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**OPTIMIZING OPERATOR SYSTEMS THROUGH THE USE OF FLEXIBLE  
COMPOSITE PIPE**

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**ABSTRACT**

Pipelines play a critical role in the world-wide demand for energy. Pipeline operators face ever-increasing challenges in operating high-pressure pipelines, and the need for safely and reliably transporting oil and gas products has never been more demanding in terms of our world-wide aging infrastructure. Global expectations associated with Environmental, Social, and Governance (ESG) criteria present even greater challenges for pipeline operators.

The installation of flexible composite pipe offers an alternative to current integrity management practices such as localized repair methods, as well as more invasive methods such as HDD and pipe replacements. In addition to rehabilitating aging pipelines, flexible composite pipe can be used as a means for repurposing existing infrastructure for transporting and storage of non-conventional products like hydrogen and CO<sub>2</sub> for carbon sequestration.

With the aging pipeline infrastructures and the world-wide interest in ESG, flexible composite pipe offers an opportunity as a transformational technology to meet the current and future needs of pipeline operators. It is not uncommon for innovative technologies to experience slow adoption. This is especially true in industries that are capital intensive and regulated, such as the transmission pipeline industry.

This paper looks at the use of flexible composite pipe technology on operator systems, the selection criteria involved in determining where installation would be most advantageous to an operator, and the long-term benefits offered by the installation of flexible composite pipe during a time where the ability to navigate through the energy transition towards a carbon neutral industry is critical. Worldwide demand for energy will continue to increase with growth in population and standards of living. As pipeline operators look to the future, flexible

composite pipe is sure to play a critical role in ensuring the continued safe operation of high-pressure pipelines.

Keywords: Integrity Management, Flexible Composite Pipe, ESG, Cost Benefit, Optimization

**NOMENCLATURE**

The following nomenclature apply to, and are mentioned throughout, this paper:

CP-CIG	Composite Pipe Collaborative Industry Group
CP	Cathodic Protection
DOC	Depth of Cover
EMAT	Electro Magnetic Acoustic Transducer
ESG	Environment, Social, and Corporate Governance
GRE	Glass Reinforced Epoxy pipe
HCA	High Consequence Area
HDD	Horizontal Directional Drill
HDPE	High Density Polyethylene
HSE	Health, Safety, and Environmental
ILI	In-line Inspection
IMCI	Integrity Management Continuous Improvement
INGAA	Interstate Natural Gas Association of America
JIP	Joint Industry Project
MAOP	Maximum Allowable Operation Pressure
MPR	Maximum Pressure Rating
NDE	Non-Destructive Examination
NPV	Net Present Value
PFR	Product Family Representative
RNG	Renewable Natural Gas
ROW	Right of Way
RTP	Reinforced Thermoplastic Pipe
SOAR	Strengths, Opportunities, Aspirations, Results

## 1. INTRODUCTION

It is widely recognized that challenges exist for pipeline companies in operating aging transmission pipelines that are the backbone of the worldwide energy systems. Pipeline operators in North America are seeking innovative ways to maintain the integrity of their pipeline systems with minimal disruption to both operations and the environment. Significant advances in the capabilities of current in-line inspection technologies provide operators with key information required for identifying and locating defects that pose threats to pipeline integrity. However, it is not practical to excavate and repair every feature, so operators must consider alternatives to conventional repair methods including welded steel sleeves and composite repair technologies. This is even more important when considering the number of pipeline defects is only going to increase as pipelines get older.

Additionally, the worldwide demand for transporting non-conventional products like CO<sub>2</sub> and hydrogen using the existing steel infrastructure system requires the use of non-metallic technologies due to inherent degradation of carbon steel and elastomers.

Several North American operators have explored the use of composite pipe technologies as internal liners in steel pipelines. Composite pipe technologies are the most common class of composite pipes that have been considered. Composite pipes can act as a standalone product for gathering lines or as an inserted repair or replacement based on the intent of the installation. Rehabilitation is often used when the existing steel pipeline can no longer meet its operation needs due to existing defects and threats. Using composite pipe technologies, pipelines can also be re-purposed to transport non-conventional products like CO<sub>2</sub> and hydrogen.

