# INTEGRATED PIGGING APPROACH FOR SAFE AND EFFECTIVE PRE-CCS PIPELINE PREPARATION

By: Iain Shepherd, Halliburton, UK
Scott MacKenzie, Halliburton, UK
Giselle Braganza, Halliburton, UK
Elena Fokina, Halliburton, UK

## Abstract

Preparing gas pipelines for decommissioning or repurposing — especially for future use in Carbon Capture and Storage (CCS) — brings a unique set of technical and operational challenges. This paper outlines the successful cleaning and de-inventorying of two high-pressure gas pipelines: a 24-inch onshore line and a 20-inch offshore line, both of which were previously in sour gas service.

A staged pigging strategy was used to remove residual hydrocarbons, scale, and pyrophoric dust. The operations involved multiple pig runs using a combination of gas and chemistry along with foam pigs. Key focus areas included controlling pig velocity, managing oxygen ingress, and handling the complexities of receiving debris at the terminal end. To reduce the risk of pyrophoric ignition, nitrogen purity was dynamically adjusted during the early phase of each run.

Real-time monitoring of pressure and pig location helped prevent stalls and ensured a safe and controlled process throughout. A final camera inspection confirmed the cleanliness of the pipeline and helped assess its readiness for future use.

This paper shares practical lessons learned from the field, with a focus on operational reliability, safety, and efficiency. It offers a clear, experience-based guide for operators planning similar campaigns in aging pipeline infrastructure.

## Introduction

As global momentum builds toward net-zero targets, CCS has emerged as a crucial strategy in industrial decarbonisation. One cost-effective pathway is the reuse of decommissioned hydrocarbon pipelines for $CO_2$ transport. This reduces both environmental impact and capital costs compared to constructing new infrastructure [1][2]. However, transitioning such pipelines to dense-phase $CO_2$ service demands significantly higher cleanliness and integrity standards than conventional decommissioning [3].

This paper details a recent case involving two legacy pipelines that underwent staged pigging and chemical treatment to meet pre-CCS requirements. Each pipeline had unique contamination profiles and operational histories that required tailored strategies.

The project involved two distinct assets:

• A 34 km, 20-inch carbon steel subsea pipeline with a history of sour gas transport and corrosion inhibitor dosing.

• A 27 km, 24-inch onshore pipeline that had transported sweet gas and was known to contain pyrophoric dust and trace NORM (Naturally Occurring Radioactive Material).

Both pipelines had not been pigged in many years. As a result, thick sludge and debris accumulation presented significant cleaning and safety challenges [3][4]. Based on the information available, cleaning programs were develop specific to each pipeline.

## Results and Observations

The campaign used a progressive pigging sequence:

- Foam pigs to confirm piggability and remove bulk fluids.
- Gauge pigs to detect internal restrictions.
- Bi-directional pigs with magnets and brushes for aggressive mechanical cleaning.
- Chemical slugs to dissolve sludge and flush contaminants [2][5].
- Camera pigs to capture high-resolution internal imagery and assess cleanliness.

Pig trains were custom-configured and launched in sequence to gradually improve internal condition, minimising the potential for large volumes of debris build up which could result in stuck pigs or less effective cleaning performance.

Due to space limitations offshore, the subsea pipeline pigging operations were reversed from the normal / historical direction (offshore to onshore) with pigs launched at the onshore terminal and received at the offshore platform. This allowed for optimal deployment of nitrogen generation equipment, chemical pumping equipment and waste fluid handling systems. It also simplified logistics and improved safety during fluid recovery.

To mitigate pyrophoric ignition risk, the nitrogen purge strategy was dynamically adjusted based on real-time oxygen concentration measurements. This ensured that pigging began under inert conditions, particularly critical in the 24-inch line where black powder was present [4].

Laboratory tests were performed on a sample of residue which had previously been collected from the 20” pipeline, based on these tests, the most effective cleaning solvent was chosen. Demineralised water was identified as suitable to wash any remaining debris and retained solvent from the pipeline following the solvent cleaning runs. In the 24” line, a solvent was not required, and only demineralised water was used for cleaning. In both the 20” and 24” lines, MEG was chosen to remove residual free water from the previous runs.

