CO2SafePipe JIP: Design and Operation of CO$_2$ Pipelines

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1 ABSTRACT

As the Carbon Capture and Storage (CCS) sector is maturing and experiences are gained through R&D and projects, keeping the industry standards up to date and aligned with the latest knowledge is central to quickly tackle challenges as they arise and for the development of a cost-effective industry. This is especially true for pipelines, where both new built pipeline projects and use of existing infrastructure are key for the development of a sustainable CCS value chain. The DNV Joint Industry Project '**CO2SafePipe**' was kicked off in September 2023 with more than 20 participants. The aim is to collect industry best practice, close knowledge gaps and provide guidance towards pipeline system design, safety, operability, and transport capacity with a view to update DNV's RP-F104 '*Design and operation of carbon dioxide pipelines'* /1/ at the end. An important decision for a CO_2 pipeline system is whether the product is to be transported in gaseous or dense phase. Even though dense phase may be considered the most attractive option from a pipeline CAPEX perspective, local regulations and/or safety risk assessments may favor gaseous phase, e.g. for CO_2 gathering networks in densely populated areas. It is acknowledged that the criteria for documenting fracture arrest differ between gaseous and dense phase, also considering possible variations in CO_2 compositions and the effect on the CO_2-decompression curve. Arresting running ductile fractures in pipelines transporting CO_2 has proven to be more challenging than in transporting natural gas, and many pipelines fall outside the applicability range of the requirements laid out in DNV-RP-F104. Another topic is the impurities in the CO_2 composition. As cleaning the CO_2 from the various industry emitters comes with a cost, it is desirable to limit the need for cleaning of harmful impurity elements by keeping its composition as wide as possible without jeopardizing the risk of corrosion and material degradation. Collecting the latest R&D results and providing guidance is key to the cost-effectiveness of CCS.

2 INTRODUCTION

A Carbon Capture and Storage (CCS) value chain relies on the transport of carbon dioxide (CO_2) from location of capture to location of storage in a safe and cost-effective manner. Pipelines has to date been the preferred option for transport of larger volumes across moderate to long distances. Ship transport of CO_2 is to date limited to smaller ship sizes with small to moderate transport capacities. It is foreseen that CO_2 carriers with larger transport capacities will be developed to meet the demands of a large-scale CCS market. Hence, transport of CO_2 in context of CCS is foreseen to include both ship and pipeline transport within different parts of the value chain. The preferred options will be a function of main drivers such as transport volumes, transport distance, need for continuous transport and the expected design life of the transport value chain. For onshore transport of larger volumes, pipelines will likely be an attractive option compared to truck, rail or barge transport. Repurposing of both onshore and submarine pipelines may be an attractive option to enable reduced capex cost, ref. e.g. the Re-Stream study published in October 2021 /3/, where the objective was to identify on a high level the potential for repurposing existing onshore and offshore pipelines (within E27, UK and Norway) for transport of either H_2 or CO_2.

Since the CCS industry is still in the springtime of life compared to oil and gas, it is essential to develop safe and cost-effective solutions for both new build assets and existing assets to ensure the sustainability of the CCS value chain. As the sector matures and experiences are gained through R&D and projects, it is crucial to keep industry standards up to date and aligned with the latest knowledge to quickly tackle challenges as they arise.

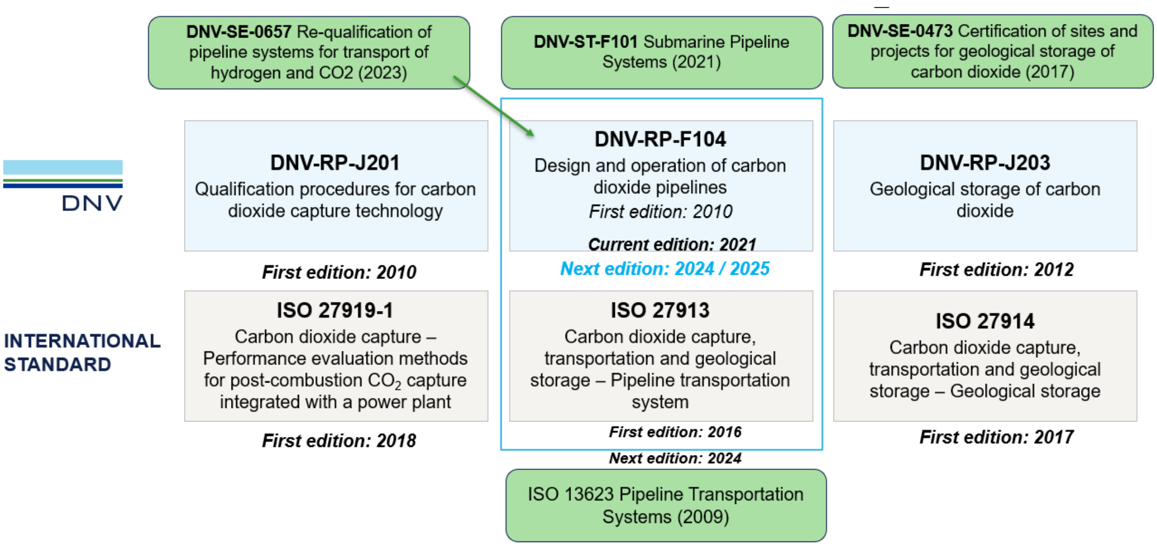
The Recommended Practice (RP) DNV-RP-F104 /1/ provides guidance on design and operation carbon dioxide pipelines. As the CCS market is moving forward, it is recognised by the industry that, based on the experience from and challenges met in recent research studies, upcoming new-build projects and studies looking into repurposing of existing pipelines, the current revision of the recommended practice does not provide sufficient guidance to meet the demands of the future.