The purpose of this paper is to provide the pipeline industry with background information on composite pipe technologies that can be used to both rehabilitate and repurpose existing carbon steel transmission pipeline systems. The sections of this paper that follow include a Background section that highlights the history and background of composite pipes. The Technology Assessment section provides information on industry standards for composite pipe technologies, as well as an assessment of existing composite pipe technologies that considers strengths, opportunities, aspirations, and results (SOAR). The Industry, Regulatory, and Governance section discusses ESG and energy demands, regulations, and the opportunity for joint collaboration from industry partners. Finally, the Results and Discussion section addresses selection criteria and concepts associated with the formation of a Composite Pipe Collaborative Industry Group (CP-CIG) to bring key stakeholders together including operators, regulators, and technology companies.

## 2. BACKGROUND

Over the past 30 years, composite pipe technology has advanced in the energy industry. The first widely-used composite pipe technologies were rigid glass fiber reinforced epoxy (GRE) pipes that demonstrated superior external and internal corrosion resistance compared to carbon steel pipelines. The construction

costs and the health, safety, and environmental (HSE) impact of GRE pipelines are similar to steel pipelines [1]. More recently, flexible composite pipe technologies have matured and gained industry attention for their ease of installation, lower environmental impact, corrosion resistance, and ability to be pulled through existing steel pipelines to act as a freestanding structural pipeline system. These attributes make composite pipe technologies attractive candidates for both rehabilitating and repurposing existing steel pipelines.

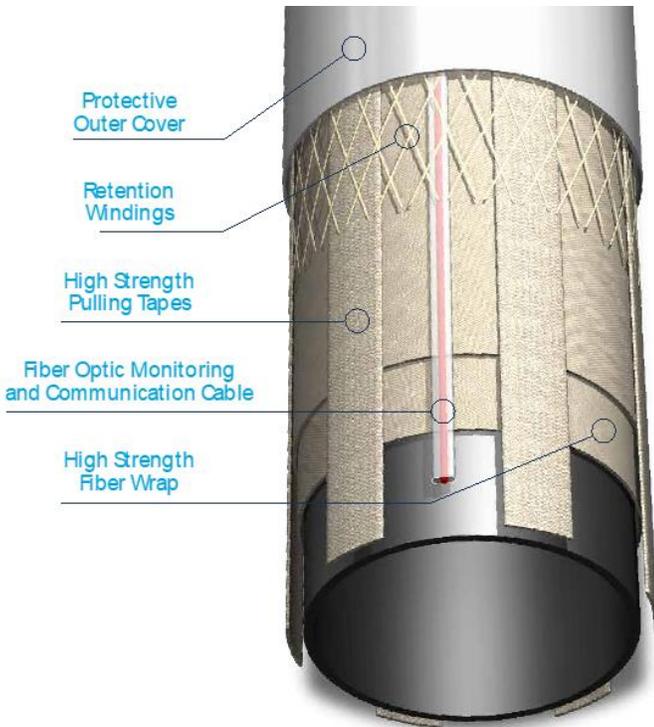
The term composite pipe encompasses several different types of non-traditional pipe including composite stick pipe, spoolable pipe, and field constructed composite pipe. Composite stick pipe generally refers to fiberglass filament wound rigid pipe with an epoxy matrix binder [2]. Composite stick pipe is commonly-available in size ranges of 2-inch to 24-inch and pressures up to 3,000 psig. Joints of composite stick pipe are connected using threaded connections machined directly into the fiberglass. Rigid composite stick pipe is not feasible to install as a pull-thru liner and is not considered in the context of this discussion.

Spoolable pipe is the second category of composite pipe that is defined by API Specification 15S [3] as a pipe that can be provided as a coil or on a structural reel for transportation [3]. The third category is composite pipe that is manufactured onsite in long, continuous lengths. There are two main types of spoolable pipe that include Reinforced Thermoplastic Pipe (RTP) and Glass Reinforced Epoxy pipe (S-GRE). RTP consists of a thermoplastic liner on which is wound the structural layer that typically consists of an even number of balanced helical windings or reinforcement members. Reinforcement members can either be metallic (steel) or non-metallic (fiberglass or aramid fibers). S-GRE is a type of spoolable composite pipe in which the structural layer typically consists of an even number of balanced helical windings of continuous glass fibers in an epoxy thermoset resin matrix.

The two categories of pipe listed above can be used as stand-alone buried or surface lay pipelines. They can also be pulled through an existing steel pipeline as a freestanding internal liner.

A third category of composite pipe is manufactured onsite in continuous lengths of pipe and can be utilized as a freestanding internal liner or directly buried. This category of pipe includes technologies like Smartpipe.

