



GHGT-10

## Towards a CO<sub>2</sub> infrastructure in North-Western Europe: Legalities, costs and organizational aspects

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### Abstract

This paper serves to highlight work completed within the EU FP7 CO<sub>2</sub>Europipe project, which aims to provide guidance to elements of an EU master plan for the development of large scale European CO<sub>2</sub> infrastructure. In the last 5 years there have been some significant advancements in EU and international regulations that serve to facilitate CO<sub>2</sub> transportation, however there is little guidance on how multi-user transport networks should be organized and financed. Poor planning and initial underinvestment in CO<sub>2</sub> pipeline capacity can lead to inefficient networks and higher lifetime costs. Although shipping of CO<sub>2</sub> may be a favourable transport option under certain circumstances, the monitoring and verification guidelines for this form of CO<sub>2</sub> transportation are currently deficient. Cost estimates have been provided by industrial project members for CO<sub>2</sub> pipelines (on/offshore), compression and shipping. Economies of scale are exhibited for pipelines, shipping and compression installations, however in order for operators to take advantage of economies of scale in pipelines, the intentions of governments regarding the regulation of tariffs for third-party network users need to be consolidated as soon as possible.

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Keywords: CCS, transport, large-scale infrastructure, Europe

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### 1. Introduction

One of the key conditions governing the proliferation of CCS in Europe is the development of a CO<sub>2</sub> transport network, which will likely include a combination of pipelines and transportation via ship, where technically and economically feasible. Given the correct incentives, a ramp-up of CCS deployment in Europe may lead to a substantial demand for transport capacity running up to 2050 and beyond. Currently the European regulatory

environment surrounding the transport of CO<sub>2</sub> remains underdeveloped, and information on the size of the investments required and the division of costs is limited.

The contents of this paper, derived primarily from Work Package 3.3 of the CO<sub>2</sub>Europe Project, focuses on highlighting the legal aspects of CO<sub>2</sub> transport and infrastructure development; presenting cost estimates for pipelines, compression and shipping from industrial partners; and a review of current literature regarding the organizational issues of CO<sub>2</sub> transportation networks. The paper begins by presenting a source-sink scenario analysis completed as part of the CO<sub>2</sub>Europe project.

## 2. Possible CO<sub>2</sub> Transport Network Developments to 2050

It has been expressed that during the demonstration phase of European CCS projects up until 2020, CO<sub>2</sub> transport infrastructure will be restricted to local cost-effective point-to-point pipelines [1]. Depending of course on the success of the demonstration projects, post 2020 may see the first large scale deployment of CCS in the power sector. Due to the presence of clusters of CO<sub>2</sub> point sources in areas such as the Rotterdam/Antwerp harbours, and the industrialized German Ruhr area, there may be a requirement for public policy that encourages the development of optimized networks. Development of networks are expected to reduce costs, utilize limited space, broaden participation and deepen deployment of CCS [2].

Additional work completed in the CO<sub>2</sub>Europe project concentrating on CO<sub>2</sub> source-sink matching to 2050 in Europe [3], uses scenarios based on extrapolated projections from the PRIMES economic growth model developed by the University of Athens to explore potential pipeline capacity requirements. Three scenarios have been developed, one based on primarily national onshore storage of CO<sub>2</sub> (Reference), a scenario where only offshore storage takes place (Offshore), and a third scenario whereby offshore storage takes place with possibilities for EOR. The scenarios also assume that a suitable legal framework and sufficient economic incentives are available.

Table 1: Possible CO<sub>2</sub> backbone pipeline requirements in 2050

Year	Backbone <sup>1</sup> requirements (km)			Cross border transport (% of total)		
	Reference	Offshore	EOR	Reference	Offshore	EOR
2020	2.300	4.200	5.300	-	7	19
2030	14.300	20.900	20.900	25	70	71
2050	21.800	32.000	33.200	18	70	70

Based on the projection of 1222 MtCO<sub>2</sub>/yr being captured in North-Western Europe in 2050, it has been calculated that 21,800 km of backbone pipeline will need to be completed to transport the CO<sub>2</sub> to onshore storage locations. If offshore storage becomes the only option for storage, the length of backbone pipelines required rises considerably.