As a response to this experience, DNV kicked off the **CO2SafePipe** Joint Industry Project (JIP) in September 2023 with now almost 30 participants, ref. **Figure** 2-1, covering the entire spread of stakeholders from operators to authorities. The aim of the JIP is to explore identified knowledge gaps which will in turn give input to the next update of the recommendations in the recommended practice. The JIP looks into 13 various topics as briefly presented in Section. 3.

Figure 2-1 Overview of participants in the CO2SafePipe JIP pr. 31.01.204

2.1 THE VALUE OF INDUSTRY STANDARDS & GUIDELINES

Industry standards, recommended practices and guidelines that ensures that materials, products, processes, and services meet the required quality. Further, they provide guidance for the safe management of pipeline infrastructure. Ultimately, they reflect industry experience and are often results of joint industry projects which establish trust and confidence between different stakeholders, authorities, and society. For pipeline transportation of CO_2, there are existing design codes that provides design criteria and guidance specifically for CO_2 transport such as e.g. DNV-RP-F104 /1/ and ISO 2791**3 /2/. Figure 2-2 p**rovides a high-level overview of existing codes across the CCS value chain within the ISO and DNV regimes.



DNV-SE-0657 Re-qualification of pipeline systems for transport of hydrogen and CO2 (2023)

DNV-ST-F101 Submarine Pipeline Systems (2021)

DNV-SE-0473 Certification of sites and projects for geological storage of carbon dioxide (2017)

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
Current edition: 2021
Next edition: 2024 / 2025

DNV-RP-J203
Geological storage of carbon dioxide
First edition: 2012

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
Next edition: 2024

ISO 27914
Carbon dioxide capture, transportation and geological storage – Geological storage
First edition: 2017

ISO 13623 Pipeline Transportation Systems (2009)

***Figure 2-2** Overview of existing DNV and ISO codes related to CCS*

3 IDENTIFIED KEY TOPICS TO BE COVERED BY THE JIP

3.1 GENERAL

The **CO2SafePipe** JIP is investigating the benefits and disadvantages of transporting CO_2 in gas phase compared to dense phase, and how the selected transportation phase impacts the design of new built pipelines or the re-qualification process for existing CO_2 pipelines. The JIP is further compiling current knowledge addressing the possibility of increasing the acceptable level of impurities without raising the risk of corrosion damage and material degradation and extending the applicability range of the running ductile fracture design requirements in DNV-RP-F104, which also includes evaluations of fracture arrestors.

Over the recent years, several operators have been considering repurposing existing pipelines for CO_2 transport. For the design of new pipelines, it is an established opinion that transportation of CO_2 in dense phase rather than gas phase is preferable, and that dense phase transportation may be required for injection into the reservoirs. However, several re-qualification studies point to transportation of CO_2 in gas phase as a needed and attractive solution. As a result, improved guidance and recommendations for selecting dense phase or gas phase have been identified as a need in the industry. Furthermore, it is desirable to limit the need for cleaning CO_2 from the various industry emitters of impurity elements by keeping its composition as wide as possible without jeopardizing the risk of corrosion and material degradation. Arresting running ductile fractures in pipelines transporting CO_2 has proven to be more challenging than in transporting natural gas (NG), and many pipelines fall outside the applicability range of the requirements laid out in DNV-RP-F104.

The work done in the JIP is split into various work packages focusing on specific topics. A brief presentation of the topics that are highlighted in the JIP is outlined below.

3.2 STATE OF CO_2 PIPELINE TRANSPORT

DNV-RP-F104 currently focus on pipeline design for dense phase operation which has been considered the most cost-effective option for long distance transport of carbon dioxide and with more than 30 years of industry experience. However, based on recent industry developments within CCS, pipeline transportation in gas phase may be an attractive option, typically for repurposing of existing pipelines with pressure rating or other features insufficient for dense phase conditions, or for carbon dioxide gathering networks. Carbon dioxide pipelines operated in gas phase may under certain conditions also be a viable option for injection to depleted oil & gas formations for permanent storage. The scope of the **CO2Safepipe** JIP intends to identify and assess topics where gas phase carbon dioxide pipelines differ from dense phase pipelines. This includes limits on pipeline safety, operational conditions (see Figure 3-1), product specification, water solubility and running ductile fracture assessment etc. The JIP intends to provide further guidance on carbon dioxide pipelines for gas phase, considering pipeline system design, safety, operability, and transport capacity.

