Accelerating Technology Adoption: A Framework for Modernizing Integrity Management

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Abstract

As North America's high-pressure pipeline systems continue to age, the need for timely deployment of advanced technologies has never been more critical. The industry has seen tremendous innovation, ranging from enhanced in-line inspection tools and real-time monitoring systems to composite repair methods and advanced materials. However, widespread adoption remains slow due to regulatory complexity, commercialization challenges, and operational risk aversion.

This paper introduces the Technology Adoption Process (TAP), a structured framework developed to accelerate technology deployment and support the industry's broader integrity management goals. TAP identifies and integrates four key dimensions: Technology Readiness Level (TRL), Regulatory Acceptance Level (RAL), Commercial Readiness Index (CRI), and Operational Readiness Level (ORL). Together, these elements provide a roadmap for technology providers, pipeline operators, regulators, and investors to work collaboratively from concept through full-scale deployment.

The paper includes practical examples and lessons learned in bringing together key stakeholders through initiatives such as the Composite Technology Advancement Group (CTAG) platform that facilitates Joint Industry Programs (JIPs), networking events, and technical training. These initiatives demonstrate how technologies can be validated, communicated, and scaled in a way that align with the pipeline industry's need for practical, field-ready solutions for integrity management.

Readers are provided with a clear understanding of how to navigate the regulatory, commercial, and operational challenges that often stall innovation and how to proactively engage in shaping the future of pipeline integrity. As public scrutiny grows and infrastructure demands increase, the TAP framework offers a timely solution to transform technological potential into operational reality.

Introduction

High-pressure transmission pipelines remain essential to North America's energy distribution network. Many of these assets are more than half a century old, constructed with legacy materials, processes, and coatings that differ substantially from today's standards. This aging infrastructure faces increasing operational challenges associated with fatigue, corrosion, manufacturing anomalies, geohazards, and other threats that require modern technology solutions for safe long-term operation.

At the same time, technology development in the pipeline sector has evolved rapidly. Over the past two decades, innovations in nondestructive evaluation, robotics, composite materials, high-performance polymers, data analytics, and digital monitoring have transformed operators' capabilities. However, despite significant technical advances, the pace of field deployment remains slow. Operators frequently highlight barriers including conservative corporate culture, lengthy qualification processes, gaps in regulatory guidance, difficulty evaluating competing technologies, and challenges integrating new tools into existing workflows.

Technology companies face corresponding obstacles. Many spend years developing promising technologies only to struggle with regulatory approval, limited exposure to operators, lack of commercial strategy, or inability to demonstrate performance outside controlled laboratory conditions. The pipeline industry is historically cautious, and technologies that fail to achieve early traction often stagnate or disappear before reaching meaningful adoption. These combined

challenges limit the number of validated tools available to operators, widening the gap between innovation and implementation.

Recognizing these systemic issues, the Technology Adoption Process (TAP) was developed as a structured, multi-phase framework designed to accelerate technology deployment (1). The TAP integrates technical readiness with commercial planning, regulatory strategy, and operational engagement, enabling a coordinated pathway that reduces adoption risk and improves alignment among key stakeholders.

From the perspective of pipeline operators, a structured adoption framework can also improve internal decision-making. Integrity teams are often presented with multiple emerging solutions but lack a consistent method for comparing their maturity, regulatory status, and commercial stability. TAP provides a common language that can be used across organizations to evaluate technologies, prioritize pilot projects, and communicate with executives and regulators. In this way, the framework not only benefits technology companies seeking to enter the market but also helps operators deploy limited capital more effectively and build roadmaps that align technology deployment with long-term integrity management strategies.

Technology Adoption Framework

The TAP consists of four synergistic pillars including technology, regulation, commercialization, and operations with each contributing to the successful advancement of new tools and technologies. TAP provides an integrated view of how technologies progress from conceptual research to full-scale deployment and identifies the essential steps, milestones, and interactions required along the trajectory. Rather than treating these pillars as independent tracks, the framework emphasizes their interaction. A weakness in one dimension can delay or completely stall advancement, even when the other elements are strong.