## 3. Legal aspects of CO<sub>2</sub> transportation

If CCS is to be deployed on a European level, in synchronization with policies that incentivise investment, legal frameworks should be established to regulate the implementation and operation of CCS. The development of a comprehensive regulatory framework is a fundamental step to ensure community and industry confidence regarding the capture, transport and storage of CO<sub>2</sub> [4]. Although technologies that have the ability to capture carbon from industrial sources have been utilized over the last 30 years or so, the concept of CCS for the purpose of reducing greenhouse gas emissions is a relatively new concept, and hence little regulation exists. In addition, large long-term

<sup>1</sup> Backbone pipelines are used to transport CO<sub>2</sub> from more than one installation.

CCS projects have the potential to interact with a variety of regulations and laws at the local, state/provincial, national and international levels [5].

### 3.1. The EU Directive on the geological storage of CO<sub>2</sub>

There is currently no dedicated EU legislation that covers the transportation of CO<sub>2</sub> [6]. Transportation of CO<sub>2</sub> is covered to a certain extent in the recent EU Directive on the Geological Storage of Carbon Dioxide<sup>2</sup> (hereafter referred to as the CCS Directive). The legal provisions contained within the CCS Directive must be transposed into member state legislation by the 25<sup>th</sup> June 2011. Importantly, the Directive contains a number of amendments to existing Directives relating to waste management, and as a consequence removes a number of legal uncertainties regarding the transportation of CO<sub>2</sub>.

Of specific importance for the transboundary movement of CO<sub>2</sub>, Article 35 of the CCS Directive, amends Article 2(1)(a) of the Waste Framework Directive categorically removing from the definition of ‘waste’, carbon dioxide captured and transported for the purposes of geological storage, provided it is geologically stored in accordance with the CCS Directive [6]. Furthermore, Article 36 of the CCS Directive, removes CO<sub>2</sub> transport for the purpose of geological storage from the scope of the Transfrontier Shipment of Waste Regulation<sup>3</sup>.

### 3.2. The 1996 London Protocol

The 1996 London Protocol, is an international agreement that prohibits the deliberate disposal of all wastes into the sea, with the exception of a number of categorically listed materials. In November 2006, it was agreed by contracting parties to add an eighth category to Annex I of the London Protocol, which placed ‘CO<sub>2</sub> streams from CO<sub>2</sub> capture processes for sequestration’ on a list of wastes that could be considered for offshore disposal. However, Article 6(1) states that ‘Contracting Parties shall not allow the export of wastes or other matter to other countries for dumping or incineration at sea’. Given a large scale-up of CCS throughout Europe, and the possibility that certain European countries may not have access to suitable geological storage sites, the ability to transport CO<sub>2</sub> across borders was considered imperative by a number of contracting parties. At the 31<sup>st</sup> Meeting of Contracting Parties in October 2009, Norway submitted a proposed amendment to the London Protocol, which added an additional paragraph (2) to Article 6 as follows (in part<sup>4</sup>):

*‘Notwithstanding paragraph 1, the export of carbon dioxide streams for disposal in accordance with Annex I may occur, provided that an agreement or arrangement has been entered into by the countries concerned.’*

The amendment was adopted as a Resolution (Resolution LP.3(4)) by vote. However, in order for the Resolution to come into force (for parties that accept it), it must be ratified by two-thirds of the Contracting Parties.

### 3.3. Monitoring and verification of CO<sub>2</sub> transportation under the EU ETS

In June 2010, the European Commission released an amendment to the original MRGs for the EU ETS released in 2007<sup>5</sup>. The amendment<sup>6</sup>, in addition to providing further guidance on the determination of emissions or amount of emissions transferred using continuous measurement systems (CEMS), also contains ‘Activity-specific guidelines<sup>7</sup>’ for the determination of emissions from the transport of CO<sub>2</sub> through pipelines to geological storage sites, permitted under the EU CCS Directive.

