The First International Forum on

Transport of CO_2 for Carbon Capture and Storage

1-2 July, 2010

Hilton Newcastle Gateshead Hotel

Technical Programme

Thursday 1 July

8.30 Registration

9.00 Introduction

9.15 [1] Carbon capture and storage: a state-of-the-art overview, by **Prof. Jon Gibbins**, Professor of Power Plant Engineering and Carbon Capture, Institute for Materials and Processing, School of Engineering, The University of Edinburgh, Edinburgh, UK

9.45 [2] CO_2 Pipeline Transportation for CCS – An Operator's Perspective, by **Russell Cooper**, National Grid Gas Transmission, Warwick, UK

10.15 [3] Transport for captured CO_2, by **James Watt**, Technical Manager - Renewable Energy/CCS AMEC Power and Process, Europe, Darlington, UK

10.45 Coffee

11.15 [4] Proposed changes to the Pipeline Safety Regulations and the broader expectations of the regulator for CO_2 pipeline design and risk assessment, by **Yannis Savidis**, HM Specialist Inspector, Gas and Pipelines, HSE, Nottingham, UK, and **Mike Bilio**, HM Specialist Inspector, Offshore Safety Division, HSE, Bootle, UK

HSE has commissioned research work to compare carbon dioxide and natural gas pipelines in terms of hazard range and risk to determine the appropriateness of carbon dioxide being regulated as a dangerous fluid under the Pipeline Safety Regulations (PSR). HSE is also involved in research to examine the risk control and associated risk management of high pressure CO_2 transportation by pipeline. This presentation considers proposals for modification to PSR in light of current findings, explores the current regulatory regime and expectations for CO_2 pipeline design, operation and risk management.

11.45 [5] Economic modelling, by **Prof. Alex Kemp**, Director, Aberdeen Centre for Research in Energy Economics and Finance, University of Aberdeen Business School, Aberdeen, UK

12.15 [6] Techno-economics of a phased approach to developing a UK carbon dioxide pipeline network, by **Saulat Lone**, Sui Northern Gas Pipelines Ltd, Pakistan, **Dr Tim Cockerill**, ICEPT, Imperial College London, UK, and **Prof. Sandro Macchietto**, Department of Chemical Engineering, Imperial College London, UK

12.45 Lunch

13.45 [7] Fracture propagation – the what, the why and the how, by **Dr Andrew Cosham**, Atkins Boreas, Newcastle, UK

The past provides valuable lessons for the present. In the 1960s and 70s, the pipeline industry undertook extensive research work to solve the problem of fracture propagation in lean and rich gas pipelines, and the result was semi-empirical methods for estimating the toughness required to arrest a fracture, based on the drop-weight tear test and the Charpy V-notch impact test. The previous research informs the work that is required to solve the same problem in the

next generation of CO_2 pipelines that will be required for the successful implementation of carbon capture and storage. In this paper, the similarities and differences between lean and rich gas pipelines, and CO_2 pipelines are discussed, and an outline of the research work that is required to solve the problem is presented.

14.15 [8] A Dynamic Boundary Ductile Fracture Propagation Model for Pressurised Pipelines, by **Prof. Haroun Mahgerefteh**, Professor of Chemical Engineering, Department of Chemical Engineering, University College, London, UK

14.45 [9] Numerical simulation of unstable crack propagation and arrest in CO_2 pipelines, by **Prof. Shuji Aihara** and **Kei Misawa,** Department of Systems Innovation, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan

Unstable crack propagation and arrest behaviours in CO_2 pipelines are analysed by a numerical simulation model developed by the authors. Interaction between crack propagation and decompression of fluid in pipeline is important, especially in CO_2 pipelines due to complex thermodynamic behaviour of CO_2. The model takes account of the interaction and simulates the transient behaviours of crack initiation, propagation, and arrest. The paper shows how fluid impurities affect crack propagation and arrest behaviours, and discusses the crack arrest toughness values required for CO_2 pipelines.

15.15 Coffee

15.45 [10] Will fractures propagate in a leaking CO_2 pipeline?, by **Robert M Andrews,** BMT Fleet Technology, Loughborough, UK, **Dr Jane V Haswell**, Pipeline Integrity Engineers, Newcastle, UK, and **Russell Cooper**, National Grid Gas Transmission, Warwick, UK

A hypothetical concern has been raised that leaks in a CO_2 pipeline could escalate to a propagating fracture due to the potentially large temperature drop associated with the expansion of either gaseous or dense phase CO2 to ambient conditions. It is suggested this local cooling would lower the pipe wall temperature to an extent that a brittle fracture would initiate followed by a transition to a propagating fracture. Although such a mechanism could theoretically occur in natural gas pipelines, there is increased concern for CO_2 transport because of the different thermodynamic behaviour of the contents, particularly for dense phase transport.

