WHEN TRUST MATTERS

Enabling CCUS Technology

Knowledge Gaps & Technology Opportunities

Jeff/Ramgo

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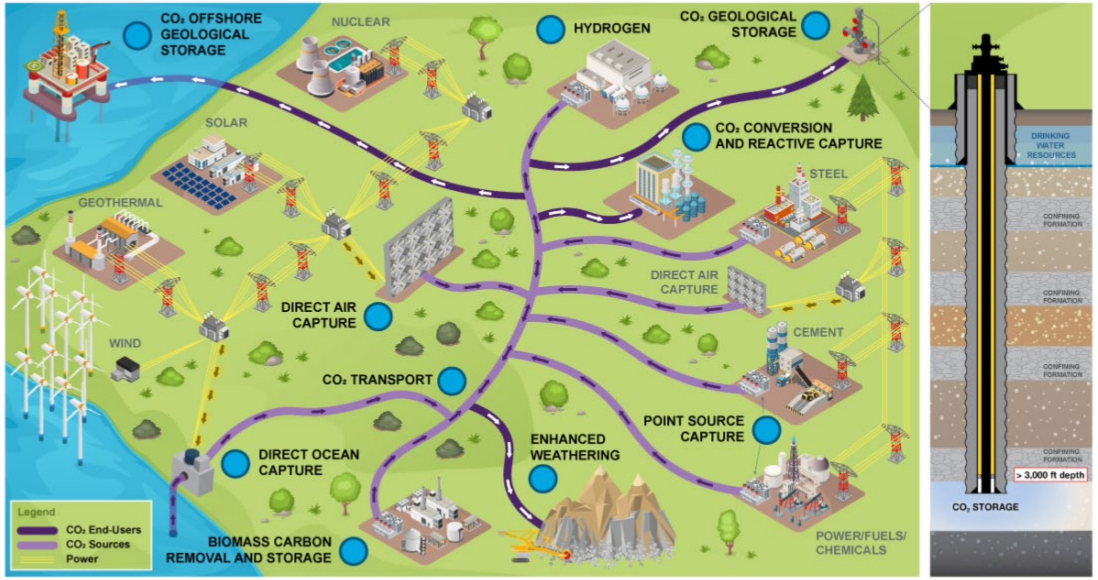
Background → Drivers for CCUS

CarbonSAFE Targets	2025 VALIDATION	2030 ACTIVATION	2035 EXPANSION	2040 AT SCALE	…	2050 MIDCENTURY
Injectivity	5 million metric tons (MT)/year	65 million MT/year	250 million MT/year	450 million MT/year	…	> 1 billion MT/year
Commercial Storage Potential	250 million metric tons (MT)	2,000 million MT	7,500 million MT	13,500 million MT	…	> 30 billion MT