Provided in Figure 1 is a framework that illustrates the inter-connected process by which a technology can traverse from concept to full deployment. Listed below are four pillars of the TAP, each having been ascribed a relative scale to provide key stakeholders with a means for assessing the level of advancement associated with each pillar.
- Technology Readiness Level (TRL)
- Regulatory Acceptance Level (RAL)
- Commercial Readiness Index (CRI)
- Operational Readiness Level (ORL)

Provided on the following pages is a brief description of each of the above four elements.
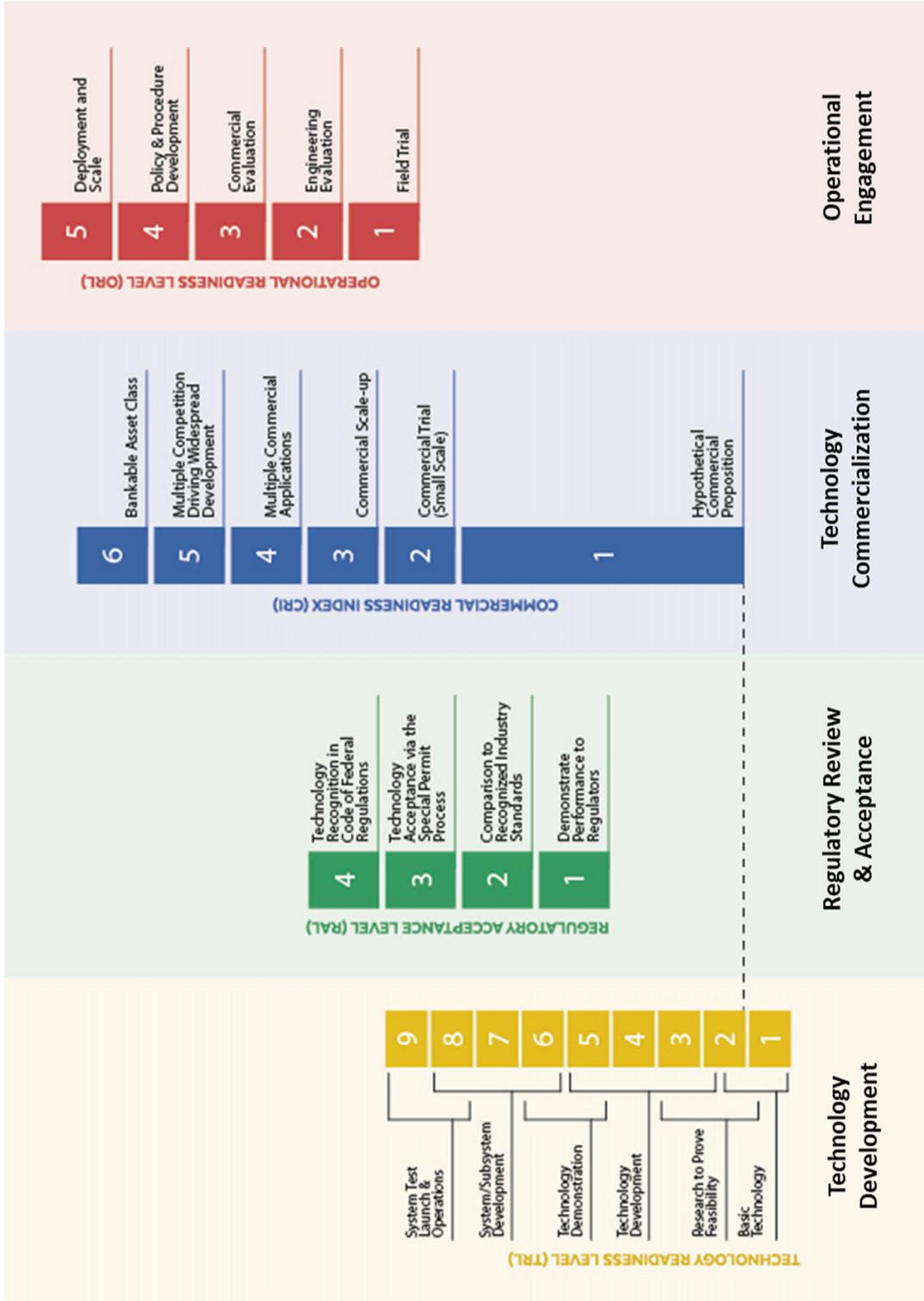
Figure 1. Framework for the Technology Adoption Process

