

Safe CO₂ Operations – Key Considerations (Major Accident Hazards)

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Key Message

“There is **no reason** why the **major accident risks** from a CO₂ handling system within a CCS operation **cannot** be low and well **within acceptable limits**.

To **achieve this** will require the **application** of **existing** rigorous **hazard management** processes combined with an **adequate understanding** of the properties and behaviours **of CO₂**.”

Existing Industry Guidance



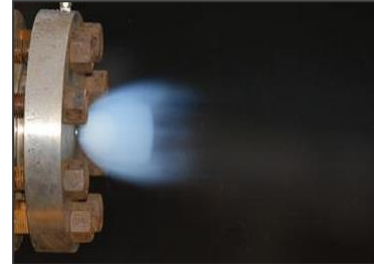
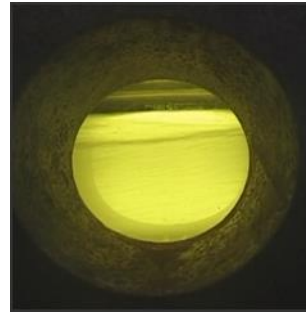
“Guidance on CCS CO₂ Major Accident Hazard Risk Management”

Developed by DNV GL and the following organisations:

- Air Liquide
- AMEC
- Chevron
- Environment Agency
- E.ON
- Gassco AS
- Gassnova SF
- Global CCS Institute
- Health & Safety Executive
- IEAGHG
- Institute for Studies and Power Engineering
- Maersk Oil
- National Grid
- Petroleum Safety Authority
- Scottish Environment Protection Agency
- Shell

