CO_2 shipping for storage: CO2LIQUID project

Dr. Kumar Patchigolla

k.patchigolla@cranfield.ac.uk

www.cranfield.ac.uk

Outline of presentation

- Spotlight on energy in UK/EU

- Why the renewed interest?
  - Recent studies
  - Work in progress

- Recent project
  - RCUK—CO2LIQUID

Spotlight on Energy in UK/EU

COP21: A very high-level, but absolutely crucial, discusses 'six thematic areas with high mitigation potential, opportunities for action and various co-benefits, namely

- renewable energy,
- energy efficiency,
- the urban environment (including transport),
- carbon capture, use and storage,
- methane and other non-CO_2 GHGs and

Dept of Energy & Climate Change - HM Government Statement Re Carbon Capture, Storage
Released 14:57 25-Nov-2015

RNS Number : 9664G
Dept of Energy & Climate Change
25 November 2015

£1 billion ring-fenced capital budget for the CCS Competition is no longer available

HM Government Statement to Markets Regarding Carbon Capture and Storage Competition

25 November 2015

Today, following the Chancellor's Autumn Statement, HM Government confirms that the £1 billion ring-fenced capital budget for the Carbon Capture and Storage (CCS) Competition is no longer available.

This decision means that the CCS Competition cannot proceed on its current basis. We will engage closely with the bidders on the implications of this decision for them.