Composite technologies generally use the same three-layer construction as shown in the Smartpipe line pipe example in FIGURE 1 [4]. An internal thermoplastic liner acts as a chemical barrier between the transported product and the pipe reinforcement layer. A metallic or non-metallic reinforcement layer is wound around the internal liner. This reinforcement layer acts as the structural member of the pipe and gives it flexibility. These reinforcement layers may consist of helical wound steel strips or wires, glass fiber epoxy laminate tapes, liquid crystal polymer or aramid fiber tapes. The third layer is an outer thermoplastic cover that protects the reinforcement layer from damage, abrasion, and exposure to the elements.



**FIGURE 1: SMARTPIPE COMPOSITE PIPE [4]**

The most common diameter range for composite pipes is 2-inch to 8-inch. However, at least one high-pressure composite pipe system is currently available up to 16-inch, with 24-inch product in the design phase. Pipe diameters greater than 6-inch NPS become difficult to manufacture and spool on a reel for transport. Common pressure ratings are 750 psig to 3,000 psig, although this varies between manufacturers. Maximum allowable operating temperatures are typically between 60°C to 65°C (140°F to 150°F) for the standard product and up to 85°C (185°F) if the manufacturer offers a high temperature product. Temperature is typically limited by the polymeric materials in the internal liner.

The Appendix section lists most commercially available composite pipe technologies with reinforcement type, available nominal pipe sizes, and pressure ratings. This table is based on published information available from the eight manufacturers. Steel reinforced products include FlexSteel and Shawcor FlexCord, while the remainder of the composite pipes in Table 1 use non-metallic fiberglass, liquid crystal polymer, or aramid fiber reinforcements. S-GRE composite pipes are less common but include the NOV-Fiberspar pipe that consists of a glass-fiber reinforced epoxy laminate for its reinforcement layer. Smartpipe uses a mobile facility to manufacture pipe onsite in the field, and offers larger diameter and longer length composite systems as they are not constrained by a highway-limited reel size. Primus Line offers larger diameters, and more closely resembles a lay flat hose as reflected in its lower pressure ratings.

### 3. TECHNOLOGY ASSESSMENT

#### 3.1 API and Non-API Testing

Tests and procedures: Barlow’s formula in 49 C.F.R. 192.105 cannot be used to determine the pressure rating of composite pipe. API Specification 15S, Second Edition, states that steel reinforced pipe does not have significant regression properties while nonmetallic reinforced pipe has significant regression properties. For this reason, the Maximum Pressure Rating (MPR) of Product Family Representative (PFR) for non-metallic reinforced pipe is confirmed by long-term hydrostatic pressure testing in accordance with Section 5.3. Long-term hydrostatic pressure of PFR has been developed adhering to the methodology of ASTM D2992-12, Procedure B. Qualification of associated Product Variants are tested as per API 15S Section 5.3.5.2.

Testing of flexible composite pipe and conclusions from such testing (adherence to ASTM and API standards) shall be completed before installation.

Representative portions of the pipe shall be factory pressure tested to actual burst test failure pressures that are consistent with the short term burst tests of the product family representative or product variant.

To demonstrate factory acceptance of composite pipe manufactured on-site and prior to installation, burst testing shall be done on representative samples and recorded for traceability. The only permissible mode of failure shall be the tensile rupture of the reinforcement

Such test records shall be traceable to all line pipe installed, or purchased for subsequent pipe repairs or replacement, and shall include: pressure test reports and all pressure testing parameters (pressure, time, procedure and/or standard number, date, etc. and test acceptance parameters) and pressure testing recorders with current calibration records. The pipe manufacturer shall provide certification that the factory acceptance tests were completed and that all pipe was visually checked during the pressure tests for leaks.

#### 3.2 SOAR Analysis

To understand the role that flexible composite pipe can play in the future of the energy industry and the advantages it can provide for operators, a SOAR analysis is performed. This analysis captures the Strengths, Opportunities, Aspirations, and Results associated with composite pipe and will help operators better understand how this technology fits within their long-term integrity management. The Strengths section captures the advantages provided by flexible composite pipe to an operator. The Opportunities section captures areas of potential growth that composite pipe can offer an operator. The Aspirations section hones in on what an operator wants to accomplish with their system, either through standard integrity management or future utilization of their right of way (ROW). Finally, the Results section captures how an operator will track their progress towards achieving the items laid out under the Aspirations and Opportunities sections.