### 20-inch Offshore Pipeline

A pigging program was developed based on the expected deposits in the line, however, this was subsequently amended with the addition of additional pig runs due to the large volumes of residue which were removed. The revised pigging campaign was completed as follows:

| No. | Description | Comments |
|---|---|---|
| 1. | Degassing pig | The degassing pig displaced the pipeline hydrocarbon gas and left the pipeline filled with Nitrogen as intended. The pig also returned a sphere pig which was held in the pipeline from previous operations. Minimal debris was removed from the pipeline: as expected: the intention of the foam pig was to de-gas the pipeline only. |
| 2 | Single pigs | These removed pipeline residue as intended. The residue was highly-viscous and was comparable to the previous sample which was taken to identify a chemical solvent. The initial removal of the residue was desired to reduce the likelihood of over saturating the Solvent |
| 3. | Solvent pig trains | The Solvent pig trains were found to return pipeline residue with each run. It was noted that the viscosity of the returned residue decreased during the Solvent pig runs, indicating that it was effective in dissolving and removing the residue from the pipeline |
| 4. | Demin. water pig trains | The demineralised water trains continued to remove the pipeline residue with significant debris being returned with all 3 trains. Due to the level of returned debris, the provision of additional cleaning pig trains was identified |
| 5. | MEG pig train | |
| 6. | Single Pig | Revised run – single pig instead of a train |
| 7. | Demin. water pig trains | Additional runs added |
| 8. | MEG pig train | |
| 9. | Drying pig train | Foam pigs and Bidi pig train |
| 10. | Camera Pig | |

The following figures show the condition of the pig receiver and pigs on receipt.

**Figure 1: Pig Run No. 1, the foam pig removed minimal debris as intended and left the pipeline free of hydrocarbon gas and nitrogen filled.**

**Figure 2: A very heavy and viscous residue was recovered by the initial Bi-Di pig runs.**

**Figure 3: the solvent pig trains reduced the viscosity of the residue, with increased volumes of residue/debris returned compared to the BiDi pig runs, as expected. The application of the solvent fluid batches was considered successful:**

**Figure 4: The demineralised water trains continued to remove significant residue and debris from the pipeline.**

Based on the above results, it was decided to add further demineralised water pig trains to the cleaning program to continue removing residue from the line. After running these additional demin. water trains, significant residue was still being removed. Due to the constraints of the overall project schedule, it was decided to then run a MEG swabbing train followed by a foam pig drying train prior to the camera pig inspection. The camera pig confirmed that there was still significant residue in the line and that further cleaning would be required at a later stage in the CCS commissioning project.

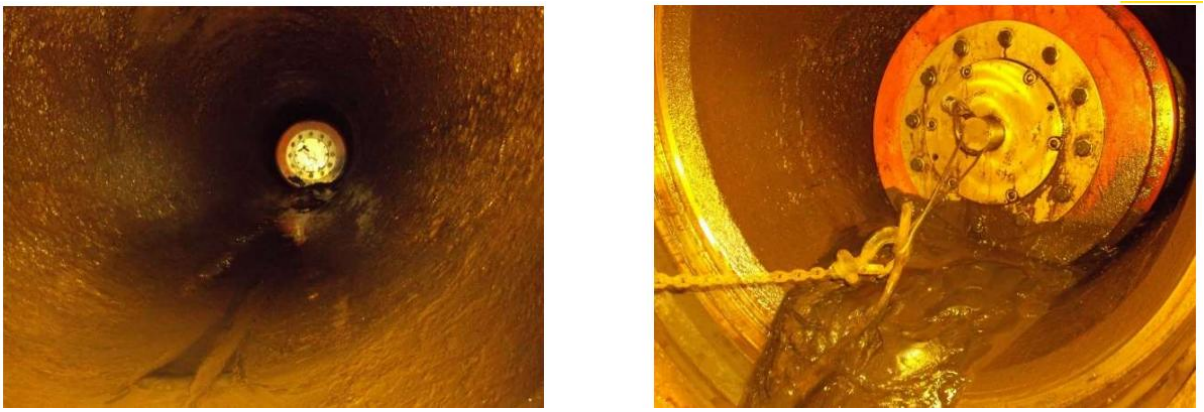

**Figure 5: Significant residue and debris is still evident even after additional pig trains were run.**

**24-inch Onshore Pipeline.**

It was believed that the condition of the 24” pipeline was cleaner than the 20” line. Based on this, the following pigging program was planned and successfully performed.

