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CCUS Transport and Storage – Designing for Success

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Introduction

Carbon capture, utilisation and storage (CCUS) is an essential part of reducing greenhouse gas emissions and Genesis Energies is a leading provider in the engineering and design of the transportation systems for carbon dioxide from the emitter to the geological store.

Compared with conventional hydrocarbons, carbon dioxide management in pipeline transportation systems brings a new set of challenges that are very different from conventional hydrocarbon production systems. This includes the management of new risks that must be understood and mitigated during the design phase.

Conventional hydrocarbon production is a mature industry used to operating with the most arduous conditions (highest temperatures and pressures) in the early phase of operations. As a field matures and the reservoir depletes, the operating conditions become more benign. However, with carbon dioxide storage the well profile is almost the opposite with early operations having fewer emitters, lower injection and reservoir pressures before ramping up as new emitters come online and the reservoir starts to fill.

Rather than providing details on specific projects, this paper outlines the challenges for whole system design of the transportation network, common areas of technical uncertainty as well as managing the risk and designing for the full field life to ensure successful commercial operation.

The insights shared are based on key lessons learned from Genesis's extensive track record in CCUS projects, including pre- and post-combustion capture, ranging from 0.2MTPA to 35MTPA, and developed through executing over 90 studies and projects (including in excess of 45 transportation and storage scope) in more than 20 countries. Specifically in the United Kingdom, Genesis has had some level of involvement in many of the UK CCS clusters including:

- The FEED and currently EPIC integrator scope for the Northern Endurance Partnership Transportation and Storage CCUS project
- Currently executing the Peak Cluster CCUS Transportation FEED
- Viking CCUS FEED
- White Rose CCUS FEED
- Solent Cluster Conceptual Studies

Technical Uncertainties

Technical uncertainty needs to be managed through the system design and it is essential to ensure the system can manage potential fluctuation or variation with no impact on safety or reliability. The following are the key focus areas to be managed during the system design:

Upstream Process Control

Compared to conventional hydrocarbon projects, CCUS transport and storage projects are the complete reverse and therefore the upstream aspect is the most significant challenge in designing and executing these projects compared to a conventional subsea/pipeline project.

Conventional hydrocarbon development is designed based on production fluids flowing from the well with a predicted production profile that underpins robust flow assurance with a generally stable flow regime in normal operation. Conversely in a CCUS transportation and storage system, it is the opposite end of the process chain and very dependent on the upstream processes where the technology and process requirements are still being developed.

Rather than producing fluids from one or multiple wells in a reservoir, the upstream supply is from numerous emitters supplying carbon dioxide at different rates using potentially different technologies with defined battery limits and specifications into the transportation system. The upstream process control system needs to interact with each emitter and monitor key process data such as temperature, pressure and composition. It is critical the upstream process system protects the pipeline network from process upsets that could potentially impact the integrity of the pipeline network.

This is a fundamental shift in the requirements of a project that requires a similarly fundamental shift in the approach to the design of the system.

Temperature

The temperature profile for carbon dioxide transportation is the opposite of a conventional hydrocarbon system with the higher temperatures seen onshore. The process train, its control system and inherent reliability can have a significant impact on the temperature at the pipeline entry and the variation in throughput and flowrate affects the distance that high temperatures progress down the pipeline and – critically – through the shore crossing.

Unlike a conventional pipeline system this means the buried onshore system and the shore crossing is exposed to the majority of the pipeline expansion during operation. This means greater attention needs to be given to axial loads, buckling and upheaval in the buried sections, which is a significant change to traditional design practices.

Pressure

In a conventional hydrocarbon system there are typically two pressure scenarios:

1. Well flowlines, where the pressure generally reduces with life of field as the reservoir depletes and enhanced recovery techniques are required to maintain production.
2. Export pipelines from a platform, where the pressure is often significantly lower than design pressure and remains constant (within say +/- 5 bar) except for preplanned, well-defined shutdowns and reasonably well understood accidental shut-ins.