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## Strengths

- Serves as an alternative to pipe replacement, HDD, and new pipe installation
- Comparative project cost, especially in high consequence locations
- Non-corroding
- Non-metallic structure ideally suited for transporting non-conventional products (i.e., hydrogen, CO<sub>2</sub>, etc.)
- Design requirements held to a higher safety standard (combined safety factor) compared to steel
- API confirmed product life and extensive testing portfolio
- Technologically sound for deployment
- Can be pulled through installation in some cases and use steel carrier pipe as a barrier to third party damage. This is safer to install and less invasive than traditional pipe replacement
- On site QA/QC during installation
- Patented features such as steel strips (FlexSteel), embedded fiber optics (Smartpipe), etc. vary by manufacturer
- Minimal post-installation maintenance requirements

## Opportunities

- Build good working relationship with regulators by demonstrating safety and environmental advantages
- Industry consortium, JIP
- Development and implementation of sensing technologies to enhance monitoring and inspection capabilities
- Applicability for liquids and gas, as well as upstream, midstream and distribution systems
- Application for other products (gas, liquids, hydrogen, CO<sub>2</sub>)
- Leverage expertise from other operators who have used flexible composite pipe
- Develop technology for larger diameters and/or higher pressure
- Drive operators to compete (market need) with adoption of technology, which will help drive down price of composite pipe
- Recognition in codes and standards as permanent repair technology
- Improved ESG profile for operators

## Aspirations

- Preservation of long term integrity management and reliability
- Flexibility to use ROW for transportation of different products
- Overall acceptance from industry, regulators, public, and investors/owners
- Strive for regulatory acceptance of the widespread use of composite pipe as a means for repair and long term integrity management

## Results

- Continuous monitoring of system through real time leak detection, and quantitative risk and reliability modelling
- Set objectives around mileage of composite pipe installation across system
- Track special permit approval process and engagement with regulators
- Set objectives through the formation of a Joint Industry Project (JIP) or Collaborative Industry Group (CIG)

Flexible composite pipe can serve as a transition technology that represents the next evolution in transport technology. The ability to transition select segments of an operator's system to transporting non-conventional products like CO<sub>2</sub> and hydrogen provides new opportunities from an economic standpoint. It also allows an operator to address the growing demand for ESG-focused solutions, as well as reduced emissions and carbon footprints, while enhancing environmental security and public safety. However, the authors recognize that transporting such fluids produces challenges with permeability given the smaller molecular structure of CO<sub>2</sub> and hydrogen. Operators and pipe technology companies will need to address this challenge and optimize their technology over time.

The use of non-metallic materials in composite pipe eradicates the potential for traditional degradation mechanisms that plague carbon steel material and alleviates concerns associated with hydrogen embrittlement that will occur as the demand for transporting hydrogen occurs with the anticipated hydrogen economy.

The most expensive aspects of traditional steel pipeline operation involve extensive integrity management activities, which include inspection, maintenance, and repair. The degradation mechanisms associated with carbon steel require these activities to be executed on a continuous basis. Current inspection technologies primarily involve in-line inspection and in-the-ditch non-destructive examination (NDE) methods. Leak monitoring technologies have been installed on a limited basis on current transmission pipelines. The industry continues to look for advances in steel pipeline ILI technologies to improve detection capabilities and deploy leak monitoring technologies.

Installing flexible composite pipe would alleviate the need for traditional steel pipe inspection for two reasons. First, non-metallic materials are not susceptible to carbon steel degradation

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mechanisms. Secondly, the use of continuous monitoring (i.e., through embedded fiber optics) would create the ability to immediately detect and provide the location of localized excessive strain or temperature change, product leak, or third-party impact along the length of the pipeline. Still more must be done to develop additional inspection technologies to maintain the long-term structural health of these systems. This challenge is currently being addressed by individual manufacturers, an ADV Integrity JIP and a PHMSA-funded three-year study led by the Gas Technology Institute.

## 4. INDUSTRY, REGULATORY, AND GOVERNANCE

### 4.1 ESG and Energy Demand

ESG is defined as Environment, Social, and Corporate Governance, which are elements that operators are being challenged to commit objectives to in order to provide guidance towards achieving a low carbon future. Operators are being challenged to provide such guidance not only by society, but by regulators and investors/owners. Being publicly traded entities, many operators must meet ESG targets in order to satisfy requirement set by many financial institution holdings and funds. This push towards a low carbon future from many audience perspectives around the globe is inherent in the natural energy transition that the industry finds themselves a part of.

According to the Annual Energy Outlook 2021 produced by the U.S. Energy Information Administration [5], over the next decade natural gas production is anticipated to grow by 18%. To accommodate increased production, expansion in transport capacity will be required. Considering the general opposition to new pipeline construction, increased demands will be placed on existing aging pipeline systems that are already operating at near maximum capacities. Therefore, it is likely that abandoned pipeline systems will need to be brought back on-line and increased demands will be placed on already-operational pipelines.

