REX2024
PRCI Research Exchange

Research Exchange REX 2024

CO_2 Pipelines – Deep Dive Session

ConocoPhillips
Feb. 28, 2024
Mohsen Achour

LEADING PIPELINE RESEARCH

Pipeline Research Council International

CO2 Pipelines Deep Dive Session … Agenda

Mohsen Achour
Corrosion & Asset Int…
ConocoPhillips

Mark Piazza
Senior Policy Advisor …
American Petroleum I…

D B

David Burns
Pipeline Engineering …
Enbridge

Robert Smith
Carbon Transport Pro…
US Department of Ene…

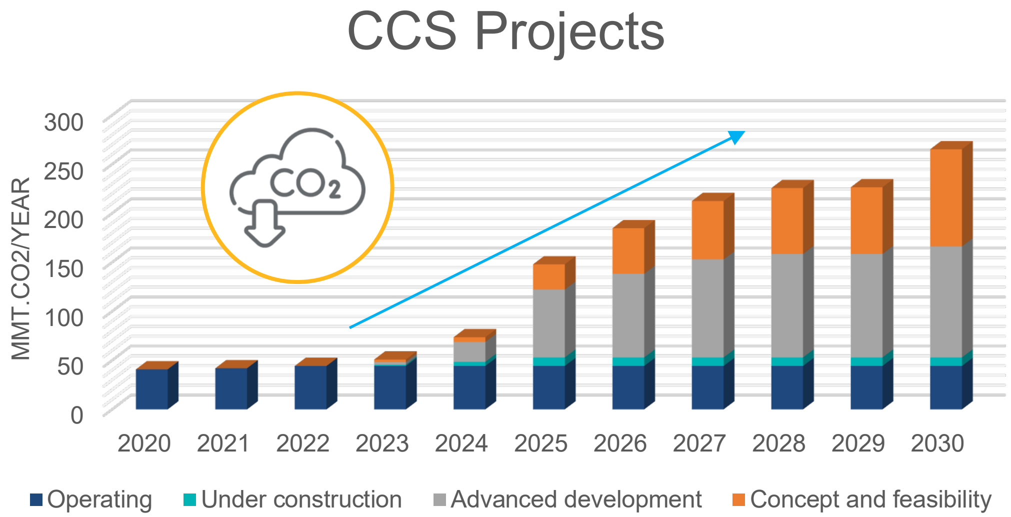
1:00 – 1:05	Introductions & Agenda – Mohsen Achour, session facilitator
1:05 – 1:20	Development of CO2 Pipeline Design Standards for Carbon Hubs – David Burn, Enbridge
1:20 – 1:35	DOE Carbon Transport RD&D – Robert Smith, US Department of Energy
1:35 – 1:50	API CO2 Policies and Programs – Mark Piazza, API
1:50 – 2:05	Inventory of CCS Research in Industry & Academia – Mohsen Achour, ConocoPhillips
2:05 – 2:30	Q&A

Agenda

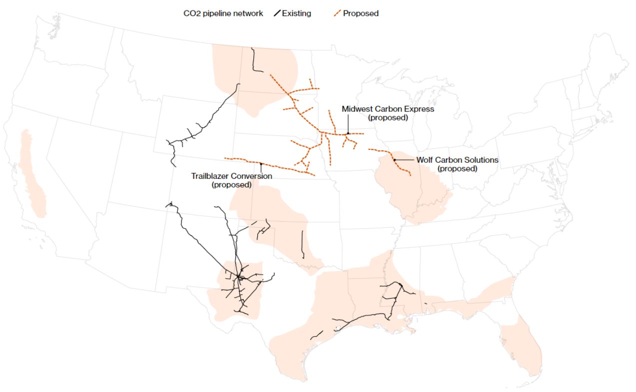
- Background of CCS
- Safety Facts on CO2
- Objective of Developing CO2
  - Challenges with developing Multi-emitter hubs
- Impact of Impurities
- Other Technical Considerations
  - Hydraulic Modelling
  - Material Selection
  - Control Philosophy
- Balancing Risks
- Conclusions

CCUS in North America

- As of 2023, there were approx. 5,200 mi of CO_2 pipelines in North America. To enable forecasted growth in Carbon Capture and Sequestration (CCS) more pipelines are required.
- Most CO_2 pipelines, in operation and proposed, transport the gas in 'dense phase', which is a liquid-like state.
- The first large-scale pipeline was the Canyon Reef Pipeline built in the 1970s and the industry has decades of experience operating CO_2 pipelines.
- Shell Quest in Alberta Canada (2015) and Sleipner in Norway (1995) (and several others) are full scale projects that sequester CO2.



[1]



[2]

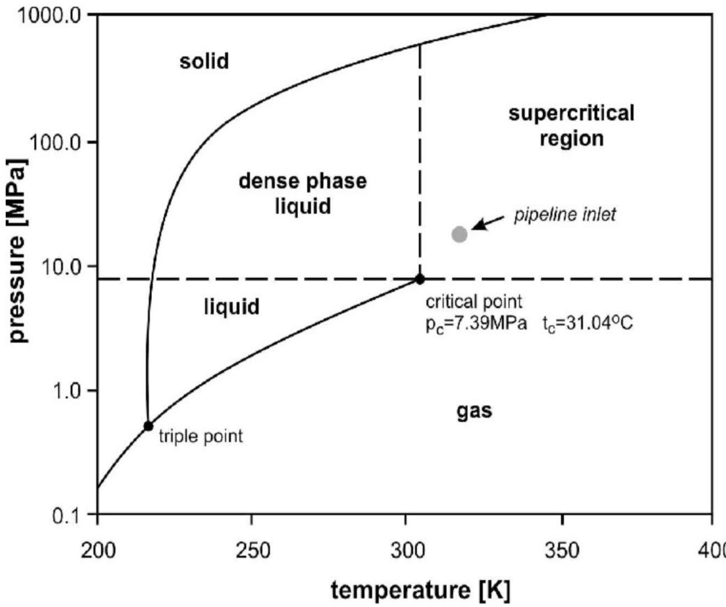
[1] EA, Capacity of large-scale CO2 capture projects, current and planned vs. the Net Zero Scenario, 2020-2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/capacity-of-large-scale-co2-capture-projects-current-and-planned-vs-the-net-zero-scenario-2020-2030, IEA. Licence: CC BY 4.0

[2] https://www.bloomberg.com/graphics/2023-green-revolution-needs-96000-miles-of-new-pipeline/

CO_2 Safety Facts

- Unlike natural gas, CO_2 is heavier than air. In the event of a release, CO_2 will dissipate slower than natural gas & accumulate in low-lying areas, displacing oxygen in the affected area.
- Symptoms of mild CO_2 exposure may include headache and drowsiness, and higher CO_2 levels will cause rapid breathing, confusion, increased cardiac output, elevated blood pressure, and increased arrhythmias may occur.
- CO_2 release from liquid form inside of a pipeline will transform into gas/solids due to temperature & pressure changes.
- CO_2 may accumulate static electricity, even when being filled into properly grounded containers, and reacts with water to form carbonic acid (H_2CO_3).
- Most CO_2 pipelines operate in dense phase

Rupture of a carbon dioxide pipeline near Satartia, MS in February 2020



CO2 Pipeline Standards Development

- Objective
  - Develop a suite of fit for purpose standards to support engineering and construction of new CO2 pipelines for Multi-Emitter Hubs at Enbridge
- Challenges
  - Anthropogenic emissions contain various impurities of concern
  - Research gaps leave a degree of certainty for setting design limits
  - Carbon Hubs need to operate flexibly to allow access for emitters of various differing operating conditions and process streams
- PRCI SOTA Prioritized Gaps

