# TECHNICAL ARTICLE 3

# Technoeconomic of Repurposing Natural Gas Pipelines to Carry Carbon Dioxide: Malaysia Landscape

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Modern gas transmission pipelines are usually engineered to remain operational for the next 40 to 50 years or even more. Design considerations for transmission and distribution pipelines are different as the distribution pipelines goes through populated areas. With efficient maintenance and effective management practices, it is possible to extend the service life of the pipeline by an additional 25 to 30 years beyond its original design life. The natural gas pipelines account for about 70-80% of the global pipeline network, with the remaining shares primarily dedicated to the transportation of oil, refined petroleum and chemicals. Currently, the global network of natural gas transmission and distribution pipelines that are in operation spans about 1 million kilometres. As the global energy transition advances, the integration of renewable energy sources with existing gas systems offers a practical and efficient approach to reduce carbon footprints. Furthermore, the increasing focus on hydrogen and carbon capture, utilization, and storage (CCUS) technologies is driving the repurposing and modernization of existing natural gas pipelines.

By repurposing the existing natural gas pipelines, the costs for the activities above can be significantly minimized by leveraging the existing infrastructures that are already in place. This approach not only extends the operational relevance of the pipelines but also aligns with global decarbonization goals. The objective of this report aims to assess the techno-economic and environmental challenges that can be considered when repurposing natural gas transmission pipelines to carry $CO_2$.

## 2. Technical Feasibility

$CO_2$ exhibits unique phase behavior transitioning between gas, liquid, and supercritical states depending on pressure and temperature. The phase behavior significantly impacts its flow characteristics within pipelines. At low pressures and high temperatures, $CO_2$ exists as a gas. In this state, it behaves similarly to natural gas, with relatively low density and high compressibility. At high pressures and low temperatures, $CO_2$ exists as a liquid. This phase has a higher density and lower compressibility compared to the gas phase, affecting flow rates and pressure drops. Above the critical point (73.8 bar and 31.1°C), $CO_2$ exists in a supercritical state. This phase has properties intermediate between those of a gas and a liquid, with high density and low viscosity. The supercritical $CO_2$ can exhibit complex flow behavior, including density stratification and phase separation, which can lead to operational challenges.

The maintenance of $CO_2$ pressure and temperature within the desired phase range is crucial for efficient and safe transportation to ensure continuous flow of $CO_2$. If not controlled properly, the $CO_2$ can undergo phase separation leading to the formation of liquid and gas slugs and eventually lead to significant fluctuations in pressure and flow rates. The choice of pipeline material must consider the corrosive nature of $CO_2$. The requalification process of the pipeline for $CO_2$ transport has been proposed and documented in DNV-RP-F104 [1]. The integrity of the pipeline needs to be first assessed for its condition. Supervisory Control and Data Acquisition (SCADA) system was suggested to be identified and applied as a basis for identifying gaps towards the requirements for $CO_2$ pipelines. Following the integrity assessment, a flow assessment should be conducted to identify the feasibility of refurbished pipelines. Based on flow assessment, the requirement for modifications can be identified and evaluated. Other requirements such as additional block valves, leak detection upgrades etc. can be identified along the way.

### 2.1 Materials

All materials should withstand the operating pressure of $CO_2$. The $CO_2$ pipelines operate at pressure ranges from 1250-2200 psi (Type II and Type III pipelines), while the NG pipelines operate at pressure ranges 1200 psi and below (Type I pipelines). The specific requirements for each parameter vary depending on the type of $CO_2$ stream [2]. The choice of pipeline material has evolved over the years, which is driven by factors such as increasing pressure requirements, safety concerns, and technological advancements. Grade A and Grade B carbon steel have limited pressure-bearing capacity compared to higher-grade steels. As the natural gas industry has progressed over the years, there has been a demand for higher-pressure pipelines to transport larger volumes of gas efficiently. Higher-grade steels, such as X65 and X70, offer significantly higher yield strength and tensile strength, making them suitable for high-pressure applications. The high toughness of API 5L grades also helps resist cracking under pressure, which is crucial when transporting NG at high velocities or in regions with significant pressure fluctuations.

Low-carbon steels, like those used in NG pipelines, have an additional advantage in their weldability, making them easier to join during pipeline construction and repair. Welding is a common method used to connect pipeline segments, and materials that are highly weldable, like API 5L grades, help ensure the structural integrity of the system.

DNV-RP-F104 stated that carbon-manganese steel pipelines can be used for $CO_2$ pipelines where the water content in the $CO_2$ stream is controlled.