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<sup>2</sup> Directive 2009/31/EC

<sup>3</sup> Regulation (EC) No 1013/2006

<sup>4</sup> The sub-sections (2.1 and 2.2) to the new paragraph also provide provisions for permitting in accordance with the London Protocol, and measures to take when exporting to a non-contracting party.

<sup>5</sup> Decision 2007/589/EC

<sup>6</sup> Decision 2010/345/EU

<sup>7</sup> Annex XVII of Decision 2010/345/EU

In order to accurately report potential emissions from CO<sub>2</sub> transport pipelines, two approaches are permitted via the recent amendment to the EU ETS monitoring and reporting guidelines. Method A, is based on a mass-balance calculation by measuring the CO<sub>2</sub> entering and exiting the pipeline, added to the emissions from the transport networks own activities (i.e. fuel use from booster stations). Method B involves calculating the CO<sub>2</sub> emissions of the network through a summation of vented CO<sub>2</sub>, leakage events, installations (i.e. booster stations) and fugitive emissions<sup>8</sup>. The operator must demonstrate that the chosen method provides the most reliable results and the least uncertainty.

At present there are no European guidelines for the transportation of CO<sub>2</sub> via shipping. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories state that, *'The amounts of gas should be metered during loading and discharge using flow metering and losses reported as fugitive emissions of CO<sub>2</sub> resulting from transport by ship'*. This guidance seems to be similar to the mass-balance approach Method A, however further clarification is needed. Furthermore, there are only recommendatory guidelines for the calculation of CO<sub>2</sub> emissions from marine vessels<sup>9</sup>.

## 4. Legislation concerning the development of CO<sub>2</sub> transportation infrastructure

### 4.1. Environmental impact assessments for pipelines

Article 31 of the EU CCS Directive is associated with the amendment of the existing EU Environmental Impact Assessment (EIA) Directive<sup>10</sup>, which defines public and private projects that are subject to an EIA. The article stipulates that pipelines with a diameter greater than 800mm and over 40km in length for the transport of CO<sub>2</sub>, will be subject to a mandatory EIA, implemented through an addition to Annex I of the EIA Directive. The amendment also states that CO<sub>2</sub> transportation pipelines for the purpose of geological storage with physical dimensions that fall outside of the criteria outlined above, are subject to a screening procedure by the national authorities to determine whether the proposed pipeline project requires an EIA. Similar amendments have been outlined for capture installations and geological storage sites.

According to Article 7 of the EIA Directive, for projects that are likely to have a significant environmental impacts in another Member State, information must be provided to the potentially affected Member State and involvement in environmental decision-making procedures must be made possible. This legal provision is often referred to as the 'Espoo procedure'<sup>11</sup>, stemming from the UNECE Convention on Environmental Impact Assessment in a Transboundary Context, the principles of which were incorporated into the EIA Directive in 1997. Given this possibility, developers of cross-border pipelines must be diligent of transboundary EIA processes.

### 4.2. Third-party access and dispute settlement

Chapter 5 of the EU CCS Directive, entitled 'Third-party access', covers the issues of access to transport networks and storage locations. Article 21 of the Directive states that Member States should take necessary measures to ensure that potential users are able to access transport facilities, and that the granting of access will be done in a transparent and non-discriminatory manner determined by the Member State. The article also states that access to the network will follow the objectives of fair and open access.

Open access means that the owner of the transport pipeline or network would not be able to restrict the use of the transport network for its own purposes, and must provide access to third-parties. The Directive does acknowledge issues such as technical incompatibility, or a lack of capacity, however the owner must provide duly substantiated

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<sup>8</sup> Fugitive emissions should be calculated by the operator using emission factors for equipment where fugitive emissions can be expected, such as valves, seals and measurement devices.

<sup>9</sup> See Marine Environment Protection Committee (MEPC) Circ.471

<sup>10</sup> 85/337/EEC

<sup>11</sup> Named after the town in Finnish city where the convention was adopted in 1991.

reasons for refusing access. In addition, paragraph 4 of the article adds that operators refusing access due to lack of capacity or lack of connection must make any necessary enhancements as far as it is economic to do so or when the potential customer is willing to pay for them.