1. Impacts of Impurities
2. Fracture Control
3. Re-Purposing Pipelines
4. Safety and Dispersion Modeling

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CO2 Composition

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Pathway to Corrosion (CO2 + presence of SO_2, NO_2, H_2S, O_2)

- $H_2O + CO_2 \rightarrow H_2CO_3$ (Carbonic acid)
- $H_2O + SO_2 \rightarrow H_2SO_4$ (Sulfuric acid)
- $H_2O + NO_2 \rightarrow HNO_3$ (Nitric acid)

Acidic formation leads to corrosion of steel, oxygen accelerates corrosion process

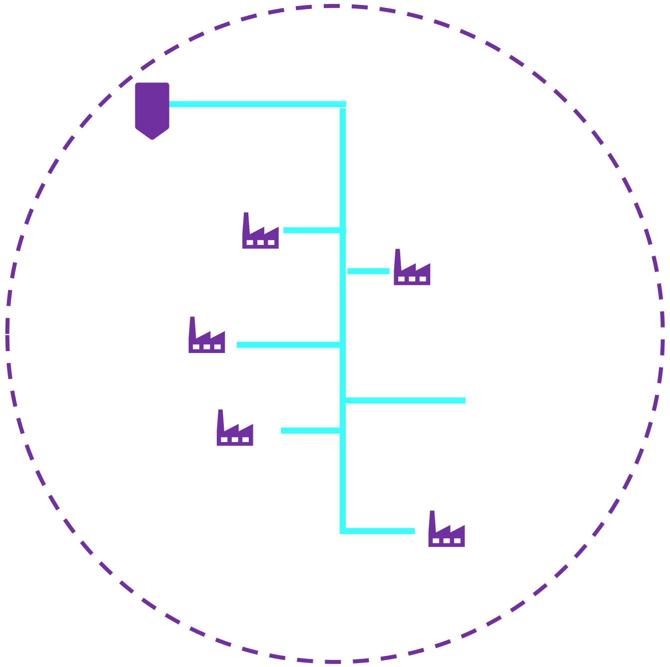
- $H_2O + H_2S \rightarrow HS^- + H^+$
- $H_2O + H_2S \rightarrow S^{2-} + H^+$

Weak acids, atomic hydrogen and Sulphur leads to Hydrogen and sulfide induced cracking

- Key Effects of Impurities
  - Reservoir- formation of acids and hydrates downhole can lead to plugging/corrosion
  - CO2 equations of state are sensitive to impurities which impacts system hydraulics
  - Integrity risks
    - H2S cracking and avoiding dealing with sour gas during operations
    - Corrosion fatigue
    - Hydrogen embrittlement
    - Water solubility impacts from NOx and SOx levels
    - Water drop out during operation leading to corrosion

Multi-Emitter Carbon Hub System Planning

- Systems thinking approach
  - CO_2 Composition Standard and how it can impact subsurface, pipeline and facilities
  - Metering and Control at custody transfers
  - Well injectivity and system hydraulics response
  - Lifecycle MMV Plans
    - Optimization- pipe diameter, intermediate pumps, MOP
- Issues to tackle
  - Avoid multi-phase flow (safety critical)
  - Perform Scenario analysis
    - Low flow
    - Variability in emitter operations
    - Transient analysis (e.g. impact on pipeline stress)
    - Blowdown (Joule-Thomson effect greater than natural gas)



Multi-emitter Carbon Hubs are complex and early engagement on these issues will benefit future Operations

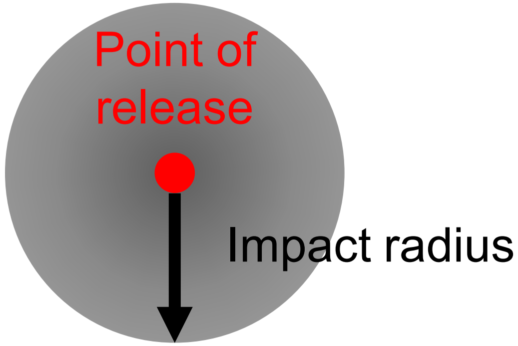
CO2 Safety: Dispersion Modeling

- **‘Potential impact radius’ for CO_2 is non-linear**
- **Simplified plume vs. complex computation model depending on:**
  - Pipeline operating characteristics (size, pressure)
  - Surrounding topography & land uses
  - Atmospheric conditions
  - Fluid components that could affect vapor dispersion

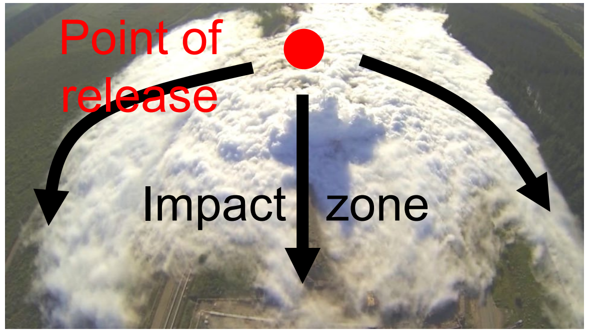
Risk assessment inputs affecting design/operations

(valve spacing, vent design, pipeline routing, pipe toughness, etc.)

Conventional Model



Dispersion Model



High Reliability Systems

- Pipelines reliability targets suggested to be 1x10-5 by Hassanien et al [1] – perhaps suitable for CO_2 pipeline but need to consider Human health impacts.

- CO_2 Projects perform Quantitative Risk Assessment- options to mitigate risk:
  - Enhanced Pipeline Monitoring and leak detection (e.g.Hifi Monitoring System)
  - Heavier wall thickness
  - Re-routes
  - Gas phase CO_2 (lower pressure)

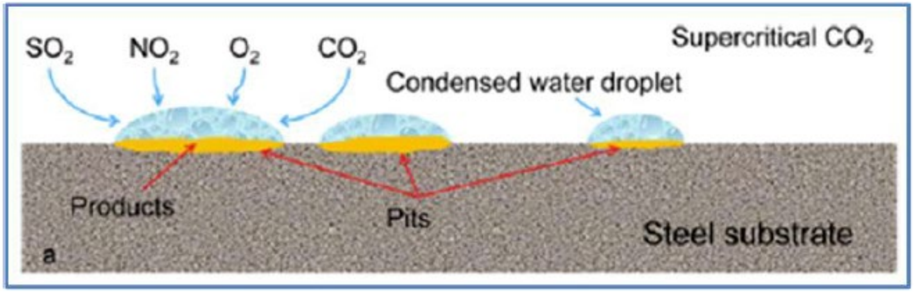
With gaps in knowledge how can we sure that the reliability targets can be met?

How to provide guidance to projects in development with the uncertainty in the research?

[1] **Hassanien et al,** Towards an Acceptable Pipeline Integrity Target Reliability, IPC 2016

Conservatism and Consensus Engineering

Literature Review and SOTA



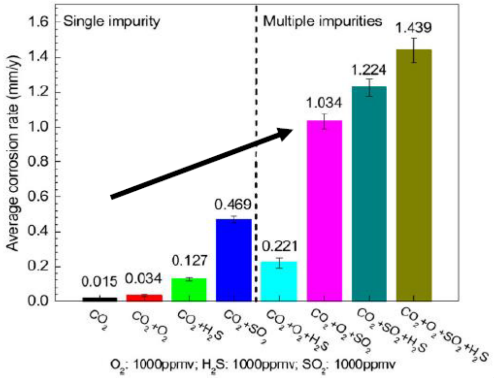
Internal and External subject matter expertise


New Energy Technology
Hydrogen
Pipeline
DRAFT
Onshore H2 Pipelines Design Standard
STANDARD
2023-09-27
ST-30-BBFC-B1BA.1.0.0

Ongoing Research

Table 4: Draft Composition Impurity Limit [3] [6] [7] [8]