Reviews on Shipping

Cranfield Energy and Power

CHIYODA CORPORATION

SUPPORTED BY GLOBAL CCS INSTITUTE

Preliminary Feasibility Study on CO_2 Carrier for Ship-based CCS

October 2011

ieaghg

2c energy

Scottish Enterprise

SCCS

nexen

The Scottish Government

Ship transport of CO_2 for Enhanced Oil Recovery – Literature Survey

January 2015

Dr Peter Brownsort, SCCS

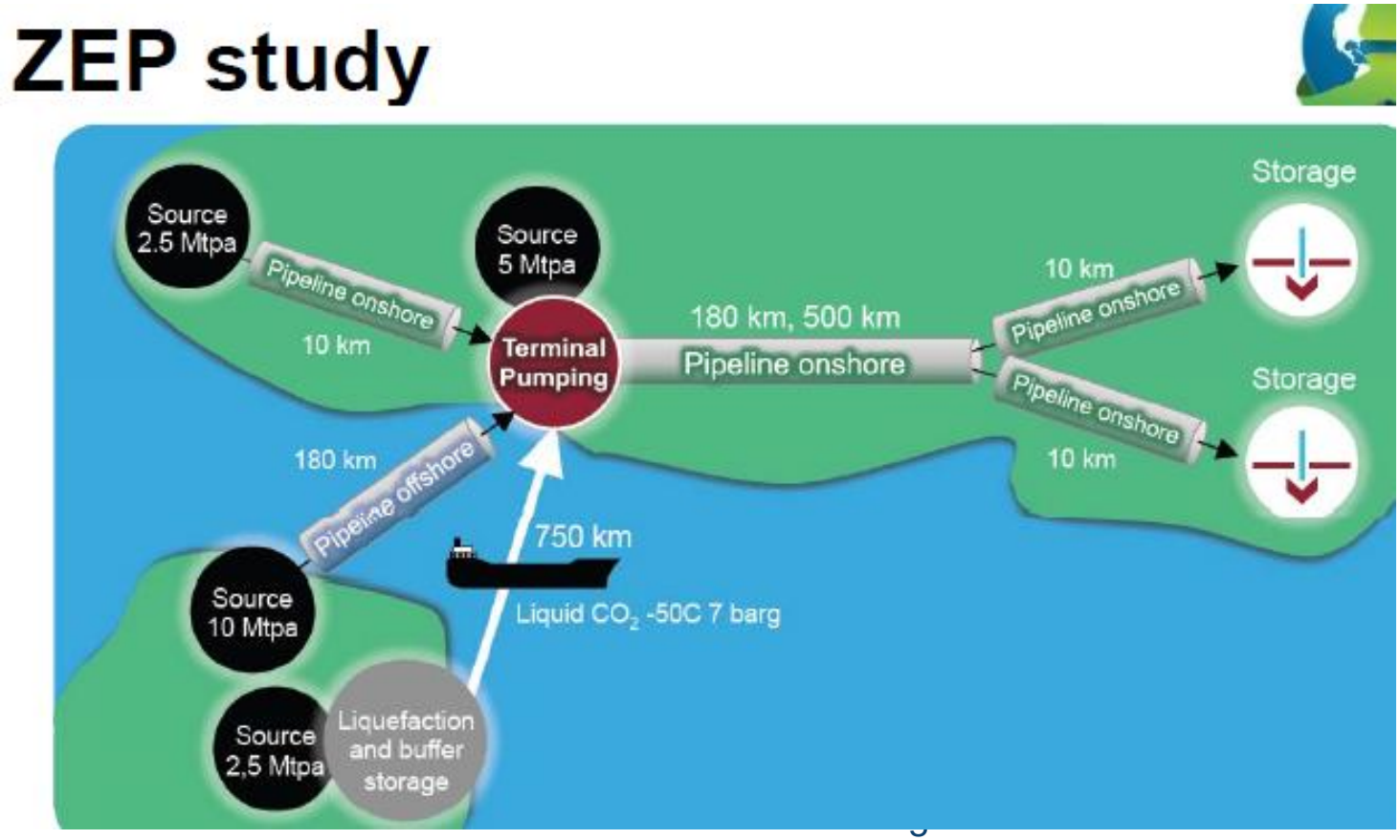
CO_2 Transport via Pipeline and Ship

Stanley Santos

IEA Greenhouse Gas R&D Programme

Cheltenham, UK

Reviews on Shipping



More studies

EERA

EUROPEAN ENERGY RESEARCH ALLIANCE

CO_2 Capture and Storage (CCS)

Sub Programme on CO_2 transport

Version: 1

Last modification date: 2013-05-31

Contact person: Amy Brunsvold, amy.brunsvold@sintef.no

Additional drafting authors:

Hannah Chalmers, Júlio Carnerio, Guiseppe Demofonti, Mona J. Mølnvik, Carlo Maria Spinelli

DRAFT

Research on investigating shipping logistics, loading and unloading scenarios

Table A2: List of projects related to Shipping of CO_2 (incomplete)

Project	Type	Coordinator	Years Active	Shipping		
				Liquefaction	Loading / unloading	Ship concept and logistics
ECCO	EU FP7	SINTEF ER	2008-2011			X
COCATE	EU FP7	IFP, France			X	X

Recent studies

ANTHONY VEDER

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- SEGMENTS
  - SMALL SIZE GAS SHIPPING
  - MID SIZE GAS SHIPPING
  - LNG SHIPPING
  - CO2 SHIPPING
- INNOVATIONS

CO_2 SHIPPING

Similar to LPG, carbon dioxide (CO_2) is liquefied to be transported by ship. The liquefied phase is reached by pressurizing and cooling. Anthony Veder has gained extensive experience with the transport of CO_2 with its one of a kind dedicated CO_2 carrier the "Coral Carbonic". With the latest developments in Carbon Capture & Storage (CCS) and offshore Enhanced Oil/Gas Recovery (EOR/EGR) the need and opportunity to transport CO_2 on a larger scale has come forward.

Extensive experience running CO_2 vessels:
Larvik shipping
Brevik Engineering

More studies

Norway Examines Feasibility of CO2 Shipping

Gijon Knutsen

By **MarEx** 2016-02-29 15:09:24

Norwegian state operator Gassco has commissioned Knutsen OAS Shipping and Larvik Shipping to study transport of CO2 by ship in connection with the Norwegian government's full-scale project for managing this greenhouse gas.

Why the renewed interest?

- OPEX differential between onshore and offshore EOR
  - Will allow shipping transport for the greater distance
- To enable other industries to be part of CCS
  - Depending on various factors-capacity, distance, operating parameters
- Shipping transport might be attractive for sites without ready pipeline access or difficult to build the infrastructure
  - ex: Korea

Key technology gaps

Transportation has not received the same degree of attention as other parts of the CCS chain.

- How to achieve the operational conditions appropriate for transportation by ship in an energy efficient and controlled manner?

- What impact on the operational methods, will it be as a function of types of impurities and its concentrations?

- Would these impurities permit the long-term and stable transportation of CO_2 under shipping conditions? Ex. Transportation period?

