Topic Paper #4-1

TECHNOLOGY COMMERCIALIZATION CHALLENGES IN THE MIDSTREAM OIL & NATURAL GAS SECTOR

Prepared for the

Technology Advancement and Deployment Task Group

On December 12, 2019 the National Petroleum Council (NPC) in approving its report, *Dynamic Delivery – America's Evolving Oil and Natural Gas Transportation Infrastructure*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Permitting, Siting, and Community Engagement for Infrastructure Development Task Group. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 26 such working documents used in the study analyses. Appendix C of the final NPC report provides a complete list of the 26 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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# Topic Paper (Prepared for the National Petroleum Council Study on Oil and Natural Gas Transportation Infrastructure)	
4-1	**Technology Commercialization Challenges in the Midstream Oil & Natural Gas Sector**
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SUMMARY

Oil and natural gas pipeline and storage technology advancements have been instrumental in the significant improvements in safety, environmental performance, and operational efficiencies in the industry and are critical for energy access and security. This topic paper will briefly discuss the evolution of the midstream sector, as well as provide a perspective on the various challenges that the midstream industry faces with respect to research, development, commercialization, and adoption of new technologies. If these challenges are fully recognized and understood, the relevant stakeholders can identify effective solutions to overcome them and enable technology advancements to continue to play an important role in propelling the industry forward.

I. Introduction

Advancements in technology have presented significant opportunities in the midstream oil and natural gas sector to improve safety, environmental performance, efficiency, and cost-savings and are critical for advancements in energy access and security. The midstream oil and gas sector refers to companies that own and/or operate oil and natural gas pipelines, storage facilities, marine transport, rail transport, and road transport (trucking) assets and can be broadly grouped into three stages: gathering & processing, transport, and storage. Gathering processes and the transportation of liquified natural gas (LNG) are outside of the scope of this topic paper and are not discussed in detail.

While extensive research and development (R&D) is being carried out by many stakeholders, including oil and gas companies, government agencies, and technology companies, technology commercialization and adoption in the midstream has moved slower as compared to upstream oil and natural gas as well as other technology-based industries[1] due to current market- and company-level challenges to technology commercialization.

While rail, truck, and marine contribute to the transportation of oil and natural gas, this topic paper will focus on technology commercialization challenges as it relates to pipeline and storage facility operators. Pipelines are the most prominent methods of transporting hydrocarbons, especially over longer distances, with 91% of crude oil, 68% of petroleum products and 100% of all dry natural gas shipped by pipeline to end users.[2] Storage – both underground natural gas storage and above ground liquids storage - is critical as consistent availability of energy is fundamental to both energy and national security.

This topic paper will briefly discuss the evolution of the midstream sector, as well as provide a perspective on the various challenges that the midstream industry faces with respect to research, development, commercialization, and adoption of new technologies. Both primary and secondary research methods were utilized to develop the topic paper. Primary research included 14 interviews with various stakeholders, including midstream executives, regulators, midstream operators, technology commercialization experts, and industry groups. Secondary research focused on open source research based on trends in the midstream sector to identify challenges and best practices in technology commercialization across other industries and to understand how these lessons could be applied to the midstream sector's commercialization challenges.

Emergence of the Midstream

The midstream sector emerged with the discovery of oil since producers needed a way to transport their product to a refinery and ultimately, to consumers. Transport is a crucial part of midstream oil and gas operations as production is generally far away from refining facilities and demand centers. The prevalence of pipeline operators in the United States increased in the early 1860s shortly after the first commercial well was drilled in 1859 in Pennsylvania, because they were an economical and efficient method of transporting oil as compared with wagons.[3]

As the link between the upstream and downstream sectors of the oil and natural gas industry, the midstream sector's success is connected to the health of both segments of the oil and natural gas value chain. Upstream operations involve exploration and production (E&P) of hydrocarbons while the downstream sector involves the refining of crude oil, processing of raw natural gas and marketing and distribution of oil and natural gas products to end consumers. Without demand from the downstream, the upstream sector will have less reason to move as much volume through the midstream sector.

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[1] Slaughter, Andrew, Gregory Bean, and Anshu Mittal. "Connected barrels: Transforming oil and gas strategies with the Internet of Things." Deloitte Insights. https://www2.deloitte.com/insights/us/en/focus/internet-of-things/iot-in-oil-and-gas-industry.html
[2] "Other Means of Transport." Pipeline 101. https://pipeline101.com/Why-Do-We-Need-Pipelines/Other-Means-Of-Transport
[3] Ibid.

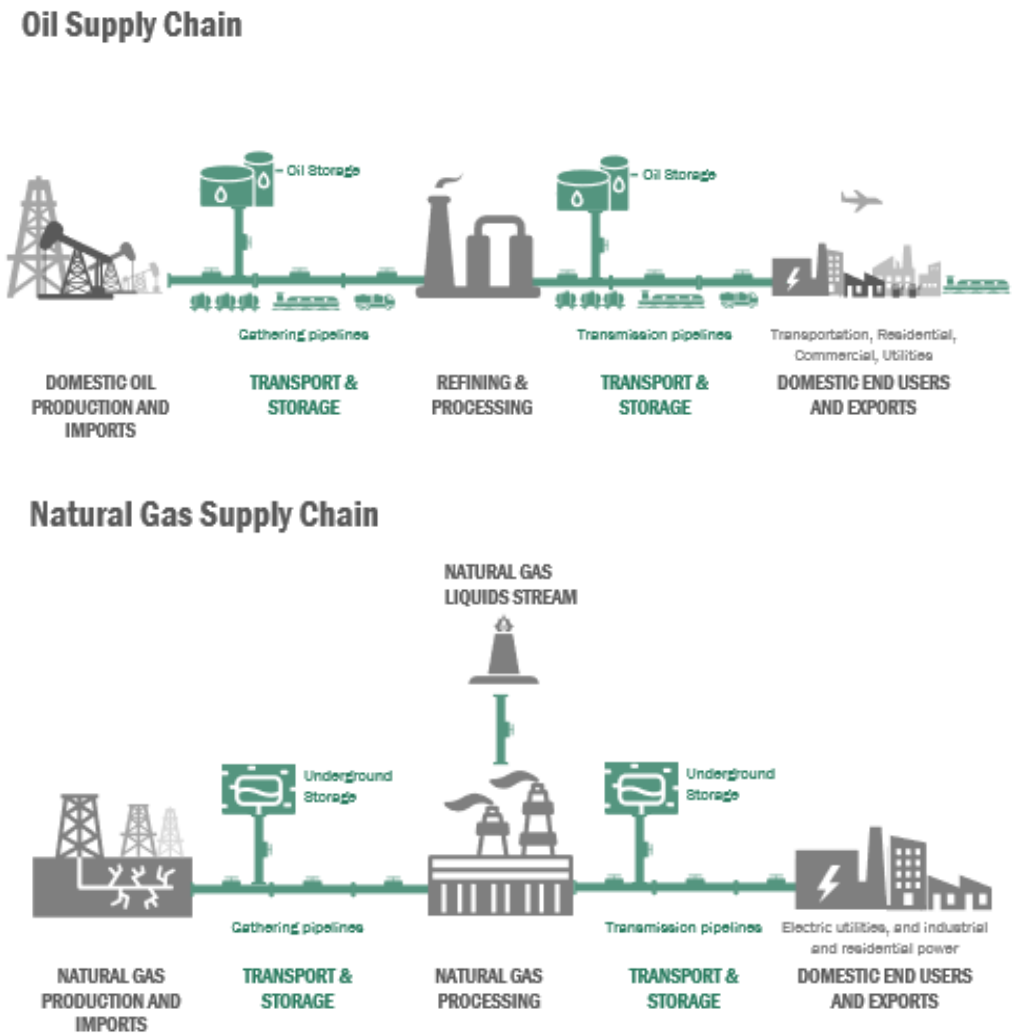

Figure 1: Midstream Oil and Natural Gas Supply Chains

After upstream companies extract raw hydrocarbons from a well, some hydrocarbons are transferred to the midstream sector for gathering and/or processing (natural gas/natural gas liquids (NGLs) only) prior to long-distance transport.