The integration of flexible composite pipe is a plausible solution for placing abandoned pipelines back into service and increasing the throughput capacity of existing pipelines. An additional benefit in deploying composite pipe as a transition technology is the minimal impact to the existing infrastructure, environment, and general public.

Although increased production and transport of natural gas is favorable to an operator, the transport of non-conventional products like CO<sub>2</sub> and hydrogen should also be considered. These emerging facets of our economy will place unprecedented demands on existing pipeline infrastructure. Although additional research is required to fully-understand the risk associated with transporting CO<sub>2</sub> and hydrogen, the consensus among leading metallurgical experts is that the potential exists for damaging pipeline systems if these products are transported in carbon steel pipelines. The integration of flexible composite pipe and its use of non-metallic materials provide the solution required to help operators properly manage this risk and provide a more secure operating system,

### 4.2 Commentary on Regulations

The PHMSA natural gas pipeline safety regulations at 49 C.F.R. §§ 192.53(c), 192.121, 192.150, 192.619(a), 192.624, and 192.710 do not address the use of composite, reinforced thermoplastic pipe (RTP). Composite RTP pipe is a non-corroding high pressure pipeline replacement technology that has been tested and qualified pursuant to industry standards [6] and has been tested by the Department of Energy for hydrogen transmission.[7]

Composite RTP pipe is installed pursuant to robust design and construction specifications, it reduces the environmental impact and earth disturbance associated with pipe replacement, and it has been successfully installed and operated in existing oil and gas pipeline applications with approval by PHMSA. Further, Special Permit conditions will provide an equivalent or higher level of safety — in lieu of compliance with the requirements referenced above — by improving the integrity of the pipeline and implementing alternative risk control activities based on integrity management principles, including the use of embedded fiber optics to provide continuous leak detection and monitoring. This material and method of installation warrants further utilization as a means of upgrading certain pipeline infrastructure and/or to provide for the increased transportation of hydrogen by pipeline.

PHMSA recently issued a notice of virtual meeting and public forum regarding various initiatives in support of the “Biden-Harris Administration’s whole-of-government approach to mitigating climate change” and the “market shift to more climate friendly commodities,” including various aspects of transportation of hydrogen by pipeline. *PHMSA Pipeline Transportation, Hydrogen and Emerging Fuels Research and Development Public Meeting and Forum*, 86 Fed. Reg. 58389 (Oct. 21, 2021). Further, recent Congressional amendments to the Pipeline Safety Act in the Protecting our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act of 2020 include a provision mandating that PHMSA issue a rulemaking to implement leak detection and repair regulations for natural gas pipelines. PIPES Act of 2020, Section 113 (revising 49 U.S.C. § 60102). Consistent with the Agency’s increased focus on renewable resources and leak detection, certain composite RTP pipe expands the network of pipelines capable of transporting hydrogen by pipeline and (2) include fiber optic continuous leak detection monitoring among the special permit conditions

Special Permit Sections must identify any high consequence areas (HCAs) as defined in 49 C.F.R. § 192.5. and any moderate consequence areas (MCA) as defined in 49 C.F.R. § 192.3, geohazards and other potential threats. Mitigation methods for potential threats must be identified. Pipeline design, construction and operating information must be presented. MAOP, operating history, cathodic protection surveys, close interval surveys (CIS), ILI history, leak history, Safety Management System (SMS) per API RP 1173, repair history should be identified. Damage prevention measures set forth in its Operations & Maintenance (O&M) manual, consistent with 49 C.F.R. § 192.614 must be complied with. Special Permit sections must

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identify the regulations that the pipeline operator is seeking relief from.

## 5. DISCUSSION

### 5.1 Selection Criteria

To help assist an operator in pinpointing where exactly on their system composite pipe would be most suitable at, a selection criterion has been developed. By taking into considerations the aspects from the SOAR analysis, and other industry, regulatory, and governance considerations, an operator can use a selection criterion to understand when composite pipe offers a suitable repair alternative when performing integrity management.