CO2LIQUID: Project details

- Title: CO2 shipping-compression, liquefaction and dehydration
- Acronym: CO2LIQUID
- Partners: 3 in total
- Duration: 2 years (2016-2018)
- Budget: £101,215

CO2LIQUID

The aim is to conduct underpinning research to aid the development of low pressure, cost effective CO_2 shipping transportation in an energy efficient and controlled manner. It addresses the effects of the relevant contaminants in loading and unloading scenarios, with experimental validation supported by thermodynamic calculations and flowsheet models

The specific measureable objectives:

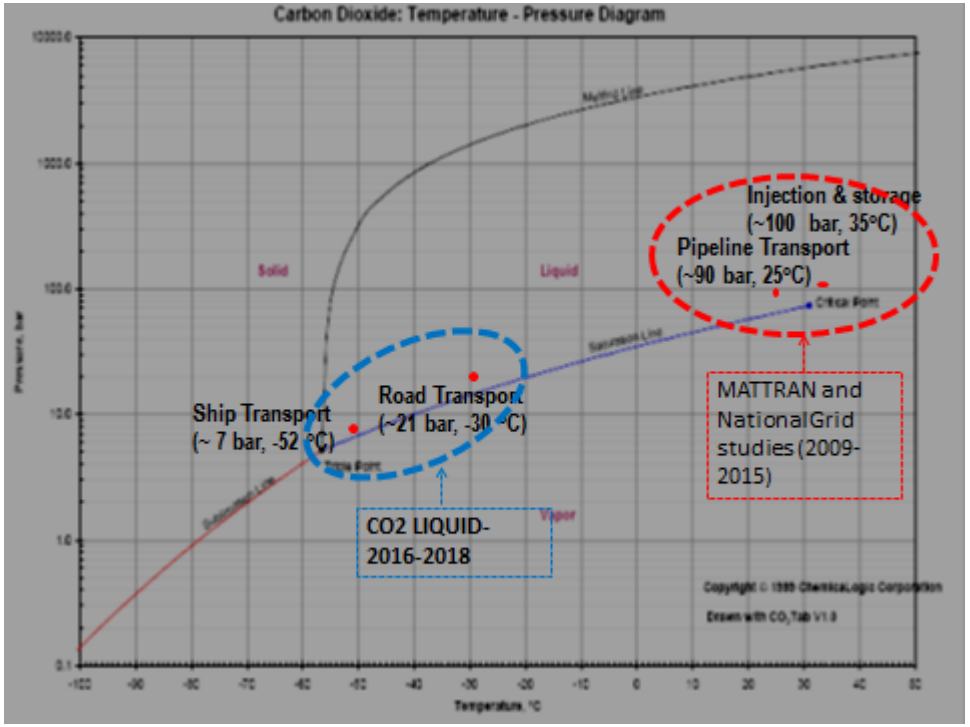
- To investigate the impact of these new conditions on liquefaction performance and to establish a first assessment of safe operation limits by measuring all process parameters in real time.
- To develop guidelines for transporting CO_2 with trace contaminants for shipping and to further the understanding of the impact of these contaminants in the captured CO_2 rich stream under liquid conditions (i.e. impact of SOx, NOx & O_2 etc.).
- To investigate and measure the CO_2 outflow in the immediate vicinity of leak from a shipping system and its impact on the local environment, and to deliver information on operation and maintenance strategies during loading and idle periods.

Know-how gained from activities at Cranfield will address these technology gaps

EPSRC – MATTRAN Project (2009-2014)

National Grid-Corrosion studies (2014-2015)

Tested for 225 bar



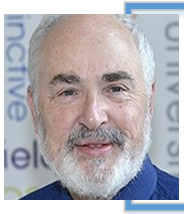
CO_2 transport flow rig as part of UKCCSRC PACT facilities

Research team

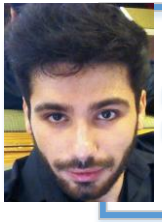
Prof John Oakey
Project Advisor

Dr Kumar Patchigolla
Head of Project

Dr Stefano Mori
Postdoctoral researcher



Prof Ben Anthony
Project Advisor



Hisham Al Baroudi
Research student

Adeola Awoyomi
Research Student

CO_2 shipping to decarbonize power and industrial sectors: development of more efficient, reliable operations and the impact of impurities

Hisham Al Baroudi

Research Problem

To understand the extent for which impurities (including water) need to be removed from CO_2 so as to mitigate handling issues in the shipping chain – such as keeping CO_2 in liquid phase on both ship and terminal during

