



REX2024
PRCI Research Exchange

Research Exchange REX 2024

CO2 Pipelines – Deep Dive Session

ConocoPhillips
Feb. 28, 2024
Mohsen Achour



Pipeline Research Council International

CO2 Pipelines Deep Dive Session ... Agenda

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Mohsen Achour
Corrosion & Asset Int...
ConocoPhillips



Mark Piazza
Senior Policy Advisor ...
American Petroleum I...



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

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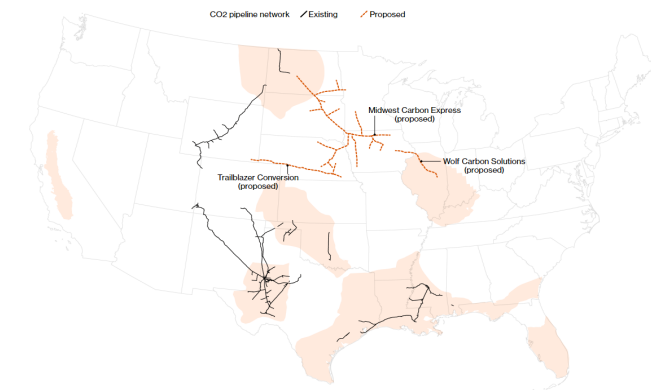
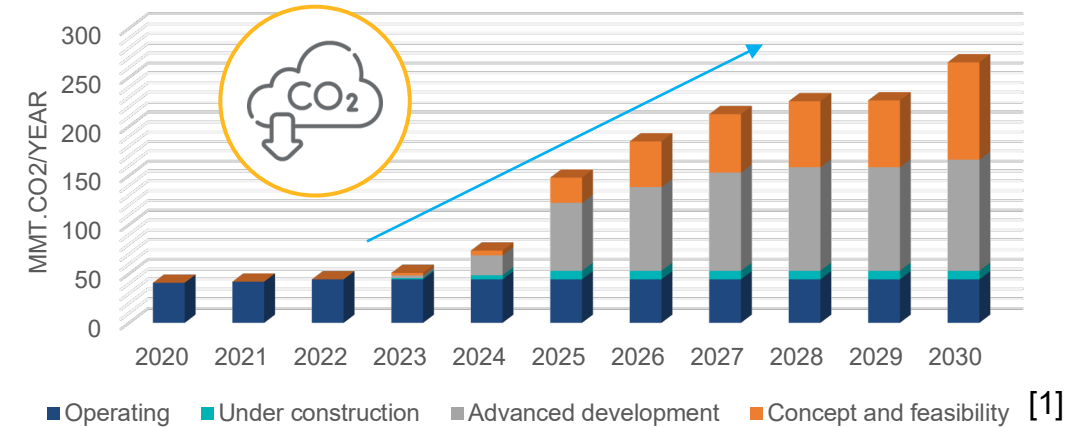
- Background of CCS
- Safety Facts on CO₂
- Objective of Developing CO₂
 - Challenges with developing Multi-emitter hubs
- Impact of Impurities
- Other Technical Considerations
 - Hydraulic Modelling
 - Material Selection
 - Control Philosophy
- Balancing Risks
- Conclusions

CCUS in North America

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- As of 2023, there were approx. 5,200 mi of CO₂ pipelines in North America. To enable forecasted growth in Carbon Capture and Sequestration (CCS) more pipelines are required.
- Most CO₂ 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 CO₂ pipelines.
- Shell Quest in Alberta Canada (2015) and Sleipner in Norway (1995) (and several others) are full scale projects that sequester CO₂.

CCS Projects



[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/>

[2]

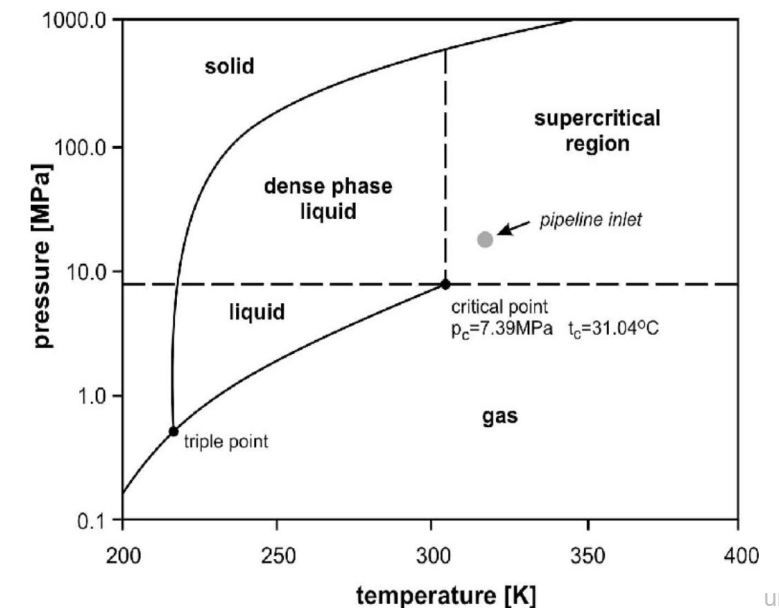
CO₂ Safety Facts

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- Unlike natural gas, CO₂ is heavier than air. In the event of a release, CO₂ will dissipate slower than natural gas & accumulate in low-lying areas, displacing oxygen in the affected area.
- Symptoms of mild CO₂ exposure may include headache and drowsiness, and higher CO₂ levels will cause rapid breathing, confusion, increased cardiac output, elevated blood pressure, and increased arrhythmias may occur.
- CO₂ release from liquid form inside of a pipeline will transform into gas/solids due to temperature & pressure changes.
- CO₂ may accumulate static electricity, even when being filled into properly grounded containers, and reacts with water to form carbonic acid (H₂CO₃).
- Most CO₂ pipelines operate in dense phase