#### Non Piggable Pipe

An operator should consider the length of pipe on their system that is non-piggable, either due to smaller diameters or the nature of the pipe configuration. It is difficult to apply continuous integrity monitoring to non-piggable pipe, which relies heavily on hydrotesting or direct assessment to prove the pipe integrity. The decision on where to carry out direct assessments will depend on the pressure profile of the line, geohazard strain gauge readings, elevation profile, and areas where degradation of the steel is thought to be of greatest concern. Ultimately, however, this decision will still contain an element of randomness since exact locations where integrity concerns exist are unknown. Instead of spending capital dollars on pipe replacement programs or make-piggable programs, composite pipe applications can be leveraged to be installed directly inside of non-piggable pipe sections, where the steel pipe will serve as a pseudo-casing to the composite pipe.

#### High Consequence Areas and Class Locations

Executing standard integrity management can be difficult in HCAs and higher class locations, either due to challenging site characteristics, permitting requirements and timelines, and construction scope that would be inherent to access the pipe. HCAs depend on nearby receptors that could result in an increase consequence if a failure were to occur. Consequence receptors can be in the form of populated areas, waterbodies, commercial navigable waterways, endangered species habitats, and other environmentally-sensitive areas. Pipelines located in these areas with anticipated future integrity management may provide a suitable location for the implementation of composite pipe.

In addition, the threat of encroachment from the development and expansion of HCAs can increase the class location of a particular section of pipe. In doing so, these pipe sections will have to be managed to standards that apply to the new class location. This may result in a need to hydrotest the affected pipe section, derating of the existing pipe, change or upgrade pipe to thicker wall or different pipe grade, all of which may be challenging to do depending on where the pipe is located and customer demand. Installing composite pipe in areas where the threat of encroachment is high removes the need to upgrade

or change pipe characteristics in the event that class location does in fact change.

#### Hard to Access Pipe and Cased Pipe

Building on the above criteria, operators will have many areas along their system where the right of way (ROW) is difficult to access. This could be due to the surrounding environmental area, or because the pipeline runs underneath a highway, railroad, waterbody, or other third-party ROW. Pipeline crossing under third party ROWs or under waterbodies typically have higher depths of cover (DOC), or having a casing installed around them for additional armoring and strength where excessive loading from above is frequent (i.e., road, railway, etc.).

Hard to access pipe poses many challenges when an integrity-driven repair is needed at that location, both from a construction perspective and permitting perspective. Costs to do repairs on hard to access pipe are much higher than routine dig costs, as there are other factors that need to be addressed when determining a repair option. The existence of hard to access pipe alone may drive an operator to completely change their repair approach for a target feature at this location, switching from a localized repair to something more capital intensive and commercially-impacting like a Horizontal Directional Drill (HDD) or pipe replacement. Having composite pipe installed inside steel pipe at these locations would remove the need for traditional steel pipe inspection and costly repairs.

#### Abandoned Pipe

Installing composite pipe into abandoned pipe sections could still prove the feasibility of the technology on an operator's system without having to worry about commercial impacts from taking an outage during installation. Installation of composite pipe in abandoned pipe sections does have the potential to effectively bring these lines back up to pressure and into service in the future. Even if the decision to abandon the older steel pipe was integrity-driven in the past, the existing steel pipe could still function as a secondary source of containment to the composite pipe in place and allow for permanent usage of its existing ROW. This could lead to potential new revenue streams not only from new downstream customers, but across the entire value chain, with the installation of composite pipe in abandoned pipe sections across an operator's system. There is also the environmental benefit of not having to disturb the ROW when retrofitting existing infrastructure already in the ground.

An important potential limitation of which to be mindful when considering abandoned pipe is that pipe assets from one valve section or trap to another may not be fully abandoned in place. It should be expected that there may be some stretches of suitable pipe within a segment, with sporadic abandoned pipe sections that have been cut-out and removed, and/or grout or concrete filled. This is quite common around road, railway, or water crossings where HDDs or pipe replacements have been completed in the past, with the old pipe abandoned and filled in place in parallel. These kinds of abandoned pipe sections would complicate the installation of any composite pipe through

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existing steel infrastructure, and would certainly pose logistical and cost challenges. An operator will need to rely on ROW drawings and other historical records to confirm these locations.

### Pipe Diameter or other Limiting Characteristics

A primary limiting characteristic of many composite pipe technologies is the maximum diameter to which they can be manufactured and installed into an existing steel pipeline. This will limit an operator’s ability to install composite pipe on certain parts of their system in order to maintain current throughput levels or other capacity requirements. In addition, operating pressure and temperature will also dictate the wall thickness required for the composite pipe design. A technical design in conjunction with a system planning exercise is needed to determine if a composite pipe proposal is sufficient to meet an operator’s existing volume of customer obligations.