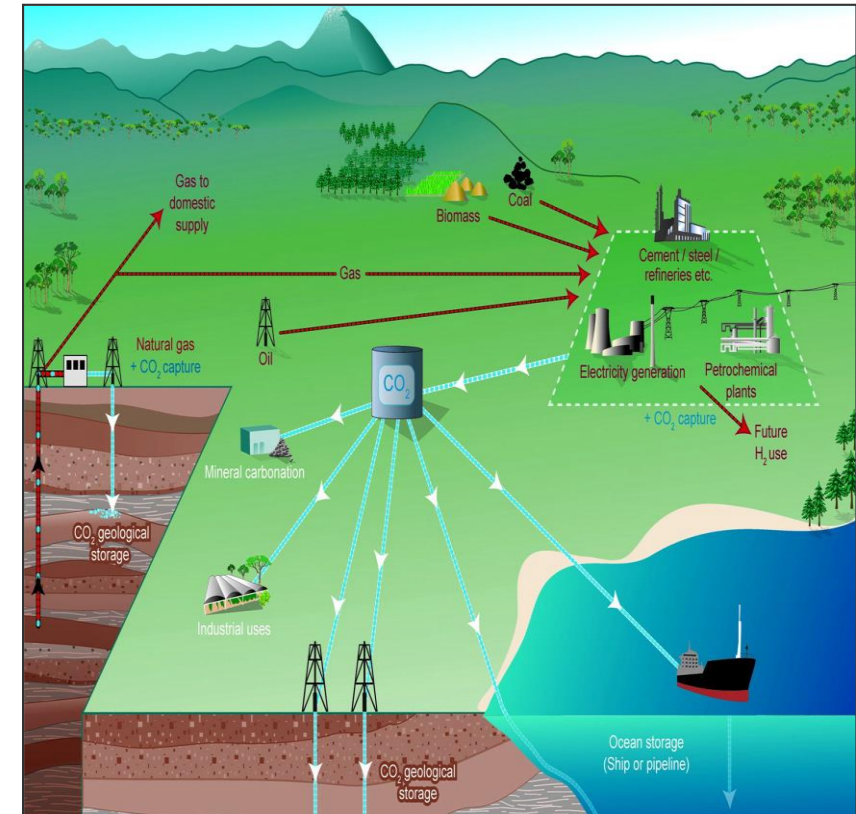
Downloadable from: www.dnvgl.com/ccus

Knowledge Gain – Spadeadam Large Scale CO₂ Releases



CCUS CO₂ Context

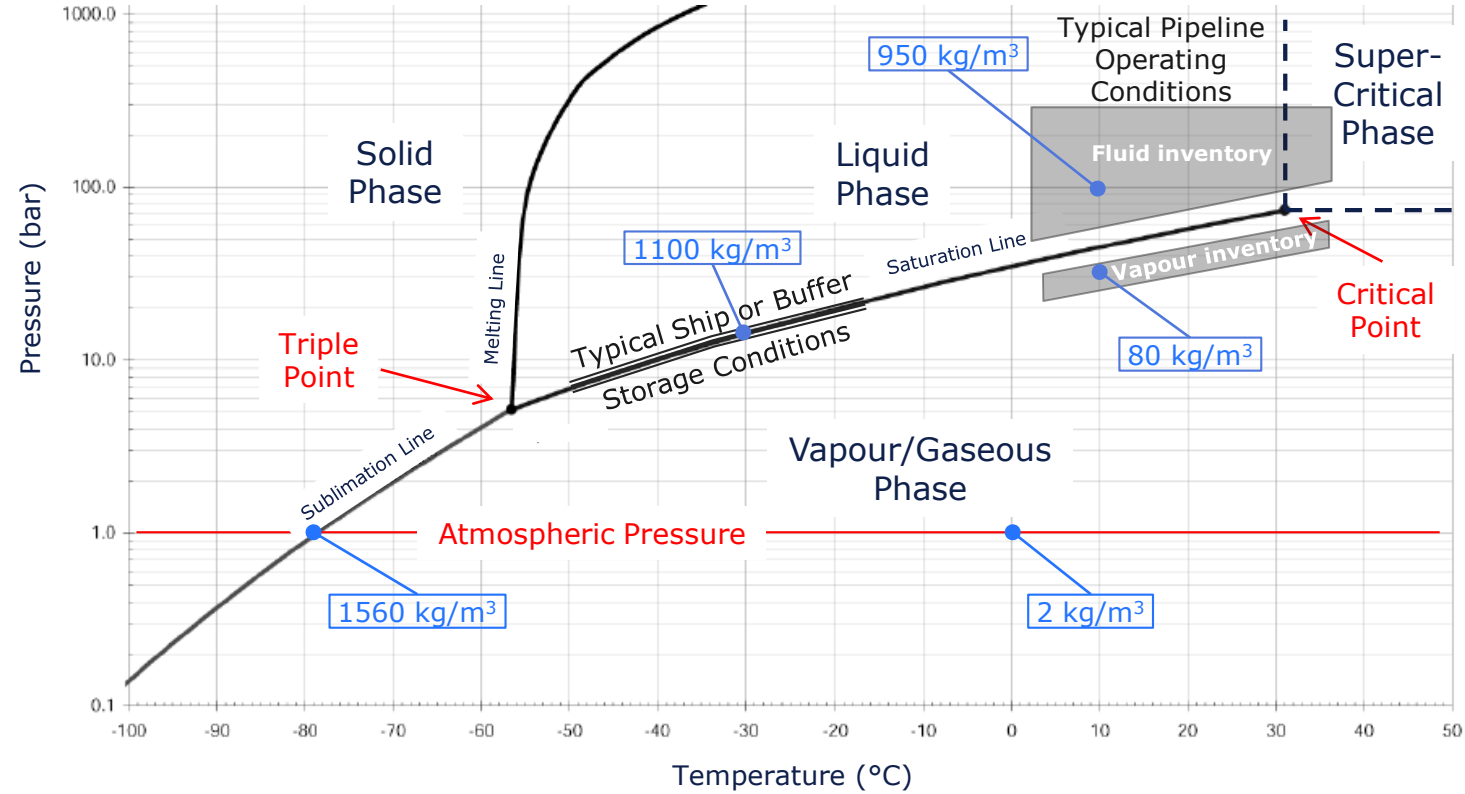
- Very large inventories of CO₂
- Transitions between gas, liquid and supercritical phase CO₂
- Geographical spread across land and subsea
- Point to point and integrated clusters
- Pipelines & ports located near populated areas
- Different stakeholders along the CCUS chain
- Dependency between links for hazard management
- New, untried or scaled up technologies
- Lack of experience and/or misplaced cross-industry learning
- Impurities vary considerably between sources
- Uncertain major accident regulatory oversight
- Many drivers for rapid, cost efficient and widescale deployment



Perception of some that CO₂ is not hazardous

Key Aspects of CCUS CO₂

- Pure CO₂:
 - Can only exist as a solid or vapour at atmospheric pressure
 - Depressurising liquid CO₂ will phase change to a mixture of low temperature gas and solids
 - Colourless, odourless & invisible vapour
 - Water vapour cloud only indicates chilled air
 - CO₂ vapour is heavier than air (x1.5)
 - Carbonic acid forms with water
 - Liquid & SC CO₂ are excellent solvents
 - Toxic (>5%) & asphyxiant (>50%)
- Impurities (e.g. SO_x, NO_x, H₂, N₂, etc.) change phase envelopes and the above



Example inventories:

- 100km 90cm dia pipeline – gas phase: ≈5,000 tonnes CO₂
- 100km 90cm dia pipeline – liquid phase: ≈60,000 tonnes CO₂
- 10m high 20m dia storage tank – gas/liquid phase: ≈3,500 tonnes CO₂

Major Accident Potential !