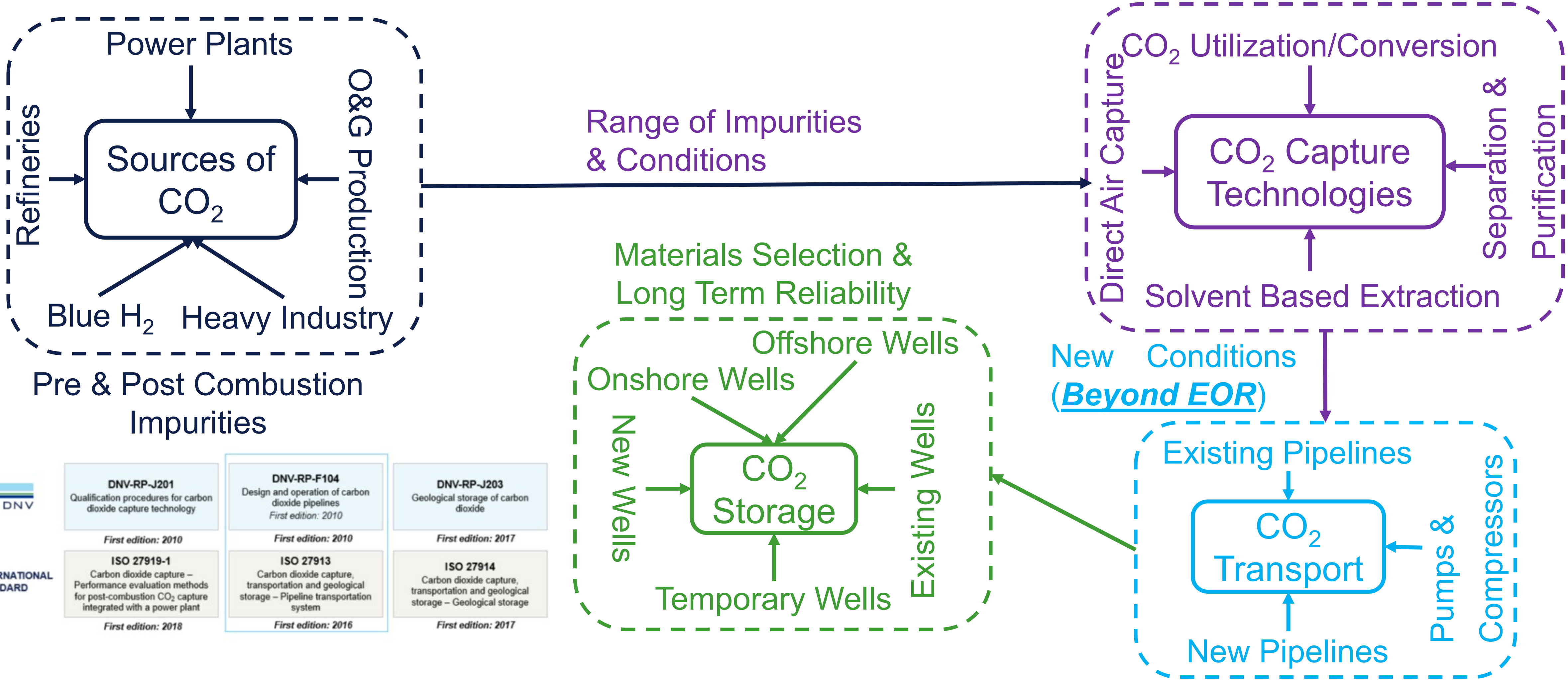
Driver for CCUS – What if we do nothing?

Model for CCUS Value Chain



Development of CCUS solutions is critical in transitioning to a clean energy future

CCUS Framework → Capture to Storage

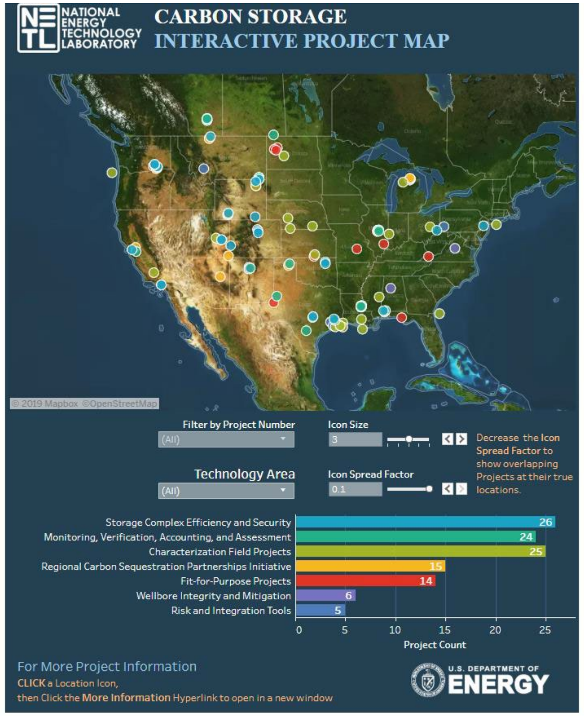


DNV	DNV-RP-J201 Qualification procedures for carbon dioxide capture technology *First edition: 2010*	DNV-RP-F104 Design and operation of carbon dioxide pipelines *First edition: 2010* *First edition: 2010*	DNV-RP-J203 Geological storage of carbon dioxide *First edition: 2017*
INTERNATIONAL STANDARD	ISO 27919-1 Carbon dioxide capture – Performance evaluation methods for post-combustion CO_2 capture integrated with a power plant *First edition: 2018*	ISO 27913 Carbon dioxide capture, transportation and geological storage – Pipeline transportation system *First edition: 2016*	ISO 27914 Carbon dioxide capture, transportation and geological storage – Geological storage *First edition: 2017*