### Future Potential System Expansion Opportunities

If there are known areas of an operator’s system that are being considered for future expansion opportunities, then composite pipe should be considered as an alternative to achieve this expansion. Expansion can be in the form of additional throughput required by existing customers, or in the form of transportation of different fluids other than what is currently transported through the existing steel pipe asset. As mentioned earlier, using composite pipe to achieve expansion is likely to be more cost effective and easier to install as opposed to invasive alternatives such as HDD or pipe replacement.

### Case Study

Based on the discussed selection criteria above, an operator can begin to consider areas along their system which not only have one of these characteristics, but also share many of these characteristics. Tabulating a matrix like the one below can highlight subsections of an operator’s system that encompass multiple selection criteria.

Below are two case studies, company A and B. Each have different prioritizations of selection criteria. The matrix below shows the difference in how each of these operators may select certain areas on their system to use flexible composite pipe based on their system characteristics. Assume both Company A and B have equal length systems.

**Table 1: Company A System Characteristic Mileages (1000 mile System)**

Company A	Non Piggable	HCA	Class 2+	Cased	Abandoned	<24” Diameter
Non Piggable	100	10	5	1	1	2
HCA	10	100	70	1	2	100
Class 2+	5	70	80	1	1	80
Cased	1	1	1	3	0	3
Abandoned	1	2	1	0	5	5
<24” Diameter	2	100	80	3	5	500

### Key Considerations for Company A

- 10% of system is non-piggable
- 10% of non-piggable pipe is located in an HCA
- 10% of system is HCA
- 70% of HCAs are Class 2+ areas
- 50% of system is less than 24” diameter
- All HCA and Class 2+ pipe is less than 24” diameter

**Table 2: Company B System Characteristic Mileages (1000 mile System)**

Company B	Non Piggable	HCA	Class 2+	Cased	Abandoned	<24” Diameter
Non Piggable	10	0	0	5	5	10
HCA	0	20	20	20	5	10
Class 2+	0	20	20	20	5	10
Cased	5	20	20	50	5	25
Abandoned	5	5	5	5	25	20
<24” Diameter	10	10	10	25	20	200

### Key Considerations for Company B

- 1% of system is non-piggable
- 2% of system is HCA
- 2% of system is Class 2+ areas
- 5% of system is cased, and 2.5% of system is abandoned
- 20% of system is less than 24” diameter
- 80% of abandoned pipe is less than 24” diameter
- 50% of cased pipe is less than 24” diameter
- All pipe located within HCAs is cased pipe

Given the system characteristics for operators A and B, preference and priority over where to consider composite pipe will differ, and these will be weighted differently in the decision-making process. An example of how Company A and B may weigh their decision making based on their site characteristics is shown below:

**Table 3: Case Study Operator Priorities**

Characteristic	Selection Criteria Priority	
	Company A	Company B
Non-Piggable	✓	
HCA	✓	
Class 2+	✓	
Cased		✓
Abandoned		✓
<24” Diameter	✓	✓

The weightings of importance around each of these characteristics will also depend on an operator’s economic drivers, commercial impact, or opportunity cost of forgoing the alternative integrity management option. Additionally, an operator’s integrity risk tolerance and previous experience or history with new technologies will partially dictate when and where on a system composite pipe installation would be most advantageous given an operator’s system characteristics.

## 5.2 Industry Collaboration

Of all sectors within the energy industry, over the past 50 years the transmission pipeline industry has demonstrated the greatest level of collaboration and intra-sector cooperation. The existence and member breadth of organizations like the Pipeline Research Council International (PRCI) and Interstate Natural Gas Association of America (INGAA) are testimony to the willingness of pipeline operators to work together to solve difficult and challenging problems for the greater good. Additionally, the formation of more than 50 Joint Industry Programs (JIPs) over the past 20 years by organizations such as DNVGL, Battelle, and ADV Integrity, Inc. provide additional examples of the collaborative ecosystem that exists among pipeline companies. The partnerships that exist are driven in part by strong federal regulations, but also the collegial mindset that exists among the leadership of most pipeline operators.

One concept developed by the authors is the formation of a Composite Pipe Collaborative Industry Group (CP-CIG) that will bring together key stakeholders including pipeline operators, regulators, and technology companies. The concept involves an annual subscription model to foster continued technology development, ensure materials are ready for rapid deployment, and serve as a collaborative body to interface with the regulatory agencies.