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



CO2 Pipeline Standards Development

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- 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



CO₂ Composition

Pathway to Corrosion (CO₂ + presence of SO₂, NO₂, H₂S, O₂)

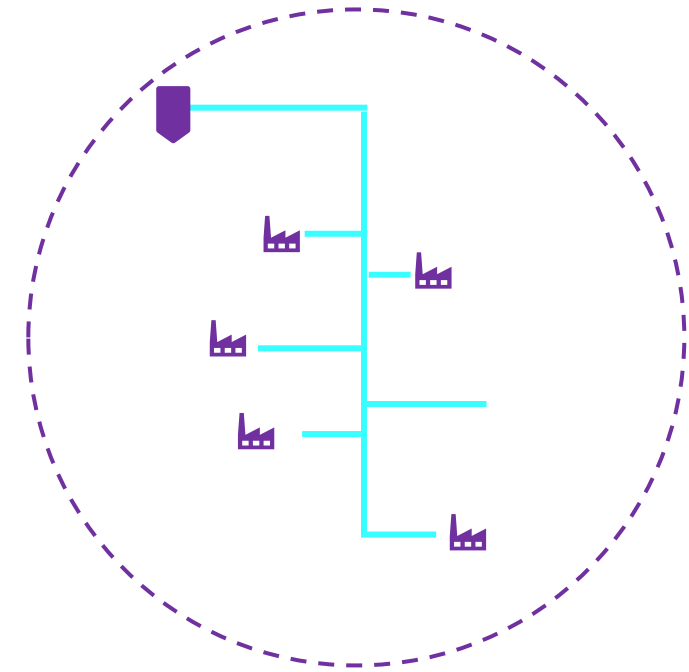
- $\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$ (Carbonic acid)
 - $\text{H}_2\text{O} + \text{SO}_2 \rightarrow \text{H}_2\text{SO}_4$ (Sulfuric acid)
 - $\text{H}_2\text{O} + \text{NO}_2 \rightarrow \text{HNO}_3$ (Nitric acid)
 - $\text{H}_2\text{O} + \text{H}_2\text{S} \rightarrow \text{HS}^- + \text{H}^+$
 - $\text{H}_2\text{O} + \text{H}_2\text{S} \rightarrow \text{S}^{2-} + \text{H}^+$
- Acidic formation leads to corrosion of steel, oxygen accelerates corrosion process*
- 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 NO_x and SO_x levels
 - Water drop out during operation leading to corrosion

Multi-Emitter Carbon Hub System Planning

- **Systems thinking approach**
 - CO2 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

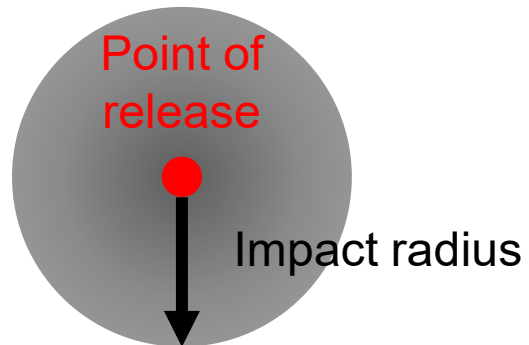
CO2 Safety: Dispersion Modeling

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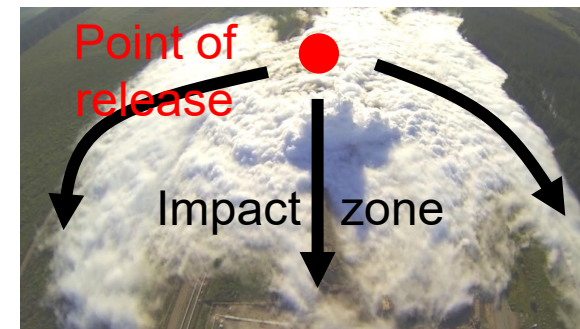
- ‘Potential impact radius’ for CO₂ is non-linear
- **Simplified plume vs. complex computation model depending on:**
 - Pipeline operating characteristics (size, pressure)
 - Surrounding topography & land uses
 - Atmospheric conditions
 - Fluid components that could affect vapor dispersion

Risk assessment inputs
affecting design/operations
(valve spacing, vent design, pipeline
routing, pipe toughness, etc.)