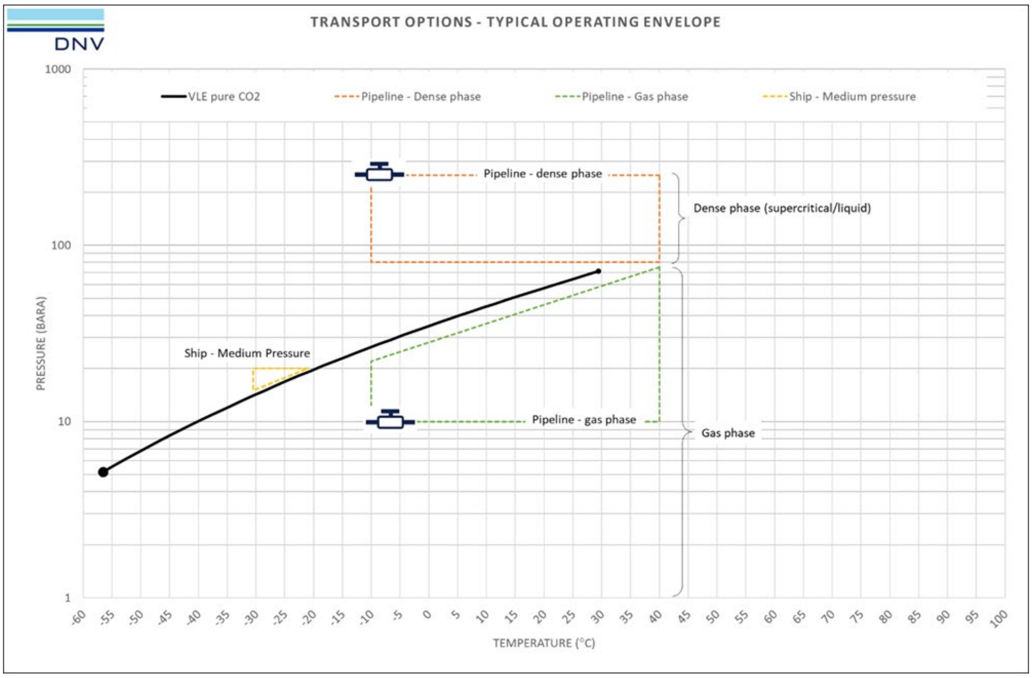


Figure 3-1 Phase envelope for 100% CO2; transport conditions for gas phase vs dense phase

3.3 CHEMICAL COMPOSITION - CO_2 SPECIFICATION:

The current revision of DNV-RP-F104 (2021) provides guidance on typical carbon dioxide compositions to be expected within the context of CCS, depending on the source from which the carbon dioxide is captured/extracted, the capture technology and the value chain. The RP also provides guidance on what the different impurities may affect, considering safety, pipeline integrity and operability. Indicative maximum levels of individual impurities are provided specifically for dense phase pipeline transport of carbon dioxide products.

As the CCS marked is now being realized and a market developed, there is increasing attention to the carbon dioxide product specification, acknowledging the implications for the entire CCS value chain from capture to storage or utilization. The recent developments take into consideration the different parts of a CCS value chain, including capture technology, liquefaction or compression, intermediate storage and ship transport as well as pipeline operation. In this context it should be acknowledged that a carbon dioxide pipeline may be located differently within the value chain, e.g. as a gas phase gathering line, dense phase pipeline directly connected to capture plant (typical for North America) or a dense phase pipeline in the final stage of a ship value chain (e.g. Northern Lights).

Aligning on the carbon dioxide product specification is instrumental to the success of developing a commercial market, considering all aspects of safety and system integrity as well as commercial and contractual agreements. With regards to system integrity across the value chain, reducing the level of various impurities to an absolute minimum would potentially be the preferred solution. However, there is a balance between what levels of impurities can practically be achieved and also measured with existing technology and to what cost and what can safely be handled within the value chain.

The **CO2SafePipe** JIP focuses on carbon dioxide pipelines and intends to provide reference to what limitations in product specification may be imposed by other parts of the value chain, e.g. associated with ship transport, storage or utilization. From a cost perspective use of carbon steel would normally be considered as the base case for pipeline material selection. In that respect, content of impurities that may impact the integrity of the pipeline needs to be controlled by for example avoid dropout of an aqueous acidic phase due to chemical reaction between inorganic gaseous with subsequent risk for corrosion and possible formation of solids.