Motivation

- To contribute to the development of the CO_2 shipping industry
- To respond to the need of de-carbonizing the power and other industrial sectors by providing invaluable information on how to generate a flexible, energy efficient and safe CO_2 shipping chain

Research objectives

- To investigate leakage behaviour and mechanisms leading to boil-off
- To assess propensity for operational issues – e.g. as hydrate and dry ice formations in the chain
- To investigate performance and shelf life of elastomer O-ring seals in cryogenic LCO_2 during standard and emergency operations
- To perform a validation of experimental results on a shipping model constructed on gPROMS

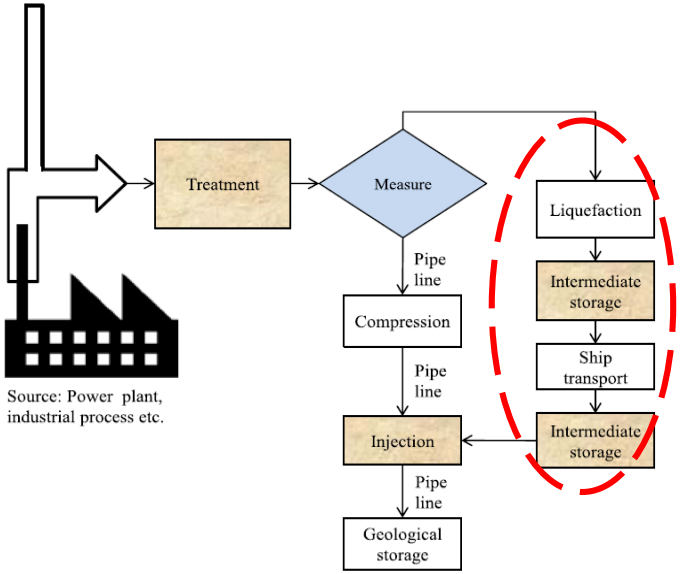
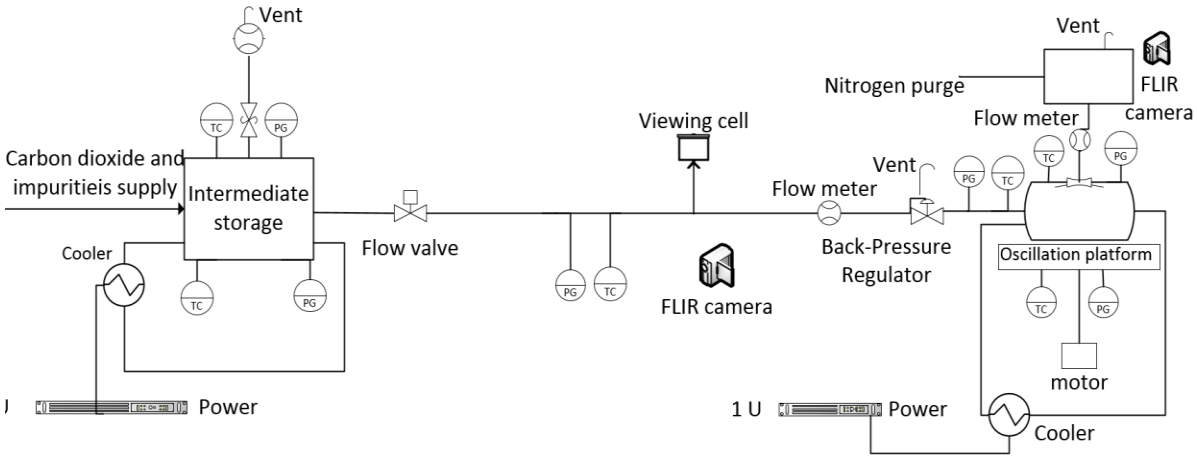


Figure – Transport schemes and options
(Onyebuchi et al., 2017)

Methodology:

The current PACT facility at Cranfield will be further upgraded to operate at CO_2 shipment conditions

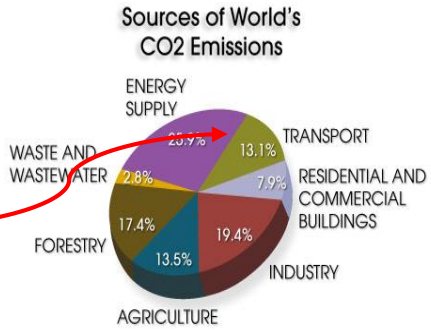


CO_2/SO_2 gas emission treatment system and losses from CO_2 shipping infrastructure.