Conventional Model



Dispersion Model



High Reliability Systems

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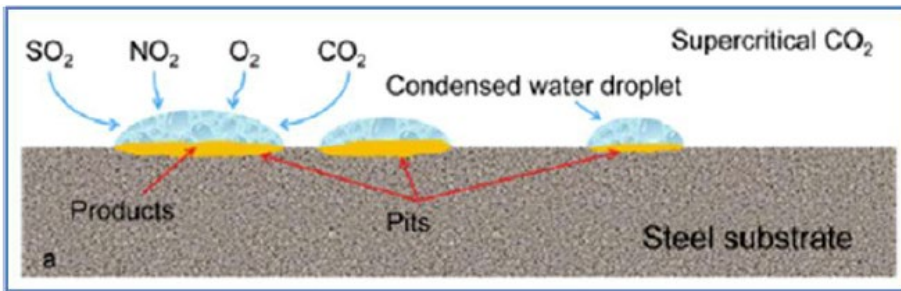
- Pipelines reliability targets suggested to be 1×10^{-5} by Hassanien et al [1] – perhaps suitable for CO₂ pipeline but need to consider Human health impacts.
- CO₂ Projects perform Quantitative Risk Assessment- options to mitigate risk:
 - Enhanced Pipeline Monitoring and leak detection (e.g. [Hifi Monitoring System](#))
 - Heavier wall thickness
 - Re-routes
 - Gas phase CO₂ (lower pressure)

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

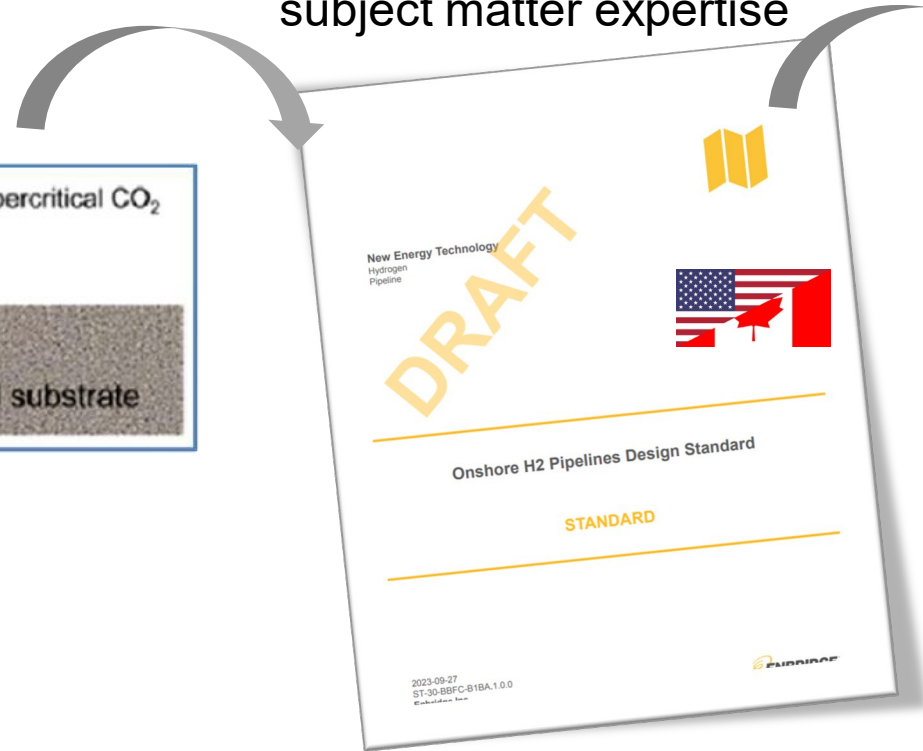
How to provide guidance to projects in development with the uncertainty in the research?

Conservatism and Consensus Engineering

Literature Review and SOTA



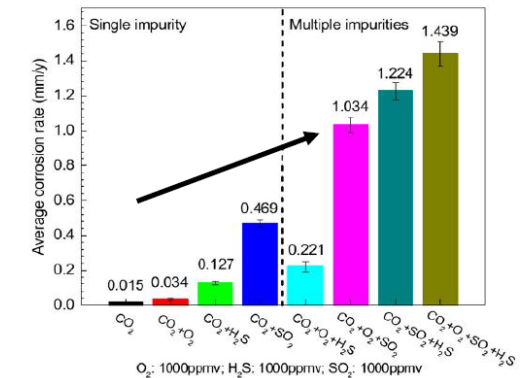
Internal and External subject matter expertise



Ongoing Research

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

Constituent	Limit	
Carbon Dioxide, CO ₂	> 95 mol%	
Water, H ₂ O	< 50-100 ppmv	
Sulphur Oxides, SO _x	< 10 ppmv	
Nitrous Oxides, NO _x	< 2.5-10 ppmv	
Hydrogen Sulphide, H ₂ S	< 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 ₂ OH) ₂	< 0.3 US gal/MMSCF	
Ethanol, C ₂ H ₆ O	< 20 ppmv	
Methanol, CH ₃ OH	< 500 ppmv	
Ammonia, NH ₃	< 125 ppmv	
Amines, -NH ₂	< 1 ppmv	
Particulates	< 1 ppmw	
Mercury, Hg	< 5 mg/sm ³	



Summary

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- 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 CO2 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

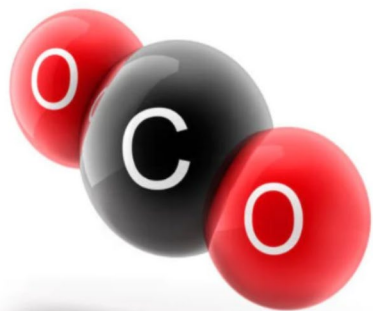


DOE Carbon Transport RD&D: 2024 Update

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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References herein to any specific commercial product, process, or services by trade name, trademark, manufacturer, or otherwise, do not constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or DOE or its contractors or subcontractors.”

Lab Work Addressing Feb 2023 DOE Applied R&D Workshop

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Thermodynamic study of the effect of impurities on phase behavior of dense phase CO₂

- Investigate effect of impurities (e.g., CO, O₂, H₂, NO_x, SO_x) on the phase boundaries of CO₂.
- Review impact of impurities on water solubility limits (water dropout) in dense and vapor phase CO₂.
- Understand speciation pathways for acid formation and solubility due to interaction of various impurities with water.
- Develop thermodynamic models to predict fluid (CO₂ + impurities) behavior in pipelines.