The initial gathering step is a critical part of the midstream supply chain, and may include processes such as fractionation, vaporization, or compression. Once, the hydrocarbons have been "gathered," they are ready for transport. Several modes of transport facilitate the movement of oil and natural gas from supply to demand points, including pipeline, rail, ship, and truck. Other processes such as liquefaction or regasification play an important role in the transport of natural gas. These processes help cool natural gas into its liquid form LNG to ship in cryogenic tankers. When transport by pipeline is not feasible, the industry relies on LNG shipping as a form of long-distance transport for natural gas.

Once the hydrocarbon reaches its destination, it is either consumed immediately or stored for future use. The midstream sector uses a variety of techniques to store oil and natural gas, which range from natural and mined geological formations to manufactured steel tanks. These supply chain processes are highly interrelated and advances in one technology sometimes drive or necessitate the requirement for advances in the other. Evidence of this highly correlated relationship is prominent in the transport and storage segments of the midstream supply chain.

II. Impact of Technological Advances on the Midstream Sector

Technology advances in the midstream oil and natural gas sector provides context to the challenges that the industry faces today with respect to technology commercialization and adoption. The following advances and innovations have improved the sector's safety, environmental performance, operational efficiencies and energy access and security.

Safety

Advances in pipeline technology have contributed significantly to safety improvements in the midstream sector. Enhanced coating and durable epoxies have reduced pipeline corrosion, thereby reducing pipeline failure.[4] Corrosion that is not detected and addressed can cause leaks and even explosions in extreme circumstances. Load moment indicators protects workers installing pipeline by warning operators if a machine is at risk of tipping[5] and new artificial intelligence tools alert operators with early leak detection so that these can be remediated before they become safety threats.

Midstream safety incidents have driven technology adoption in the past. In 2010, the National Transportation Safety Board (NTSB) determined that an explosion at a PG&E natural gas transmission pipeline in San Bruno, CA, was caused by welded seam defects that the utility did not detect and adequately address. The utility took 95 minutes to shut off the natural gas from the faulty pipeline, which prompted review of the procedures and technologies in place during in emergencies. The NTSB claimed that the lack of automatic shut-off valves and remote-controlled valves were factors in the slow response by the utility.[6] After the incident, automated and remotely controlled valves were installed on their transmission pipelines.[7]

The pervasiveness of older pipelines has created demand for new technologies to monitor pipeline integrity and assist with maintenance and the advent of "smart" pipeline inspection gauges (PIG) for in-line inspection (ILI) is helping with gathering information about pipeline condition, allowing operators to make safety improvements quickly.

The role of maintenance technology enhances inspection and repair procedures to improve safety and reduce manual labor hours. Some of these technologies range from invasive underwater robotics equipped with sensors, water samplers, and video cameras to non-invasive internet connected sensors coupled with machine learning tools used to detect irregular volumes of hydrocarbons in the environment.[8]

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[4] "Pipeline Failure Causes." Pipeline and Hazardous Materials Safety Administration. https://www.phmsa.dot.gov/incident-reporting/accident-investigation-division/pipeline-failure-causes

[5] Canadian Energy Pipeline Association. "6 Pipeline Technologies You'll Want to Know About." About Pipelines. https://www.aboutpipelines.com/en/blog/6-pipeline-technologies-youll-want-to-know-about/

[6] Weikel, Dan. "San Bruno pipeline explosion: 'A failure of the entire system.'" Los Angeles Times. https://www.latimes.com/local/la-xpm-2011-aug-30-la-me-0831-san-bruno-20110831-story.html

[7] Morris, J.D. "San Francisco pipeline blast puts spotlight on PG&E's shutoff abilities." San Francisco Chronicle. https://www.sfchronicle.com/business/article/San-Francisco-pipeline-blast-puts-spotlight-on-13598976.php

[8] Canadian Energy Pipeline Association. "Exploring Pipeline Technology: Digital Sensors and Leak Detection." About Pipelines. https://www.aboutpipelines.com/en/blog/exploring-pipeline-technology-digital-sensors-and-leak-detection/

Technological advancements in tank storage have focused on safety and efficiency improvements. Innovations in automated tank cleaning (reducing safety risks associated with manual cleaning) exist in the market but have not been adopted widely. Corrosion solutions such as all-fiberglass tanks, fiberglass coatings, and cathodic protection technology have been readily adopted for in-ground tanks and pipelines. 3M and Dow Hyperlast have begun designing for offshore storage solutions that require high-temperature corrosion protection due to the operational temperatures of deep-down-hole oil and gas production.[9] Metering and monitoring technology allow for constant monitoring of infrastructure to ensure safety: full flow pressure relief valves release pressure automatically, while overpressure shutdown allows operators to shut down equipment before they can contribute to accidents.

Environmental Performance

Research funded by the National Energy Technology Laboratory (NETL) involves reducing methane leaks from natural gas pipeline infrastructure by analyzing legacy and new plastic pipelines, as well as the utility of plastic liners.[10] Pipeline coatings are particularly important because they reduce corrosion and the risk of leaks damaging the environment around it. These external barrier coating and cathodic protection systems must be resistant to soil, chemicals, bacteria, and local flora while also providing electrical resistance to prevent any reactions on the surface of the pipeline.[11]

Technology advancements led to modern underground natural gas storage which allows for the conversion of a depleted oil or natural gas reservoir to a storage facility.[12] Underground gas storage advancements today focus on improving gas storage well integrity, reservoir integrity, and mitigating gas leakages that release gas into the air and potentially endanger the health of workers and residents. The high visibility of the Aliso Canyon natural gas well blowout in 2015-2016 increased the attention on natural gas storage integrity across the country.[13] For aboveground storage of crude oil, metering monitoring technologies also contribute to the reduction of spills and the resulting clean-up of the surrounding environment.

Operational Efficiencies, Energy Access, and Energy Security

Improvements in installation techniques, pipeline coatings and durable epoxies increase the lifespan of infrastructure and improves operational efficiency. This reduces cost, risks, construction time, and extends the life of existing infrastructure. Similarly, advances in storage technology like automatic tank cleaning reduce the down-time of tanks, thus improving efficiency.