However in carbon dioxide transport pipelines, there are a variety of inlet scenarios to be considered:

- Constant base load
- Daily cyclic loading from an emitter
- Tanker offloading (maybe every few weeks)
- Something in between

During front-end design it is impossible to know how the inlet conditions will evolve during the life of the system, with unknown emitters and injection wells being added into the system at unknown times. Although it might be assumed that increasing the number of emitters contributing to the pipeline system will smooth out the peaks and troughs, without an understanding of the future emitters and the overall expansion of the system this is not necessarily the case. It may be that future emitters are also cyclic in nature (such as a gas-fired power station with higher use during the day) and therefore the cyclic behaviour is further amplified.

It is possible to say the same about future tie-ins to hydrocarbon systems, with hot taps and inline tees. But generally pipeline systems are designed for the worst case in early life and capacity increases later in life by allowing tie-ins to use the ullage, or spare capacity, in the system. In the case of CCUS, we know the worst-case design scenario is the last day of life with many emitters trying to inject CO2 into a reservoir approaching capacity.

Fatigue

The fatigue requirements of the system are entirely based on the robust understanding of how upstream process control, pressure and temperature affect the pipeline over its life. Furthermore, without an understanding of the future operating conditions, it is not practical to perform a definitive fatigue assessment.

To be able to assess the pipeline fatigue, it is essential to have a clear understanding of the future operating conditions of the pipeline to define the basis of the fatigue assessment that can be maintained and updated over the life of the pipeline.

Material Selection and Corrosion

The selection of appropriate materials that can withstand the high pressures and low temperatures associated with dense phase carbon dioxide is a key consideration in designing the transportation systems. The unique fluid properties and conditions present some specific challenges with regard to the potential for rapid longitudinal propagation of a crack by brittle fracture along the pipe that may lead to catastrophic pipeline loss of containment. Typically, carbon steel is preferred due to its mechanical strength and cost-effectiveness.

Carbon dioxide transport on the predicted scale for CCUS is a new application and the implications of potential corrosion in the short or long term is not very well understood or documented. It is known that some contaminants, such as water, can significantly accelerate corrosion and potential contamination can severely impact the life of the pipeline. Additionally, the performance of current tools used to detect corrosion and the feasibility to operate those tools on a regular basis is not fully known.

An important consideration is the carbon dioxide entry specification (water, solids, etc.) and the need for dehydration and filtration equipment. This is required to preserve the pipeline and the injectivity of the reservoir. Thus, the near 100% availability and reliability of the CO2 treatment equipment is essential for ensuring the integrity of the transportation and storage system. However, the potential for CO2-induced corrosion necessitates the use of corrosion-resistant alloys or the application of protective coatings.

The design assumptions used to assess the risk of corrosion in the pipeline system are currently very subjective and range from “it can’t happen” to “it won’t happen” past “but what if it does happen” to “it will happen at some point.” In the worst case, the transport system is entirely at the whim of the upstream process system and its design to prevent impurities in the fluid stream that may damage the pipeline or reservoir. How this risk is assessed has significant impact on the material selection and corrosion assessment for the transportation system and the associated costs. This risk assessment is highly dependent on the upstream process control and how it controls potential contamination into the transportation system.

Future Expansion

The critical uncertainties above generally apply upstream of the injection system; however there is also a significant amount of uncertainty about the downstream and injection development. Not only does this have flow assurance implications but it brings practical considerations around topics like field layout and pre-commissioning.

In a hydrocarbon system we may provide a future tie-in point, but we don’t necessarily give much consideration to how a future party will execute that tie-in. CCUS systems are often engineered for installation in phases with an explicit consideration of future expansion requirements. The expansion requirements are impacted by all the upstream uncertainties we have already discussed.

Designing for Success

Material requirements and pre-commissioning challenges are largely dictated by the initial pipeline scope and aside from corrosion are immune from future third-party design decisions. Although integrity management is not discussed separately, the critical uncertainties discussed previously have a significant influence on the integrity management plan development.