Content of non-condensable gases may also typically affect pipeline flow assurance and running ductile fracture, particularly for dense phase operation. The guidance provided is intended to reflect carbon dioxide pipelines operated in both dense and gas phase, and cover operations from pre-commissioning through first fill to normal operation and shut down.

The work will leverage on recent and ongoing industry initiatives run by or available to DNV as well as input from the JIP members through workshop meeting(s) and review comments. This also includes learnings from DNV's ongoing **CO_2Safe&Sour** JIP that investigates the integrity of CO_2 pipelines exposed to H_2S, in a CCS setting, where testing is done to quantify the safe operating limits for H_2S content and prospective corrosion in the event of upset condition. Moreover, to validate if SSC testing at ambient conditions can be used for dense phase exposure condition.

3.4 FRACTURE ARREST

The requirement to arrest a running ductile fracture is still a concern both for new and existing pipelines. Over the last decade several full-scale fracture arrest tests have been conducted, and the conclusion is that the Battelle Two-curve method (BTCM) as applied for natural gas has been shown to be non-conservative for dense phase CO_2 pipelines. The current revision of DNV-RP-F104 presents design requirements for fracture arrest for CO_2 pipelines based on the public available fracture arrest tests, see Figure *3-2*. However, there are limitations in terms of e.g., pipe geometries and line pipe production methods causing challenges for CCS projects. In addition, a rather large minimum value of fracture toughness is required. It is therefore considered of great value to extend the applicability range of the design requirements in DNV-RP-F104, both for design of new pipelines and repurposing of existing natural gas pipelines. Addressing lower Charpy V-notch CVN toughness values and additional linepipe grades (e.g., seamless, X42-X70) should also be considered. In addition, there is a need to better determine the effect of different backfill conditions (soil, water) and the contribution to fracture propagation resistance from different coatings.

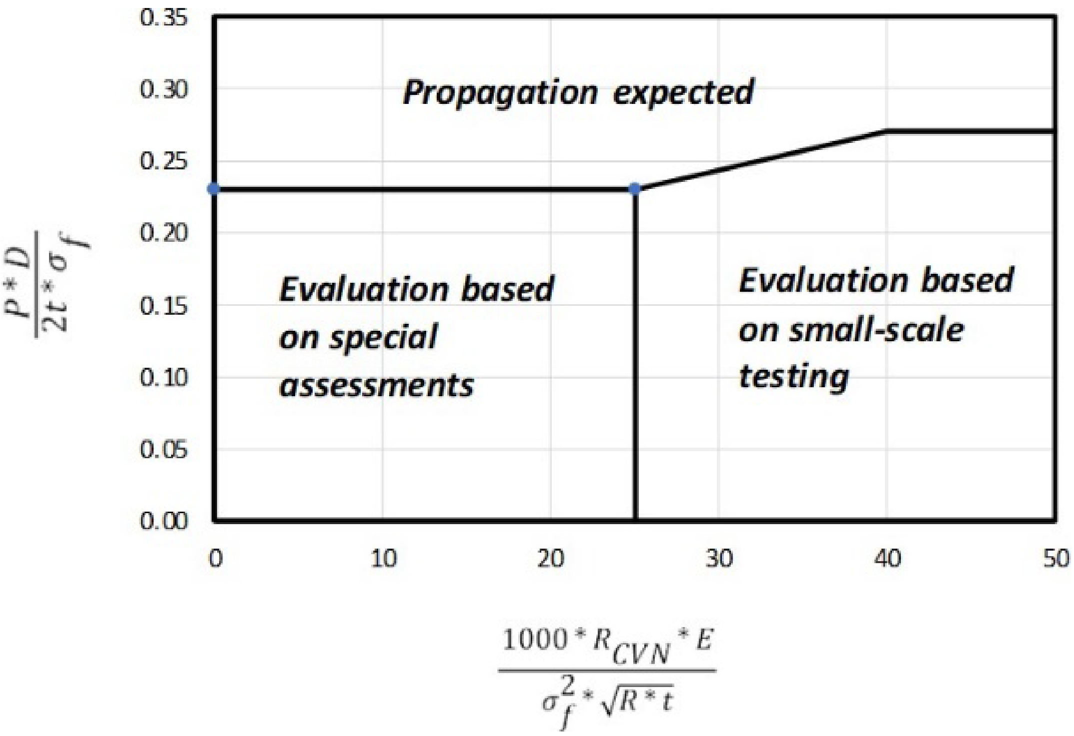


Figure 3-2. The simplified empirically based running ductile fracture model in DNV-RP-F104.

Decompression behaviour: There are also uncertainties regarding the decompression behaviour in different dense phase CO_2 compositions, and theoretical models do not fully capture experimentally observed behaviour. It is thus of interest to explore if developments are made regarding improving this discrepancy, or potentially looking onto the use of experimental techniques such as shock-tube testing to determine governing decompression behaviour.

