CO_2 transport by ship: the way forward in Europe

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Abstract

Introduction
This paper presents the results of a study into the functional requirements and optimisation of the CO_2 shipping chain, with a focus on the offshore offloading system. The goal was to evaluate the feasibility of a generic approach to the development of ship-based CO_2 transport and storage system in the North Sea, using a range of typical North Sea reservoirs (saline formations or depleted hydrocarbon fields). The feasibility of such a generic approach would help develop the ship transport option that is widely regarded as an important option of developing offshore CO_2 storage (or enhanced recovery with CO_2). This will be especially true in the first phase of CCS, when capture locations are few and at large distance from eachother, and ship transport is the best option to collect the captured CO_2 and to deliver to one or two storage or enhanced recovery sites.

The results provide insight into the requirements for offshore offloading from a ship into an injection well, for a range of potential North Sea storage reservoirs. The results of the analysis are presented in terms of pumping and heating requirements (to bring the CO_2 from the conditions in the ship to conditions acceptable for the injection well) and the required investment cost and operational cost of shipping CO_2.

Setup of study
The study focused on the CO_2 transported in liquid form by ship, followed by injection into reservoir formations at several depths. In one scenario the CO_2 is injected directly from the ship into a well; pumps and heaters are installed on the ship. In a second scenario the CO_2 is pumped from a ship to a platform and from the platform into a well; most of the heating and pump capacity is installed on the platform. In a third scenario, the ship offloads into a temporary storage near the platform. The 'platform' approach allows higher injection pressures than injection directly from the ship, as no high-pressure flexible hose is involved.

A range of hypothetical storage reservoirs was used. Both saline formations and depleted hydrocarbon reservoirs were considered, at depths between 1 km and 4 km. A total of 16 combinations of reservoir type (varying reservoir quality and initial reservoir pressure) and depth were made to cover all potential future offshore storage systems. For each of the 16 reservoirs, the window of operation was established (in terms of injection pressure, temperature and flow rate), taking into account limitations arising from reservoir mechanical strength, thermal stress due to injection of relatively cold liquid, formation of hydrates and flow-related phenomena in the tubing.

Results

Reservoir properties, well completion and well depth determine the electrical and thermal power necessary to prepare the CO_2 for injection. Direct injection from a CO_2 carrier is feasible for a range of typical injection wells, with high rates (several megatonnes per annum) feasible in many cases (exceptions include shallow depleted reservoirs). Power requirements allow equipment for compressing and heating the CO_2 prior to injection to be installed on the ship; the required heating capacity can be provided through heating with sea water and surplus heat from the ship's engines.

For a ship capacity of 10,000 tonnes, offloading time is in the range of 24 – 36 hours, using a single injection well. With temporary, near-well storage, ship-offloading times are shorter, even for larger size ships, allowing for a more efficient use of the shipping fleet. This results in lower overall cost, relative to direct injection from the ship into the well.

The cost of ship-based transport in the North Sea is estimated to be in the range of 13 - 27 €/tCO_2, for a distance of 400 km, 17 – 30 €/tCO_2 for a distance of 800 km and increases to 20 – 33 €/tCO_2 for a distance of 1200 km. Figure 1 shows the results for a distance of 800 km. Unit cost is about 10 – 25 % higher in case of direct injection from the ship into the well, compared to injection from a platform (which can be a temporary platform).

A single design for the ship and near-well installations could be used to develop CO_2 injection into a variety of fields in the North Sea. This makes it possible to develop a uniform approach to storage in deep saline formations (which hold most of the storage capacity in the North Sea), oil fields (including the option to do enhanced oil recovery) and depleted gas fields. When a storage reservoir is filled to capacity, the storage related systems can be transferred to the next location, to be re-used. This will decease cost, enable cooperation among different nations and, hence, accelerate CCS development in Europe.

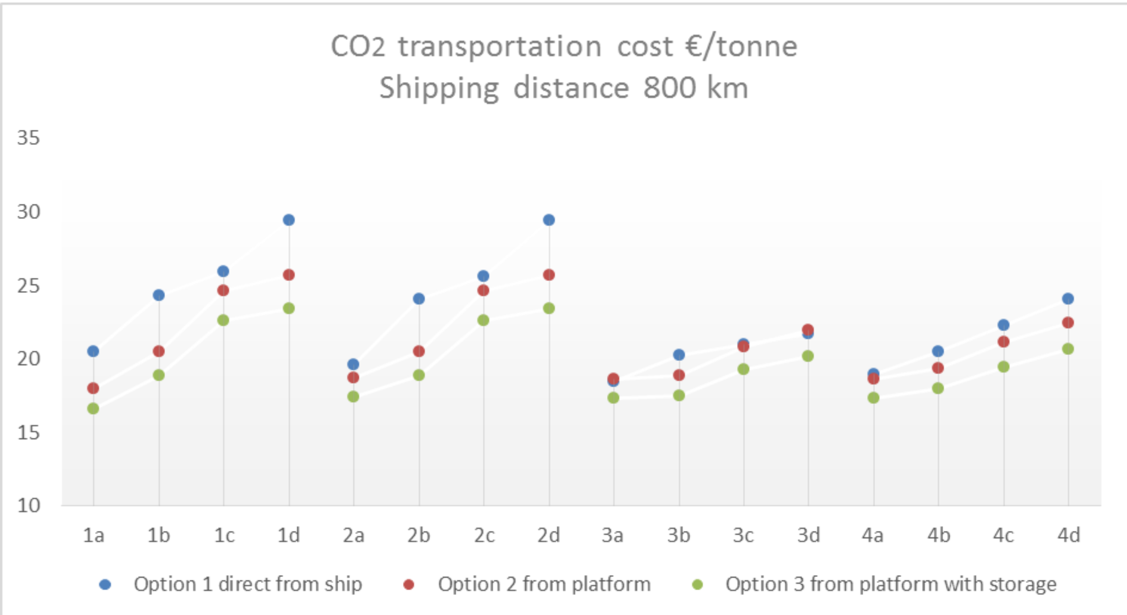

Figure 1 – Estimated cost of ship transport for three options: 1) Option 1 is direct injection from the ship into the reservoir; 2) option 2 is offloading of the ship to and subsequent injection from a platform; 3) option 3 is offloading of the ship to a temporary storage at the platform. Lower costs are predicted for Option 3. Cases a, b, c and d represent storage reservoirs at depths of 1 km, 2 km, 3 km and 4 km, respectively. Storage reservoirs are either saline formations (1a through 2d) or depleted gas fields (cases 3a through 4d).