Evaluation of the risk of corrosion with presence of aqueous/acid phase (continuous or droplets) in CO₂ with impurities

- Review literature for corrosion, stress corrosion cracking (SCC), and depressurization related fracture in CO₂ transport.
- Establish test methodologies to investigate general corrosion and pitting corrosion in CO₂ containing impurities.
- Determine general corrosion mechanisms, behavior and rates on pipeline steels in the presence of water dissolved in dense phase CO₂.

Stress Corrosion Cracking of carbon steels under CO₂/CO/H₂O environments in process piping before water treatment or CO₂ pipeline with water dropout due to upset.

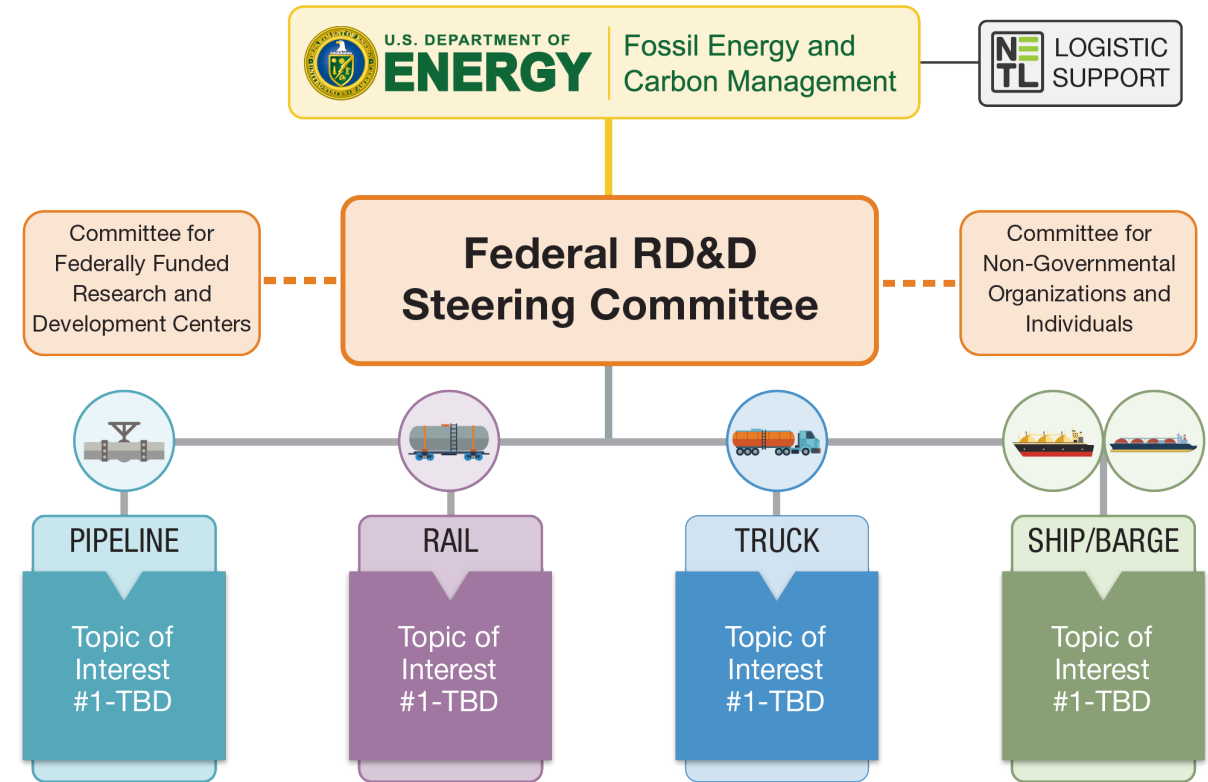
- Establish test methodologies to investigate stress corrosion cracking in CO₂ pipeline steels in the presence of impurities.
- Determine SCC behavior on steels under CO₂/CO/H₂O environments.
- Develop a predictive model for SCC of pipeline steels and validate it using experimental data.

Carbon Transport RD&D Consortium

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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

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- **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!



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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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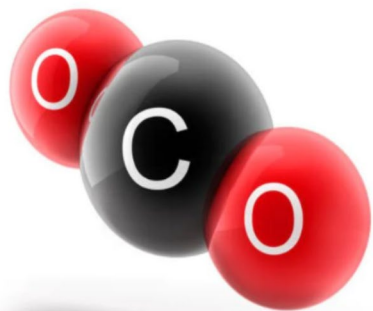
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API CO2 PIPELINES POLICY & PROGRAMS