Large-Scale testing vs reduced/smaller test setups: Large-scale testing, see Figure 3-3, has played an important role with respect to investigations of running ductile fracture, and has been instrumental in highlighting some of the challenges with dense phase CO_2. It is expected that large-scale testing will play a further important role in the development of better guidance and acceptance criteria for how to avoid running ductile fracture in CO_2 pipelines, and the JIP aims at identifying gaps regarding large-scale tests, i.e. which pipe geometries etc. which are preferably addressed in upcoming tests. However, large-scale testing of running ductile fracture typically requires an expensive multi-pipe layout, and it would be of interest to explore whether fracture arrests can be robustly documented with reduced/smaller test setups for specific cases.

Figure 3-3 Large-scale testing of running ductile fracture in dense phase CO2. Picture from the CO2SafeArrest JIP.

Numerical modelling: The JIP will also look into numerical models for simulation of running ductile fracture, and different technologies will be explored both with respect to modelling of existing large-scale test and as a basis to perform sensitivity studies to expand the knowledge of parameters affecting the problem. The objectives are to establish a state-of-the-art with respect to the use of such approaches and to provide general guidance with the respect to the potential use of such tool as complementary approaches to large-scale testing.

CO2 in gas phase: Moreover, as also identified and discussed above, there is an increasing interest in transport of gaseous CO_2, especially for onshore pipes. As a basis, the gaseous CO_2 is often considered as more similar to natural gas. Thus, it has been claimed that running ductile fracture could be assessed using the BTCM for gaseous CO_2. This claim could turn out to be correct, but it lacks a more formal evaluation in order to be subjected to stronger recommendations. Thus, there is a need to have a more formal assessment of the aspects related to CO_2 gas composition, and the possibility to enter into 'plateau regions' during the decompression. As this scenario is relevant for repurposing of existing pipelines with low toughness, it is of importance to better clarify under which conditions decompression in CO2 gaseous phase could eventually be more challenging than natural gas.

3.5 FRACTURE ARRESTORS – SOLUTIONS AND SPACING

In case fracture arrest cannot be ensured in the base material of the line pipe, fracture arrestors should be considered installed as a mean to reduce the consequences of a running ductile fracture. As per today, there are no 'off the shelf' fracture arrestor solutions that may be applied.

One fracture arrestor alternative may be to introduce pipe-sections of pipe with increased resistance to running ductile fracture at certain intervals. It is however not known how such section should be selected in terms of thickness, strength and fracture toughness. Therefore, testing of such arrestors will add value for design of CO_2

pipelines. For re-qualification of pipelines to CO_2 transport, such thicker sections may not be applicable as they involve significant installation effort including cutting of existing pipe and welding into the pipeline. Alternative for re-qualification may hence be to add clamps or similar which have less complicated installation, and such alternatives should be explored in CO2Safepipe JIP and a solution for further evaluations and testing is planned proposed.

Further, as part of the fracture arrestors solution, the spacing between arrestors and selection of location of these arrestors are essential. In the various pipeline codes, there is limited guidance on these aspects. Therefore, it is proposed to develop guidance on how to select the spacing between arrestors and the preferred locations of arrestors. Such work will consider threats to third parties as well as consequences for the operator in terms of repair/downtime.

3.6 POTENTIAL LOW TEMPERATURE BRITTLE FRACTURE

Within the industry there has been a general concern that the smaller CO_2 leaks can develop into a larger failure due to local low temperature in the vicinity of the leak caused by the cooling effect from the leaking CO_2. Leaks may be associated with equipment (e.g., seals) or pipeline through-wall cracks (e.g., fatigue cracks). The concern is that a small leak may escalate in form of brittle fracturing caused by low temperature embrittling the material. There is currently no well-established practise for how to analyse this risk and there are currently no confirmed acceptance criteria. Further progress in this respect would be of benefit for CO_2 pipeline design.

There are also scenarios that could lead to larger parts of the pipeline being cooled down to lower temperatures. There is a need to arrive at a procedure for how to assess the general criticality of such scenarios, and to what extent such lower temperatures may affect the integrity of the pipeline.

The scope and guidance will reflect the experience drawn from recent projects and industry experience.

3.7 SAFETY AND ENVIRONMENT

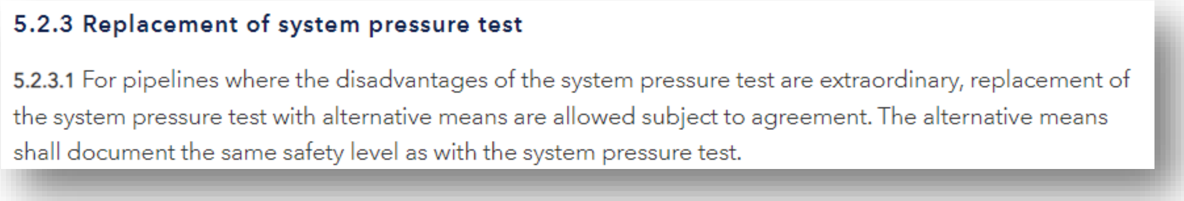
Intentional or unintentional release of carbon dioxide to atmosphere or sea/water may have implications for both safety of life and environment.

