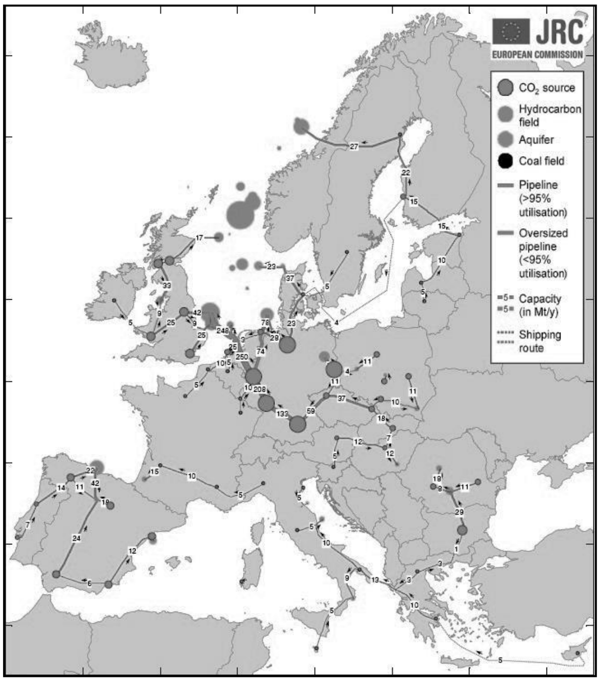
SUMMARY

Carbon Capture and Storage (CCS) is considered to be a promising technology and an effective tool in the struggle against climate change. The method is based on the separation of air-polluting CO_2 from fuel gases and its subsequent storage in different types of geological formations. The outlet points and formations used as CO_2 storage sites are often very far from each other. According to certain recently announced, medium-term EU plans, a 20,000 km long pipeline system will be established for the transportation of the gas by 2050, at a cost of 28.5 billion Euros. Obviously, not only technical ad safety planning, but also detailed, itemized financial and investment plans based on cost calculations (including construction and operation costs), are required to make such a grandeus enterprise economically feasible. We reviewed several studies from available literature that use different computational models to determine pipeline construction costs, based on the technical and financial data of natural gas transport pipelines and CO_2 pipelines built for Enhanced Oil Recovery (EOR) projects. In the following paper, these cost models are collated and analysed, with regard to their applicability to CCS process planning.

Keywords: CCS technology, CO2 transportation; pipeline; cost model
Journal of Economic Literature (JEL) code: Q57

INTRODUCTION

Since the industrial revolution began, the amount of greenhouse gases (GHGs) has constantly grown in the atmosphere, and as a result, global warming has been drastically accelerated. In recent years the CO_2 content of the total GHG emissions has reached 80%. According to the data of the European Environmental Agency (EEA), in the year 2010 this ratio exceeded 3,891 billion metric tonnes of CO_2 across the EU-27. By analysing the 'emission mix' of the economic sectors, it can be stated that the largest emitter is the heat and electricity sector, including power stations (31.3%). The second largest amount of CO_2 is being emitted by the transport sector (26.6%). At the same time the emission parameters of these two sectors differ significantly. While a limited number of resource points are represented by power stations, millions of small emitters (like motor vehicles) are present in the transport sector. In other words, one-fourth of the overall CO_2 emission is produced by relatively few polluters, and actually these are the places where the sequestration of CO_2 from fuel gases and safe storage can be technologically performed. Transportation takes place either through pipelines or by tankers (marine routes), since there are often huge distances between the outlet points and the points of underground injection. The CCS-chain consists of: detachment, transportation, storage and monitoring.



Source: JRC[1] (2010)

Figure 1. The planned CO_2 network system in 2050

[1] *Joint Resources Centre*

The transportation of CO_2 by pipeline is not a new task, since various methods for transmitting the gas to the producer units have been applied by enhanced oil recovery (EOR) technologies[2] for several decades.[3] Today, the length of the CO_2 pipelines is globally more than 6,000 km; however, it is under 500 km within Europe. Even if CCS is not assumed to be a final solution, the EU considers this technology to be an important tool in the pursuit of climate protection. Due to the lack of proven operational experience, presently only the investment and operation costs of model projects are covered. For the future, the construction of a complex CO_2 pipeline structure (see Figure 1), similar to the natural gas transportation network existing nowadays in Europe, has been set forth by the European Committee (JRC, 2008).