Constituent	Limit	
Carbon Dioxide, CO_2	> 95 mol%	
Water, H_2O	< 50-100 ppmv	
Sulphur Oxides, SO_x	< 10 ppmv	
Nitrous Oxides, NO_x	< 2.5-10 ppmv	
Hydrogen Sulphide, H_2S	< 5-10 ppmv	
Carbon Monoxide, CO	< 1000 ppmv	
Hydrogen, H_2	< 1 mol%	Total < 4 mol%
Argon, Ar	< 1 mol%	
Nitrogen, N_2	< 4 mol%	
Oxygen, O_2	< 10-20 ppmv	
Methane, CH_4	< 2 mol%	
Other Hydrocarbons	< 1 mol%	
Total Sulphur	< 35 ppmw	
Glycol, $(CH_2OH)_2$	< 0.3 US gal/MMSCF	
Ethanol, C_2H_6O	< 20 ppmv	
Methanol, CH_3OH	< 500 ppmv	
Ammonia, NH_3	< 125 ppmv	
Amines, $-NH_2$	< 1 ppmv	
Particulates	< 1 ppmw	
Mercury, Hg	< 5 mg/sm³	



Summary

- System thinking provides better insight in the design decisions that impact the overall system reliability and costs.
- Conservative Consensus Engineering was the chosen methodology because:
  - Pipeline permitting and construction is complex and increasing opposition to CO_2 pipelines.
  - Reputational risks of pipeline failure would impede the ability to permit new projects
  - Outsized risk to the pipeline corrosion vs the cost to process the gas to meet pipeline specification
- Be flexible to change and anticipate direction of R&D

Rupture of a carbon dioxide pipeline near Satartia, MS in February 2020

U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

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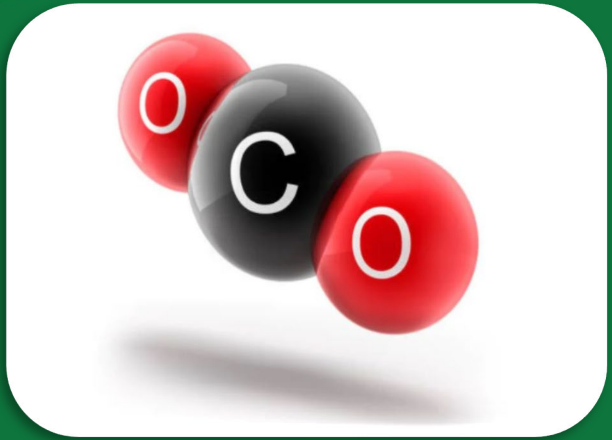
DOE Carbon Transport RD&D: 2024 Update

Robert Smith
Carbon Transport and Storage (CTS) Program
Office of Fossil Energy and Carbon Management

February 27, 2024





"The following PowerPoint was created for the PRCI 2024 Research Exchange Meeting.

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Lab Work Addressing Feb 2023 DOE Applied R&D Workshop

Thermodynamic study of the effect of impurities on phase behavior of dense phase CO_2

- Investigate effect of impurities (e.g., CO, O_2, H_2, NOx, SOx) on the phase boundaries of CO_2.
- Review impact of impurities on water solubility limits (water dropout) in dense and vapor phase CO_2.
- Understand speciation pathways for acid formation and solubility due to interaction of various impurities with water.
- Develop thermodynamic models to predict fluid (CO_2 + impurities) behavior in pipelines.

Evaluation of the risk of corrosion with presence of aqueous/acid phase (continuous or droplets) in CO_2 with impurities

- Review literature for corrosion, stress corrosion cracking (SCC), and depressurization related fracture in CO_2 transport.
- Establish test methodologies to investigate general corrosion and pitting corrosion in CO_2 containing impurities.
- Determine general corrosion mechanisms, behavior and rates on pipeline steels in the presence of water dissolved in dense phase CO_2.

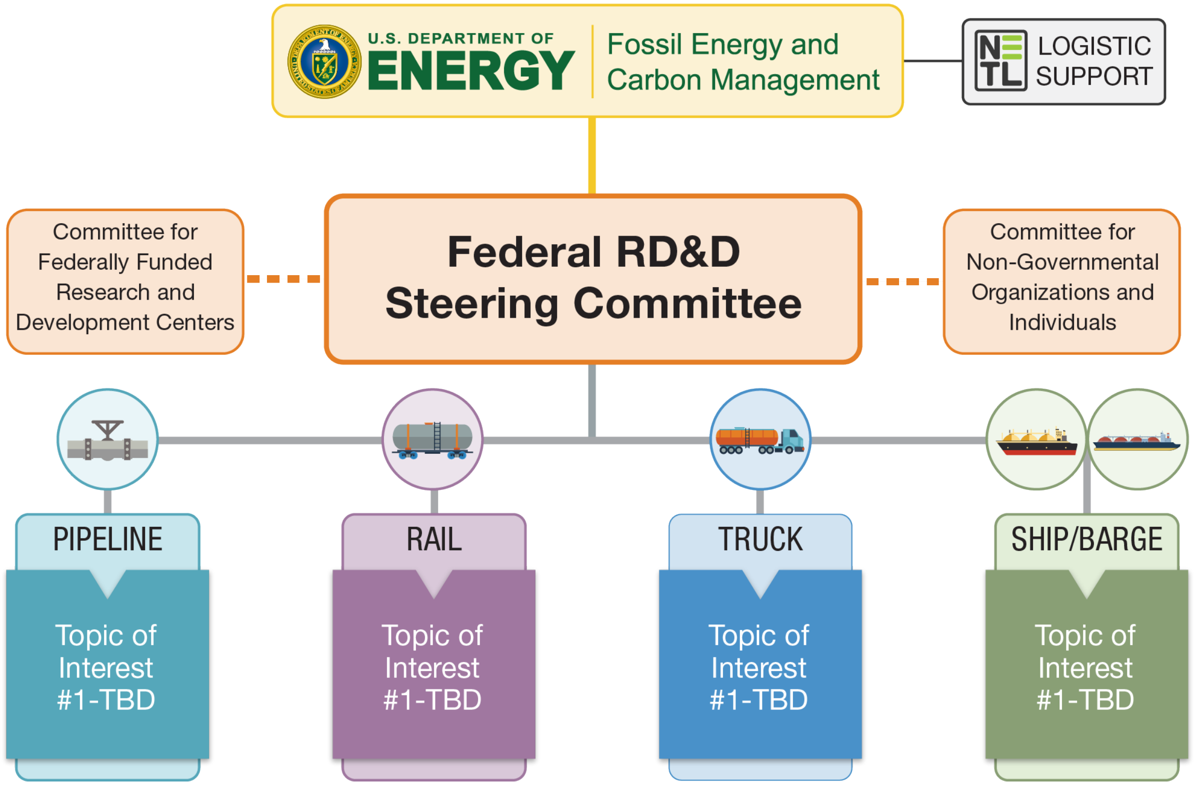
Stress Corrosion Cracking of carbon steels under CO_2/CO/H_2O environments in process piping before water treatment or CO_2 pipeline with water dropout due to upset.

- Establish test methodologies to investigate stress corrosion cracking in CO_2 pipeline steels in the presence of impurities.
- Determine SCC behavior on steels under CO_2/CO/H_2O environments.
- Develop a predictive model for SCC of pipeline steels and validate it using experimental data.

Carbon Transport RD&D Consortium

Benefits

1. Awareness, work sharing and reduced costs
2. Increased credibility
3. Improve chances to achieve goals
4. Growing network of knowledge
   - Increased access to experts
   - Increased access to organizations
   - Increased access to peer reviewed knowledge
   - Increased access to intermodal transport companies
5. Access to federally funded R&D laboratory resources



Carbon Transport RD&D Consortium – Next Steps

- **Release Request for Information (RFI)**
  - What the consortium is, what are our goals, how can you get involved, etc.
- **Review RFI Responses**
  - Register those who want to get involved into relevant committee
- **Inaugural Committee Meetings**
  - Develop/finalize committee governance
- **Launch Consortium Portal/Webpage**
- **DOE Funding Announcements – Future**

Leave no knowledge behind! Collaborate, coordinate, co-fund, categorize & collate consortium tracked research in an open access public portal.