| No. | Description | Comments |
|---|---|---|
| 1. | Degassing gauge pig | |
| 2. | Pig Train 1 | Gauge BiDi, Brush BiDi, Brush BiDi pigs with slugs of demineralised water |
| 3.<br>4.<br>5. | Brush BiDi pigs | With slugs of demineralised water |
| 6. | Brush Bidi pigs | With slugs of Nitrogen |
| 7. | Brush Bidi pigs | With slugs of MEG |
| 8. | Brush Bidi pigs | With slugs of Nitrogen |
| 9. | Foam pigs | With slugs of Nitrogen |
| 10. | Brush Bidi pigs | \with slugs of Nitrogen |
| 11. | Camera Pig | |

The results of the cleaning program in the 20” pipeline were excellent, with much less residue evident than in the 24” line. The following figures show the condition of the pig receiver and pigs on receipt.

**Figure 6: pigs in receiver, very little residue evident**

**Figure 7: pigs removed from receiver in good condition**

Based on the above results achieved, the program continued as planned, with the cleaning program containing slugs of MEG to condition the line, followed brush cleaning pigs and foam pigs to dry the line and a final brush pig train prior to the camera pig inspection.

The camera pig inspection confirmed a high level of cleanliness, with only minor diesel residue observed in a few segments. Despite its age, the internal condition was excellent. No pyrophoric reactions or NORM-related safety incidents occurred, validating the cleaning strategy.