PRCI 2024 RESEARCH EXCHANGE
SAN DIEGO, CA
FEBRUARY 28, 2024

MARK PIAZZA, API
SENIOR POLICY ADVISOR

DOE Grant Opportunities

Pipeline Infrastructure Development		Stakeholder Engagement		Pipeline Safety & Security		Climate & Low Carbon Energy	
Communication & Education	Permitting	Public Engagement & Awareness	Conservation	Regulations & Legislation	Strategic Plan & Safety Standards	Low Carbon Policy & Technical	Climate
Communications, Advocacy & Education <ul style="list-style-type: none"> - Benefits of Pipeline Campaign - State General Assembly advocacy & legislative response 	Federal <ul style="list-style-type: none"> - Advocacy to CEQ Phase 2 NEPA reform - Monitor & respond to any potential NWP proposals 	RP 1185 <ul style="list-style-type: none"> - Comment Resolution - RP 1185 outreach / roll-out - Implementation resource development & support 	Energy for Ecosystems (E4E) <ul style="list-style-type: none"> - Launch Program Website - Build out toolkit - Establish Reporting Framework - Track projects & maturity 	PHMSA Reauthorization <ul style="list-style-type: none"> - 2020 implementation - 2023 Advocacy for API priorities 	API-LEPA Pipeline Excellence Strategic Plan (2023- 2025) <ul style="list-style-type: none"> - Organizational& Workforce Excellence - Innovation& Technology - Engagement & Awareness - Cybersecurity Threats - Safe & Sustainable Energy Future 	R&D <ul style="list-style-type: none"> - R&D through PRCI EFI & CO2 Taskforce - Engagement with DOE & PHMSA on R&D Alignment 	The Environmental Partnership <ul style="list-style-type: none"> - Strengthen operator participation - Initial reporting of 2023 data for 2024 annual report
Polling / Modeling Refresh <ul style="list-style-type: none"> - Refresh polling & modeling in Q3 to evaluate the effectiveness of BOP messaging - Consider expansion to include H2 & increase in CO2 	State & local <ul style="list-style-type: none"> - Advocacy against harmful eminent domain & permitting legislation - Monitor & respond to local zoning ordinances 	RP 1162 <ul style="list-style-type: none"> - PHMSA advocacy on IBR - Continued implementation through website 		Regulatory - Safety <ul style="list-style-type: none"> - Monitor & Respond to Natural Gas, HL & LNG regulations HL Reform, Idle Pipe, CO2 Pipelines & Repair Criteria		Regulations & Standards <ul style="list-style-type: none"> - Develop RP for CO2 Pipeline Safety - Drive narrative around CO2 reg update 	
				Regulatory-Security <ul style="list-style-type: none"> - Comment on ANPRM regs - Continue facilitating field visits with TSA leadership 	Significant Standards <p>Safety - RP 1185, RP 1176, RP 1187, RP 1173</p> <p>Security - RP 1164 implementation & maintenance</p>	Training <ul style="list-style-type: none"> - Finalize build-out of CO2 ER curriculum with National Association of State Fire Marshals 	

Workforce Development & Diversity
<ul style="list-style-type: none"> - 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 project.

[OGJ editors](#)

Energy Transition

Harbour Energy wins UK North Sea CO2

UK Oil and Gas Authority has awarded a CO2 appraisal Energy. Harbour's V Net Zero proposal would reuse d

[OGJ editors](#)

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

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

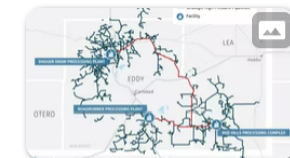
Woodside Petroleum Ltd. plans to invest US\$5 billion in new low-carbon energy projects over the next 2 decades while still supporting its petroleum business, including the benefits...

[Rick Wilkinson](#)

Dec. 8, 2021

Energy Transition

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



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

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

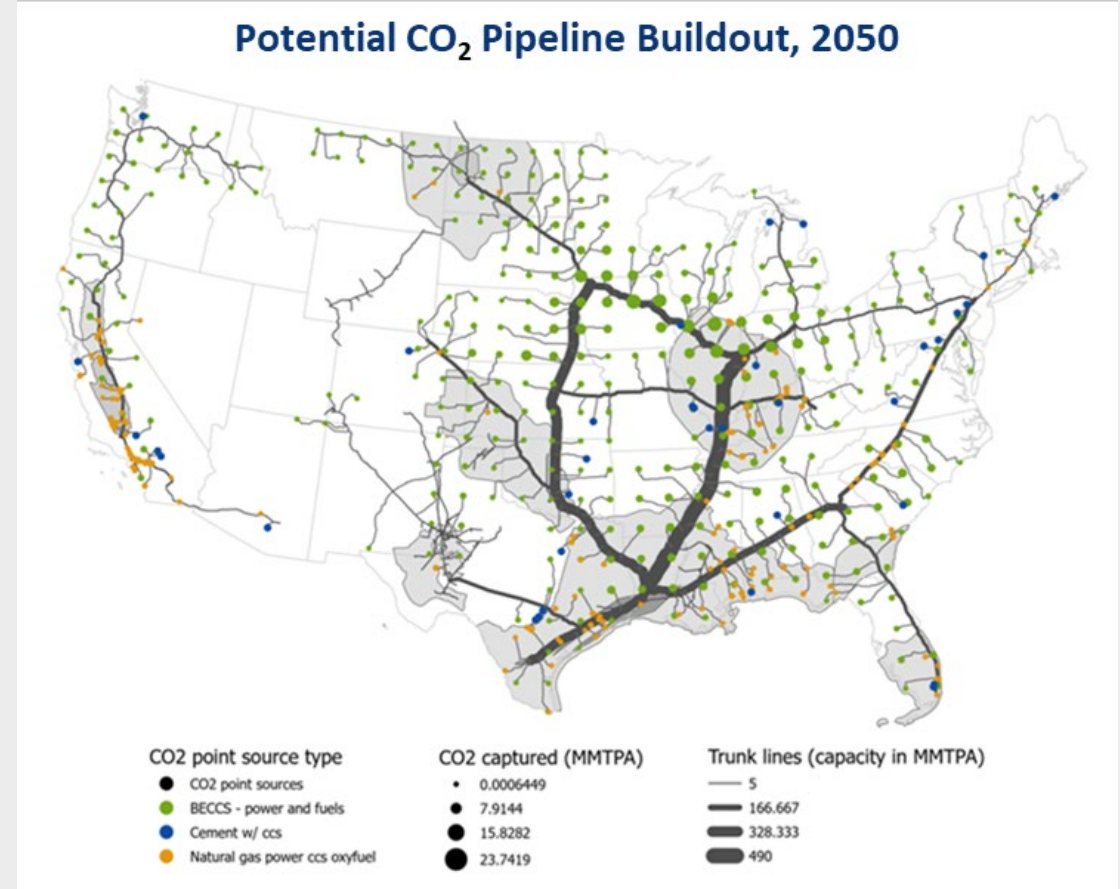
Why Carbon Capture?