Adeola Awoyomi

Problem statement:

- Shipping share of global CO_2 and SO_X emissions are 2.2 % and 13 % respectively (3rd IMO GHG study).
- Residual fuel accounts for 75 % o bunker consumption in 2013 (Bunker fuel market research for 2014-2020).

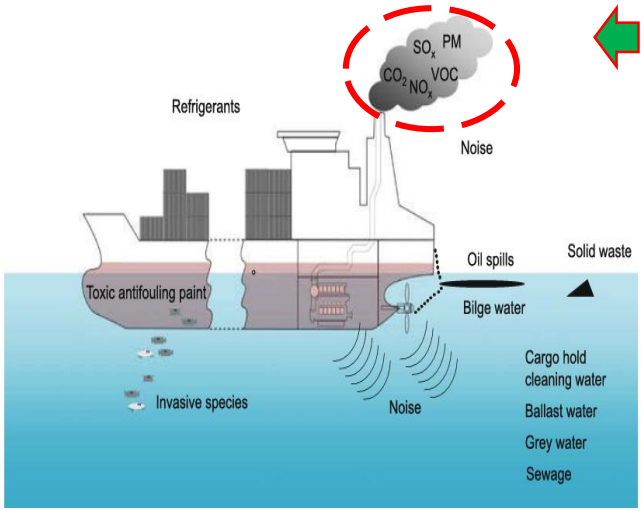


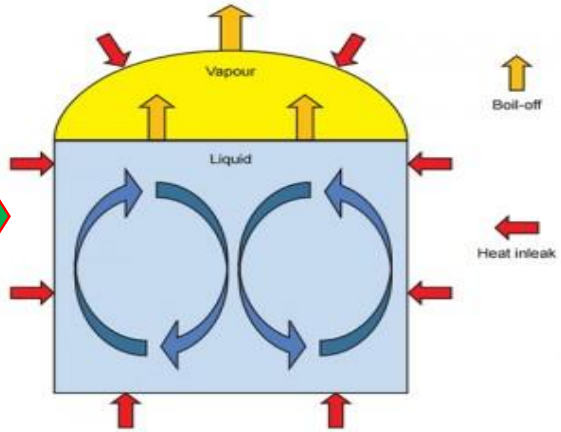
Motivation/Regulation:

The sulphur content of any fuel oil used on-board ships shall not exceed the following limits: 0.5% m/m on and after 1 January 2020 (**Regulation 14 in MARPOL 73/78 Annex VI**).

Research Questions:

- How a PPC plant can be retrofitted on-board of a CO_2 carrier?
- Economic feasibility of LNG as a marine fuel for CO_2 carriers for net-zero emissions.





Methodology:

- An alternative solvent unlike MEA is considered, **aqueous ammonia**, for the simultaneous removal of SO_2 and CO_2.
- Combined re-liquefaction of the boil-off gas and the CO_2 emissions by ammonia and cooling water.

Case study (-54 °C and 7.5 bar)

- Ship size - 20,000 m^3
- 10 % ullage
- 0.1 - 0.15 % of the cargo capacity as BOG/day
- Length of voyage - 21 day
- Captured liquid flowrate - 7438 kg/hr
- Space occupied by CO_2 emissions - 15.34 %
- Allowable ship capacity - 76.66 %

Dissemination so far..

Conference attended	Poster presented
UKCCSRC Winter School, University of Nottingham – February 2017	• *CO_2 shipping: development of more efficient and safer procedures as function of key impurities* by Hisham Al Baroudi
UKCCSRC Biannual Meeting, Imperial College London – April 2017	• *CO_2/SO_2 gas emission treatment system and losses from CO_2 shipping infrastructure* by Adeola Awoyomi • *CO2 shipping: development of more efficient, reliable operations and the impacts of impurities* by Hisham Al Baroudi
UKCCSRC Biannual Meeting, University of Sheffield– September 2017	• *Development of efficient and reliable large scale CO_2 shipment with related emissions management* by Hisham Al Baroudi and Adeola Awoyomi

Any Questions???

Kumar Patchigolla
Sr Lecturer in Low Carbon Energy Systems
School of Water, Energy and Environment
Email: k.patchigolla@cranfield.ac.uk