Thank You!

U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

https://www.energy.gov/fe/office-fossil-energy

Sign up to receive DOE FECM's email updates here.

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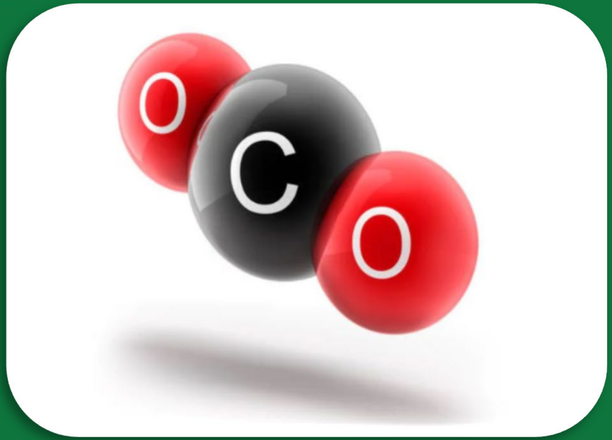

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API CO_2 Pipelines Policy & Programs

Mark Piazza, API
Senior Policy Advisor

API 2024 Pipeline Strategic Priorities

Pipeline Infrastructure Development

Communication & Education

Communications, Advocacy & Education
- Benefits of Pipeline Campaign
- State General Assembly advocacy &législative response

Polling / Modeling Refresh
- Refresh polling & modeling in Q3 to evaluate the effectiveness of BOP messaging
- Consider expansion to include H2 & increase in CO2

Permitting

Federal
- Advocacy to CEQ Phase 2 NEPA reform
- Monitor & respond to any potential NWP proposals

State & local
- Advocacy against harmful eminent domain & permitting legislation
- Monitor & respond to local zoning ordinances

Stakeholder Engagement

Public Engagement & Awareness

RP 1185
- Comment Resolution
- RP 1185 outreach / roll-out
- Implementation resource development & support

RP 1162
- PHMSA advocacy on IBR
- Continued implementation through website

Conservation

Energy for Ecosystems (E4E)
- Launch Program Website
- Build out toolkit
- Establish Reporting Framework
- Track projects & maturity

Pipeline Safety & Security

Regulations & Legislation

PHMSA Reauthorization
- 2020 implementation
- 2023 Advocacy for API priorities

Regulatory - Safety
- Monitor & Respond to Natural Gas, HL & LNG regulations

HL Reform, Idle Pipe, CO2 Pipelines & Repair Criteria

Regulatory-Security
- Comment on ANPRM regs
- Continue facilitating field visits with TSA leadership

Strategic Plan & Safety Standards

API–LEPA Pipeline Excellence Strategic Plan (2023- 2025)
- Organizational& Workforce Excellence
- Innovation& Technology
- Engagement & Awareness
- Cybersecurity Threats
- Safe & Sustainable Energy Future

Significant Standards

Safety - RP 1185, RP 1176, RP 1187, RP 1173

Security – RP 1164 implementation & maintenance

Climate & Low Carbon Energy

Low Carbon Policy & Technical

R&D
- R&D through PRCI EFI & CO2 Taskforce
- Engagement with DOE & PHMSA on R&D Alignment

Regulations & Standards
- Develop RP for CO2 Pipeline Safety
- Drive narrative around CO2 reg update

Training
- Finalize build-out of CO2 ER curriculum with National Association of State Fire Marshals

Climate

The Environmental Partnership
- Strengthen operator participation
- Initial reporting of 2023 data for 2024 annual report

Workforce Development & Diversity

- Workforce Development Strategy: Develop and execute workforce development strategy to include education, recruitment and retention initiatives
- Pipeline Conference: Advance phase 2 of Workforce/DEI&A initiative into the 2024 API Pipeline, Control Room and Cybernetics Conference
- Diverse Supplier Resources: There are a variety of non-profit organizations focused on developing and promoting diverse suppliers. These organizations typically provide their own certifications and databases for corporate engagement.
- Engage Directly with Diverse Stakeholders: Our stakeholder allies are interested in hearing from you directly and are always looking to advance individual company engagement.

The "Energy" Behind Carbon Capture and Storage

Energy Transition

ExxonMobil plans to increase carbon capture at LaBarge

ExxonMobil initiated the process for engineering, procurement, and construction contracts as part of its plans to expand carbon capture and storage (CCS) at its LaBarge, Wyo. ...

OGJ editors Oct. 21, 2021

Energy Transition

Air Products to build Louisiana blue hydrogen plant, CCS system

Air Products & Chemicals Inc. is developing a 750-MMscfd blue hydrogen complex near Burnside, Ascension Parish, La.

OGJ editors Oct. 15, 2021

Energy Transition

Consortium lets drilling contract for North Sea Greensand carbon storage

The Nini Joint Venture, operated by INEOS Oil & Gas Denmark and Wintershall Dea AS, has entered a framework agreement with Maersk Drilling for Phase 2 of the Greensand offshore...

OGJ editors Oct. 14, 2021

Energy Transition

Harbour Energy wins UK North Sea CO2 storage license

UK Oil and Gas Authority has awarded a CO_2 appraisal and storage license
Energy. Harbour's V Net Zero proposal would reuse depleted Rotliegend...

OGJ editors

Energy Transition

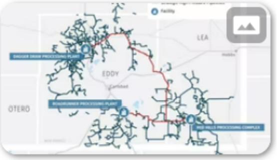
Woodside to invest $5 billion in new low carbon energy projects

Woodside Petroleum Ltd. plans to invest US$5 billion in new low-carbon energy projects over the next 2 decades while still supporting its petroleum business, including the benefits...

Rick Wilkinson Dec. 8, 2021

Energy Transition

Lucid Energy advances plan to develop Permian's largest CCS project



Robert Brelsford Jan. 11, 2022

Energy Transition

Talos, Freeport LNG to develop Gulf Coast CCS project

Talos Energy Inc. and Freeport LNG Development LP intend to develop a carbon capture and sequestration project, the Freeport LNG CCS project, immediately adjacent to Freeport ...

OGJ editors Nov. 16, 2021

Energy Transition

PETRONAS, Technip Energies establish framework for carbon capture collaboration

PETRONAS and Technip Energies signed a heads of agreement (HoA) establishing a collaboration framework for the further development and commercialization of carbon capture technologies...

OGJ editors Nov. 15, 2021

Pathway to Reaching Climate Goals

Increasingly recognized: there is no pathway to reach global climate targets without carbon capture technology.