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[9] "Tank Technologies Keep It Clean." Hydrocarbons Technology. https://www.hydrocarbons-technology.com/features/feature61552/

[10] "Classification of Methane Emissions from Industrial Meters, Vintage vs New Plastic Pipe, and Plastic-Lined Steel and Cast Iron Pipe." National Energy Technology Laboratory, Aug 2019. https://www.netl.doe.gov/node/2218

[11] Larsen, Kathy Riggs. "Using Pipeline Coatings with Cathodic Protection." Materials Performance, Apr 2016. http://www.materialsperformance.com/articles/cathodic-protection/2016/04/using-pipeline-coatings-with-cathodic-protection

[12] "The Basics of Underground Natural Gas Storage." U.S Energy Information Administration, Nov 2015. https://www.eia.gov/naturalgas/storage/basics/

[13] Freifeld, et al. *Well Integrity for Natural Gas Storage in Depleted Reservoirs or Aquifers.* National Energy Technology Laboratory (NETL), Dec 2016. https://edx.netl.doe.gov/dataset/well-integrity-for-natural-gas-storage-in-depleted-reservoirs-and-aquifers/resource_download/9994e232-03a9-4a80-b4f5-036462f1e70a

The industrialization and success of the U.S. economy is tied to the development and advances of intra- and interstate pipelines[14] as supply regions are frequently far from demand centers. Pipelines facilitate this energy resource access, create sustainable economic benefits

and employment opportunities and promote energy security. Storage technologies also promote energy security by ensuring a steady supply of hydrocarbons in the event of planned or unexpected production stoppages and stored hydrocarbons can improve power grid resiliency.

The technological developments that have happened in the industry to date have been essential contributors to improving the safety, environmental protection, and operational efficiency of the midstream sector. However, further technological research and advancements are essential to continuing to improve the sector across these domains. While technological development is ongoing, improvements are only effective if adopted and deployed by companies. Understanding the challenges to technology commercialization in the midstream sector is a critical first step to develop innovative and effective solutions and ultimately, build upon the significant performance improvements that the industry has achieved to-date.

III. Challenges to Midstream Technology Commercialization

Through extensive research and interviews with midstream industry professionals and oil and natural gas experts, five core challenges to technology commercialization and adoption were identified and summarized in Table 1 below.

Table 1: Overview of Challenges to Technology Commercialization in Midstream Sector

Market and Competitive Environment	Utility-like industry limits profit margins and available cash for R&D investment.
Operating Model and Structure	MLP structure prioritizes quarterly owner distributions over retaining earnings.
Business Case and Risks of New Technologies	Overly conservative safety threshold can constrain interest in new technology adoption.
Integration and Change Management	Integration of new technologies with legacy infrastructure and the modernization of processes, culture, and skill sets is lengthy and complex.
Government Policy and Regulation	Inflexible regulations can hinder commercialization and adoption of new technologies.

Market and Competitive Environment

In recent years, increased competition among midstream pipeline operators in the United States has led to reduced profit margins, fueling a wave of consolidations that began in the late 1990s. Reduced margins meant less capital that could potentially be invested in R&D activities. Due to expected investment returns, R&D activities by operating companies tend to focus on shorter-term solutions versus long-term efforts. There are definite advantages to focusing on

[14] "2016 State of American Energy." American Petroleum Institute. http://f1fa37e0697c05ce80aa-6afa3cf29a0c87fcae6f2ae0a7834648.r12.cf2.rackcdn.com/API_SOAEReport_2016.pdf

technologies that can be commercialized in the short term, however, limited investment in long-term R&D can potentially be short-sighted for an industry that operates assets with a long useful life.

Midstream pipeline operators generate revenues through two primary mechanisms: fees and regulated tariffs.[15] Often times, these fixed fees are charged as part of long-term contracts established with suppliers. While these long-term contract structures provide stability, it may pose a challenge to midstream companies to invest in researching, commercializing, and adopting new technologies. For example, if a midstream company invests in adopting a new technology within this time frame, it will incur additional costs without being able to adjust prices to maintain current margins, if contract renegotiations are not possible.

With interstate pipelines, the tariffs are regulated by the Federal Energy Regulatory Commission (FERC) to ensure that rates charged for oil and natural gas transport are considered reasonable.[16] Regulated tariffs are set so that operators can cover their costs, deliver an acceptable profit margin for investors, and maintain their safety, environmental, and other obligations. As such, midstream companies cannot easily adjust their rates to account for investments in new technologies. Consequently, the potential upside for additional investment in technology by individual operating companies can be limited. In contrast, upstream competitors whose revenues are directly linked to commodity prices have a much higher potential upside as shown in Figure 2, due to the greater risk inherent in their operations. Figure 2 illustrates the difference in net profit margins for both industries.

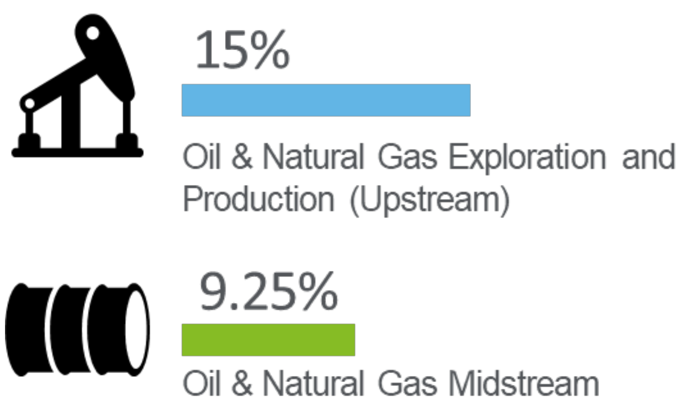

Figure 2: Average Net Profit Margins of Midstream and Upstream Sectors, 2018[17]

Storage pricing is not regulated in the same way as pipelines, and as such, has the opportunity for a higher profit margin. However, storage assets tend to make up a much smaller portion of midstream business operations, and as such, may not be able to offset the utility-like revenue structure of the pipeline-dominated midstream sector.

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[15] DiLallo, Matthew. "An Investor's Guide to Midstream Oil and Gas." The Motley Fool, LLC. https://www.fool.com/investing/2018/11/21/an-investors-guide-to-midstream-oil-and-gas.aspx
[16] Ibid.
[17] https://app.dnbhoovers.com/company/d5d4c5c1-6a80-3518-aca3-83942e94d1aa#report/company_ratio_comparison

Midstream companies have attempted to de-risk their reliance on upstream activities by establishing "take-or-pay" or "minimum volume" contracts, which guarantees payment regardless of the volume of crude oil, crude oil products, natural gas or NGLs that are transported.[18] In recent years however, the shale boom has caused some producers to seek more short to medium-term contracts, due to the short-cycled nature of shales. These shorter-term contracts have put the conventional long-term contracts at risk, thereby reducing the stability of midstream returns over longer periods of time.[19] With greater instability in returns, midstream companies are even less willing to invest in long-term technology development.

The midstream sector also lacks an enabling system that promotes technology development by developers and deployment by operators. Limited interest by technology investors in midstream makes it more difficult to rapidly validate and commercialize new technologies.

Finally, while collaboration exists in the midstream sector, the industry lacks consortia that engage in activities to support technology development. Multiple experts cited the use of consortia as an effective method to encourage collaboration among different stakeholders. These organizations can also play a role in de-risking technologies to facilitate their commercialization and adoption. Organizations such as the Pipeline Research Council International (PRCI) engage with the midstream sector and developers to drive collaboration and deliver research that can specifically improve pipeline and underground storage systems.[20] However, PRCI is just one organization in a vast industry that could benefit from more of such organizations.