Public Safety & Acceptance → Structural Reliability → Material Reliability → Commercial Viability

DNV

Background → CO_2 Transport

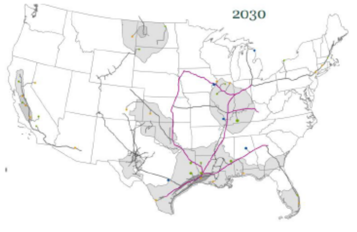


CO2 Transport Modeling

Today: 5,300 miles of pipelines

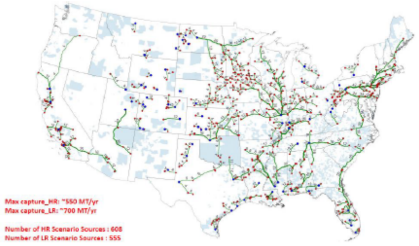
NPC: Meeting the Dual Challenge (2019)

2030: 11,000+ miles of pipelines



Modeling from Princeton's Net-Zero America Study (2020)

2050: 25,000+ miles of pipelines

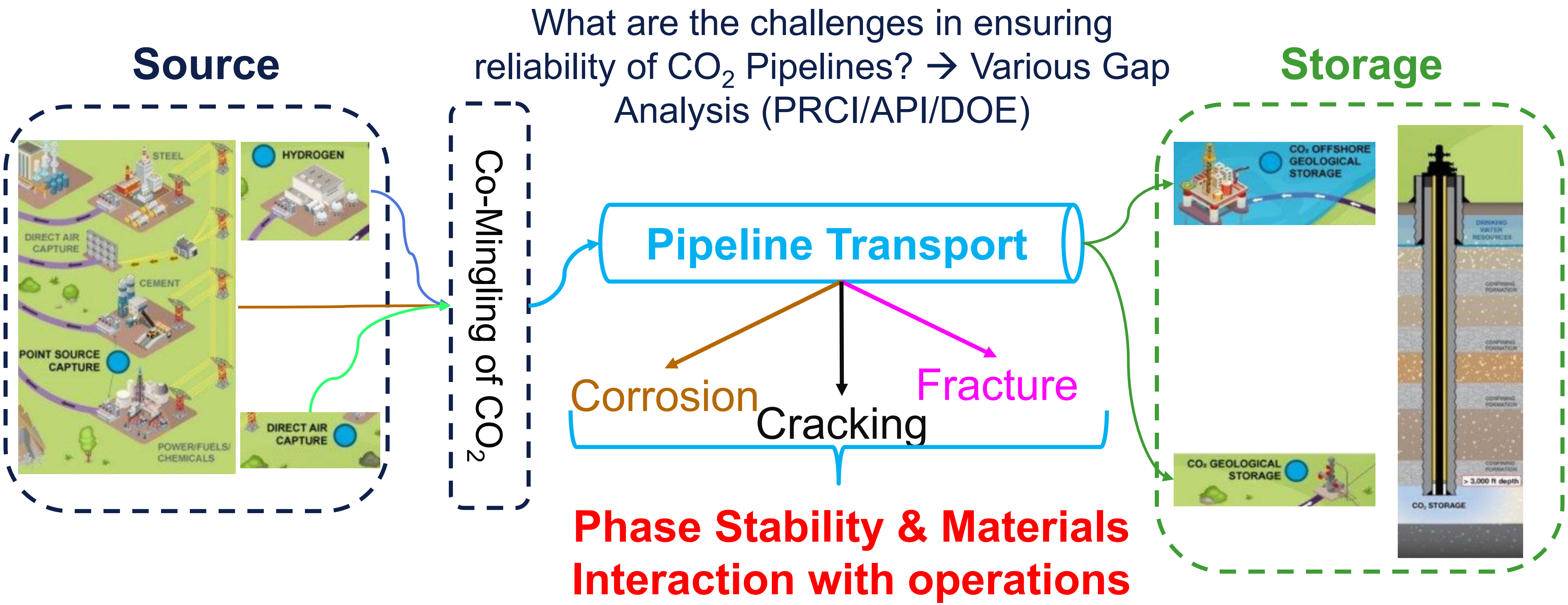


Modeling from Los Alamos National Laboratory (2022)