The first major pillar, Technology Readiness Level (TRL), evaluates a technology's technical maturity. TRLs help characterize progress from early conceptualization through laboratory testing, prototype development, controlled full-scale demonstration, and field validation. Technologies with high TRLs demonstrate repeatable performance, robust engineering validation, and predictable outcomes under operational conditions. In the pipeline context, this often includes full-scale destructive testing, representative material characterization, and validation under the range of pressures, temperatures, and loading conditions expected in service. However, technologies may still stall even at high TRLs if other elements of adoption are not equally mature.

Regulatory Acceptance Levels (RAL) form the second pillar (2). Transmission pipelines operate under a complex regulatory environment governed by prescriptive and performance-based codes. For new technologies regulatory acceptance can often present decisive hurdles, especially those involving structural repair, in-ditch NDE, or inspection of challenging threats. Meaningful regulatory engagement involves more than simply submitting documentation at the end of development. Instead, TAP encourages early-stage dialogue with regulators to identify applicable codes, understand expectations for safety margins, and define the evidentiary basis for demonstrating risk reduction. This collaborative approach helps to ensure that investments in development and testing produce information that is useful not only to operators, but also to regulators.

The third pillar, Commercial Readiness Index (CRI), evaluates the ability to bring a technology to market in a way that is economically sustainable and attractive to investors (3). The CRI addresses questions such as: Who are the primary and secondary customers? What unmet need does the technology address, and how does it compare with existing alternatives? How should pricing be structured to balance value and adoption? What is required to scale manufacturing, training, or deployment across multiple regions? How will the company support the technology over its life cycle? Because a significant percentage of technology companies fail due to commercial misalignment rather than technical inadequacy, CRI is treated as a core component of TAP, not an afterthought once the technical work is complete.

Operational Readiness Levels (ORL) represent the fourth pillar (3). ORLs assess whether technologies can be effectively integrated into real-world operations. This includes evaluating field procedures, safety protocols, crew training, data handling, and alignment with existing integrity management programs. A technology may be technically sound and commercially attractive yet still struggle if it complicates field operations, requires highly specialized skills, or produces data that cannot be easily interpreted or integrated into existing systems. Technologies with strong ORLs demonstrate consistent usability, clear documentation, and repeatable performance under a variety of field constraints.

The TAP framework integrates these four pillars across four primary phases: Development, Positioning, Field Introduction, and Operational Engagement. The Development phase includes conceptual design, early prototyping, laboratory testing, and initial full-scale validation. Positioning addresses regulatory strategy, commercial planning, early stakeholder collaboration, and preparation of technical documentation and marketing materials. Field Introduction includes pilot programs, controlled deployments, structured data collection, and refinement of procedures based on field feedback. Operational Engagement represents full deployment, scaling across assets and regions, integration into standards and internal practices, and ongoing monitoring of performance in service. By integrating TRLs, RALs, CRIs, and ORLs into a unified adoption model, TAP offers operators and technology developers a roadmap for aligning expectations, identifying barriers early, and coordinating the activities required for successful deployment.