This paper critically reviews the literature associated with this postulated failure mechanism and other studies on the cooling of cracks and holes by escaping fluid. It is concluded that pipelines constructed to modern standards are not at risk. Limited crack extension may occur when the leak is through a "tight" crack in a material of low toughness. However, the crack will arrest as it enters warmer material remote from the leak. Escalation to a propagating fracture can be controlled using methods which are widely used and understood in the pipeline industry.

16.15 [11] Transport of dense phase CO_2 – when is corrosion a threat? by **Arne Dugstad** and **Bjørn Morland**, IFE, Norway

Both field experience and laboratory data indicate that the corrosion rate in pure dense-phase CO_2 is near zero if no free water is present. It is expected, but not confirmed, that this also applies when other contaminants such as SOx, NOx, H_2S and O_2 are present in moderate amounts.

In a pipeline network with different types of CO_2 sources, the commingling of streams with various impurities can give a very complex mixture and side reactions such as oxidation and decomposition of impurities can be foreseen. An important issue is how the contaminants partition between the various phases during pressure reduction and when free water is present. The corrosion mechanisms under these conditions are not very well understood, and it becomes increasingly uncertain what will happen when the concentration of contaminants, including water, increases. The paper will address these issues and discuss recent results obtained in corrosion and partitioning experiments carried out in flow loops and autoclaves at IFE.

16.45 [12] CO2 pipeline design, material and operation technical challenges, by **Colin McKinnon**, J P Kenny, Staines, and **Antonio Caraballo**, WG Integrity Management, London

Successful carbon capture projects will require safe and economic transport of CO_2. This paper describes how the various CO_2 pipeline design, material and operational technical challenges can be overcome, including:

- *code and regulatory requirements - code coverage of CO_2*
- *what are the challenges for obtaining a licence to operate?*
- *design issues - design factors and population proximities*
- *process issues - phase issues and flow modelling*
- *welding and material issues such as ductile fracture at low temperature*
- *safety philosophy differences from gas pipelines*
- *risk assessment and dispersion modelling*
- *operating philosophy needed to manage swing within and outside the dense phase envelope*
- *pump technology - do we need compressors as backup during low pressure conditions?*
- *integrity monitoring requirements*
- *leak-detection methodologies*
- *existing CO_2 pipelines*

The paper identifies the technology gaps that need to be filled in order to deliver cross-country and subsea CO_2 pipelines in Europe or the Middle East, and draws on recent CO_2 pipeline design experience in the UK, Middle East, and USA.

17.15 End of day 1

18.30 Boat trip on River Tyne and dinner, sponsored by the Prof. Inst. of Pipeline Engineers and Pipelines International
The North East of England Branch of the Professional Institute of Pipeline Engineers (PIPE) will be delighted to welcome aboard forum delegates, regional members and their guests for a cruise along the river Tyne. This will be an unrivalled way to experience the famous riverside and as an added engineering treat it has been arranged for the Gateshead Millennium Bridge to be lifted in our honour. Complimentary drinks will include a wide range of region ales. Food will be provided by the highly regarded Kisii East African/Indian restaurant of Whitley Bay.

The mooring is on the North Bank a short walk from the Gateshead Hilton. Embarkation will start from 18:30. Sailing will be at 19:00. Return is at 21:00. Final disembarkations will be at 22:00.

PIPE is the international membership organization organization for those who work in the design, construction, operation, and maintenance of oil and gas pipelines. For information on the range of discounts and benefits available to PIPE members visit www.pipeinst.org.

Friday, 2 July

9.00 [13] How capture impacts the transportation phase of CO_2, by **Dr Tim Hill**, Technical Head, Environmental Sciences & Climate Change Sustainable Energy, E.ON Engineering, Nottingham, UK

Seen as a delivery system taking a refined product from an industrial process to a storage facility, the CO_2 pipeline must be designed to meet the joint requirements of low-risk of containment failure and flexibility in volume flow, whilst keeping costs to a minimum. With a wide range of capture technologies potentially available to create a concentrated CO_2 stream, the chemical composition of the CO_2 and its physical characteristics may vary considerably. This presentation will provide an overview of the range in CO_2 quality that could be expected from different CO_2 capture plant and other factors due to plant operation that might impact on the design requirements of CO_2 pipelines.