- Sites for carbon storage are far removed from sources of emission.
- Enabling transport of CO_2 from source to storage will be critical in achieving net zero by 2050
- Achieving net zero by 2050 will require repurposing and building new pipeline infrastructure for CO_2 transport

What are the considerations for repurposing and building new pipeline infrastructure for CO_2 transport?

CCUS → Transport



Defining the challenges (Knowledge & Technological) of CO_2 pipeline transport

Developing a framework to address the challenges

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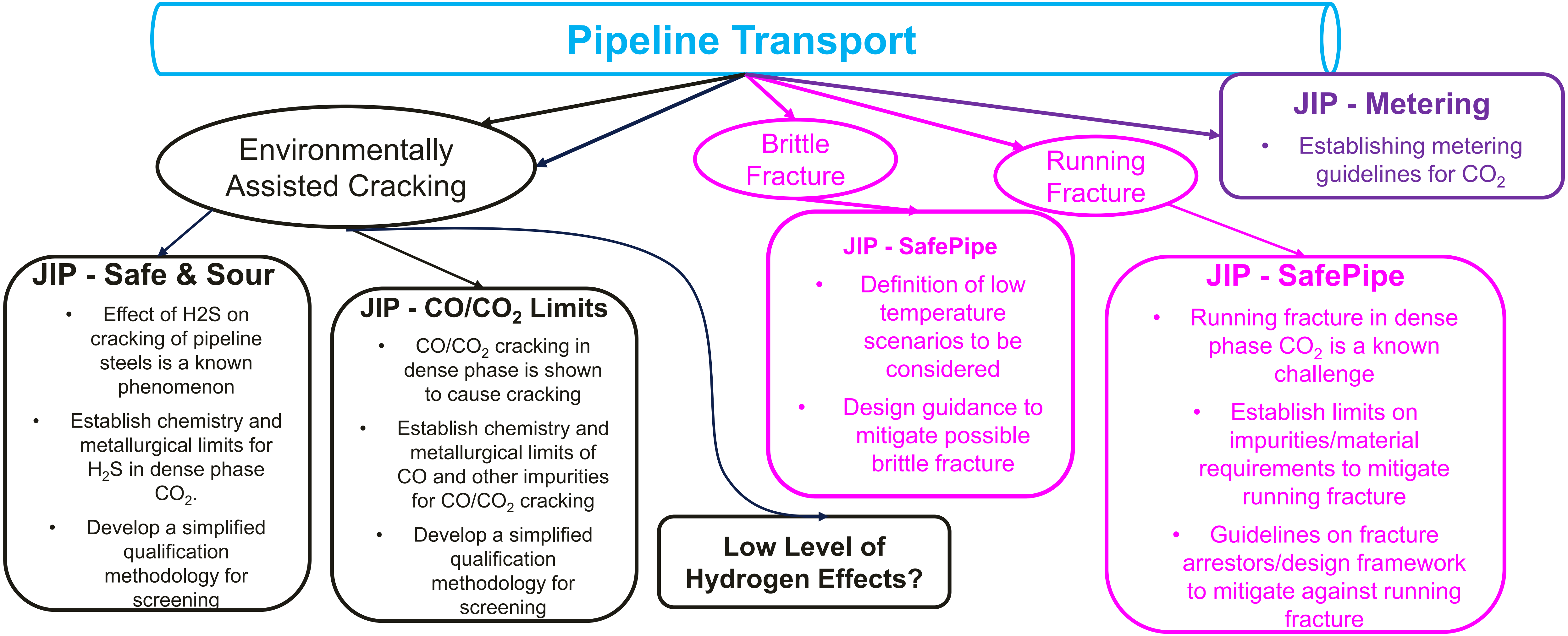
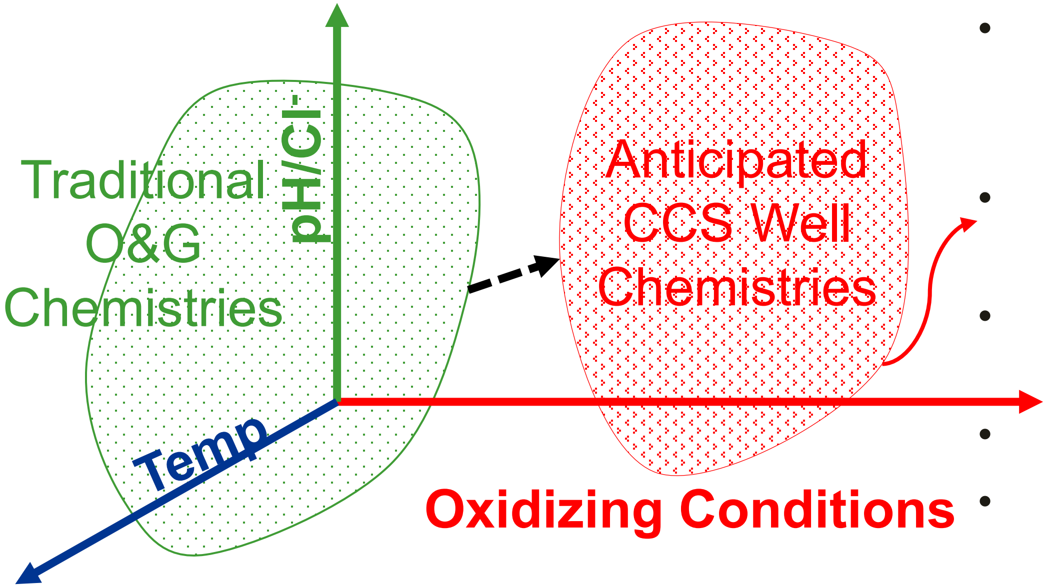
CCUS → Transport Solutions → DNV Lead Efforts