According to EU expectations, the changes introduced in the Emissions Trade System (ETS) starting in 2013 will give positive incentives to the implementation of these huge, cost-intensive plans. The new regulation declares that from 2013 on, captured and safely stored amounts of CO_2 are not to be considered to be emitted quantities and will not be charged as emitted shares to the country involved (Lauranson, 2011). This means that, due to probably high share prices, when the total shares will be traded later on the stock market high emitters are likely to be interested in the use of this kind of technology.

ECONOMIC MODELS OF CCS

Naturally, not only technological but also economic studies have been carried out to promote the spread of environmentally safe CCS technology. Although specialists have great experience in CO_2 transmittance, its economic modelling has not yet been fully developed. Transportation activities can vary along the CCS chain – considering the localisation of resource points and storage sites. Resource points can be ‘anywhere’ on land (onshore), while storage formations can be found onshore, near marine sea shelves, coastal platforms or offshore, in deep marine areas as well. The offshore sites are expected to gain priority (over onshore sites) because of their distance from any populated area.

Consequently, CO_2 transmitters can include:

- onshore pipelines,
- subsea pipelines,
- tankers.

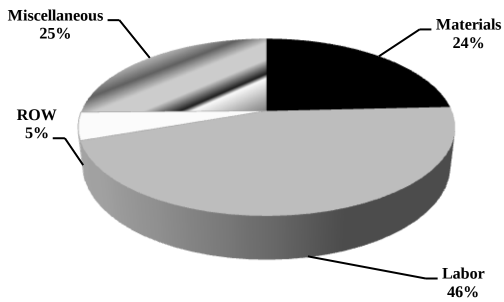
Regarding Hungarian conditions, only onshore type pipeline transportation can be taken into consideration. The cost models mentioned below also deal with this kind of transportation. When determining either CAPEX[4] or OPEX[5] parameters, the technological and safetyparameters of the pipeline are of prime importance:

- pipeline length,
- pipeline inlet pressure,
- pipeline outlet pressure,
- pipeline inlet temperature,
- CO_2 flow.

Naturally, the capital cost of the investment is not determined merely by the physical parameters of the operating pipeline. Capital costs can be divided into the following components:

- materials,
- right of way,
- labour,
- miscellaneous (e.g. engineering costs).

The share of the above components in total capital cost is represented in Figure 2. Recent studies show that in the case of a 12 inch (300 mm) diameter CO_2 transportation pipeline, the proportionate shares of these cost parts remain constant, regardless of pipeline length.



Source: van der Zwaan et al. (2011)

Figure 2. Distribution of capital costs

Cost models of CO_2 pipelines are mostly based on the cost inspection of the constantly expanding EOR-CO_2 or natural gas pipelines. The models concentrate on the parameters and the establishment costs of the pipeline. Although sizing is determined based primarily on technological and safety reasons, it gives a further basis for economic calculations.

The following models are mentioned in the literature available:

- Ogden model
- MIT[6] model
- Ecofys model
- Parker model,
- IEA GHG PH4/6 model
- IEA GHG 2005/2 model
- IEA GHG 2005/3 model.

[2] *Providing surplus oil production by CO2 injection into hydrocarbon reservoir formations.*
[3] *The first CO2 pipeline was established in the early 1970s in the USA, and in 1972 in Hungary.*
[4] *capital cost/expenditure*
[5] *operating expense*
[6] *Massachusetts Institute of Technology*

Comparing the models, it can be stated that only the Parker model offers an alternative route (Parker, 2004), since the Ogden model is comprised of other theoretical research works (Ogden et al., 2004). The MIT (Heddle et al., 2003) and Ecofys (Hendriks et al., 2003) models determine the pipeline diameters by applying the same method as used in natural gas pipeline sizing.

The International Energy Agency GHG models (IEA GHG, 2002; 2005) consider booster stations (used to increase pressure along longer pipelines) for the calculations. In models dealing with the North American area, annually published cost data from the Oil & Gas Journal (OGJ) are considered. In the following, the MIT, Ecofys and Parker models will be described:

MIT Model

As published in a study in 2003 (Heddle et al.), the technologically most appropriate pipeline diameter was determined by the Reynolds number and Moody diagramme – the way these formulae are used in engineering practice. Total capital cost can be given by the parameters calculated from basic pipeline data, with the cost data from OGJ added.

$$\text{TotalAnnualCost}\left(\frac{\$}{\text{Yr}}\right)=(\text{CC}\times\text{D}\times\text{L}\times\text{CRF})+(\text{OM}\times\text{L}) \quad (1)$$

where:

CC construction cost ($/km) – as a function of the diameter, including material cost

D pipeline diameter (in)

L pipeline length (km)

CRF capital recovery factor (at given year considering project lifetime, e.g. CRF for a 20-year project is on average 0.061[7])

OM incremental costs – not a function of the diameter.

$$\text{Levelized Cost}\ (\$/\text{tonne CO2})=\frac{\text{Total Annual Cost}}{(\text{Q}\times\text{CF}\times\text{DPY})} \quad (2)$$

where:

Q CO2 mass flow rate (tonne/year)

CF plant capacity factor (80% in accordance with authors of the model)

DPY day per year.