With regards to safety risk, the DNV-RP-F104 currently provide guidance on CO_2 pipeline failure frequencies and hazardous CO_2 concentrations for humans. Based on recent experience with CO_2 pipeline concept and detailed design, there is an identified need for further guidance on consequence modelling for planned or accidental CO_2 releases, onshore and subsea. For onshore pipelines the dispersion of CO_2 may depend strongly on topography due to the higher density of CO_2 compared to air. For subsea releases, the fraction of CO_2 dissolved in water column as function of water depth and release rate may significantly affect the amount of CO_2 released to sea surface. The scope of the JIP will include guidance on when semi-empirical models such as e.g. PHAST/SAFETI or similar may be sufficient, and when further detailed Computational Fluid Dynamic (CFD) dispersion simulations are recommended. Detailed CFD (KFX) modelling of a selection of representative CO_2 release cases will be included for demonstration and for comparison with semi-empirical models. With reference to pipeline consequence zone, further guidance will be provided on pipeline safety distances and pipeline segmentation.

With regards to environmental implications, it is taken as a premise that the environmental effects of pipeline construction will not be different for a carbon dioxide pipeline compared to other onshore and submarine pipelines. However, it is acknowledged that a minimum of documentation is also required to confirm potential environmental risk associated with carbon dioxide pipeline operation, considering planned and unplanned release of product. The environmental effects relate mainly to the effect of reduced pH from release of carbon dioxide to sea, rivers or wet land. Increased concentrations of carbon dioxide in seawater may affect different species to various degree. Photosynthetic algae and seaweed may benefit from higher concentrations, while other species such as clams, cold water corals and plankton may be negatively affected. Many aquatic species are made from calcium carbonate obtained from carbonate ions dissolved in water. When carbon dioxide is releases to seawater, it reacts with carbonate ions creating carbonic acid and reduce levels of carbonate ions. The ECO2 /5/ framework is applied as basis for better guidance on environmental risk assessments specifically for onshore and submarine carbon dioxide pipelines. The scope and guidance are intended to be covered by a desktop study, including workshops with the JIP participants, also leveraging on the experience from recent safety and environmental studies performed.

3.8 PRE-COMMISSIONING

The safety level of a CO_2 pipeline is closely linked to the water dew point in the CO_2 stream being held below acceptable levels due to potentially high corrosion rates in these systems. It is unavoidable that certain levels of humidity will enter the pipeline during construction activities, and the pre-commissioning activities should ensure drying of the pipeline to push the humidity level below the project acceptance criteria. While the drying stage of pre-commissioning is ultimately of the utmost importance for a CO_2 pipeline, there is an alternative pre-commissioning methodology, replacement of the system pressure test, that would provide the advantage of not introducing large volumes of water in the pipeline. This alternative is proposed in section 5.2.3.1 in DNV-ST-F101, ref. Figure 3-4. The prospect of this method being used is highly relevant for CO_2 projects on the background that introducing water in the pipeline is associated with disadvantages and calls for rigid drying procedures before CO_2 can enter the pipeline.



5.2.3 Replacement of system pressure test

5.2.3.1 For pipelines where the disadvantages of the system pressure test are extraordinary, replacement of the system pressure test with alternative means are allowed subject to agreement. The alternative means shall document the same safety level as with the system pressure test.

Figure 3-4 Excerpt from DNV-ST-F101 on replacement of system pressure test

DNV has previously run a JIP called ’Replace JIP’, that resulted in a guideline presenting a pre-commissioning methodology without the system pressure test in 2020. It is at term planned to include this methodology in the recommended practice DNV-RP-F115 ‘Pre-commissioning of submarine pipelines’.

DNV is now performing a study to clarify relevant threats by CO_2 in a pipeline and how the ‘Replace JIP’ can be relevant for such projects. This scope is intended covered by a desktop study and a risk assessment workshop with the participant of this JIP.

3.9 LEAK DETECTION

Given the number of projects in development and the large-scale plans for CCS, pipeline leak detection will play a vital role in detecting and locating leaks in the pipelines as quickly and efficiently as possible, both for onshore and offshore pipelines. Leak detection systems (LDS) are crucial for mitigating the risks associated with a leak or rupture on a CO_2 pipeline.

State of the art on various leak detection technologies for onshore/offshore pipelines transporting CO_2 in dense and gas phase will be looked into unlocking if there are different needs related CO_2 transport compared to traditional oil & gas transport divided in;

- Software-based methods use computer software packages to constantly monitor data of pressure, temperature, and flow rate for detecting leaks in a pipeline. Examples of these methods are flow and pressure change detection, mass-volume balance, dynamic-model based systems, and pressure point analysis. Current CO_2

onshore pipelines primarily uses SCADA / CPM (continuous pipeline monitoring) system that essentially monitors the pressure and flow with alarms.