Development of Guidelines and RP's for CO_2 Transport → Critical to success of CCUS

CCUS → Storage



Challenges with CCUS wells

- How does current experience with O&G wells translate to CCUS wells?
- Varying CO_2 compositions → What should the limits be?
- Materials Selection for well materials?
- Can old wells be repurposed?
- Ensure structural integrity over long time

DNV JIP – CCS Wells → Materials Challenges

- Establish environmental windows for various well materials in CCS applications?
- Help in defining gas quality specifications for injection
- Development of a framework to evaluate long term materials performance

CCUS wells will require mapping existing damage mechanisms in a new set of conditions

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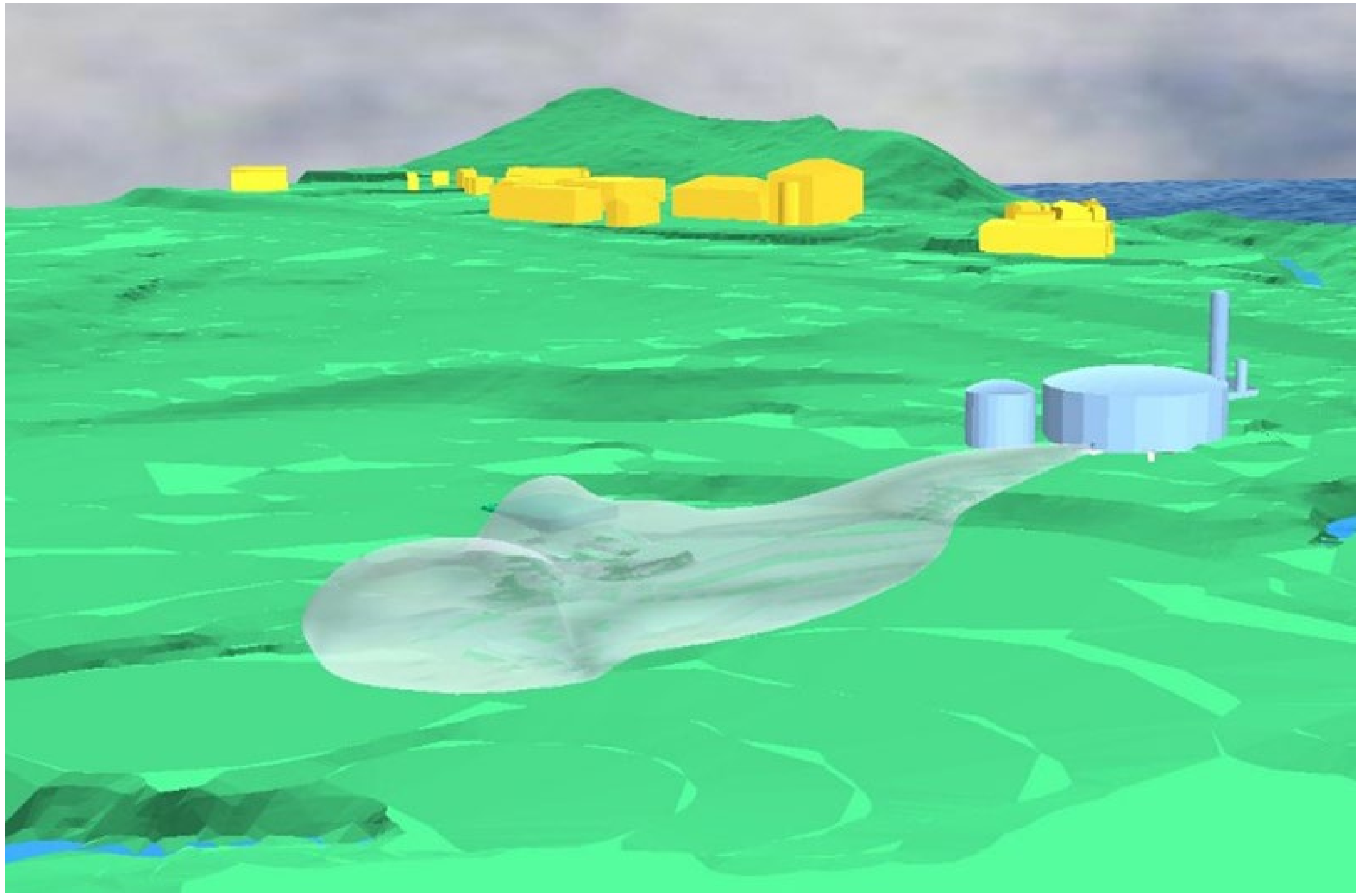
CCUS → Dispersion Modelling & Safety

Societal Concern: CO_2 is heavier than air and will replace air near the ground. Releases of CO_2 will therefore typically follow the contours of the terrain and accumulate in pits, valleys and other lower-lying grounds and consequently represent a significant hazard in these areas.

Challenge: CO_2 is typically stored as liquid and can potentially cause multi-phase flow, including dry-ice formation and sublimation when released. The complicated flow physics and thermodynamics impact the dispersion pattern significantly.

Outcome: Modelling and validation of the complex thermodynamics and heat transfer processes for release of liquid CO_2 are a must. This includes the dry ice formation of released CO_2 in atmosphere, deposit of dry ice (solid CO_2 particles) on the ground and in complex geometries, sublimation of dry ice, when also accounting for wind conditions.



Key Takeaways

Knowledge Gaps

- Role of impurities on phase stability & speciation
- Fundamental understanding of damage mechanisms of pipeline and wells materials in CO_2 environments

Technology Gaps

- Development of guidelines on impurity type and level to mitigate various damage mechanism
- Defining materials limits for CO_2 pipelines
- Design requirements for CO_2 pipelines
- Recovery from Upsets → Can performance be recovered if so how quickly?
- Defining processes and procedures for consequence modelling to ensure safety to public and surroundings

Ongoing Efforts

- Gap Analysis for CO_2 Transport
  - PRCI/API/DOE
- DOE Initiatives
  - Developing a program within DOE to engage national labs/industry
  - Development of a consortia
- Industry Lead Efforts
  - Joint Industry Programs to address
    - Running fracture
    - H_2S and CO limits
    - Limits for CCUS wells

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