9.30 [14] Design and operation of CO2 pipelines – a DNV Recommended Practice, by **Kaare Helle**, **Kim Johnsen**, **Sigbjørn Røneid**, and **Frøydis Eldevik** , DNV, Hovik, Norway

A unified Recommended Practice (RP) for safe and reliable design, construction, testing, operation and maintenance of steel pipelines for transmission of CO_2 has been developed through the CO_2PIPETRANS Joint Industry Project (JIP). The RP applies to pipelines for large scale transmission of CO_2 and is intended as a supplement to existing recognized standards for both onshore and submarine pipelines.

The fundamental properties of CO_2 and CO_2 compositions relevant in the context of CCS are covered, and the RP identifies main concerns associated with various CO_2 sources and the typical impurities present. Particular challenges related to CO_2 streams as a medium are identified and guidance's provided to meet these challenges both considering compliance with existing pipeline standards and issues related to public acceptance and safety.

A set of knowledge gaps was identified in the development of the recommended practice. The second phase of CO_2PIPETRANS will perform at set of R&D activities to close these knowledge gaps and issue an updated version of the DNV Recommended Practice in 2011. This paper also delineates the planned and ongoing activities of CO_2PIPETRANS phase 2.

10.00 Coffee

10.30 [15] Greenhouse gas emissions from CCS upstream and downstream transport processes, by **Dr Tim Cockerill**, ICEPT, Imperial College, London, UK, **Dr Naser Odeh**, AEA Technology (*and formerly University of Reading*), Reading, UK and **Scott Laczay**, ICEPT, Imperial College, London, UK

Headline figures suggest CCS technology will capture 90% or more of the CO2 produced by a power plant. While this may be true at the stack, on a full lifecycle basis the GHG savings offered are more modest thanks to significant resource consumption in upstream and downstream processes. Our analysis suggests lifecycle GHG emissions can be reduced to approximately 170 gCO_2/kWh for an integrated gasification combined cycle (IGCC) plant with 90% capture efficiency. This still represents approximately an 80% saving compared to conventional coal plant, but is considerably higher than the better performing renewables such as wind that produces only 10-20 gCO2/kWh in good locations

This paper examines the origin and importance of upstream and downstream CCS GHG emissions, in particular identifying those associated with transport processes. Sensitivity studies investigate which major design and operational characteristics of a CCS system are likely to have an important impact on transport GHG emissions. Drawing on these results, high level strategies for emission minimisation from transport are also discussed.

The scope for combining biofuels with CCS in order to improve lifecycle performance is considered. In principle BioCCS could produce a system with overall negative atmospheric GHG emissions. However that potential is constrained by emissions arising from the production and transportation of biofuels.

11.00 [16] Material selection for supercritical CO2 transport, by **Shiladitya Paul**, **Richard Shepherd**, **Amir Bahrami**, and **Paul Woollin**, TWI, Abington, UK

Understanding materials' behaviour and assessing their integrity when in contact with supercritical CO_2 is crucial to the success and sustainable implementation of carbon capture and sequestration plans. Of critical importance for the successful and cost effective operation of existing and new-build, infrastructure components, is quantifying materials' integrity in representative high pressure and supercritical CO_2. This will enable confident materials selection, safe operation and accurate remaining life assessment to avoid the consequences of unexpected failure, as well as removal and replacement.

One of the most critical technical issues is quantifying degradation of different transport components, including pipes, pumps and valves, in CO_2 as a high pressure gas or as a supercritical fluid, particularly in the presence of impurities. Although there is considerable experience of testing materials in lower pressure CO_2, there are no standard test methods and few data for supercritical CO_2. This paper explores the state-of-the-art in this field and highlights the areas of technology gap. It further describes some of the ongoing work at TWI to address some of the critical issues which should be resolved to allow confident new build design or rerating of existing infrastructure.

11.30 [17] Practical aspects of CO_2 pipelines, by **Patricia Seevam**, BP, Sunbury on Thames, UK

12.00 [18] The use of OLGA software for simulation of CO_2 transport: results from a recent project, by **Monica Håvelsrud**, Principal Consultant Flow Services, SPT Group AS, Stavanger, Norway

12.30 [19] Challenges and opportunities for the development of CO_2 pipeline infrastructure by **Dr Harsh Pershad**, Senior Consultant, Element Energy Ltd, Cambridge, UK

13.00 Lunch

14.00 [20] Keynote: Regulatory and funding issues and the long-term issues of developing strategic CO2 transport networks/ hubs, by **Jeff Chapman**, Chief Executive, Carbon Capture & Storage Association, London, UK

14.30 Open session: discussion and formation of a transportation network

(15.45 Coffee)

17.00 End of Forum