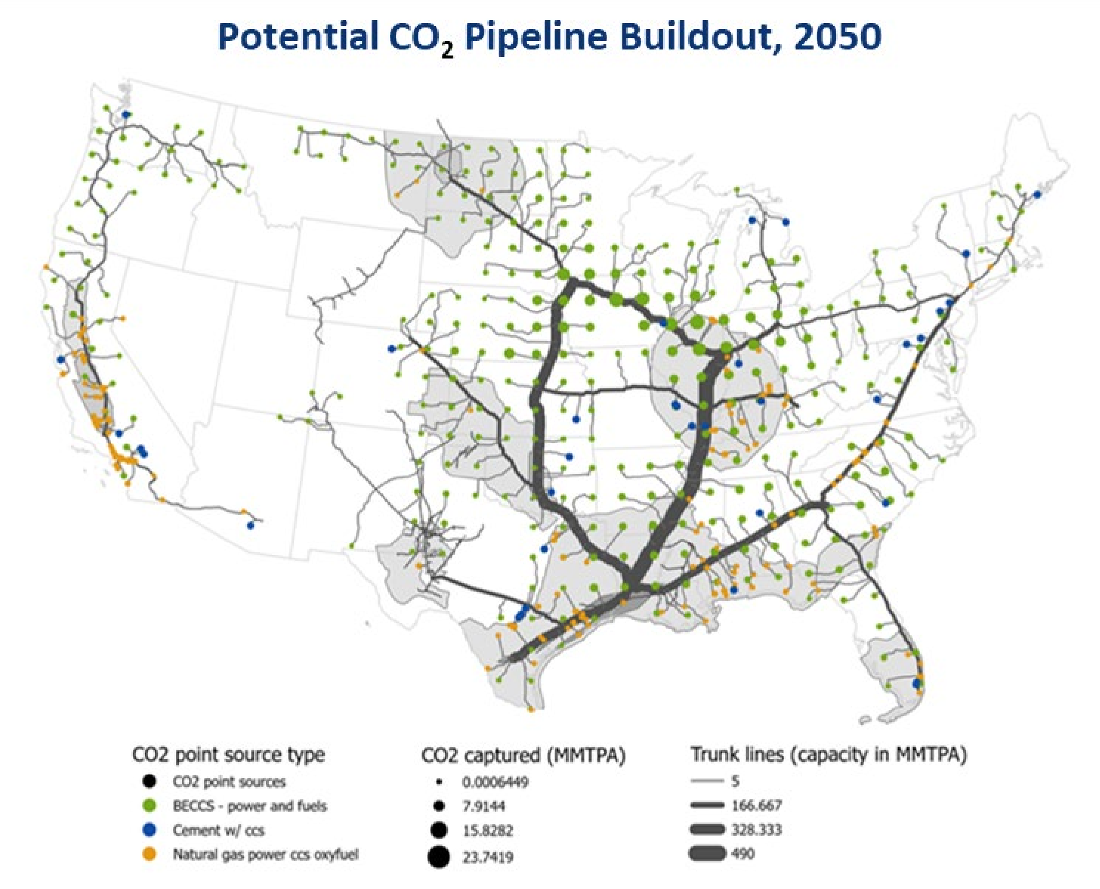
Why Carbon Capture?

- Could play a key role in achieving net-zero GHG emissions in manufacturing and industry (hard-to-abate sectors)
- Provide low-carbon dispatchable power
- Enable low-carbon hydrogen production at scale
- US geology provides for abundant sequestration opportunities
- Meet increasing demand for low-emissions products, carbon-derived products, and carbon offsets

The *Inflation Reduction Act* increased the tax credit value for both capture and storage as well as utilization to levels that unlock economically viable opportunities to develop CCS/CCUS at scale

API Midstream Low Carbon Energy Focus

- **Scope**
  - All issues related to the transportation and storage of low carbon energy sources from the oil and natural gas industry
- **Purpose**
  - Provide strategic and tactical direction and guidance to API as it advocates for and supports the development of a robust infrastructure system for low carbon energy initiatives of the US oil and natural gas industry
- **Key Considerations**
  - US and Global activities – coordination with other SDOs, e.g., ASME, ISO, IOGP, etc.
  - Positioning API to be the leading resource
  - Leverage existing efforts and programs (e.g., eminent domain, integrity management, etc.)
  - Holistic approach to addressing gaps (i.e., research, standards, regulations, etc.)



Source:

American Petroleum Institute

Technology & Innovation Lead to Improvements in CO_2 Pipeline Safety

Identification of CO_2 Integrity & Safety Risks	Prioritization of Risks for CO_2 R&D	CO_2 Research & Development	CO_2 Standards	CO_2 Regulations
	Industry Roadmaps Company ERM Public Policy Strategic Research Priorities	PRCI GTI OTD NYSEARCH PHMSA DOE Academia	API ASME AMPP CSA ISO NFPA	49 CFR §192* 49 CFR §194* 49 CFR §195

* CO2 pipelines are not currently regulated under these Parts

Driving Safety of CO_2 Pipelines

- **Research & Development**
  - Recognition that additional research is needed to inform any future rulemaking
  - Extensive ongoing work through USDOT, USDOE, PRCI and Emerging Fuels Institute

  API taking a leadership role in shaping direction of R&D to support standards development

- **Standards**
  - Understanding landscape and gaps in standards and leading practices and driving updates to support expanded use of hydrogen and CCS development
  - CO_2 emergency response tactical guide created and published

  API actively working on new CO_2 pipeline standard and updating others as appropriate

- **Regulations**
  - PHMSA regulates H_2 pipelines under 49 C.F.R. Part 192
  - PHMSA regulates supercritical phase CO_2 pipelines under 49 C.F.R. Part 195 & moving forward with regulations for gas-phase CO_2 pipelines

  API to review and comment on CO_2 Pipeline Safety NPRM (at OMB)

API American Petroleum Institute

Pipeline Safety
STARTS WITH YOU

API Pipeline Standards

INTEGRITY

RP 1110 Pressure Testing of Steel Pipelines for the Transportation of Gas, Petroleum Gas, Hazardous Liquids, Highly Volatile Liquids, or Carbon Dioxide

RP 1133 Managing Hydrotechnical Hazards for Pipelines Located Onshore or within Coastal Zone Areas

RP 1160 Managing System Integrity for Hazardous Liquid Pipelines

Std 1163 In-line Inspection Systems Qualification

RP 1176 Assessment and Management of Cracking in Pipelines

Bull 1178 Integrity Data Management and Integration

TR 1179 Hydrostatic Testing as an Integrity Management Tool

RP 1181 Pipeline Operational Status Determination

RP 1183 Assessment and Management of Dents in Pipelines

RP 1188 Hazardous Liquid Pipeline Facilities Integrity Management

CONSTRUCTION, INSPECTION, AND REPAIR

RP 1111 Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines

UNDERGROUND STORAGE

RP 1115 Design and Operation of Solution-mined Salt Caverns Used for Liquid Hydrocarbon Storage

RP 1170 Design and Operation of Solution-mined Salt Caverns Used for Natural Gas Storage

RP 1171 Functional Integrity of Natural Gas Storage in Depleted Hydrocarbon Reservoirs and Aquifer Reservoirs

PUBLIC SAFETY AND DAMAGE PREVENTION

RP 1102 Steel Pipelines Crossing Railroads and Highways

RP 1109 Marking Liquid Petroleum Pipeline Facilities

RP 1162 Public Awareness Programs for Pipeline Operators

TR 1166 Excavation Monitoring and Observation for Damage Prevention

GATHERING LINES

RP 80 Definition of Onshore Gas Gathering Lines

RP 1182 Construction, Operation, and Maintenance of Large Diameter Rural Gas Gathering Lines