Although a design basis is prepared for the CCUS transportation system, it is not clear how relevant it will be once the system is operating or as the system is expanded. The reason is the understanding of the design will change as performance data is generated and assumptions made proven right or wrong and holds for uncertainty are clarified.

The use of a combination of robust assumptions and a healthy dose of reverse engineering makes it possible to define ranges of inputs that the system could tolerate. These aspects grow and shrink by the amount of uncertainty that the aspect can tolerate and the level of conservatism built into the design.

Once the design is matured among all stakeholders, the design basis is refreshed to accumulate the updated uncertainty in these inputs. The revised uncertainties are compared with the uncertainties that we can accommodate to understand the level of robustness in the design. The variation is not assessed against a single project, but more the general trend in uncertainties found across a range of projects.

In a typical hydrocarbon project, it is possible to assess that the design has captured the uncertainties in the inputs and quantify the reliability. It is possible to freely move to the next phase of the project, knowing that there can be further improvement in reliability or removal of some conservatism. But in CCUS projects, it is likely to demonstrate that there is more than adequate reliability in some aspects and too little reliability in other aspects.

It is possible it may be feasible to reduce the reliability in some aspects if it will help to increase the reliability in other areas, which becomes a multidimensional optimisation problem.

For example, during the review of the design it may be found that the corrosion assumptions are extremely robust, but insufficiently robust in pressure containment. This presents the opportunity to potentially reallocate some of the excess corrosion allowance to increase the pressure containment capacity of the system and perhaps relax some of the requirements for the control system. It is important to appreciate that it is not known how these circles will overlap at the beginning, and therefore how is the project structured to achieve this?

There's been an increasing trend to use industry buzzwords such as "agile", "sprints" etc. and this is generally used to imply flexibility and dynamisms. But these terms originated in software development and have a very specific meaning. They really focus on understanding the requirements of stakeholders, defining a series of tasks that will lead to an outcome and prioritising those tasks to achieve the most critical outcomes quickly and – most importantly – visibly, so that outcomes and progress are immediately well understood by stakeholders. It also allows tasks to evolve and develop as outcomes become known and understanding grows.

Applying this to a conventional project phase such as FEED, this means a second phase needs to be added to solve this optimisation problem and arrive at a design that can accommodate the uncertainties arising from upstream and downstream variabilities. This involves developing a "backlog" of tasks in the order of criticality and beginning to execute those tasks. This "backlog" is revisited weekly to share findings with stakeholders, receive updates from third-party inputs and reprioritise work as necessary.

By doing this, discrete tasks can progress in parallel with blockers being identified and tasks developed to address them, or existing tasks reprioritised accordingly. Through this process it is possible to demonstrate a change in the capacity for uncertainty until it can accommodate any necessary external variability.

The process described above does not just happen. It takes a lot of moving pieces to be coordinated and working towards a series of well-defined common goals through the noise of the uncertainties discussed as well as many others. This takes multidiscipline teams with a clear understanding of how each disciplines' outcomes affect other aspects of the project.

It takes collaborative working. It takes frequent check-ins to explain progress. Disciplines working closely with other disciplines they don't often engage with.

It requires processes and tools to be adapted from our typical hydrocarbon projects based on deterministic approaches to become faster and more parametric to allow efficient evolution of design aspects.

Conclusion

It's critical to remain agnostic. Until the technology becomes more mature, as a new industry it is critical not to force the design into a particular solution or vendor. It is essential to encourage development across the industry.

Most importantly, the system must be addressed holistically and must identify areas where additional capacity can be used to add capacity to other areas, and where improvements in one area can realise improvements in another.

Finally, it is important to demonstrate transparent decisions have been made to ensure the projects provide value for money, particularly when the taxpayer is contributing to the cost of these systems.

Taken together, all of this will allow designing for success in CCUS.