Operating Model and Structure

The operating model and structure of the midstream sector informs how investment priorities and business decisions are determined. Pipeline and storage companies can be structured as independent midstream companies or integrated oil and gas companies. Understanding the difference between these two types is important because the drivers behind their investment decisions and the risks they face differ. Integrated energy companies can leverage benefits from R&D investments across their value chain, whereas independent midstream companies are limited to investment levels that fit within their fee-based business model.

Independent Midstream Companies

An integrated oil and natural gas company engages in E&P, refinement, and distribution of oil and natural gas and related products. In the 1980s, several integrated companies began spinning off their midstream operations into Master Limited Partnerships (MLPs), contributing to the rise of independent midstream oil and gas companies.[21] MLPs are publicly traded entities which are treated as partnerships rather than corporations for tax purposes. Their association with the midstream oil and natural gas sector became more prevalent after the Tax Reform Act of 1986 which limited the use of MLPs to companies with 90% qualifying income – or income from

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[18] Keuer, Whit. "North American Midstream Strategy in a Time of Uncertainty." Bain & Company. https://www.bain.com/insights/north-american-midstream-strategy-in-uncertainty/

[19] Dickson, Duane, and Andrew Slaughter. "Back to basics: Solving the capital conundrum of US midstream companies." Deloitte. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-mid-stream-report-2018.pdf

[20] "History & Mission." Pipeline Research Council International (PRCI). https://www.prci.org/About/Mission.aspx; https://www.prci.org/Research/UndergroundStorage.aspx

[21] Stetzer, Doug. "Oil 101 – Introduction to Midstream Oil and Gas." EKT Interactive. https://www.ektinteractive.com/podcast/oil-101-podcast/002-oil-101-midstream/

exploration, production, or transportation of natural resources or real estate.[22] Today, MLPs remain an important player in the midstream sector.[23]

In the 1980s, MLPs were focused on low capital expenditures to provide higher distributions to investors. By the 2000s, MLPs began focusing on growth opportunities, through acquisitions and additional projects.[24,25] To finance activities beyond operations and routine maintenance, like organic growth opportunities or acquisitions, MLPs rely on access to capital markets.[26] Since 2015, many MLPs reduced their distribution growth, which led to a self-funding model, relying more on retained earnings than equity markets to fund growth projects.[27]

Some independent midstream companies in the United States are structured as corporations, and in recent years, a number of MLPs have converted to a corporate structure. The table below illustrates the top 10 midstream companies by enterprise value and their corporate structure (as of August 2019).[28]

Table 2: Midstream Company Structures

Company	Corporate Structure
Enbridge	Corporation
Energy Transfer	MLP
Enterprise Products Partners	MLP
TC Energy	Corporation
Kinder Morgan	Corporation
Williams Companies	Corporation
Cheniere Energy	Corporation
MPLX	MLP
ONEOK	Corporation
Plains All American Pipelines	MLP

The main advantage of the MLP structure to investors is that unlike corporations, the MLP's taxable income is passed through to investors, along with offsetting deductions, rather than taxed

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[22] Chen, James. "Master Limited Partnership – MLP." Investopedia. https://www.investopedia.com/terms/m/mlp.asp
[23] "The rise of the midstream." Deloitte, 2013. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-the-rise-of-the-midstream.pdf.
[24] O'Hare, John, and Judy Xanthopoulos. "Midstream Energy Master Limited Partnerships Economic Analysis – Contributions to Employment and Income." Quantria Strategies, 2012. https://www.mlpassociation.org/wp-content/uploads/2015/08/MLP_Jobs_Final_Document_6-22-12.pdf;
[25] Ross, Chris. "Back to Basics: Evolution of the Midstream Sector." Forbes. https://www.forbes.com/sites/uhenergy/2018/01/22/back-to-the-basics-evolution-of-the-midstream-sector/#d7dc5c17169e
[26] Arbogast, Stephen. "The Midstream Promises Value – Unpacking the Market's Most Underappreciated Sector." Energy Center, UNC Kenan-Flagler Business School. https://energyatkenanflagler.unc.edu/index.php/the-midstream-promises-value-unpacking-the-markets-most-underappreciated-sector/
[27] "GSAM Energy & Infrastructure Team: Market Review and Outlook." Goldman Sachs Asset Management. https://www.gsam.com/content/dam/gsam/pdfs/us/en/fund-literature/quarterly-fund-update/GSAM-US-Energy-and-Infrastructure-Quarterly-Update.pdf?sa=n&rd=n
[28] DiLallo, Matthew. "An Investor's Guide to Midstream Oil and Gas." The Motley Fool, Aug 2019. https://www.fool.com/investing/2018/11/21/an-investors-guide-to-midstream-oil-and-gas.aspx;

at the entity level. Due to lower oil prices, regulatory changes, and the 2017 U.S. tax reform, the MLP business model has been negatively impacted over the last 5 years. In 2019, corporations make up a growing portion of total midstream market capitalization as shown in Figure 3 below.[29]

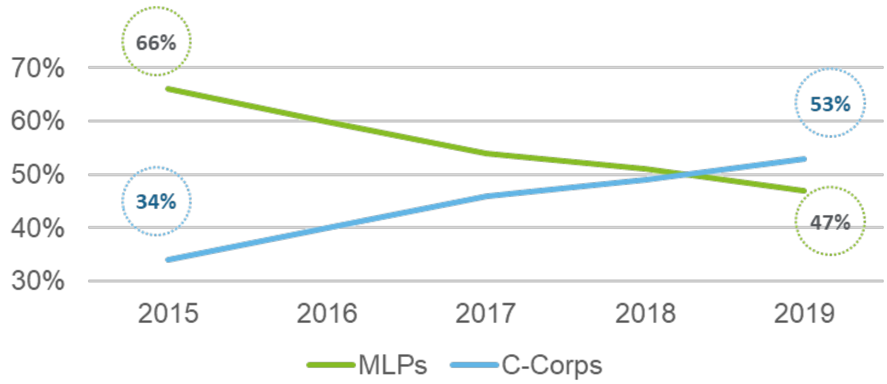

Figure 3: Evolution of Midstream Company Structure as Percentage of Midstream Market Capitalization from 2015-2019[30]

Integrated Oil and Natural Gas Companies

Integrated oil and natural gas companies have an advantage in directing midstream investments due to their insights into the needs of the parent company's upstream and downstream sectors[31]. They can make larger investments in new technologies as they have access to more capital, they have more opportunities across their business lines, and innovation in new technologies can improve their competitive advantage. This is evidenced by several major integrated oil and natural gas companies with large R&D portfolios that place a strong emphasis on technology commercialization. For example, ExxonMobil invests about $1 billion a year in R&D activities and partners with universities and other organizations to continually improve their insights and adoption of new technologies. Shell has multiple technology centers focused on R&D activities, a corporate venture arm called Shell Ventures, and an innovation program called Shell Techworks, which partners with technology developers and start-ups outside of the energy industry to understand how their technologies may be applied to the energy industry.[32] Chevron owns its own energy technology company and a venture company that focuses on developing and commercializing new technologies.[33]

Challenge of Commercializing Midstream Technologies

As of 2019, MLPs still make up approximately 47% of midstream market capitalization. MLPs are specifically structured to have to distribute "available cash," paying out a significant portion