MANAGEMENT SYSTEMS

RP 1160 Managing System Integrity for Hazardous Liquid Pipelines

RP 1173 Pipeline Safety Management Systems

RP 1174 Onshore Hazardous Liquid Pipeline Emergency Preparedness and Response

RP 1175 Pipeline Leak Detection - Program Management*

RP 1177 Quality Management Systems for Steel Pipeline Construction

CYBERNETICS AND CONTROL ROOM

RP 1130 Computational Pipeline Monitoring for Liquids*

TR 1149 Pipeline Variable Uncertainties and Their Effects on Leak Detectability

Std 1164 Pipeline Control Systems Cybersecurity

RP 1165 Pipeline SCADA Displays*

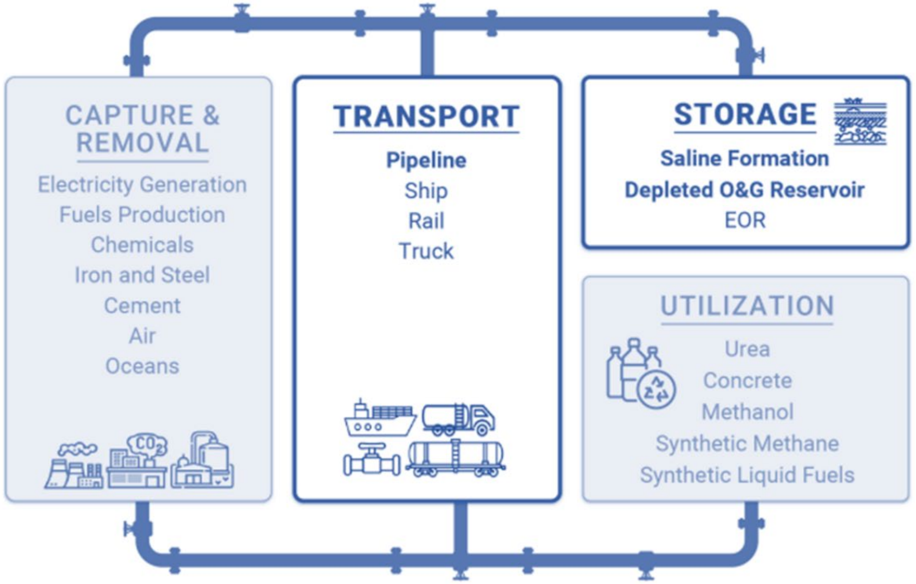
RP 1167 Pipeline SCADA Alarm Management

RP 1168 Pipeline Control Room Management

RP 1175 Pipeline Leak Detection - Program Management*

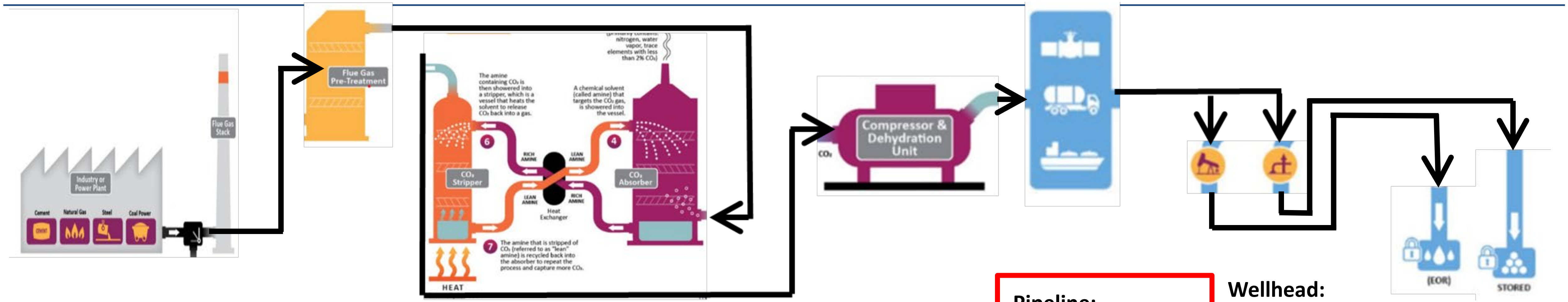
Low Carbon Energy Infrastructure Subcommittee (LCEIS) CO_2 Pipelines

- **Pipeline Safety**
  - DOE & PRCI CO_2 pipeline safety workshops – industry roadmaps developed & consistent
  - PRCI CO_2 pipelines SOTA Report – how to we address gaps through PRCI and partner with others
  - EFI – Champion level membership in 2023 & 2024
    - Integrated API GIS Team into PRCI R&D Programs
    - Linking R&D with standards – API, ASME, AMPP
  - API CO_2 Pipeline RP – coordinating with ASME, AMPP, DNV, ISO, IOGP, others as appropriate
  - CO_2 Pipelines as a Strategic Research Priority and API-LEPA 2023-2025 Strategic Plan – *Safe and Sustainable Energy Future*
  - Continuing to work on revisions to existing standards or the need for new standards – repurposing and new construction
    - Monitoring PRCI, PHMSA & DOE R&D programs
    - Materials, measurement, pipeline operations, and underground storage
  - DOE Funding Opportunity Announcements



Source: Labor Energy Partnership, "Building to Net-Zero: A U.S. Policy Blueprint for Gigaton Scale CO² Transport and Storage Infrastructure," June 2021

API CO_2 Pipeline RP vs. PRCI Guidelines



Balance of Plant:
- Ducting
- Purification
- Waste Handling
- WHRU
- Process Control
- Utility

Capture Island:
- Technology providers
- Performance
- Efficiency
- Reliability

Balance of Plant (Cont'd):
- Compression
- Dehydration
- Process Control
- Chemical Mgmt

Pipeline:
- Wall thickness
- Dispersion
- Overpressure protection
- Inspection
- Corrosion control
- Impurities
- LDS
- Coordinate API Guidance
- Gathering system design

Wellhead:
- Materials
- Control philosophy
- Inspection

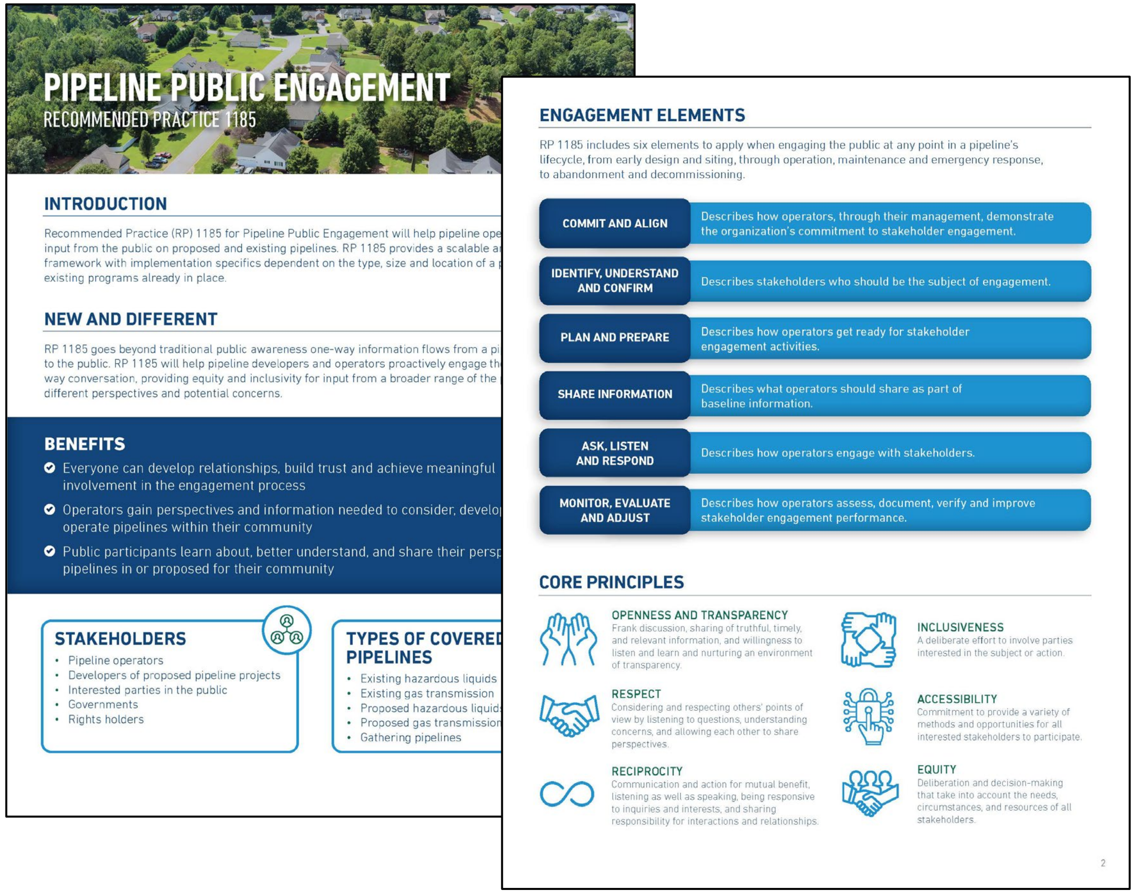
Subsurface:
- Geology
- MMV

Overall:
- Permitting matrix, ERP, safe handling procedures

Source: PRCI CO2 Task Force (B. Vonau)

Low Carbon Energy Infrastructure Subcommittee (LCEIS) CO_2 Pipelines (cont.)

