Meeting the technical challenges of large-scale CO$_2$ shipping and terminals

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Presentation documents:
Page 2: Karin Kuipers, Anthony Veder Group
Page 13: Michael Joos, Element Energy
CO$_2$ Shipping and Terminals: technical challenges

Karin Kuipers – Process Engineer
INTEGRATED SHIPOWNER

PEOPLE

COMMERCIAL OPERATION

TECHNICAL OPERATION
SEGMENTS

Petrochemical / LPG

LNG

22
4,000 – 10,000

12
5,800 – 30,000
CO2 SHIPPING
WHERE DO WE START

Product Properties

Experience in Liquid Gas Shipping
WHERE DO WE WANT TO GO

Source: Sintef 2020
What does this do to the design?

<table>
<thead>
<tr>
<th>Main Particulars</th>
<th>Cargo Containment System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length overall</strong></td>
<td><strong>Cargo capacity</strong></td>
</tr>
<tr>
<td>Abt. 165m</td>
<td>Abt. 15,000m3</td>
</tr>
<tr>
<td><strong>Beam</strong></td>
<td><strong>Cargo density</strong></td>
</tr>
<tr>
<td>Abt. 22.5m</td>
<td>Max. 1.11t/m3</td>
</tr>
<tr>
<td><strong>Design draught</strong></td>
<td><strong>Design temperature</strong></td>
</tr>
<tr>
<td>Abt. 10m</td>
<td>-30 deg. C</td>
</tr>
<tr>
<td><strong>Design speed</strong></td>
<td><strong>Design pressure</strong></td>
</tr>
<tr>
<td>Abt. 15kts</td>
<td>18 bar(g)</td>
</tr>
<tr>
<td><strong>Propulsion</strong></td>
<td><strong>Tank type</strong></td>
</tr>
<tr>
<td>Direct drive CPP</td>
<td>Type C</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td></td>
</tr>
<tr>
<td>7,000nm</td>
<td></td>
</tr>
</tbody>
</table>
WHAT ARE OUR CHALLENGES

CLIENTS

GAS HANDLING SYSTEM

LNG FUEL TANKS

CO2 CARGO TANKS
Techno-economic challenges of CO₂ Shipping

Riviera webinar: Meeting the technical challenges of large-scale CO2 shipping and terminals

16th August 2021

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Element Energy, a consultancy focused on the low carbon energy sector

Element Energy covers all major low carbon energy sectors:

- CCUS & industrial decarbonisation
- Energy Networks
- Smart Energy Systems
- Hydrogen
- Low Carbon Transport
- Built Environment

Selected clients:

Public sector:
- Department for Business, Energy & Industrial Strategy
- Committee on Climate Change
- Transport for London
- Birmingham City Council
- Scottish Cities Alliance
- Sustainable Energy Authority of Ireland
- Greater London Authority

NGOs:
- IEA
- European Climate Foundation
- UNDP
- WORLD BANK GROUP

Public-Private Partnerships:
- LowCVP (low carbon vehicle partnership)
- FCH

Private Sector:
- Shell
- OGC
- Equinor
- UK Power Networks
- Toyota
- Nissan
- EDF Energy
- British Gas
- Rolls-Royce
- ESB
- Daimler
- Zipcar

Element Energy
an ERM Group company
Large scale deployment of Carbon Capture, Utilisation, and Storage (CCUS) is expected to be necessary to reach net zero

10 Mt CO2 pa CCUS in the UK by 2030

65 Mt CO2 pa GGR in Germany by 2045

58 Mt CO2 pa GGR in the UK by 2050

A 1 Mt CO2 per annum project will require about 1 20kt ship

CO2 shipping is more economic than pipeline transport at low volumes and long distances and involves less risk

![Graph showing the breakeven distance between shipping and pipeline transport](image)

- Shipping more economic than pipeline transport at **low volumes and long distances** (left\(^1\))
- Shipping requires lower CAPEX investment than pipeline transport (right\(^2\)) and thus involves **less risk**
- **Many emitters** are **too far from** potential **storage** sites for pipelines to be viable
- Thus, significant demand for CO2 shipping likely in early as well as more mature phases of CCUS

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1) For a flow rate of 1 Mtpa
2) For a flow rate of 1 Mtpa, a distance of 1,000 km
Key challenges of CO2 shipping – an overview

1. **Cross chain risks**
   - Managing risks of different parts of the chain in development and operational phase, e.g. storage availability, variability of emissions, technology compatibility