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[29] "GSAM Energy & Infrastructure Team: Market Review and Outlook." Goldman Sachs Asset Management. https://www.gsam.com/content/dam/gsam/pdfs/us/en/fund-literature/quarterly-fund-update/GSAM-US-Energy-and-Infrastructure-Quarterly-Update.pdf?sa=n&rd=n

[30] "GSAM Energy & Infrastructure Team: Market Review and Outlook." Goldman Sachs Asset Management. https://www.gsam.com/content/dam/gsam/pdfs/us/en/fund-literature/quarterly-fund-update/GSAM-US-Energy-and-Infrastructure-Quarterly-Update.pdf?sa=n&rd=n

[31] Ross, Chris. "Back to Basics: Evolution of the Midstream Sector." Forbes. https://www.forbes.com/sites/uhenergy/2018/01/22/back-to-the-basics-evolution-of-the-midstream-sector/#d7dc5c17169e

[30] "Shell Techworks." Shell. https://www.shell.com/energy-and-innovation/innovating-together/shell-techworks.html

[33] "Creating Innovative Solutions." Chevron. https://www.chevron.com/technology

of distributable cash flow to unitholders as stipulated in the partnership agreement. As a result, MLPs are very dependent on ratable cash flows, making the reliability and safety of their assets key to the overall ability to continue delivering cash to unitholders. These competing priorities present a challenging choice for MLPs of whether to re-invest more of their earnings in technology development that can improve the reliability and safety of the assets or to distribute those earnings to unitholders. Inevitably, the imperative of providing a consistent cash distribution to unitholders surpasses that of increased investment in R&D. Consequently, MLPs are left with only enough capital to fund their operations and maintenance expenses, and have limited capital to invest in significant R&D. [34,35]

The MLP structure can make it difficult to justify large technology investments, especially investments that require large upfront capital. With limited cash available after distributions, MLPs either lack sufficient funds to invest in new technologies or rely on capital markets to obtain the necessary funding.

The fixed-fee nature of midstream margins combined with the tax structure of MLPs can also make it more difficult for midstream companies to justify significant investments in R&D activities. As a result, MLPs do not often have extensive R&D divisions focused on the development and commercialization of new technologies. While some larger corporations and integrated oil and natural gas companies have established R&D groups, smaller midstream operators may not have internal R&D.

Figure 4 below shows The Technology Adoption Curve[36] which offers a lens into how the different structures of midstream companies can impact how quickly technology can be adopted. Midstream companies & MLPs, because of their business model of delivering modest, stable, and predictable returns for investors, are likely to fall on the right-hand side of the curve as late majority adopters of new technologies. Conversely, integrated companies and technology supply organizations will likely represent innovators and early adopters as their significant R&D investments allow them to develop new technology in-house as well as adopt new innovations more easily.

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[34] Arbogast, Stephen. "The Midstream Promises Value – Unpacking the Market's Most Underappreciated Sector." Energy Center, UNC Kenan-Flagler Business School. https://energyatkenanflagler.unc.edu/index.php/the-midstream-promises-value-unpacking-the-markets-most-underappreciated-sector/

[35] Slaughter, Andrew, Anshu Mittal, and Vivek Bansal. "The new frontier: Bringing the digital revolution to midstream oil and gas." Deloitte Insights. https://www2.deloitte.com/insights/us/en/industry/oil-and-gas/digital-transformation-midstream-oil-and-gas.html

[36] Von Hippel, Eric. "The User Innovation Revolution." MIT Sloan Management Review. https://sloanreview.mit.edu/article/the-user-innovation-revolution

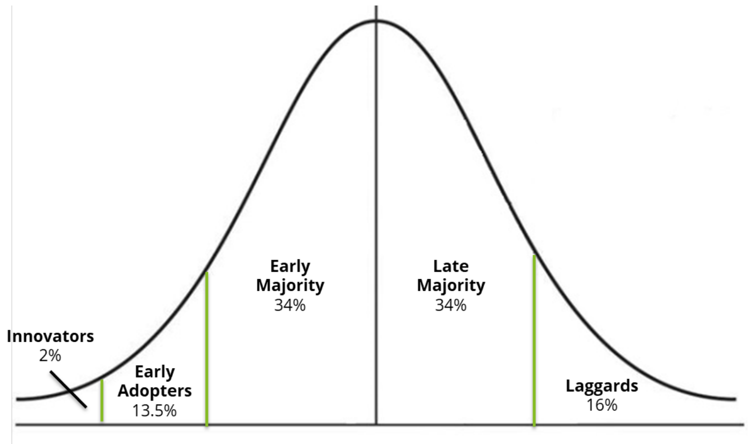

Figure 4: Technology Adoption Curve

Business Case and Risks of New Technologies

The midstream sector is a relatively mature industry and has been able to demonstrate safe and reliable transportation of hydrocarbons. A barrel of crude oil or refined product moved by pipeline is safely delivered to its end-point more than 99.999% of the time.[37] Similarly, most underground and aboveground storage facilities have safe operating histories; however, when accidents have occurred, they have had significant impacts on health, safety, and the environment. Technological and safety advancements have been accelerated by these incidents. While stakeholders expect continuous improvement in the safety, efficiency and environmental performance of pipeline and storage operations, proving the effectiveness of new technologies can be difficult. Trials can take longer than expected and there can be delays to scale-up adoption. This has historically led to a slower rate of new technology adoption in the oil and natural gas transportation industries in comparison to some other industries such as information technology (IT).

It is also important to demonstrate a favorable benefit-cost analysis of new technology to facilitate adoption. Innovation will not gain traction without a demonstrated favorable benefit-cost ratio and evaluating the benefits and costs of new technology can be difficult because of their inherent uncertainty. While there are both economic and non-economic benefits to consider, the latter are difficult to quantify. For example, risk reduction resulting from the implementation of safety technologies is a non-economic benefit that is difficult to measure. From a cost perspective, initial costs of new technology tend to be very high and can be driven down as technologies mature and through deployment at scale. To drive down costs requires additional investment in technology development and the magnitude and time horizon in which that cost reduction can be achieved is uncertain. Some new technologies can have far-reaching impacts across the oil and natural gas supply chain, translating to very high implementation costs that should be factored into the decision-making process.

This benefit-cost analysis may affect the potential of utilizing "big data" and the Internet of Things (IoT) in the midstream. Both big data and the IoT focus on collecting, analyzing, and using data to make effective business decisions and while these digital technologies can provide

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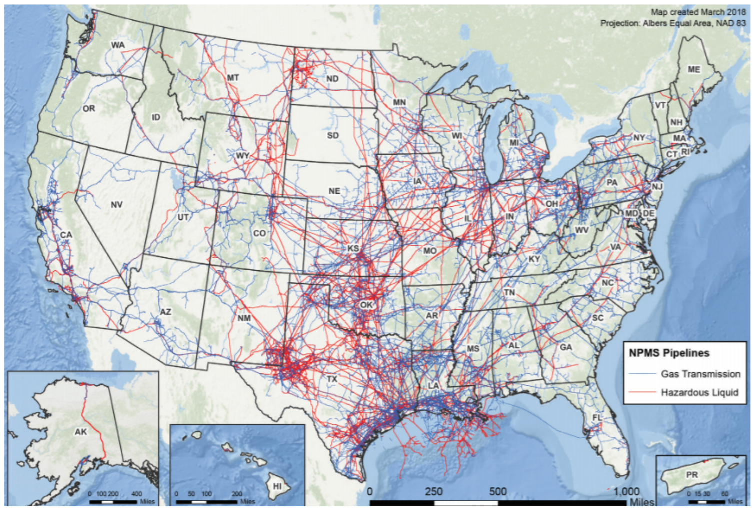
[37] "Are Pipelines Safe?" Pipeline 101. https://pipeline101.org/Are-Pipelines-Safe

value propositions to midstream companies, there are a few notable risks. Installing sensors can provide vast amounts of data that may be useful for asset and operational integrity, but the potential risk of cyber-attacks may outweigh the benefits.