Article 22, stipulates that Member States must have an independent authority capable of settling disputes between operators and potential users of a network. However, the CCS Directive provides no guidance over setting tariffs for pipeline capacity, or whether operators would be able to reserve capacity for their own future requirements. A lack of clarity on tariff setting leads to uncertainty for developers, and may perhaps delay investment. With no overarching framework, Member States may enact different national legislative frameworks to govern investment and tariff setting, potentially leading to problems with cross-border networks.

## 5. Cost estimations of CO<sub>2</sub> transport infrastructure

Cost assessments of the various components of a CO<sub>2</sub> transmission system is provided here, namely compression, pipelines (on/offshore) and shipping. The cost estimations have been provided by the project members from industry and are entirely indicative and may vary considerably due to specific details of each application. The underlying assumptions between the cost analyses are also inconsistent, and therefore no comparisons can be made.

### 5.1. Compression costs

Cost estimates for a number of compressors were made by Siemens AG in 2010. The price estimates are based on a manufacturer standard assuming middle European installation, i.e cooling water resources and net frequencies. The cost estimates are “high-level price estimates” and should be considered with an accuracy of +/- 20%. It excludes dehydration units, noise hoods and sour condition due to H<sub>2</sub>S (NACE) but includes re-cooling to 32 °C by water cooling. The compressor capacities of 1.5 and 3 MtCO<sub>2</sub>/yr are arranged in single trains, whereas the 6 and 12 MtCO<sub>2</sub> are arranged as 2 and 4 trains respectively. The cost estimates are provided below, with single data points for 1.5, 3, 6, and 12 MtCO<sub>2</sub> joined by a smooth line for presentation purposes only. Data is presented for the optional discharge pressures of 150 and 200 bar.

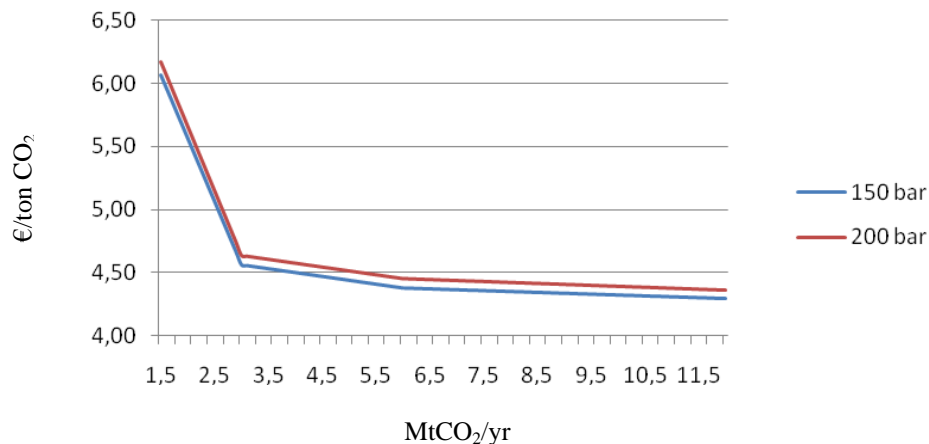


Figure 2: CO<sub>2</sub> Compression cost for different capacities, with two discharge pressures

### 5.2. Pipeline costs

The approximate costs of pipelines are given in Euros per inch of pipeline diameter per meter of pipeline length (€/"/m), provided by Dutch gas network operator Gasunie Engineering BV in 2010. The costs are based on maximum operating pressures of 150 bars for onshore transport and 200 bars for offshore transport. For more accurate calculations, detailed information on the trajectories is needed. The CAPEX of onshore pipelines is 50

€/m, with offshore pipelines costing 75 €/m. For an approximation, the following rule of thumb of the CAPEX build-up of a CO<sub>2</sub> pipeline with a diameter greater than 16" can be used:

Table 3: Typical CO<sub>2</sub> pipeline cost parameters

	Onshore	Offshore
<b>Total CAPEX</b>	50 €/m (€800,000/km)	75 €/m (€1,200,000/km)
<b>Material</b>	1 %/m	30-50 %
<b>Engineering</b>	10-30 %	5-15 %
<b>Construction</b>	50-60 %	40-60 %
<b>Total OPEX</b>	7000 €/km/yr	