- 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

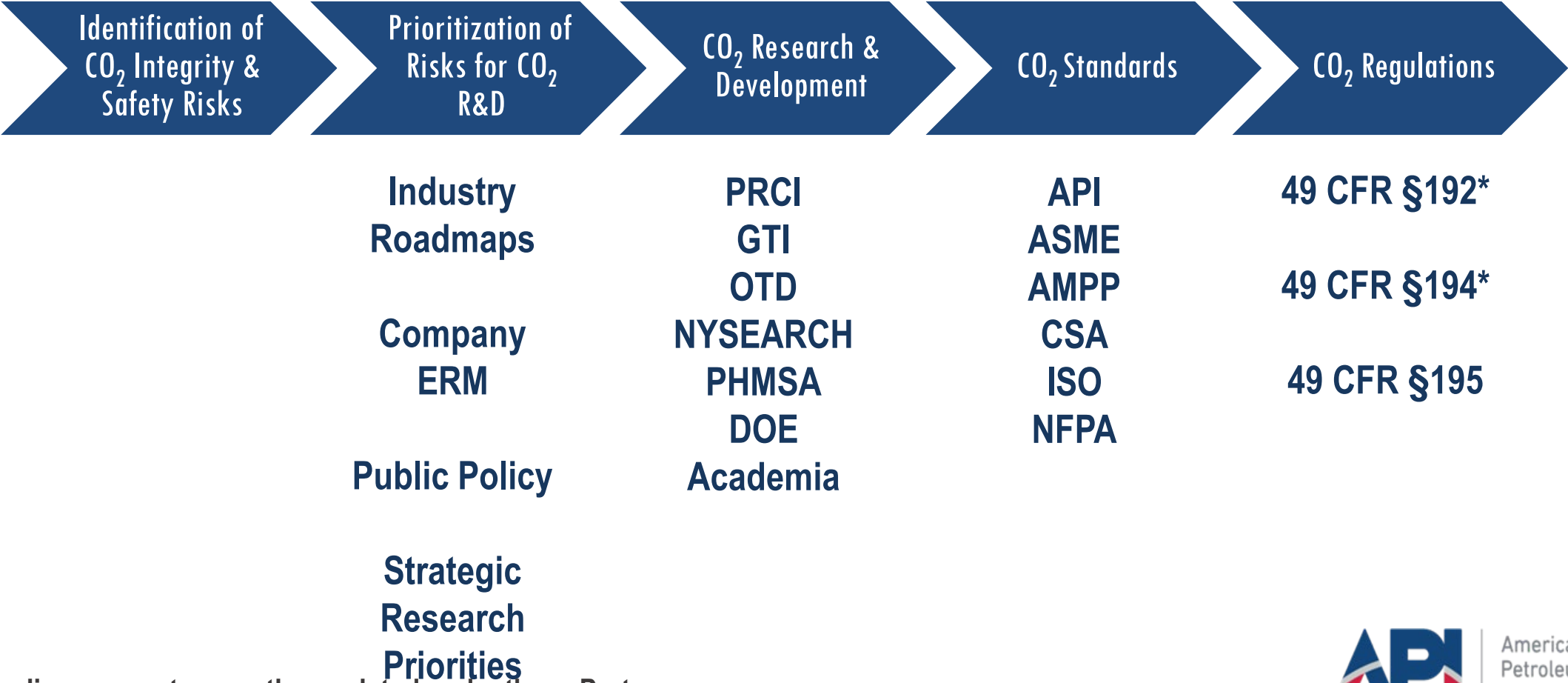
The *Inflation Reduction Act* increased the tax credit value for both capture and storage as well as utilization to levels that unlock economically viable opportunities to develop CCS/CCUS at scale

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.)



Technology & Innovation Lead to Improvements in CO₂ Pipeline Safety



* CO₂ pipelines are not currently regulated under these Parts

Driving Safety of CO₂ 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
- CO₂ emergency response tactical guide created and published

API actively working on new CO₂ pipeline standard and updating others as appropriate

- **Regulations**

- PHMSA regulates H₂ pipelines under 49 C.F.R. Part 192



Pipeline Safety STARTS WITH YOU

API Pipeline Standards



Pipeline SMS



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 Hydrate 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