As such, choosing a proven technology, that offers operators efficient, safe, and reliable transportation, and has demonstrated a consistent level of performance is more appealing than a new technology that has not yet proved its value in an operational setting, even if it claims to offer better performance standards. For example, failure of a new technology that is meant to improve the quality of in-line inspection (ILI) tools to accurately provide assessments of the asset integrity of a pipeline can result in failures that not only threaten profits, but also threaten lives. Similarly, failure of cement or epoxy squeezes meant to restore underground well integrity could threaten lives through slow leaks of gas. These potential risks have led the industry to require rigorous and extensive testing of new technologies before they are willing to deploy them.

Integration and Change Management

Currently, the U.S. pipeline system network has older assets that remain in use; more than 50% of the pipelines in operation are over 40 years old.[38] The current U.S. oil and natural gas transmission pipelines are shown below in Figure 5.



Gas transmission (blue) and hazardous liquid (red) pipelines in the United States as of March 2018. Image does not include gas distribution lines. Hazardous liquid pipelines are mostly those used for crude oil, refined products, and other petroleum liquids, but also include pipelines used to transport ammonia and carbon dioxide. Image credit: Pipeline and Hazardous Materials Safety Administration.[1]

Figure 5: U.S. Oil and Gas Transmission Pipeline Network, March 2018[39]

Storage also has an extensive legacy asset base, including legacy reservoirs and monitoring equipment (as shown below in Figure 6).

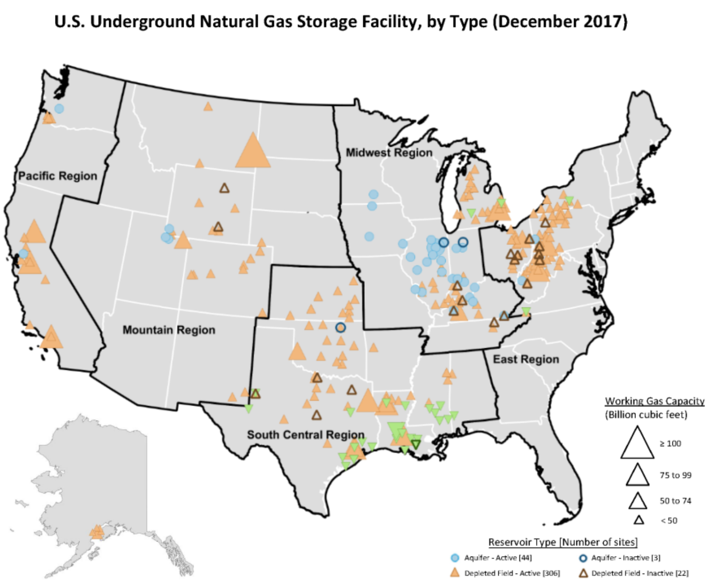


Figure 6: U.S. Underground Natural Gas Storage Facility by Type, December 2017[40]

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[38] Ibid

[39] Allison, E, and B. Mandler, "Transportation of Oil, Gas, and Refined Products." American Geosciences Institute. https://www.americangeosciences.org/sites/default/files/AGI_PE_Transportation_web_final.pdf

[40] Ondiflo. "Blockchain Use Cases for Midstream Oil & Gas." Medium, September 2018. https://media.consensys.net/blockchain-use-cases-for-midstream-oil-gas-609033457e33

Such an asset base is characterized by mechanical operating processes, although automation has become more prevalent.[41] Retrofitting legacy infrastructure with new high-end technologies can be technically complex and costly and can slow the technology adoption process.

In addition to the technical complexities associated with integrating new technologies, changing established business processes and cultures of existing companies and industries is an important need and requires skillful efforts to ensure change is successful and sustainable. Understanding how a new technology will integrate with a legacy asset and system may require substantial change management support, which may further drive up costs. Even if a new technology can improve operational efficiency and safety, the complexity of implementation may result in risks to other parts of the system. Preparing for new technologies requires a strong change management strategy and process that may seem expensive and cumbersome for companies, which creates another barrier to technology commercialization and adoption.

Equally relevant is the challenge of technology integration. The midstream oil and natural gas sector has an established culture and business process and the introduction of new technologies may require the workforce to develop new skills to fully optimize the potential value of new technologies. The implementation of new technologies can bring about transformational change to both processes and people within an organization, especially for a mature industry. For example, the increased penetration of digital technologies requires organizations to adapt to process automation and the accompanying systems and tools. They must also learn to collect, analyze, and utilize vast amounts of data at a rapid pace to make effective business decisions. This paradigm shift demands additional skills and expertise from the workforce and that transition takes time and investment. These technologies also introduce new risks such as those associated with the cyber security of operating system technologies and information. The costs and risks associated with such transformational change can be a significant barrier to new technology adoption.

Government Policy and Regulation

Existing regulations can be a challenge to the advancement and deployment of new technology because they can hamper an operator's ability to cost-effectively address potential problems through the application of the most innovative technology, critical engineering assessment processes, and fit-for-purpose repair criteria based on data and sound engineering principles.

Lack of Standardized Procedure in Testing, Evaluation, and Acceptance Process

Midstream operators have cited a lack of clear process around testing, evaluation, and acceptance procedures for new technologies as a barrier to commercializing new technologies that can produce better operational and safety outcomes. Interstate pipeline transport of oil and natural gas, aboveground liquids storage, and underground natural gas storage are regulated by an agency of the Department of Transportation called the Pipeline and Hazardous Materials Safety Administration (PHMSA). PHMSA establishes policies, sets, and enforces standards, educates,

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[41] Slaughter, A, A. Mittal, and V. Bansal. "The new frontier." Deloitte Insights. https://www2.deloitte.com/us/en/insights/industry/oil-and-gas/digital-transformation-midstream-oil-and-gas.html?id=us%3A2sm%3A3tw%3A4di4729%3A%3A6er%3A20181101171000%3A&utm_source=tw&utm_campaign=di4729&utm_content=er&utm_medium=social&linkId=59024455

and conducts research to reduce pipeline safety incidents, as well as prepares first responders on how to react effectively to incidents.[42] PHMSA has two special permits for emerging and new technologies but they serve as exception mechanisms rather than routine methods that encourage and standardize testing, acceptance, and evaluation of new technologies.

Permitting Process

PHMSA utilizes two special circumstance permitting processes for incorporating new technologies: "Other Technology Notifications" and "Special Permits," but these processes can be challenging for operators.