- **Permitting**
  - Significant challenges to CO_2 pipeline permitting
  - Midwest states public opposition
  - Preemption, eminent domain, setback, and other state and local issues
- **Emergency Response**
  - Published Tactical Guidelines for CO_2 Emergency Preparedness/Response
  - NASFM Training Portal
  - Texas A&M TEEX CO_2 pipeline training
- **Public Engagement and Education**
  - Working with all stakeholders
  - RP 1185 – will be an important element of CO_2 pipeline infrastructure build out
  - Roll-out and "How To" guidelines
  - Benefits of Pipeline Campaign



thank you

REX2024
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WHEN TRUST MATTERS

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DNV Led CO_2 / CCUS JIPs

Summary of DNV Led CO2 Pipeline JIPs

Title	Topic	Timeline
CO_2 Safe & Sour	Integrity of pipelines subjected to H_2S from CCS. Sulfide stress cracking/hydrogen embrittlement. Corrosion	2022 – 2024
CO_2SafePipe	Update of DNV-RP-F104 “Design and Operation of Carbon Dioxide Pipelines”	2023 - 2024
Materials Performance in CCS Storage Wells	Damage mechanisms of Corrosion Resistant Alloys in CCS well applications. Materials selection, operational windows, and assess long term performance of materials in CCS storage wells.	2023 - 2025
CO/CO_2 SCC	Chemistry and metallurgical limits of CO and other impurities to prevent CO/CO2 cracking. Develop a simplified qualification methodology for screening	2024 – 2026
SubCO_2 Phase 3	Subsurface and atmospheric dispersion and dynamics of underwater CO_2 pipe leaks in deeper, more representative water than before.	2024 – 2025
CO_2GASMET Flow Metering	Development of a traceable CO_2 flow standard for medium & low pressure and low temperatures enabling performance assessment and calibration of flow meter technologies along the CO_2 value chain.	2023 - 2024
CO_2LIQMET Flow Metering	Development of a CO_2 flow reference system for high to extreme high pressure and low temperature applications, liquid and dense phase CO_2.	2023 - 2024
KFX-CO_2	Development of CO_2 dispersion simulation technology for 3D industrial analyses, which considers important effects of CO_2 thermodynamics, geometries, topography and atmospheric conditions.	2019 - 2024
Skylark (CO_2Dispersion)	Address challenges related to the dispersion behavior of CO_2 that are important for pipeline risk assessment, operational practice and emergency response	2024 - 2027

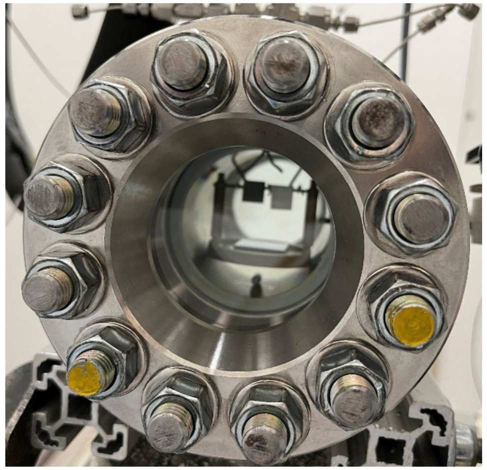
Norway IFE (Institute For Energy) Dense Phase JIPs

JIP #1: Kjeller Dense Phase CO_2 Corrosion IV (KDC-IV) - Objective

- Provide a tool for simulation of solubilities and chemical reactions in dense phase CO_2 by extending the capabilities of the OLI thermodynamic model to include reactions in dense phase CO_2.
- Provide experimental results that can be used by the CCS industry to prevent negative effects of impurities with respect to chemical reactions, corrosion and formation of solids in the CO_2 transportation system.

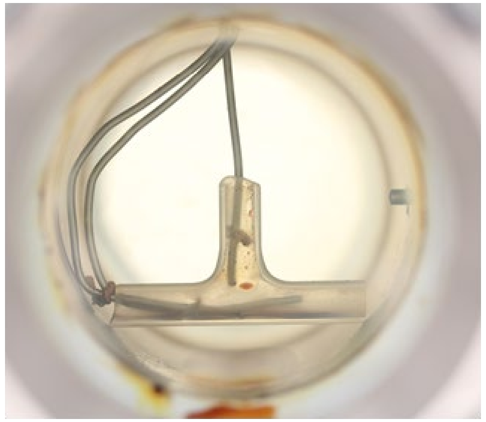
JIP #1: KDC-IV … Scope

1. Effect of low (but not zero) impurity concentrations, e.g. low ppm NO_2, and 10 ppm of H_2S, SO_2, O_2
2. Low pressure or low temperature conditions (including gas phase CO_2)
3. Practical consequences of liquid phases (corrosive phases, including acids)
4. Partitioning of impurities (in two-phase situations)
5. Thermodynamic modelling (OLI): Experimental results from the JIP will be used to improve the dense phase CO_2 prediction capabilities in the OLI model



Extensive laboratory capabilities with close control of impurities in dense phase CO2

(a) 20 hours: SO_2 /O_2



(e) 102 hours: All impurities

*Morland, Tjelta, Norby, Svenningsen, *International Journal of Greenhouse Gas Control, 87, (2019) pp. 246-255.*
**Morland, Dugstad, Svenningsen, *International Journal of Greenhouse Gas Control, 119, (2022) p. 103697.*

JIP # 1: KDC-IV … Participation & Timeline

Participants

- Shell
- TotalEnergies
- Equinor
- BP
- Chevron
- ExxonMobil
- Saudi Aramco
- Wintershall Dea
- Neptune Energy
- Gassco
- EBN
- ArcelorMittal
- Vallourec
- AirProducts
- Fluxys
- Gasunie

Duration

Four years, Sept 2023 – June 2027

Possible to join for new companies against an entrance fee giving access to previous JIP results

IFE JIP #2: CO2WellMat-II … Objective

- Determine the maximum acceptable concentrations of impurities in CO2 when they are present in various combinations in a CO2 injection well
- Determine critical conditions (temperature and CO2/water ratio) for pitting and cracking of 13% Cr steel exposed in brine and condensed water equilibrated with the specification
- Determine critical conditions (temperature and CO2/water ratio) for pitting and cracking of 22%Cr and 25%Cr steel (or other alternatives to 13% Cr) exposed in brine and condensed water equilibrated with various CO2 blends
- Develop guidelines for downhole corrosion in CO2 injection wells based on experimental data generated in the CO2WellMat and KDC projects

IFE JIP #2: CO2WellMat-II … Scope

- High temperature testing, up to 120 °C
- Other impurities; effects on partitioning and corrosion
  - Determine acceptable limits for NO_2, SO_2, CO and H_2S for different materials
- Test materials: Super 13Cr, 22Cr (Duplex), 25Cr (Superduplex), Alloy 625 and/or others
  - Selection of materials to be included is still under discussion
- More targeted crevice tests (critical size, critical temperature)
- More accurate determination of O_2 partitioning
  - Expand the temperature range
  - Explore the pressure dependence
- Look into the consequence of large O_2 concentrations in the aqueous phase. What does it take to bring Cr-steels out of the passive range and into a pitting range?
  - Electrochemistry (potential sweeps)
  - Interplay between pH, chloride and O_2

JIP # 2: KDC-IV … Participation & Timeline

Participants

Shell
ExxonMobil
Cohillips
WinnocoPtershall Dea
Neptune Energy
Vallourec
Tenaris
JFE
Halliburton
Tubacex
Nippon Steel
Repsol

Duration

2 ½ years, Sept 2023 – June 2026

Possible to join for new companies against an entrance fee giving access to previous JIP results

Corrosion in CO2 Transmission Pipelines (CCT) JIP

Yoon-Seok Choi

Associate Director for Research
Institute for Corrosion and Multiphase Technology
Ohio University

CCT JIP Objective and Goals

Objective: Identify and quantify the key issues which impact corrosion of materials specifically relating to the integrity of structures for the CO_2 transport pipelines.