Commercial Guidance for Technology Advancement

Technology companies in the pipeline sector can face high failure rates, not because of poor technical performance, but because they fail to translate technical capabilities into sustainable commercial success. The TAP framework includes three core commercial guidance elements designed to increase the likelihood of long-term survival and adoption: identifying industry gaps, cultivating strategic relationships, and forecasting future needs.

Identifying industry gaps is foundational. Technologies gain traction when they address specific, well-understood shortcomings in current capabilities. These gaps may involve detection of threats that are poorly characterized by current in-line inspection tools, improvements to legacy repair systems, reduction of inspection uncertainty, or new approaches to continuous monitoring. Successful technology companies invest time listening to operators, visiting field sites, and understanding how integrity decisions are actually made. They recognize that operators work within budget constraints, regulatory requirements, and internal processes that shape which technologies can realistically be adopted. When a technology directly solves a problem that keeps integrity managers awake at night, its chances of success increase dramatically.

Relationship-building is equally essential. The pipeline industry operates heavily on trust, long-term partnerships, and demonstrated performance. Conferences, consortia, workshops, and collaborative forums such as the Pipeline Pigging & Integrity Management (PPIM) conference, the International Pipeline Conference (IPC), and CTAG, providing opportunities for technology innovators to showcase validated results, invite critique, and develop early adopter partnerships. Over time, these forums and conferences help establish credibility and demonstrate that a technology company is committed to transparency and continuous improvement. Many of the most successful deployments in the industry can be traced back to a handful of relationships where an operator champion and a technology provider jointly committed to solving a difficult problem.

In the pipeline industry there are multiple elements and players involved in bringing technologies to market. This is illustrated in Figure 2 with the four synergistic elements that include technology, regulatory, operational, and commercial. As illustrated in this graphic, successful technology deployments can only occur when there is a beneficial convergence of these four elements. The key stakeholders who contribute to this convergence include technology companies, pipeline operators, regulatory agencies, investors, and consultants. Although it is important to identify these four elements, recognition is not enough to engage key stakeholders. A process is required to help stakeholders shepherd the process of advancing technology adoption.
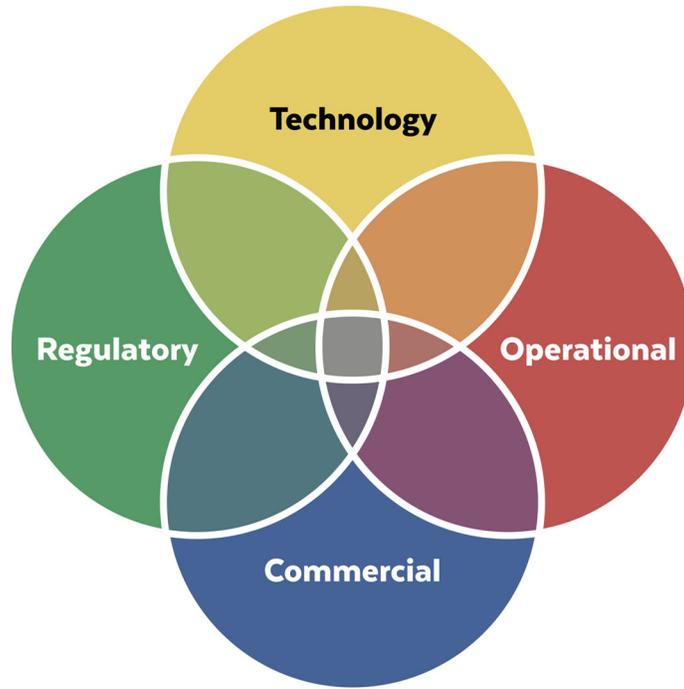
Figure 2. Key elements in the technology adoption process

Forecasting future needs is the third major commercial component. The pipeline industry is undergoing significant transitions driven by regulatory reform, increased public scrutiny, digital transformation, workforce turnover, and potential shifts toward hydrogen or renewable fuel blends. Companies that pay attention to these trends and adapt their technology roadmaps accordingly gain strategic advantage. In practice, this may mean designing tools that are compatible with multiple product types, building data platforms that can integrate with operator systems, or developing repair technologies that accommodate evolving design factors and safety margins. Long-term commercial success is directly tied to the ability to understand not only what the industry needs today but also what it will need ten or twenty years from now.