### 2.2 Degradation resistance

NG pipelines generally contain $H_2S$ moisture and other impurities. Impurities in $CO_2$ transport such as water vapor, oxygen, and sulfur compounds can react with the steel surface, forming corrosive compounds that weaken the material. The combined effect of $CO_2$ and its impurities can be more severe than either factor alone. The pipelines are often coated with external protective layers or internal liners to minimize corrosion. While carbon steel grades are generally suitable for NG transport, certain steel grades and materials are not compatible due to their susceptibility to corrosion failure. For example, low-alloy steels that contain higher amounts of sulfur, sulphide inclusions or phosphorus can be prone to embrittlement or stress corrosion cracking, especially in sour gas environments where $H_2S$ is present. Steels with poor resistance to hydrogen embrittlement, such as some high-strength, low-ductility alloys, would also be unsuitable for NG pipelines, as they could develop microcracks that lead to failure over time.

The welding area is considered the weakest point in the entire pipeline due to a higher possibility for the presence of defects and inconsistency. Some evidence suggested that robotic welding can achieve an overall high quality and consistency of the welds; however the human welding has the edge to possibly identify the errors straightaway during the welding, unlike robotic welding. Regardless of the welding process used, if a pipeline weld in a specific area requires rework, both the weld material and the existing pipeline material must be compatible and free of contaminants. Higher levels of sulfur (more than 0.05%) and phosphorus (more than 0.04%) in steel give a negative impact to the mechanical properties.

Another concern for old pipelines is fatigue, which is classified as mechanical failure. After numerous stress cycles during operation, fatigue in the pipeline would have been initiated and developed. If both fracture initial control and fracture propagation control cannot be ensured, fracture arrestors can be considered. The proportion of fatigue severity is linked to the stress-concentration features.

### 2.3 Pipeline integrity

Several factors must be considered when repurposing pipelines for $CO_2$ transportation. The primary concern is the pipeline's current condition. Some key questions to address include:

- What existing defects are present, where are they located,and how severe are they?
- Can the existing corrosion management plan be adapted to accommodate $CO_2$ transportation, or will modifications be necessary?

To answer these questions, a comprehensive inspection is necessary to identify any existing defects or damages on the pipelines, such as corrosion, dents, or cracks. The inspection program typically begins with a desktop review of all available information including pipeline records, material specifications, and operating history. Following the review, a visual inspection is required to identify any external damage on the above-ground components as well as the right-of-way.

Advanced inspection techniques such as in-line inspection (ILI) are then employed to assess the internal condition of the pipeline. Before ILI is performed, the pipeline needs to be thoroughly cleaned of debris and ensured that it is free of obstructions. As ILI tool (smart pigs) travels through the pipeline, simultaneous data such as wall thickness, metal loss, geometric deformations, internal corrosion, and external corrosion are collected.

Besides ILI techniques, there are some other Non-Destructive Testing (NDT) that are employed such as magnetic flux leakage (MFL), ultrasonic testing (UT), Eddy current testing (ECT), and radiographic testing (RT). Different tools have varying sensitivities to debris. For instance, ultrasonic tools are more susceptible to soft materials like wax and paraffin, while magnetic flux leakage tools are relatively robust against most types of debris. Additionally, fluid density and pipe wall thickness can affect tool performance. Heavy crudes and thick-walled pipes pose specific challenges, requiring specialized tools and techniques. A summary of NDT techniques used to inspect pipelines is shown in Table 1.

*Table 1: Summary of NDT techniques used to inspect pipelines*

| NDT Technique | Detection of Defects | Requires Access to Both Sides | | Material Type | Disadvantages |
|---|---|---|---|---|---|
| | | Surface | Subsurface | | |
| In-Line Inspection (ILI) | Yes | Yes | No | Most materials | Requires pipeline preparation Can be costly |
| Magnetic Flux Leakage (MFL) | Yes | Limited to near-surface | No | Ferromagnetic materials | May not detect deep subsurface defects |
| Ultrasonic Testing (UT) | Yes | Yes | No | Most materials | Requires skill operators Time-consuming for large-scale inspections |
| Eddy Current Testing (ECT) | Yes | Yes | No | Conductive materials | Not suitable for thick-walled pipelines |
| Radiographic Testing (RT) | Yes | Yes | Yes/No (depends on technique) | Most materials | Requires skill operators Time-consuming for large-scale inspections Expensive |

The data collected from various inspection and testing methods is analyzed to identify potential risks and prioritize areas for maintenance or repair. A comprehensive maintenance and repair plan needs to be developed to address the identified issues and ensure the continued integrity of the pipeline. Pressure testing and hydrostatic testing are then employed to identify leaks or weak points in the pipeline after NDT test (Figure 1). After the inspection program, laboratory testing can be sought. It provides essential insights into the material's mechanical properties (e.g., tensile strength, yield strength, and ductility) and its compatibility with $CO_2$.