Generic Knowledge For Specific CCUS Developments

CO2RISKMAN Level 3 – Table of Contents

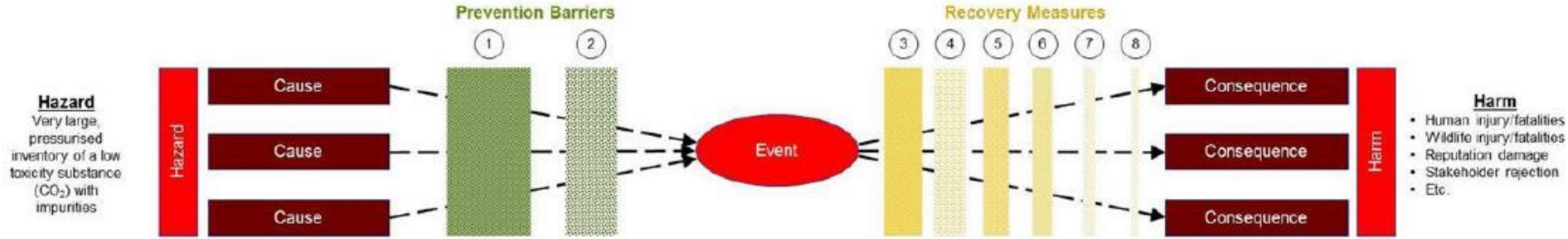
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Generic Bow-Tie Diagram

- Possible Event Causes**
- Lack of hazard awareness
 - Low temperature due to:
 - Rapid depressurisation
 - Flow restriction
 - Release impingement
 - Internal corrosion due to:
 - Free water
 - Hydrate melt
 - Impurities
 - Overpressure due to:
 - Upstream or system upset
 - Thermal expansion
 - Solid CO₂ sublimation
 - Vent or PSV blockage
 - Fluid hammer
 - Inappropriate operator action
 - Inappropriate maintenance activity
 - Inappropriate 3rd party equip
 - Inappropriate material
 - Process control error or fault
 - Inappropriate components
 - General causes including:
 - Design or fabrication defect
 - External corrosion
 - 3rd party impact
 - Adjacent event
 - Natural events
 - Cyclic loading
 - Excessive vibration
 - Etc.

- Event – Loss of Containment**
- Without escalation
 - With immediate escalation in the form of:
 - BLEVE
 - Propagating crack
 - With delayed escalation in the form of:
 - Cold temperature impingement of:
 - CO₂ system
 - Adjacent system
 - Adjacent structure
 - Road traffic accident due to vapour cloud
 - Helicopter crash at offshore platform

- Possible Consequences**
- To humans:
 - Inhalation of hazardous CO₂ concentrations
 - Inhalation of hazardous impurity concentrations
 - Inhalation of very cold air mixture
 - Exposure to very cold air mixture
 - Contact with very cold surfaces
 - Impact from rapid expansion
 - Impact from projectiles
 - Lack of visibility
 - Loss of structural integrity of surroundings
 - To environment:
 - Fauna – similar to humans
 - Flora – local damage due to cold, energy release, projectiles, etc.
 - Other:
 - Shutdown of operation
 - Cost of recovery
 - Fines and penalties
 - Negative publicity
 - Etc.



- Possible Event Prevention Measures**
- Inherent Safety**
 - Lower pressures
 - Fewer leak points
 - Reduced maintenance interventions
 - Simplified processes
 - System designed to fail safe
 - Minimised start/stop & non steady state operations
 - Heightened human error tolerance
 - Designed for worse case conditions
 - Additional corrosion allowances
 - Increased safety factors
 - Minimised need for active protection measures
 - Vent & pressure relief systems designed to prevent too rapid or uncontrolled depressurisation
 - Locating systems away from sources of physical and thermal impact
 - Etc.
 - Prevention Measures**
 - Ensuring suitable personnel competency
 - Clear concise and robust procedures and instructions
 - Training & exercises
 - Appropriate design codes & standards
 - Design for worse case temperatures
 - Ensuring materials selected are suitable for all exposed substances, conditions and change of conditions
 - Process control designed to prevent out of design specification situations
 - Alarms to provide early warning of potential hazardous situations
 - Effective corrosion management
 - Thermal impact protection
 - Physical impact protection
 - Knowledge based inspection test and maintenance
 - Effective management of change
 - Relief systems to prevent over pressurisation
 - Clear system labelling and identification
 - 3rd party education
 - Pipeline surveillance
 - Etc.