Practical Solutions for Accelerating Technology Adoption

Successful technology adoption requires more than conceptual frameworks—it requires action that is deliberate, collaborative, and sustained over time. The TAP offers practical solutions that can be implemented by both technology developers and operators to move promising ideas from concept to standard practice.

An influential and intentional initiative is the Composite Technology Advancement Group (CTAG), created to unite technology developers, operators, and research organizations around the advancement of composite repair and spoolable pipe technologies. CTAG facilitates open discussion, presents research findings, launches Joint Industry Programs, and fosters collaboration between technology companies, composite manufacturers, manufacturers, regulators, and pipeline operators. Regular meetings and working sessions provide a forum for sharing lessons learned from field

experience, identifying common challenges, and prioritizing research needs. As a structured platform, CTAG demonstrates how coordinated engagement can accelerate validation, clarify operator expectations, and promote acceptance of standardized design and installation practices.

Bridging the gap between discussions and implementation is essential for success. TAP encourages early full-scale testing to establish credible performance data, proactive regulatory engagement to reduce approval delays, and strategic operator pilot programs to demonstrate field performance under controlled conditions. Technology companies benefit from clearly documented performance summaries, including conference papers, case studies, and technical reports that communicate not only successes but also limitations and lessons learned. Over time, this transparency builds confidence and allows the industry to make informed decisions about where and how to use new tools.

Operator champions play a particularly critical role in these efforts. These individuals advocate internally for innovative solutions, help coordinate pilot projects, navigate procurement processes, and ensure that technologies are evaluated fairly. They understand both the technical and organizational dimensions of adoption and can translate between technology developers and internal stakeholders. Without strong operator champions, even well-developed technologies may struggle to move beyond isolated trials. TAP therefore encourages technology companies to invest in relationships with potential champions and to support them with clear information, responsive communication, and a long-term perspective.

Viewed collectively, these practical solutions demonstrate that innovation flourishes when the right stakeholders are connected, aligned, and empowered to act. The combination of structured frameworks like TAP, collaborative platforms such as CTAG, and committed operator champions creates an ecosystem where promising technologies can advance more quickly and reliably than they would in isolation.

Conclusions

The pipeline industry stands at a pivotal moment where aging infrastructure, evolving threats, regulatory expectations, and public scrutiny require rapid integration of innovative technologies. While technical readiness remains a fundamental requirement, successful adoption also demands alignment with regulatory frameworks, commercial maturity, and robust operational integration. The Technology Adoption Process provides a unified framework that brings these elements together into a coherent, actionable roadmap.

Through Technology Readiness Levels, Regulatory Acceptance Levels, Commercial Readiness Index, and Operational Readiness Levels, the TAP provides a multidimensional view of how technologies mature and where they may encounter obstacles. By recognizing that a deficiency in any one dimension can limit overall progress, the TAP encourages early identification of gaps and coordinated action among technology developers, operators, regulators, and investors. This coordinated approach helps ensure that development dollars are spent efficiently and that promising technologies are not abandoned prematurely due to avoidable barriers.

As the industry approaches a future characterized by increased digitalization, potential new energy products, and continued operation of aging assets, the need for advanced technologies will only increase. By adopting the TAP framework, investing in collaborative platforms, and empowering

operator champions, the pipeline community can accelerate innovation, enhance safety, reduce environmental and operational risk, and ensure the long-term reliability of high-pressure pipeline systems. In doing so, it sends a clear message to regulators, investors, and the public that the industry is committed not only to maintaining current performance but to continually improving the way pipelines are designed, operated, and managed.

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