### 3. Economic viability in Malaysia

Table 2 provides an estimated breakdown of costs associated with pipeline repurposing by assuming that the project is performed in Malaysia. If we look past the historical report about the capital expenditure (CAPEX) of building new pipelines in Malaysia, it was reported that NG allocated RM 1.4 billion to build an 800-km pipelines [3]. This suggests that the cost is around RM 1.75 million per kilometre of building new pipelines. Based on our projected cost for repurposing 20-30 years old natural gas pipelines in Malaysia, the best-case scenario has an estimated cost of RM 1.10 million per kilometre of old natural gas pipelines. As such, the repurposing offers significant savings of ~37%. For worse case scenario where half the welded joints for 1 km of pipeline have failed and require replacement, the cost will be a staggering ~60% higher than building the new pipelines, which is at RM 2.80 million per kilometre. It is therefore necessary to conduct a thorough pipeline integrity assessment to determine actual retrofitting requirements and costs. Factors such as operational risks, regulatory requirements, and potential carbon credit benefits for $CO_2$ transportation need to be considered when evaluating the repurposing of natural gas pipelines against the new construction of pipelines for $CO_2$ transportation.

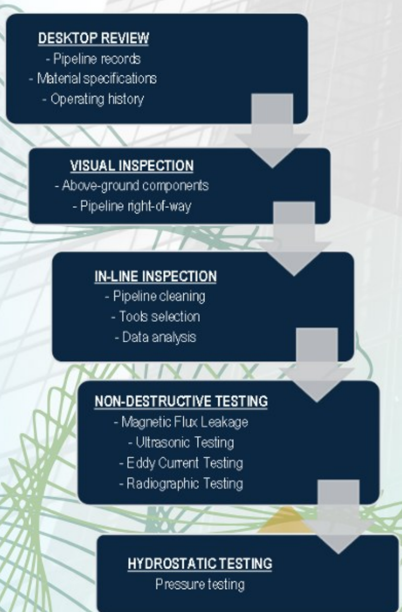


*Figure 1: Refurbished Equipment in Long-Term Storage*

According to a study by the European Union Agency for the Cooperation of Energy Regulators (2021) – Transporting Pure Hydrogen by Repurposing Existing Gas Infrastructure, it was estimated that the cost of repurposing ranges from 10-35% [4, 5]. Our estimation of 37% cost According to a study by the European Union Agency for the Cooperation of Energy Regulators (2021) – Transporting Pure Hydrogen by Repurposing Existing Gas Infrastructure, it was estimated that the cost of repurposing ranges from 10-35% [4, 5]. Our estimation of 37% cost saving is closed to the estimated cost by Det Norske Veritas (DNV). It should nevertheless be noted that this range may differ significantly if the conditions of the pipelines require the owners/operators to repair the damaged parts extensively and significantly.

### 4. Conclusion

Repurposing existing NG pipelines for $CO_2$ transport presents a promising avenue for accelerating CCS deployment and reducing carbon emissions. However, it requires careful consideration of technical, economic, and environmental factors. While carbon steel is suitable for both NG and $CO_2$, specific considerations are necessary to address the potential impacts of $CO_2$ on material properties, including corrosion and embrittlement. Rigorous assessments of pipeline integrity, including wall thickness, corrosion, and fatigue, are crucial to ensure safe operation. The unique flow characteristics of $CO_2$, particularly in the supercritical phase, must be carefully considered to optimize pipeline design and operation.

Repurposing appears economically beneficial when a thorough pipeline integrity assessment reveals minimal required repairs. The estimated CAPEX for repurposing a 1-km pipeline in Malaysia ranges from RM 1.1 million (best case) to RM 2.8 million (worst case). Compared to building new pipelines (estimated at RM 1.75 million per km), repurposing offers potential savings of 37% in the best-case scenario. The economic viability of repurposing depends heavily on the pipeline's condition. Factors like the percentage of welded joints requiring replacement and the need for extensive repairs significantly impact the costs. In the worst-case scenario with extensive repairs, repurposing might be more expensive than building new pipelines.

Table 2: Estimated cost for repurposing of NG pipelines to carry $CO_2$ in Malaysia.