"Other Technology Notifications" are listed in 49 CFR 192.921 (a)(4) and allow for pipeline operators to use emerging and new technologies for the exclusive purpose of asset integrity assessments.[43] Through this process, operators apply for and secure a permit to use a new technology to assess pipeline integrity. Once the technology is used, the Office of Pipeline Safety (OPS) conducts an audit of the technology to ensure it performed adequately and provided the necessary outcomes as mandated in the regulations. Although this provision exists to allow midstream operators to use new technologies to address pipeline integrity and has even been used successfully, securing approval this way has been described by midstream operators as cumbersome, time-consuming, and requiring multiple approvals from multiple stakeholders, which can disincentivize operators from submitting these notifications.

PHMSA is also responsible for granting Department of Transportation Special Permits. Special Permits allow for variations in the Hazardous Materials Requirements as long as new technologies would meet the safety levels set by regulations or would maintain public safety.[44] Special Permits apply to the transportation of oil and natural gas through multiple modes of transport, in addition to other hazardous materials, and offer operators an opportunity to use technologies that can adequately meet or exceed safety standards set forth in 49 CFR Part 107 or 49 CFR Parts 171-180.[45] While Special Permits can enable new technologies, they are temporary. If approved, permits last only two years, and while there are opportunities for renewals, they last only an additional four years.[46] Many applications have been denied in their requests for Special Permits, usually because operators do not have full insight of the expectations for receiving one, particularly if submitting their first application. The provision of Special Permits can be beneficial for commercializing and deploying new technologies, but is limited by the specificity of the permit, by the difficulty and lack of clarity around approval, and by the short timeframe of the actual permit.

While Other Technology Notifications and Special Permits provide opportunities for emerging and new technologies to be adopted, they serve only as mechanisms to be used in specific

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[42] "PHMSA's Mission." Pipeline and Hazardous Materials Safety Administration (PHMSA). https://www.phmsa.dot.gov/about-phmsa/phmsas-mission

[43] Notifications Concerning Use of "Other Technology." Pipeline and Hazardous Materials Safety Administration (PHMSA). https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/technical-resources/pipeline/cased-crossings-and-gwut/65961/othertechnologynotificationsfromadvisorybulletin.pdf

[44] "Hazardous Materials Approvals and Permits Overview." Pipeline and Hazardous Materials Safety Administration (PHMSA) https://www.phmsa.dot.gov/approvals-and-permits/hazmat/hazardous-materials-approvals-and-permits-overview

[45] "Hazardous Materials Special Permits FAQs." Pipeline and Hazardous Materials Safety Administration (PHMSA) https://www.phmsa.dot.gov/faqs/hazardous-materials-special-permits-faqs

[46] Ibid.

circumstances and not as methods that encourage the regular testing, acceptance, and evaluation of new technologies.

Prescriptive vs. Performance-Based Regulations

Regulations for deploying new technologies in the midstream can be categorized as prescriptive or performance-based. Prescriptive regulations refer to those that specify methods that need to be used to achieve a particular outcome, whereas performance-based regulations refer to measurable outcomes that need to be met without specifying exact methods to achieve them.[47] While both prescriptive and performance-based regulations are effective regulatory tools, they are sometimes misaligned to the technology they regulate. Consequently, operators are governed by a mismatched regulation and are challenged when attempting to innovate and deploy new technologies.

In some circumstances, prescriptive regulations can discourage the use of new technologies, even when a new technology has the potential to achieve the same or improved outcomes. An example of a prescriptive regulation is the requirement for pressure testing of hazardous liquids (49 CFR 192 Subpart E) and natural gas (49 CFR 192 Subpart J).[48] Pressure testing is required by regulations to evaluate the integrity of hazardous liquid and natural gas pipelines after construction, after replacement, relocation, or other changes.[49] However, pressure testing potentially add stress to a pipeline, and in the case of natural gas pipelines, result in additional methane emissions that operators must account for.[50] Additional methods exist with potential to achieve similar levels of inspection quality for pipelines, such as using "smart pigging" devices or electromagnetic acoustic transducer (EMAT) ILI tools, once fully validated, to achieve desired performance results. However, the use of these tools would require an "other technology" notification, and it is unclear if using smart pigging or EMAT tools would preclude the necessity of an operator to employ pressure testing.

Performance-based standards can be better than prescriptive regulations to promote innovation, but there are instances where they may cause additional challenges to operators as well. For example, leak detection and repair (LDAR) regulations require the use of Method 21 screening value (SV) measurements to determine how leaks from transmission and storage (T&S) assets need to be repaired. While this EPA regulation is designed to reduce emissions, it can force operators to address all emissions, including minor emissions that do not contribute significantly to emissions and so, even small leaks would require repair within 30 days. According to data on gas leaks, about 2.5% of gas leaks account for 50% of gas leak emissions and 15% of these leaks make up 90% of leak emissions.

The topic of prescriptive versus performance-based regulations is complicated and is an ongoing challenge for industry and regulators to determine when and how each type of regulation should be used to address the intended goals of safety and environmental responsibility.

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[47] Mamish, Nader. "Prescriptive vs Performance-Based Regulatory Approaches." Regulatory Cooperation Forum. https://slideplayer.com/slide/12921741/

[48] "Fact Sheet: Hydrostatic Pressure Testing." Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation. https://primis.phmsa.dot.gov/comm/factsheets/fshydrostatictesting.htm

[49] "49 CFR § 195.302 General requirements." Legal Information Institute, Cornell Law School.https://www.law.cornell.edu/cfr/text/49/195.302

[50] Lowell, Dana, Brian Jones, David Seamonds, and Pye Russell. "Pipeline Blowdown Emissions and Mitigation Options." M.J. Bradley & Associates LLC. http://blogs.edf.org/energyexchange/files/2016/07/PHMSA-Blowdown-Analysis-FINAL.pdf

Rulemaking Challenges

Finally, midstream operators have repeatedly cited the need to adjust regulations to be more accommodating of new technologies as the actual rulemaking process cannot keep pace with innovation. The process for rulemaking is arduous and lengthy, often taking multiple years before a new regulation is officially adopted. This challenge is not unique to midstream, as technology companies across the country comment that regulation is too slow and can be too prescriptive or too loose to effectively manage private sector innovation. The lengthy rulemaking process also makes it difficult for regulators and pipeline operators to encourage the use of innovative technologies that can enhance safety, environmental, and operational outcomes for the industry.

PHMSA has faced many challenges in updating and implementing new rules due to the complexity of the rulemaking process. Consequently, there are many proposed regulatory updates that have not been made to final rulemaking. For example, the repair criteria for pipelines has not officially been updated since 2002.[51] PHMSA has made strides to streamline the agency's rulemaking process to implement almost-finalized rules, especially in the areas of pipeline safety, pipeline rupture detection, and automatic shutoff valves.[52]

Another method PHMSA has employed to account for technological advances is through standards incorporated by reference. PHMSA has incorporated more than 60 standards and specifications that are developed by standards development organizations.[53] Organizations that develop these standards include the American Gas Association (AGA), the American Petroleum Institute (API), the American Society for Testing and Materials (ASTM), and others. These organizations update and revise their standards every three to five years to keep up with rapidly evolving technologies and technical best practices, while PHMSA maintains the responsibility of determining which standards should be added, revised, updated, or removed. One success story was the December 2016 incorporation by reference of two API recommended practices for underground storage.[54] These practices were developed through organic voluntary measures by the industry over time through a transparent process involving regulators, academia, and other interested organizations, and were incorporated into PHMSA regulation in response to the Aliso Canyon gas leak.[55] While this helps, even revising standards incorporated by reference go through the official, lengthy rulemaking process which may delay adoption of technology advancements in the midstream.