Goals:

- To understand the effect of a wide range of impurities (O_2, SO_2, NO_2, H_2S, etc.) on **the water/acid solubility and the speciation** in dense phase CO_2.
- To develop a **thermodynamic model** for predicting the water/acid solubility and the speciation in dense phase CO_2 in the presence of impurities.
- To determine impact of **environmental parameters (pressure, temperature, flow, and impurity types and concentrations)**, both individually and synergistically, on **steel corrosion** in both dense phase CO_2 and aqueous phase in the presence of impurities.
- To develop a **mechanistic model** to predict the corrosion processes in order to help determine facility lifetime.

Duration: 3 years (Jan. 2023 ~ Dec. 2025)

CCT JIP Scope of Work and Deliverables

Scope of work

- **Part 1. Thermodynamic study:** Develop a thermodynamic model of solubility of water/acid and speciation in dense phase CO_2 in the presence of impurities like SO_2, NO_2, H_2S and O_2.
- **Part 2. Corrosion study:** Evaluate long-term corrosion behavior under water unsaturated dense phase CO_2 in the presence of various impurities.
- **Part 3. Model development:** Develop a mechanistic model, which can predict the rate and mechanism of corrosion of steel in dense phase CO_2 with impurities.

Deliverables

- Biannual reports
- Thermodynamic and corrosion prediction models
- Guideline for impurity concentrations in corrosion mitigation

Sponsors: Baker Hughes, BP, Chevron, ConocoPhillips, Enbridge, Equinor, EVRAZ North America, ExxonMobil, Occidental Oil Company, Petrobras, Saudi Aramco, Shell, Slb, Tenaris, TotalEnergies.

PRCI Gap Analysis Results

CO2 Gap Summary

Area	Idea	Project Code	Proposed Project Idea Title	Rank	Sub area	GAP	Ideas	Work type
Corrosion	3647	ALT-1-8	Corrosive Impact of Trace Components in Transport of CO2	1	A - Effect of impurities on corrosion of Transportation and Storage Pipeline Assets	Corrosion mechanisms not completely know. Need to better model corrosion rate. Lack of experimental results. Acid drop out scenarios and consequences not covered in standards	Lab work e.g. electrochemical methods, autoclave testing, to improve understanding of mechanisms	Lab Testing
Corrosion	3648	ALT-1-8a	Validation for water and acid solubility in CO2 with impurities	1	B - Thermodynamic models	Need more validation for water and acid solubility in CO2 with impurities	Lab tests to measure water and acid solubility in CO2 stream with impurities. Compare to existing thermodynamic models	Desk Study/Lab Testing
Corrosion	3649	SSC-02-16	Cracking and corrosion fatigue in CO2-H2O-CO. H2 gas embrittlement	2	C - Stress Corrosion, Fatigue and Cracking	SSC and HIC due to H2S. Cracking and corrosion fatigue in CO2-H2O-CO. H2 gas embrittlement	Lab SSC crack initiation (e.g. four point),fracture mechanics+ HIC tests different CO2+H2S+H2O levels+ pipe grades, age, sour/non (phase I)	Lab Testing
Corrosion	3650	ALT-1-7	Guideance for CO2 Specifications for Pipeline Transport & Storage	3	F - CO2 specifications	Lack of detailed guidance to a CO2 specification (limits for minor components)	Create a 1st guideline/RP with threshold ranges for key impurities based on this review. Can incorporate advice on scenarios where impurity levels can be relaxed, reporting the limited experimental dataset where no corrosion occurs, show tentative limits for cracking etc.	Desk study
Corrosion	3651	NDE-X-X	Inline Inspection Tools for Dense Phase		G - Any Other Gap	Corrosion inline inspection tools for dense phase CO2 service		
Fracture	3653	MAT-8-6a	Review and Refine EOS for CO2 Transport	2	A - EOS	A reference equation of state	Compare different EOS and define the better to use	Desk Study/Modelling
Fracture	3652	MAT-8-7	Full Scale Fracture Propagation Test with Gas Phase CO2	1	B - Fracture Propagation	Extend the range of applicability of the empirical methods (cf. DNV-RP-F104). Need improved prediction models (BTCM, FEA). Need experimental verification for gas CO2	Lab and full scale testing in different conditions to extend the range of applicability of the empirical methods (cf. DNV-RP-F104)	Lab/Full Scale Testing
Fracture	3654	MAT-8-8	Effects of C02 on the ductile to brittle fracture initiation transition temperature	3	C - Fracture Initiation	Warm Pre-stressing to be investigated	(Additional) Experimental validation of Warm Pre-stressing	Lab/Full Scale Testing
Fracture	3655	MAT-8-9	Guidelines for Crack Arrest Design for CO2 Pipelines	3	D - Crack Arrestor	No established guidelines for CA design for CO2. Limited full scale tests results available	Develop CA design guidelines for CO2	Desk study/Modelling

- CO2 Treating / Quality
- EOS
- Fracture Propagation
- Odorants
- Dispersion

CO2 Gap Summary

Safety / Dispersion	3658		**Building CO2 Transmission Pipelines: A Primer**	3	**A - Social acceptance**	Bad perception about CO2 pipelines safety	Proving that CO2 pipelines are as safe as NG pipelines by performing comparative risk analysis in different scenarios	Desk study
Safety / Dispersion	3657		**Evaluation of Odorants fo C02 Service**	2	**B - Leak identification**	CO2 is odourless and can not be detected during leakage	Investigation of potential costs and benefits (in terms of social acceptance) of adding odorant in CO2 pipelines	Desk study
Safety / Dispersion	3656	ALT-1-9	**Decompression Radius Modelling of CO2 Pipeline Rupture**	1	**E - Release**	Poor release modelling. Models does not describe CO2-fluid interaction (H2O acidification) for offshore. Impact of running ductile failure length on consequence modelling setup and results	Develop better release modelling (3-phase) and testing	Modelling
Re-purposing	3661	API-2-3	**Literature Review of Technical Stamdards applicable to CO2**	2	**B - Standards**	Not all technical items properly covered in the current standards, update needed	Sistematic review of technical items in pre-standardization form	Desk study
Re-purposing	3660	EC-02-14	**Comprehensive Metal-Loss Assessment Criterion for CO2 Pipelines**	1	**C - Pipeline status**	How to deal with aged pipeline materials and/or poor material data	Develop criteria and testing for assessing aged materials	Desk study/Lab Testing
Re-purposing	3662	MAT-7-1a	**Non-Metallic Material Components for CO2 Pipelines**	3	**D - Non-metallic materials**	Material compatibility need to be assessed for components, i.e Flange Gaskets, seals, etc.	Develop testing procedure and criteria for non-metallic materials	Lab Testing

CO2 Treating / Quality
EOS
Fracture Propagation
Odorants
Dispersion