Ecofys Model

In this model, costs are given in euros, since it was first published in a study prepared for the European Commission (COM (2011) 112)The pipeline diameter is determined the same way as in the MIT model, but here, the friction factor is considered to be constant, while in the MIT model it is the function of the Reynolds number.

Total capital cost in the model:

$$\text{Totalcapitalcost}(€)=1100\,\frac{€}{m^2}\times F_T\times D\times L \quad (3)$$

where:

FT correction factor for terrain = 1 for most common terrain

D pipeline diameter (mm)

L pipeline length (km).

Annual capital cost:

$$\text{Annual captial cost}\ (€/\text{yr})=\text{Total capital cost}\Big/\frac{(1+i)^n-1}{i(1+i)^n} \quad (4)$$

where:

i discount rate

n operational life time (years).

According to the model, annual operational cost is 2.1% of total capital cost. Levelized cost is not calculated on CO_2 transportation, but it can be given on the basis of the MIT model.

The Parker Model

Parker uses OGJ cost data just like the MIT model, but determines it in a more detailed way instead of simply giving a summated number. Calculations can be performed in four different cost categories by applying the quadratic equations given as a function of pipeline length and diameter. Materials costs account for approximately 26% of the total construction costs on average. Labor, right of way, and miscellaneous costs make up 45%, 22%, and 7% of the total cost on average, respectively.

The model was originally developed for the calculation of hydrogen pipeline costs but is applicable to CO_2 pipelines as well.

THE COMPARISON OF COST MODELS

Comparing the input and output data of the described models (see Table 1), the conclusion can be drawn that while the Parker model is simply based on the geometrical parameters of the pipeline (length, diameter), the other two models also consider pipeline material- and the physical properties of the pipe and of the gas transported.

[7] *CEPA, 2012*

Table 1
Pipeline cost models with specific parameters for CO_2 pipelines

	Models		
	MIT	Ecofys	Parker
Input	pipeline roughness factor, CO_2 viscosity, friction factor, Reynolds number, inlet pressure, outlet pressure, pipeline length, CO_2 mass flow rate, Capital Recovery Factor, Plant Capacity Factor	average flow velocity, friction factor, CO_2 density, pressure drop, pipeline length, correction factor for terrain, CO_2 mass flow rate, operational lifetime, discount rate	pipeline length, pipeline diameter
Output	pipeline diameter, Total Annual Cost, Levelized Cost	pipeline diameter, Annual Capital Cost, Annual O&M Costs, Total Annual Cost	Materials Cost, Labor Cost, Miscellaneous Cost, Right of Way Cost, Total Capital Cost

General comparisons are made difficult by the following diffenerences in approach:

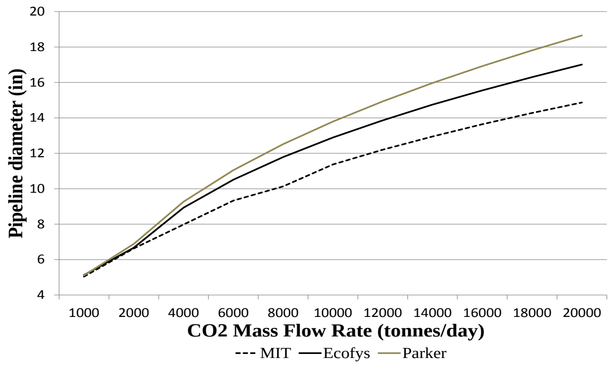
- cost calculations are nominated in USD (MIT and Parker models) versus EUR (Ecofys model)
- pipeline length and diameter are given in different standard units (e.g. diameter: inch vs. mm – 1 in= 25.4 mm)
- the Parker model uses pipeline diameter data as the basis for the calculations and applies a distinct calculation method to get to a final outcome
- the estimated lifetime of the CO_2 transmission pipeline is considered by the Ecofys model only
- O&M cost is determined as a function of pipeline length and diameter by the MIT model while it is determined as a function of the given percentage of total capital cost by the Ecofys model.