### 5.3. Shipping costs

Shipping costs were calculated by Anthony Veder Group N.V. in 2010 for two different realistic ship sizes of 10,000 m<sup>3</sup> and 30,000m<sup>3</sup>. The CAPEX includes the cost of the vessel and computing equipment, with the economic lifetime of the vessel set at 25 years. The fixed operational expenditures consist of crewing, maintenance, management, insurance and dry docking (bi-annual dry docking is common market practice) costs. The following graphs display the annual CO<sub>2</sub> capacity of both ships at difference distances, and the related approximate costs per ton CO<sub>2</sub> transported. These costs are highly indicative since they are dependent on where the vessel is to sail.

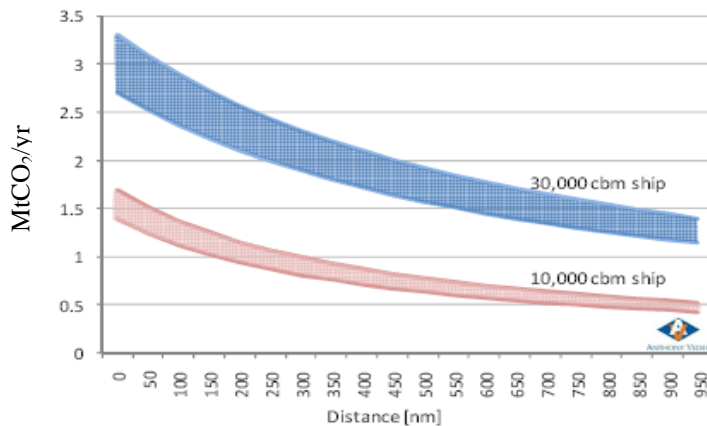


Figure 3: The capacity in Mt CO<sub>2</sub>/yr of two vessels

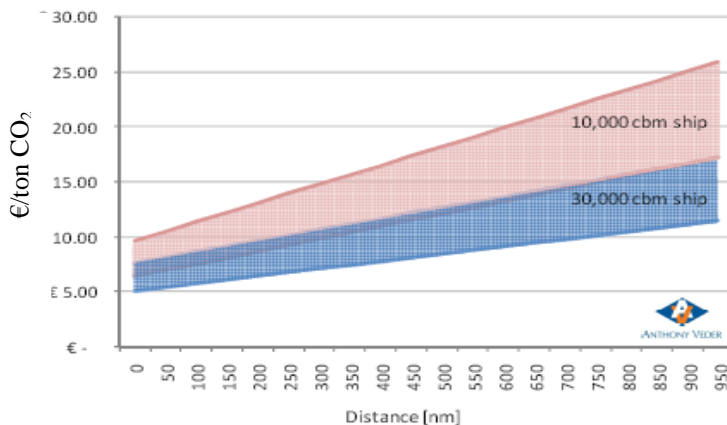


Figure 4: The related costs per ton CO<sub>2</sub> of the two vessels

## 6. Organizational aspects of CO<sub>2</sub> transport networks

### 6.1. Economies of scale and deliberate over-dimensioning

Perhaps the most prominent factor in the optimization of CO<sub>2</sub> transport networks is the exploitation of economies of scale in pipelines. A saving in CO<sub>2</sub> transport cost of 30% can be achieved, if two emitters combine their output into one 36 inch pipeline instead of two pipelines with diameters of 24 inches each [1]. This is due to the high fixed costs (approximately 80% of total costs) compared to the marginal costs of increasing the diameter of the pipe [7].

However, there are a number of economic barriers that may inhibit the deployment of an oversized CO<sub>2</sub> transport network. Firstly, private investors cannot be expected to build a transport infrastructure that is beyond current or guaranteed near-term capacity requirements. Without contracts that a ‘second comer’ would purchase capacity rights, it would be highly unlikely that a decision to oversize would pass commercial evaluation criteria. The uncertainty of external capacity demand, in terms of volume and timing would pose great financial risks to the project developer.