2. **Transport condition**
   - Determining optimal transport condition and developing standards for CO2 shipping

3. **Port infrastructure**
   - Managing constraints of port infrastructure such as maximum ship draft and length as well as jetty availability

4. **Business models**
   - Developing sustainable business models which incentivise efficiency while keeping risks manageable for each party involved

5. **Maximising design and operational efficiency**
   - Exploiting economies of scale
   - Determining routes to be served (emitters and storage sites)
   - Determining cost minimal routing of ships
Managing cross chain risks requires integrated development and operation of the CO2 shipping chain

- **Key cross chain risks of CO2 shipping**
  - Development phase
    - Availability of storage
    - CO₂ capture commitments of emitters
  - Operational phase
    - Temporary unavailability of storage
    - Variability of emissions (cp. right graph)
    - Jetty availability
    - Technology compatibility

- **Key measures to managing these risks**
  - Integrated development and operation of the shipping chain
  - Robust contracts between emitters, shipping companies, and storage operators
  - Standards for CO₂ shipping
  - Redundancy of transport and storage network

**Impact of lower utilisation on unit shipping cost**

- 100% utilisation
- 50% utilisation

Unit cost [£/tCO₂]
The CO2 transport condition affects the entire shipping chain

For **economic transport** CO2 needs to be **liquefied**

- 3 conditions mainly discussed:
  - **low** pressure (and temperature), around 7 barg and -50 deg C
  - **medium** pressure (and temperature), around 17 barg and -25 deg C
  - **high** pressure (and temperature), around 45 bar and 10 deg C

- **Lower ship cost** at **low pressure** due to higher density of CO2, etc.
- **Lower liquefaction** cost, good scalability of ships and no dry ice formation at **high pressure**
- Medium pressure most proven concept currently, but **ongoing debates** on optimal transport condition

### Shipping cost breakdown

- **Liquefaction**: Low pressure 36%, Medium pressure 42%
- **Temp. storag (loading)**: Low pressure 3%, Medium pressure 5%
- **Loading**: Low pressure 3%, Medium pressure 5%
- **Ship**: Low pressure 56%, Medium pressure 44%
- **Unloading**: Low pressure 3%, Medium pressure 5%
- **Temp. storage**: Low pressure 3%, Medium pressure 5%
- **Conditioning**: Low pressure 3%, Medium pressure 5%
Governments are currently developing business model designs for CO2 transport and storage in collaboration with industry

Due to complexity of CO2 shipping chain and low liquidity of CO2 market (CO2 is waste, not fuel) business model in which whole chain owned and operated by one entity seems preferable

- UK government envisions
  - a regulated asset base (RAB) model for CO2 transport and storage
  - a Transport and Storage Company (T&S Co) responsible for development and operation of the transport and storage network

- So far sparse information specific to shipping
- Shipping differs from pipeline transport in allowing for competition
- A RAB model might thus not be appropriate for shipping in the long term
- Extensive engagement with developers and wider stakeholders throughout 2021 to develop business model designs further
- The Norwegian government is expected to cover 80% of the cost of the first phase of the Northern Lights project through a mix of subsidies for upfront investment as well as ongoing operational costs
CO2 carrier and liquefaction dominate the overall shipping cost

- Cost of the **CO2 carrier and liquefaction dominate** CO2 shipping cost constituting around 80% of the total cost, liquefaction makes up more than 30% of the cost
- **Temporary storage, conditioning and loading/unloading** are **minor** cost components
- Hence, to reduce the cost of CO₂ transport, it is crucial to exploit cost saving **opportunities in the shipping chain**, such as economies of scale through larger carriers, minimising manoeuvring and waiting time per tCO₂ transported, maximising ship utilisation throughout the year

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1) Illustrative example for low pressure transport, source: Element Energy for BEIS, 2018, *Shipping CO₂ – UK Cost Estimation Study*
The North Sea could become a carbon storage centre for Europe

- Public opposition against onshore carbon storage (“not in my back yard” - NIMBY)
- **Significant storage potential in the North Sea** due to depleted oil and gas fields
- Significant **emission sources** in Northern Europe in close **proximity of the North Sea**
- North Sea CO2 storage projects under development in Norway, Netherlands, and Scotland
Examples of potential shipping destinations: storage locations in Norway and the UK

Potential Shipping routes to Northern Lights project

Potential CO2 storage sites in the UK

1) https://northernlightscs.com/work-with-us/
2) BEIS, 30/07/2021
Shipping operators with multiple customers have options to maximise shipping efficiency

**Hub**
- CO₂ is first collected at hub from nearby ports using dedicated (small) ship in each case.
- Collected CO₂ is shipped from hub to final storage using another dedicated larger ship.