EXAMPLES

For purposes of conducting a general comparative analysis of the models described by researchers, a standard set of parameters has been defined as follows:

- pipeline length: 100 km
- plant capacity factor: 80%
- pipeline inlet pressure: 15.2 MPa
- pipeline outlet pressure: 10.3 MPa
- CO_2 temperature: 20°C
- CO_2 density: 844 kg/m^3
- CO_2 viscosity: 6.05*10^{-5}
- reference cost year: 2005
- conversion EUR/USD: 1.2
- operational lifetime: 20 years
- discount rate: 10%
- location factor: 1.00
- terrain factor: 1.2

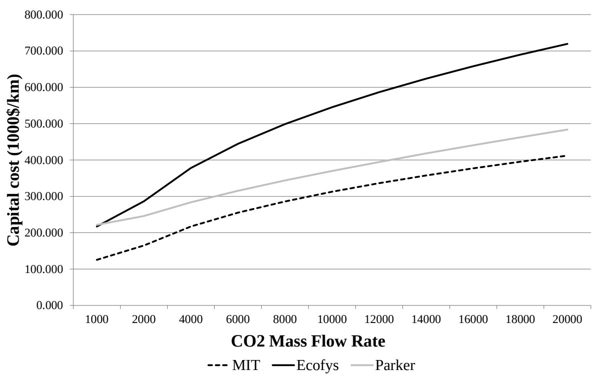
Calculation results obtained by the application of the respective models are shown in Figures 3 and 4. The calculation differences mentioned before are clearly reflected in the final outcomes. Despite the slight divergence of the results, the same type of functional relationship can be observed between pipeline diameter and mass flow rate increase for all three models. Differences practically derive from differences in the diameter calculation methods.



Source of data: McCollum and Ogden (2006)

Figure 3. Pipeline diameter vs. CO_2 mass flow rate

Figure 4 shows a more dynamic change for the Ecofys model than for the other two. The MIT and the Parker models relate capital cost results to increase in mass flow rate. The Ecofys model is somewhat more specific, as mentioned before, taking the expected lifetime of the pipeline into consideration and estimating additional costs regardless of pipeline length.



Source of data: McCollum and Ogden (2006)

Figure 4. Pipeline Capital Cost vs. CO_2 Mass Flow Rate

OBSTACLES IN APPLYING ANY OF THE THREE MODELS TO A HUNGARIAN PIPELINE PROJECT

In 2009, a CCS pilot project plan was developed involving the establishment of a 116 km long CO_2 pipeline as part of an investment plan associated with the extension of the Mátra Power Plant. The planned pipeline diameter was 350 mm (~ 14 in), inlet pressure 12 MPa, and annual flow capacity approximately millon tonnes (about 8200 t/day).

The obstacles in applying the above models to this project were the following:

- detailed, exact and reliable data on pipeline establishment costs are extremely difficult to obtain;
- the models mentioned have been developed – by European and American researchers – for natural gas or hydrogen pipelines, relying on an annually published pipeline cost database. Such a database is nonexistent in Hungary.
- The estimated construction costs of a 1 km long natural gas pipeline (of 350 mm diameter) amounts to about 51 M HUF in Hungary (Kubus, 2011). Yet, for the successful application of a cost-calculation model, incremental cost data (independent of pipeline diameters) should also be known. Such data are not public.
- The investment plan associated with the expansion of the Mátra plant has lately been suspended, which makes further cost calculations purposeless.

With the suspension of the prospective development plan, the first Hungarian CCS project has also been shelved. However, though there is no immediate need for a cost calculation for CO_2 pipelines, future developments are likely to require it someday. For this reason, it would be useful to work out a method that is applicable to the Hungarian situation. Investigations can also be made into how useful the available pipeline cost database information can be in a Hungarian context.

CONCLUSIONS

Return rates and expected profits are, of course, primary influential factors when making investment decisions on pipeline construction. From the economic aspect, however, distinction should be made between:

CO_2 pipelines related to the application of EOR technologies that aim to improve oil production performance, and CO_2 transportation pipelines integrated in the CCS technological chain, providing the transmission of the gas to the storage sites.

While the cost-efficiency of production-related, commercial CO_2 pipelines (mainly in the US) is basically determined by the fluctuations of oil market price, the assumed rentability of CCS-related transport pipelines is somewhat uncertain and might prove viable only on the long run.

Since CCS technologies enjoy the financial support of the European Union, the recent implementation of special pilot projects put focus on gaining technical-engineering expertise and field practice rather than on budgetary or commercial issues.

The economic balance of prospective investments in CCS will largely depend on forthcoming Emissions Trading Scheme implications, CO_2 quota tariffs (at present relatively low) and other governmental restrictions as well as environmental regulations (e.g. charging extra taxes on excessive CO_2 emission).

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