**Figure 8: Final pig run. As can be seen, minimal residue and debris is evident.**

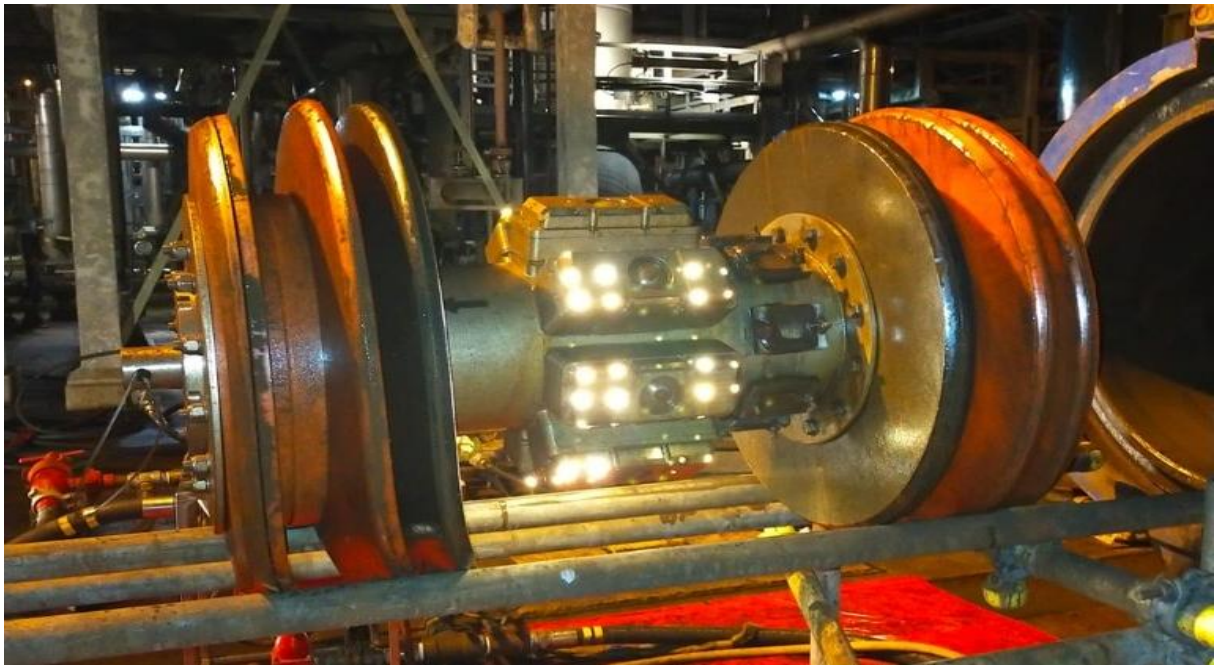

**Figure 9: Camera pig removed from pig receiver**

The camera pig inspection confirmed a high level of cleanliness, with only minor diesel residue observed in a few segments. Despite its age, the internal condition of the pipeline was excellent. No pyrophoric reactions or NORM-related safety incidents occurred, validating the cleaning strategy.

**Lessons Learned**

• Debris, sludge and other residue in the pipeline should be sampled and characterised early to determine the most effective cleaning method and chemical treatment [5].
• Reversing pig launch direction can improve efficiency where space / offshore access is constrained, especially when large pumping and / or waste handling facilities are required [6].
• Camera pigs are valuable for documenting post-cleaning pipeline condition and establishing a visual cleanliness baseline [7].
• Dynamic nitrogen control is critical for pyrophoric risk mitigation in aged sweet gas lines.
• Real-time tracking and pressure data enable proactive intervention and reduce pig stall risk during long pigging campaigns

## Conclusion

The preparation of legacy gas pipelines for $CO_2$ service presents a highly specialized challenge that combines operational complexity with stringent safety and cleanliness requirements. This paper demonstrates that with a carefully designed and dynamically adjusted pigging strategy, aging carbon steel pipelines—some with decades of hydrocarbon service—can be transitioned to a state suitable for future CCS applications.

The integration of mechanical pigging, solvent-based chemical cleaning, and visual inspection allowed operators to assess and enhance internal pipeline conditions in real time. The use of camera pigs provided an unprecedented level of assurance, producing full-length visual data that can now serve as a reference for future reconditioning and commissioning phases. In a regulatory environment where cleanliness cannot always be measured quantitatively, such visual baselines are invaluable.

Operational decisions—such as reversing the pigging direction due to offshore platform constraints—proved crucial in reducing logistical risk and improving safety. Likewise, the proactive management of nitrogen inerting and oxygen control helped mitigate the risk of pyrophoric ignition, a common hazard in pipelines with black powder residues. These safety protocols, combined with real-time pressure and pig-tracking, enabled the campaign to proceed without incident.

While the offshore pipeline continues to require additional cleaning to meet CCS readiness standards, the successful preparation of the onshore pipeline stands as clear proof of concept. This demonstrates that a phased, adaptable cleaning strategy not only delivers technical results, but also supports broader strategic goals—namely, the rapid and cost-effective deployment of CCS infrastructure using repurposed assets.

Going forward, this integrated approach offers a replicable blueprint for operators globally. As more jurisdictions pursue carbon neutrality, the reuse of existing infrastructure will become not only advantageous, but essential. The practical insights and field-based learnings from this campaign contribute directly to industry knowledge and will support safer, faster, and more reliable CCS transitions across the energy sector.

## References

[1] Liverpool Bay Area CCS: An Advanced Case Study to Achieve UK's Carbon Neutrality. Becker, B. W., Baldino, F., & Aleandri, A. 2021.
[2] Reusing Existing Infrastructure for $CO_2$ Transport: Risks and Opportunities Luna-Ortiz, E. 2022.https://doi.org/10.4043/31457-MS
[3] Repurposing the Pipeline for $CO_2$ Transportation in the CCS Project. Amirrudin, F., Hashim, W. W., Ali, Z., & Sam, M. R. 2024.
[4] UK Health and Safety Executive. Guidance on Conveying $CO_2$ in Pipelines.
[5] $CO_2$PipeHaz Consortium. Good Practice Guidelines for $CO_2$ Pipeline Safety.
[6] Reducing Costs of CCS by Reuse of Existing Pipelines. Int. J. Greenhouse Gas Control. Brownsort, P. A., Scott, V., & Haszeldine, R. S. 2016., 52, 130–138.
[7] Acorn: Developing Full-Chain CCS in a Hydrocarbon Province. J Clean Prod. Alcalde, J. et al. 2019.