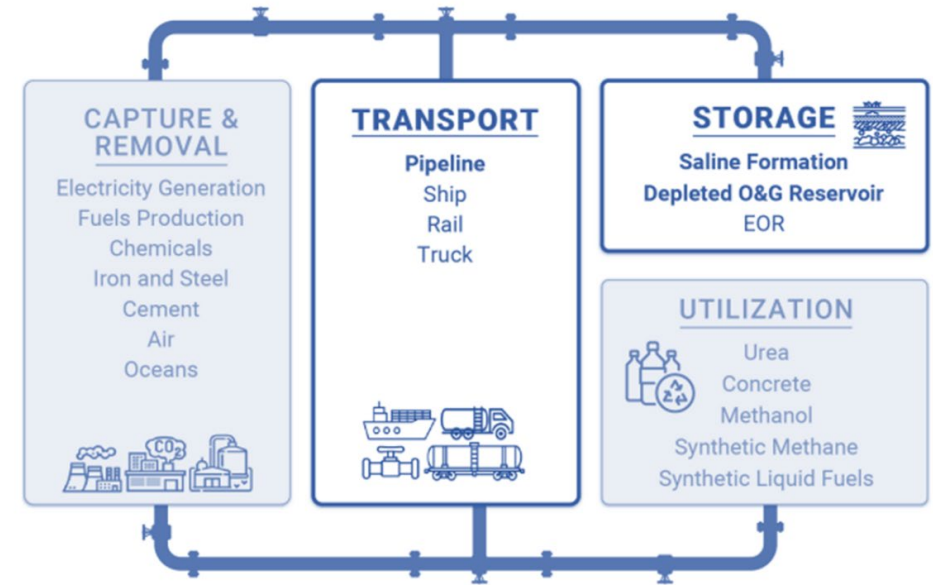
CYBERNETICS AND CONTROL ROOM

- 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)

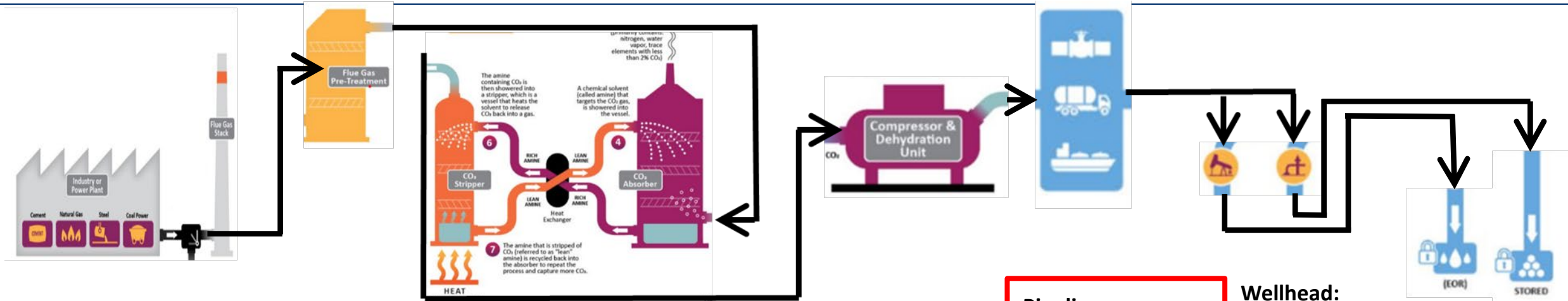
CO₂ Pipelines

- **Pipeline Safety**
 - DOE & PRCI CO₂ pipeline safety workshops – industry roadmaps developed & consistent
 - PRCI CO₂ 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 CO₂ Pipeline RP – coordinating with ASME, AMPP, DNV, ISO, IOGP, others as appropriate**
 - **CO₂ 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



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

API CO2 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)

CO₂ Pipelines

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- **Permitting**
 - Significant challenges to CO₂ pipeline permitting
 - Midwest states public opposition
 - Preemption, eminent domain, setback, and other state and local issues
- **Emergency Response**
 - Published Tactical Guidelines for CO₂ Emergency Preparedness/Response
 - NASFM Training Portal
 - Texas A&M TEEX CO₂ pipeline training
- **Public Engagement and Education**
 - Working with all stakeholders
 - RP 1185 – will be an important element of CO₂ pipeline infrastructure build out
 - Roll-out and “How To” guidelines
 - Benefits of Pipeline Campaign



PIPELINE PUBLIC ENGAGEMENT

RECOMMENDED PRACTICE 1185

INTRODUCTION

Recommended Practice (RP) 1185 for Pipeline Public Engagement will help pipeline operators input from the public on proposed and existing pipelines. RP 1185 provides a scalable and flexible framework with implementation specifics dependent on the type, size and location of a pipeline, existing programs already in place.

NEW AND DIFFERENT

RP 1185 goes beyond traditional public awareness one-way information flows from a pipeline to the public. RP 1185 will help pipeline developers and operators proactively engage the public way conversation, providing equity and inclusivity for input from a broader range of the public, different perspectives and potential concerns.

BENEFITS

- Everyone can develop relationships, build trust and achieve meaningful involvement in the engagement process
- Operators gain perspectives and information needed to consider, develop and operate pipelines within their community
- Public participants learn about, better understand, and share their perspective pipelines in or proposed for their community

STAKEHOLDERS

- Pipeline operators
- Developers of proposed pipeline projects
- Interested parties in the public
- Governments
- Rights holders

TYPES OF COVERED PIPELINES







- Existing hazardous liquids
- Existing gas transmission
- Proposed hazardous liquids
- Proposed gas transmission
- Gathering pipelines

ENGAGEMENT ELEMENTS

RP 1185 includes six elements to apply when engaging the public at any point in a pipeline's lifecycle, from early design and siting, through operation, maintenance and emergency response, to abandonment and decommissioning.