- Hardware-based methods using sensors to directly detect the occurrence of a leak and assist the localization of the leak. Typical devices used are e.g. fiber-optic sensors, acoustic emission detectors, negative pressure detectors, ultrasonic technologies, and infrared thermograph.
- Traditional leak detection methods as right of way patrolling looking for unusual patterns near the pipeline, smelling substances that could be released from the pipeline, or listening to noises generated by a leakage. For subsea lines fly over with helicopters or ROVs are also a method that is used.

Relevant existing guidelines/recommended practices as e.g. DNV RP-F302 Offshore Leak detection covering various leak detection systems with focus on offshore lines and API 1175 Pipeline Leak Detection - Program Management, will also be looked into.

3.10 RE-QUALIFICATION / REPURPOSING

The potential for repurposing existing onshore and offshore pipeline infrastructure for transporting CO_2 has over the last decade been given increased attention. Both considering cost and environmental footprint, repurposing of existing pipeline infrastructure is considered as an attractive option. Repurposing will typically require a re-qualification process to confirm acceptable pipeline integrity as well as transport capacity.

The repurposing potential for pipelines for CO_2 transport depends on several factors such as location, pipeline route, product composition, operating condition (dense or liquid phase), physical condition and other factors. There are several key criteria that need to be considered carefully, and checks that need to be made, before an onshore or offshore infrastructure may be repurposed for CO_2 transport.

The requalification process is currently described by a 10-step process in DNV-RP-F104, however a strong interest for elaborating the methodology based on the latest years increase in knowledge has been shown by the industry and thus looking into how to derive on a more detailed description of the process will be performed and also align the process with the newly launched DVN-SE-0657 ‘Re-qualification of pipeline systems for transport of hydrogen and carbon dioxide’ /4/.

For a complete re-qualification project, all steps in the 10-step process, ref. Figure 3-5 should be addressed and documented. As a general rule, the re-qualification shall comply with the same requirements when it comes to safety and operation as for a pipeline designed specifically for transportation of CO_2.

Consideration shall be given to all relevant changes, i.e. between the original and new design conditions and operational parameters. The requalification may require modifications to the pipeline system itself, depending on the assessment of new risks or safety issues related to, e.g.:

- a change in the transported fluid and physical properties compared with those originally designed for
- potential interaction between the new fluid and effects on the material properties of the pipeline
- new operating conditions
- the design life and, if applicable, life extension.

A successful re-qualification requires that all safety-related challenges and impacts of the new fluid on the pipeline system are clearly defined and adequately managed. The safety and integrity requirements necessary for re-qualification shall be equivalent to those used for the design and construction of new pipeline systems used for the transport of CO_2.