| | Estimated cost |
|---|---|
| Advanced ultrasonic testing (PAUT or ToFD) | RM 1,000 – 3,000* per day<br>A full-length inspection for 1 km pipeline was estimated to consume around 9** days by assuming the team inspects 15 welds per day for every 12 meters (weld-focus inspection).<br>*Applicable for experienced engineer (reference: personal communication with industry players)<br>**This number may vary depending on the accessibility of the pipeline (it takes longer time if the pipeline runs through challenging terrain), crew and equipment efficiency, and other factors that may arise.<br>The inspection cost was estimated to be RM 3,000 per day x 9 days = RM 27,000<br>It will take additional time for mobilization/de-mobilization and setup (2 days), and report preparation (7-10 days). Hence, it arrives to the following costs<br><u>Mob/demob</u><br>Travel distance of RM 2.00 per km for fuels, tolls, and vehicle wears. Assumption for 350 km. Hence, the cost is RM 2 per km x 350 km x 2 (for round trip) = RM 1,400<br>Labour costs for engineer = RM 150 per hour. 8 hours working. Hence, the cost is as follows,<br>RM 150 x 8 hours = RM 1,200<br><br><u>Set-up cost (2 days with 1 engineer and 1 technician)</u><br>Experience engineer's daily rate = RM 3,000 per day x 2 days = RM 6,000<br>Support technician = RM 500 – 800 per day. Assumed the experienced technician was deployed. Then RM 800 x 2 days = RM 1,600<br><u>Report preparation (assumed 10 days for experienced engineer)</u><br>Report preparation rate = RM 3,000 per day x 10 days = RM 30,000<br><br>The TOTAL estimated cost for 1 km pipeline inspection using PAUT = RM 27,000 + RM 1,400 + RM 1,200 + RM 6,000 + RM 30,000 = RM 65,600 (excluding hotel, administration fee, and other applicable taxes which can have additional 10-20% additional cost). |
| Pigging (ILI) | <u>Cleaning</u><br>Preparation for cleaning = 1 day<br>Cleaning runs assuming heavy cleaning is required to remove significant debris and other restrictions = 3-5 days<br>Using the rate of experienced engineer above, the total number of days = 6 days x RM 150 per hour x 8 hours per day = RM 7,200<br><u>Pigging</u><br>Final preparation and planning for pigging = 1-2 days<br>Tool run time: 1 day<br>Post-run activities = 1-2 days<br>Using the rate of experienced engineer above, the total number of days = 7 days x RM 150 per hour x 8 hours per day = RM 8,400<br><u>Mob/demob</u><br>Travel distance of RM 2.00 per km for fuels, tolls, and vehicle wears. Assumption for 350 km. Hence, the cost is RM 2 per km x 350 km x 2 (for round trip) = RM 1,400<br>Labour costs for engineer = RM 150 per hour. 8 hours working. Hence, the cost is as follows,<br>RM 150 x 8 hours = RM 1,200<br><br><u>Report preparation (assumed 14 days for experienced engineer)</u><br>Report preparation rate = RM 3,000 per day x 14 days = RM 42,000<br><br>The TOTAL estimated cost for 1 km pipeline inspection using ILI = RM 7,200 + RM 8,400 + RM 1,400 + RM 1,200 + RM 42,000 = RM 60,200 (excluding hotel, administration fee, and other applicable taxes which can have additional 10-20% additional cost). |
| Material Integrity analysis | RM 25,000 – RM 45,000 depending on the complexity of analysis. |
| Welded joint materials | <u>Valves</u><br>Replace existing valves with CO2-compatible ones capable of handling dense-phase CO2 pressures (80-150 bar).<br>Manual valve: RM 35,000 – 55,000 per valve<br>Automated valve: RM 65,000 – RM 120,000 per valve<br>Assumption was made that 100-km pipeline requires 10 valves. This suggests the cost per km is around RM 5,500 per km for manual valve at higher range of price and RM 12,000 per km for automatic valve at higher range of price.<br><u>Compressors</u><br>RM 500,000 – 1,500,000 depending on capacity and design<br><u>Pipeline linings and repairs</u><br>RM 100-300 per meter x 1 km pipeline = RM 300,000 based on the maximum range of charges<br><u>Leak detection systems</u><br>RM 100,000 – 200.000 per setup |
| - | The total estimated CAPEX cost for repurposing natural gas pipeline in Malaysia under certain scenario is as follows,<br>~RM 1,100,000 per km (best case scenario with the most competitive rates (lowest cost for retrofitting components, lowest replacement costs for welded joint materials and best rates for material integrity analysis), and 10% of the welded joint requires replacement, and pipeline linings repairs for the entire 1 km pipeline)<br>~RM 2,800,000 per km (worst case scenario with the most expensive rates and 50% of the welded joint requires replacement, and pipeline linings repairs for the entire 1 km pipeline) |

## 5. References

[1] DNV-RP-F104. Design and operation of carbon dioxide pipelines. 2021.
[2] Institute WR. Guidelines for Carbon Dioxide Capture, Transport, and Storage. 2008.
[3] The Star. Gas Malaysia to allocate up to RM1.4bil for CAPEX to build 800km of pipelines. 2023.
[4] Monsma V, Illson T, Hussain A. Repurposing Pipelines for Hydrogen Transportation. 2023.
[5] Monsma V. Repurposing onshore pipelines is essential to scaling hydrogen. How can it be done in practice?

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## HIGHLIGHT

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