**Stop-over**
- One single ship is used to cover all exporting ports.
- Ship successively enters exporting ports before travelling to the importing port.

**Direct**
- Individual ships are used to collect CO₂ from each exporting port.
- Ships are sized based on the exporting ports CO₂ emissions.

Hub and stop-over operational models allow three emitters to use the same ship for the bulk of their route to the storage site.
- This allows to use a bigger ship which enables economies of scale (cost per tCO₂ reduced).
Recent publicly available reports by Element Energy on CO2 shipping

- Two recent reports by Element Energy on CO2 shipping publicly available
- BEIS, 2018: Shipping CO2 – UK Cost Estimation Study
- IEA GHG, 2020: The Status and Challenges of CO2 Shipping Infrastructures

Meeting the technical challenges of large-scale CO2 shipping and terminals

APPENDIX
Core skills

- Techno-economic system analysis
- Skills and supply chain
- Economic impact assessment
- Feasibility & Market assessment
- Policy development and action plans
- Strategic insights

Industrial decarbonisation and CCUS team

CO₂ capture from:
- Power plants
- Industrial plants
- Refining & upstream
- Hydrogen production
- Direct Air Capture
- BECCS

CCUS full chain:
- CO₂ transport via shipping and pipeline
- CO₂ storage offshore and onshore
- CO₂ utilisation routes

Industrial decarbonisation:
- Low carbon fuels – electrification, hydrogen, bioenergy
- CCS application
- Energy & resource efficiency
- Cluster analysis

Hydrogen supply chain:
- Hydrogen production (green and blue)
- Transport and storage
- End-use across all economy sectors
Larger ships enable economies of scale

- Currently CO2 shipped at medium pressure in food & beverage sector at small scale
- Low pressure ships have not been built yet; technical challenges due to proximity to triple point of CO2
- High pressure ships have not been built either
- Norwegian CCUS project will build 2 medium pressure ships, significantly larger than CO2 ships currently in use\(^1\)
- Using larger ships reduces CO2 shipping cost as long as it reduces the nr of ships required (above)
- For future multi Mtpa projects, larger ships (20,000t CO2) than those in Norwegian project will be required

Dedicated CO2 ships will be required – potential for re use of infrastructure limited

- **Conversion from LPG to CO2 unlikely** since cost and time intensive and leading to sub optimal ship design
- **CO2 density significantly higher** than that of LPG, ships cannot be optimised for the transport of both
- **Dedicated ships** and infrastructure likely
- Standardization may be needed to enable flexibility across multiple projects

*Ship concepts of Northern Lights project and further recent Norwegian CO2 shipping project¹*
Ships likely to be designed to comply with constraints of existing ports

- Suitability of ports for CO2 shipping needs to be assessed in detail
- Key constraints of existing ports include:
  - maximum ship draft and length,
  - electricity grid spare capacity (liquefaction),
  - space availability (storage),
  - berth availability
- Adjustments to existing port infrastructure (e.g. increasing water depth) difficult, in particular due to environmental regulation
- Instead ships likely to be designed for particular route to comply with given constraints of port infrastructure
- Ports may choose to invest in and own part of onshore CO2 shipping infrastructure (e.g. temporary storage)
- Using ships across different routes and ports once a liquid market for CO2 shipping emerges, will require standards for CO2 shipping

Peterhead port in Scotland (CO2 receiving port in Acorn project)

Concept of CO2 receiving terminal in western Norway in Northern Lights project

The CO2 shipping chain consists of several steps requiring onshore and offshore infrastructure.

**Steps of the CO2 shipping chain (for onshore unloading)**

1. Capture & compression
2. Onshore transport
3. Liquefaction
4. Temporary storage
5. Shipping
6. Temporary storage
7. Offshore transport
8. Conditioning
9. Temporary storage
10. Storage
Onshore unloading most likely for early projects but offshore unloading is also being explored as an option.
Thank you.

Element Energy is a leading low carbon energy consultancy working in a range of sectors including industrial decarbonisation, carbon capture utilisation and storage (CCUS), hydrogen, low carbon transport, low carbon heat, renewable power generation, energy networks, and energy storage. Element Energy works with a broad range of private and public sector clients to address challenges across the low carbon energy sector.

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