- Possible Event Recovery Measures**
- Inherent Safety**
 - Minimise inventories
 - Minimise hazardous levels of impurities
 - BLEVE envelope avoidance
 - System designed to fail safe
 - Reduced manning in vicinity of systems
 - Segregation by distance, physical barriers and elevation between inventories and potential receptors of harm
 - Routing of lines / positioning of equipment for protection
 - Open / naturally ventilated areas
 - Topography used to minimise leak consequences
 - Reduced congestion around systems
 - Elevated HVAC intakes
 - Multiple diverse escape routes
 - Muster areas located at a higher elevation than systems
 - Prevailing wind directions used to minimise leak consequences
 - Explosion & energy release venting
 - Etc.
 - Detection & Warning**
 - Ensuring suitable personnel competency
 - 24/7 monitored control systems
 - Clear concise and robust procedures & instructions
 - Training & exercises
 - Process control leak detection
 - CCTV, CO₂ and thermal imaging & detection
 - Effective and appropriate detectors
 - Portable and personal detectors
 - Visual detection
 - 3rd party education and detection
 - Process alarms
 - Audible & visual alarms
 - Hardwired & mobile communication
 - Clear instructions & information given out
 - Broadcast announcements
 - Etc.
 - Severity Reduction (Control Measures)**
 - Ensuring suitable personnel competency
 - Clear concise and robust procedures and instructions
 - Training & exercises
 - 3rd party education
 - Clear instructions & information given out
 - Personal detectors
 - Wind direction indicators
 - Active forced air
 - Physical protection of safety critical systems
 - Physical protection of escalation sources
 - Use of low temperature materials
 - Suitable escape routes with appropriate signage and lighting
 - Positive pressure safe areas
 - HVAC shutdown
 - BA sets and alternative building air supplies
 - Personal protective equipment (PPE)
 - Banding, walls, and ground features
 - Etc.
 - Emergency Response**
 - Ensuring suitable personnel competency
 - On and off-site ER strategies developed for CO₂ stream hazards
 - Clear concise and robust procedures and instructions
 - Appropriate medical treatment available
 - Training & exercises
 - Clear instructions & information given out
 - Suitable & sufficient systems, tools, equipment, etc.
 - Recognition of invisible CO₂ accumulation hazard in low areas
 - Recognition of low temperature embrittlement of structures, walkways, etc.
 - 3rd party education
 - Etc.
 - Situation Recovery**
 - Ensuring suitable personnel competency
 - Recovery strategies developed for credible scenarios
 - Clear concise and robust procedures and instructions
 - Training & exercises
 - Special focus on avoiding rapid solid CO₂ sublimation
 - 3rd party education
 - Information provided to 3rd parties
 - Etc.

Regulatory Oversight

- Where?
 - When the CO₂ mass inventory is above a defined threshold to cause a major accident
- Why?
 - To provide a clear, consistent, and risk-based requirements
 - To ensure the major accident hazard risks are effectively managed down to an acceptable level
 - To help gain and maintain public acceptance
 - To help avoid “knee jerk” regulations after the first significant major accident
 - To help ensure the long term success of CCUS
- How?
 - Existing major accident regulations are available for adaption (e.g. COMAH, PSR & SCR)
 - Competent Authorities are already providing oversight to other major accident industries

Concluding Remarks

- Some CCUS CO₂ systems will have the potential to cause a major accident
- Properties and behaviours of the CO₂ stream will cause or contribute to a major accident event
- Relevant knowledge, experience and hazard management processes exist to manage the risks
- Regulatory oversight of the major accident potential of CCUS is essential for effective risk control
- Long term success of CCUS depends on all operators delivering safe operations

" if you think safety is expensive, try an accident."

Dr Trevor Kletz – Process Safety Guru

Thank you

CO2RISKMAN Guidance downloadable from www.dnvgl.com/ccus

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