Natural gas storage facilities have faced many regulatory challenges throughout their history. For example, the development of an underground reservoir requires unanimous consent of all surface owners. The challenge of reaching unanimity led to use of eminent domain to force holdout

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[51] "Research and Special Programs Administration." Department of Transportation. https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/technical-resources/pipeline/hazardous-liquid-integrity-management/61856/finalrepairrule.pdf

[52] Parfomak, Paul. "Pipeline Safety: Overdue Statutory Mandates." CRS Insight. https://fas.org/sgp/crs/homesec/IN10942.pdf

[53] "Standards Incorporated by Reference." Pipeline and Hazardous Materials Safety Administration (PHMSA). https://www.phmsa.dot.gov/standards-rulemaking/pipeline/standards-incorporated-reference

[54] Santa, Donald. "Prepared Statement to the Subcommitee on Railroads, Pipelines, and Hazardous Materials." 115 Congress, U.S. Government Publishing Office, April 2017. https://www.govinfo.gov/content/pkg/CHRG-115hhrg25309/html/CHRG-115hhrg25309.htm

[55] "Underground Natural Gas Storage." Pipeline and Hazardous Materials Safety Administration (PHMSA). https://www.phmsa.dot.gov/pipeline/underground-natural-gas-storage/underground-natural-gas-storage

landowners into agreement. Operational risks that regulators look to mitigate with detailed rules include: casing or cement failure due to cracks, corrosion, damage during maintenance and natural events; leaks in wellhead and surface pipe; issues at surface facilities; migration of gas out of the reservoir through confining layers or artificial penetration, and unexpected enlargement of a confining area.[56] Another challenge that storage faces is how many agencies are involved: gas storage is jointly regulated by FERC, PHMSA, and state regulatory authorities. For example, in many states, an oil and gas regulatory agency could manage permitting, operation, and storage facility closures; a public utility commission would regulate the gas rates.

IV. Way Forward

While developing comprehensive solutions will require stakeholder engagement and additional efforts beyond the scope of this paper, to help address the challenges with respect to R&D, commercialization, and adoption of new technologies in the midstream sector, this paper proposes the following key actions:

Balanced innovation portfolio:[57]

Successful innovators often make a concerted effort to create new products or business models across a range of ambition levels. The Doblin Innovation Ambition Matrix shows that innovation can fit into one of three levels that defines the purpose of an innovation:

1. **Core innovations:** optimize existing products for existing customers
2. **Adjacent/incremental innovations:** bring new products or businesses to a company
3. **Transformational/new innovations**: creating new products or businesses for markets that don't yet exist

While every industry and company will have their own breakdown of an innovation portfolio, until recently, Doblin found that successful innovators managed their portfolios by spending around 70 percent of their investments in core innovations, 20 percent at the adjacent level, and 10 percent at the transformational level. Although these ratios will vary, midstream companies can begin to focus more of their efforts in adjacent and transformational products, allowing them to commercialize new technologies that can readily be adopted into their businesses.

While technology adoption is often seen as externally-driven, resource-intensive, and disruptive, midstream companies can focus more on incremental, in-house solutions for operational challenges they face. "Lead-users" develop improvised, in-house solutions to improve and solve various challenges.[58] Rather than invest large amounts in R&D, the lead-user model focuses on solutions that would address individual challenges that operators face, driven by internal engineers who work with systems every day and would benefit most from improvements. Operators may be then able to develop efficient workable solutions. Over time, these incremental improvements can drive further technology innovation within individual companies and industry.

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[56] Alleman, Nate. "A Look at Underground Natural Gas Storage Operation and Regulation in the United States." GWPC 2016 UIC Conference. http://www.gwpc.org/sites/default/files/event-sessions/Alleman_Nathan.pdf
[57] "Widening the Lens: Big-picture Thinking on Disruptive Innovations in the Retail Power Sector." Deloitte Insights, 2019.
[58] Gans, Joshua, and Eric von Hippel. "To Stay Ahead of Disruption's Curve, Follow Lead Users." Harvard Business Review. https://hbr.org/2012/12/to-stay-ahead-of-disruptions-curve

A case study conducted at Hilti AG, a European manufacturer of construction materials and products, found that using the lead-user method was twice as fast and approximately half as costly to develop new products, and provided a better-quality outcome for the firm.[59]

Partnerships with technology developers:

By partnering with technology developers with proven capabilities in the oil and natural gas sector, smaller midstream companies can have a path to deploying new technologies. While midstream operators will benefit by having an open line of communication with developers and adopting new technologies to improve their performance, the technology developers will also benefit from a dedicated customer base for the technologies they develop.

Continued collaboration with government and industry groups:

While the midstream sector currently engages with PHMSA's R&D group, DOE's National Energy Technology Lab (NETL), the Environmental Protection Agency (EPA) and additional industry groups such as API, INGAA, and PRCI, it is critical to develop a comprehensive strategy for these collaborations to yield improved technology commercialization and adoption. Collaboration may also include flagging regulations that make it challenging to deploy new technologies that can improve environmental stewardship and public safety. Continued collaboration can also generate the following benefits: share costs associated with R&D, provide insights into high-priority research areas, and collectively understand how to best implement new technologies in a mature industry to speed pace of new technology field testing and deployment.

Talent acquisition and skills development:

While the midstream sector is made up of intelligent engineers, operations, and maintenance staff who have strong industry experience, there is a growing need to adapt to the digital age and the opportunities that the IoT offers. This will require a concerted talent acquisition strategy that not only hires IoT technology personnel, but also employees with the capabilities to ensure the effective integration of new technical capabilities with current business processes and legacy assets.

V. Conclusion

Understanding the core challenges that the midstream sector faces in commercializing and deploying new technologies is critical to driving safety, environmental, and operational improvements. To cultivate innovation in this sector, stakeholders must address these challenges collaboratively. While certain challenges, like the utility-like nature of the midstream sector, are not likely to change, others offer the opportunity for improvement:

- Collaboration across industry, consortia, and interested stakeholders can spread the costs of R&D, making it possible for additional total R&D investment from Midstream industry and technology service suppliers to accelerate technology innovation.
- Awareness that hyperattention on safety can limit technology development (that can improve safety and environmental outcomes) can help midstream operators be open to technology advancements.

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[59] Herstatt, Cornelius, and Eric von Hippel. "Developing New Product Concepts Via the Lead User Method: A Case Study in a "Low Tech" Field." Journal of Product Innovation Management, 1992. https://evhippel.files.wordpress.com/2013/08/herstatt-evh-journal-product-innov-management.pdf

- Midstream operators can build integration and change management into annual plans to accommodate for new technology adoption, particularly in the big data and IoT space.
- Regulators can better structure regulations as prescriptive or performance-based depending on the technology. Industry groups can aid in this process by driving the organic development of standards that can be incorporated by reference.

Technology advancements have the potential to make the midstream sector even more safe, operationally efficient, and environmentally conscious. By better facilitating technological development, the industry, regulators, and communities only stand to benefit.