COMMIT AND ALIGN	Describes how operators, through their management, demonstrate the organization's commitment to stakeholder engagement.
IDENTIFY, UNDERSTAND AND CONFIRM	Describes stakeholders who should be the subject of engagement.
PLAN AND PREPARE	Describes how operators get ready for stakeholder engagement activities.
SHARE INFORMATION	Describes what operators should share as part of baseline information.
ASK, LISTEN AND RESPOND	Describes how operators engage with stakeholders.
MONITOR, EVALUATE AND ADJUST	Describes how operators assess, document, verify and improve stakeholder engagement performance.

CORE PRINCIPLES

 OPENNESS AND TRANSPARENCY Frank discussion, sharing of truthful, timely, and relevant information, and willingness to listen and learn and nurturing an environment of transparency.	 INCLUSIVENESS A deliberate effort to involve parties interested in the subject or action.
 RESPECT Considering and respecting others' points of view by listening to questions, understanding concerns, and allowing each other to share perspectives.	 ACCESSIBILITY Commitment to provide a variety of methods and opportunities for all interested stakeholders to participate.
 RECIPROCITY Communication and action for mutual benefit, listening as well as speaking, being responsive to inquiries and interests, and sharing responsibility for interactions and relationships.	 EQUITY Deliberation and decision-making that take into account the needs, circumstances, and resources of all stakeholders.

Thank you for the opportunity to share information on this important industry topic.



CCS Research in Industry & Academia

Mohsen Achour, ConocoPhillips

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- DNV
- IFE/OLI – Norway
- Ohio University ICMT



WHEN TRUST MATTERS



DNV Led CO₂ / CCUS JIPs



Summary of DNV Led CO₂ Pipeline JIPs

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Title	Topic	Timeline
CO ₂ Safe & Sour	Integrity of pipelines subjected to H ₂ S from CCS. Sulfide stress cracking/hydrogen embrittlement. Corrosion	2022 – 2024
CO ₂ SafePipe	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/CO ₂ 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 ₂ GASMET 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 ₂ LIQMET 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 ₂ Dispersion)	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

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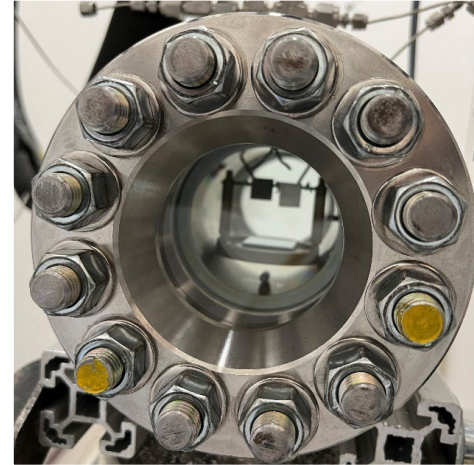
JIP #1: Kjeller Dense Phase CO₂ Corrosion IV (KDC-IV) - Objective

- Provide a tool for simulation of solubilities and chemical reactions in dense phase CO₂ by extending the capabilities of the OLI thermodynamic model to include reactions in dense phase CO₂.
- 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 CO₂ transportation system.

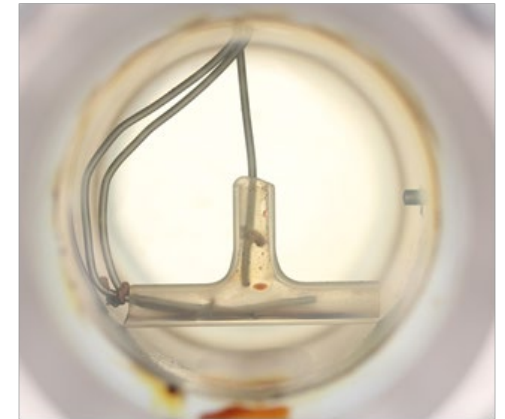
JIP #1: KDC-IV ... Scope

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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



(a) 20 hours: SO_2 / O_2



(e) 102 hours: All impurities

Extensive laboratory capabilities with close control of impurities in dense phase CO_2

*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

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Participants

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

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- 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

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- High temperature testing, up to 120 °C
- Other impurities; effects on partitioning and corrosion
 - Determine acceptable limits for NO₂, SO₂, CO and H₂S 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 O₂ partitioning
 - Expand the temperature range
 - Explore the pressure dependence
- Look into the consequence of large O₂ 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 O₂

JIP # 2: KDC-IV ... Participation & Timeline

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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

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Yoon-Seok Choi

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

CCT JIP Objective and Goals

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Objective: Identify and quantify the key issues which impact corrosion of materials specifically relating to the integrity of structures for the CO₂ transport pipelines.

Goals:

- To understand the effect of a wide range of impurities (O₂, SO₂, NO₂, H₂S, etc.) on **the water/acid solubility and the speciation** in dense phase CO₂.
- To develop a **thermodynamic model** for predicting the water/acid solubility and the speciation in dense phase CO₂ 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 CO₂ 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

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Scope of work

- **Part 1. Thermodynamic study:** Develop a thermodynamic model of solubility of water/acid and speciation in dense phase CO₂ in the presence of impurities like SO₂, NO₂, H₂S and O₂.
- **Part 2. Corrosion study:** Evaluate long-term corrosion behavior under water unsaturated dense phase CO₂ 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 CO₂ 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	Guidance 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 CO2 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

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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 CO2 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