### 6.2 Ownership and tariff setting

Whether the tariff set for capacity procurement would be regulated or not, may lead to uncertainty that the developer could be able to recover the costs of the additional investment. For example, if the tariff is based on the incremental costs of capacity, this will provide a disincentive for ‘early adopters’, as incremental costs are far less than the average costs of the pipeline (based on cost per unit volume). For the initial project developer, a tariff based on just less than the new entrant costs (i.e. the cost of a new pipeline) represents the most economically efficient outcome [7]. However in a recent industrial strategy document released by the UK government [8], the document proposes a regulation based on a modification of an existing legislative piece<sup>12</sup> whereby if an operator and third-party cannot reach an agreement on pipeline access, the Secretary of State will make a decision if the modification can take place. The access will be based on the applicant meeting the incremental costs of modification, and compensating the owner against liabilities and losses out of tie-in or modification activity. This proposal seems to be at odds with the economic theory as described above.

There are methods for reducing the financial risks brought about by demand uncertainty. For example, long term contracts can be established between the project developer and secondary users that commit to capacity requirement at a given tariff. Similarly, the UK offshore oil and gas regimes oblige pipeline developers to ‘market test’ the demand for new capacity, thus encouraging the formation of investment coalitions that pool their pipeline capacity requirements. The US interstate pipeline regulations impose an obligation to hold ‘open seasons’, encouraging multilateral investment from the project outset. Joint implementation of a pipeline project utilising near full capacity, removes the incentives for a ‘late comer’, while still exploiting economies of scale.

### 6.3 Public sector involvement in CO<sub>2</sub> transport networks

Government intervention in the form of regulations and/or direct investment in CO<sub>2</sub> transport infrastructure has been widely commented on in recent literature [2] [7] [9]. From a broad perspective, unlike the existing utility and service transport networks, market-led investments into CO<sub>2</sub> infrastructure are currently unfeasible due to the low price of carbon, and the lack of demand from CO<sub>2</sub> utilising industries (horticulture, carbonated beverages). Furthermore, with the average lead time for the permitting and construction of a new coal power plant in Europe estimated at approximately 6 years [10], demand for a CO<sub>2</sub> transport network will develop over a large time scale. Assuming greater incentives for CCS deployment in the future, individual project developers will likely focus on investing in point-to-point pipelines at high capacity utilization, assuring short term economic efficiency. In some cases, this may not lead to an optimized transport network. An argument exists for government investment to overcome high

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<sup>12</sup> The Petroleum Act 1998

discount factors intrinsic to commercial pressures in most industries, spreading the burden of risk between private and public entities and promote long term economic efficiency.

#### *6.4 A market-led approach*

In a report produced for the UK government, the case for direct public investment has been challenged. It has been stated that the only way in which public investment will improve efficiency is if the government is best informed about the probability of future demand of CO<sub>2</sub> [7]. The only information the government may possess that private entities would be unaware of, is the future value of government policy support for CCS. This case of asymmetric information could be overcome by publishing all known policy commitments or by offering long-term financial commitments to back up its statements [7].

### **7. Conclusions**

There have been significant advances in the regulation of CO<sub>2</sub> transport and the development of CO<sub>2</sub> transport infrastructure. The removal of CO<sub>2</sub> transport for the purposes of geological storage, from the classification of waste from within the European regulatory waste framework will facilitate the transportation of CO<sub>2</sub>. The calculation of emissions stemming from CO<sub>2</sub> transportation via pipelines under the EU ETS have recently been outlined, however there is no guidance concerning how emissions will be calculated for CO<sub>2</sub> shipping. Regarding the organisational development of transport networks, there remain uncertainties regarding how individual member states will approach the issue of providing third-party access to pipelines, and how user tariffs will be regulated if no further EU wide guidance is released. If CO<sub>2</sub> pipeline developers are to take advantage of economies of scale and over-dimension pipelines, the intentions of governments regarding their level of involvement and regulation of tariffs for third-party users need to be consolidated.

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