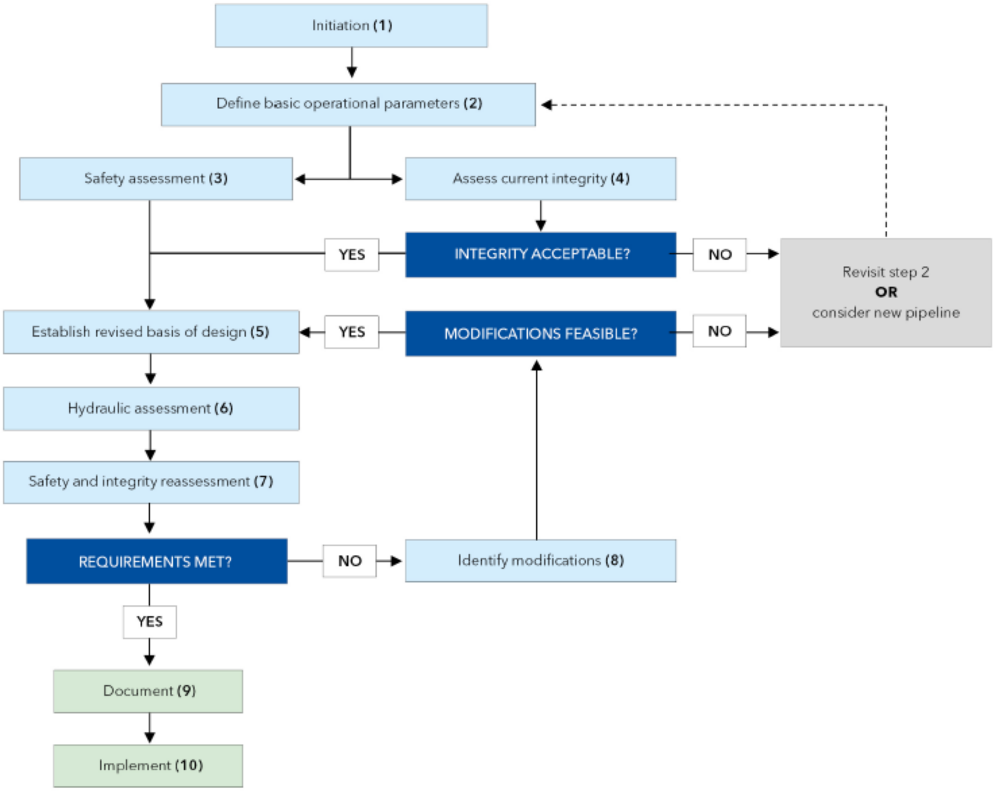


Figure 3-5 10-step process for the re-qualification of pipeline systems /4/

3.11 PRE-COMMISSIONING, COMMISSIONING AND OPERABILITY

Pre-commissioning activities are performed to prepare the pipeline system to be ready for the operation phase. This typically requires cleaning of the system and system testing activities and preparation to fill the pipeline system with the fluid intended for operation.

Commissioning activities comprises activities associated with the initial filling of the pipeline system with the fluid to be transported and should be part of the operational phase.

This operational phase involves monitoring, controlling and maintaining the pipeline and its connected systems during the transport of the product to ensure the pipeline systems integrity, efficiency and reliability during operation.

The **CO2SafePipe** JIP will identify current industry practices related to transport of CO_2 specifically. The purpose is to provide guidance on what are considered safe and cost-effective alternatives for onshore and submarine CO_2 pipelines, both for transport of CO_2 in dense and gas phase. Attention should be given to topics where CO_2 pipelines needs to be treated differently due to the nature of the product. This typically includes risk of internal corrosion, cracking and pipeline (segment) depressurization and re-pressurization. For pre-commissioning, reference will be given to DNV-RP-F115 */5/*.

3.12 SELECTION OF NON-METALLIC MATERIALS

There are several relevant applications of non-metallic materials in a CO2 pipelines system as e.g internal and external coating, non-metallic seals, lubricants etc. Additionally, the use of non-metallic pipes, reinforced or unreinforced, is an option to steel pipes, onshore or offshore. The development and qualification of thermoplastic composite pipes (TCP) has made progress during the recent years, as a viable candidate to steel pipelines.

The general challenges of non-metallic materials in CO_2 are related to permeation, swelling/extraction, incompatibility with CO_2 stream components, rapid gas decompression damage and low temperature performance. Considerable research has been done on these well-known subjects, and the knowledge database is ever increasing. In the research there has been performed several studies of in-situ performance of non-metallics in CO_2. However, there are e.g. no standardized tests to assess how swelling in CO2 affects the mechanical properties and functionality of the non-metallic.

The **CO2SafePipe** JIP will look into general state of the art of non-metallic materials in a CO_2 environment based on recent research and development, covering non-metallic seals in both new built and repurposed pipelines in addition to the effect on flow-coating in existing pipelines. It will address the effect of CO_2 both in gas phase and dense phase.

The aim is also to develop a proposal for experimental program (testing itself is however not a part of the JIP) to close gaps in knowledge on how to qualify for non-metallic applications typically covering;

- In-situ tests to assess non-metallics performance in CO_2.
- Tests to determine acceptable CO_2 stream composition, with any limitations to material selection and compatibility testing.
- Investigate safe rapid gas decompression conditions.

The work will include literature study, review of research projects and discussions with JIP-participants to provides on qualification of non-metallic coating and seals, repurposing of non-metallic applications and selection of non-metallic materials.

4 SUMMARY AND CONCLUSIONS

Use of pipelines to transport CO_2 from emitter locations to final storage locations is regarded as a backbone to reducing emissions and reaching climate goals. Industry standards, recommended practices and guidelines for design and operation of new CO2 pipelines and requalification of existing pipelines to CO_2 transport are considered the key element for scaling the CCS industry.

DNV RP-F104 provides recommendations for the safe and reliable design, construction, and operation of pipelines intended for the large-scale transportation of CO_2 that are not already covered in the existing pipeline standard DNV-ST-F101. The CO2Safepipe JIP addresses identified knowledge gaps and shortcoming for CO2 pipelines and will lead to an update of DNV-RP-F104 which in turn contributes to safe and cost-effective transportation of CO2 by use of pipelines.

5 REFERENCES

/1/	DNV-RP-F104 ‘Design and operation of carbon dioxide pipelines
/2/	ISO27913 ‘Carbon dioxide capture, transportation and geological storage – Pipeline transportation systems’
/3/	‘Re-stream – Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe’, Carbonlimit and DNV, October 2021
/4/	DNV-SE-0657 ‘Re-qualification of pipeline systems for transport of hydrogen and carbon dioxide’
/5/	DNV-RP- F115 ‘Pre-commissioning of submarine pipelines’
/6/	ECO2 Framework https://www.eco2-project.eu/