A model for the proposed CP-CIG is the RUPE (Response to Underwater Pipeline Emergencies) offshore consortium that involves 37 pipeline operators from around the world. According to a 2003 November / December article in World Oil [8], the co-owners own over \$5.4 million in diver-installed, offshore pipeline repair tools with diameters ranging from 6 inches to 26 inches. The consortium has been in operation for over 40 years and provides its co-owners a program for procuring, storing, maintaining, and delivering repair tools whenever they are required. The responsiveness of RUPE allows co-owners rapid access to repair tools in emergency situations.

Listed below are some of the major concepts and benefits associated with the formation of the CP-CIG.

- To achieve multi-operator participation, multiple pipeline companies will be invited to participate.
- Composite pipe technology companies have already expended significant funds in technology development, testing, validation, and general operation. Having multi-operator participation in the CP-CIG will distribute costs for these efforts among multiple companies and foster further technological advancements, especially in relation to inspection and real-time monitoring technologies.
- The formation of the CP-CIG ensures that materials, supplies, and equipment required to fabricate and manufacture composite pipe technologies are in stock and available when needed. With COVID-related

supply issues for many raw materials, this scenario has become even more critical.

- The collaborative nature of the CP-CIG encourages a free exchange of ideas and experiences among participants. It is envisioned that participants will meet at least annually and share experiences.

Another avenue for industry collaboration is through the INGAA Integrity Management Continuous Improvement (IMCI) 2.0 initiative titled “Safely Pivoting to Support a Zero-Carbon Future”. Started in 2021, this initiative builds off of IMCI 1.0 which focused on progressing integrity management in the industry following a number of large consequence incidents in 2010. IMCI 2.0 will bring the industry members of INGAA together to focus on improving the safety and reliability of existing natural gas transportation and storage infrastructure to support zero carbon fuels that become available through the energy transition phase as the world evolves to a zero carbon economy. The key initiatives of IMCI 2.0 include:

1. Regular Stakeholder Engagement
2. Transportation and Storage of Hydrogen
3. Transportation and Storage of Renewable Natural Gas (RNG)
4. Development of ANSI Standard for Geohazards
5. Integration of Electro Magnetic Acoustic Transducer (EMAT) In-Line Inspection into standards
6. Rupture Detection and Response
7. Managing Emissions from integrity and Maintenance Work
8. Regulatory Acceptance of Non-Traditional Pipe

Because of challenges associated with operating transmission pipelines, the role of collaboration is even more important. The formation of the proposed CP-CIG can serve the pipeline industry by helping maintain the integrity of existing assets and provide a means for transitioning to the transport of CO<sub>2</sub> and hydrogen as dictated by needs of the public for ongoing energy.

## 5.3 Future Considerations

The industry navigation through the energy transition will involve the transportation of products like CO<sub>2</sub> and hydrogen. Operators should recognize a need for improvement when it comes to the permeability of flexible composite pipe, specifically with the transport of gases like CO<sub>2</sub> and hydrogen. Permeation is a function of the pipe’s pressure (or stress) state, and this will depend on the product being transported, as well as the pipe material, or more generally, the pipe technology being used. The consideration of permeability and the strategies around addressing it is a key driver to forming a CP-CIG with multiple industry and technology partners. Having a JIP with multiple industry stakeholders can focus on improving existing flexible composite pipe technologies based on a Failure Mode and Effects Analysis (FMEA) done for a particular pipe technology,

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which can help identify key areas for improvement such as permeability.

[8] Ayres, Ray, *Clamping Down on Underwater Repairs*, World Oil RUPE Article (October/November 2003).

## 6. CONCLUSION

The inclusion of flexible composite pipe in an operator's toolbelt of repair alternatives to select from is not only beneficial to operators, but also to Regulators and Technology companies. Operators benefit from the ability to now have a composite pipe option that can support the operational needs to transport CO<sub>2</sub> and hydrogen, as well as to provide a noninvasive strategy for integrity management purposes. Regulators benefit from increased safety and operational excellence on behalf of pipeline operators, as well as the opportunity to have the formation of joint industry groups to allow regulators and operators to jointly collaborate and share ideas around the use and incorporation of flexible composite pipe. Finally, technology companies benefit from being the providers of these flexible composite pipe and monitoring technologies, which further increases the pace of innovation in the industry for improved pipeline monitoring, integrity management, and future transportation of alternative fuels.

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## APPENDIX: COMMERCIALY AVAILABLE COMPOSITE PIPE TECHNOLOGIES WITH PIPE SIZES AND PRESSURE RATINGS

Manufacturer	Product Name	Reinforcement Type	NPS	Pressure Ranges (psig)	Pressure Ranges (MPa)
Baker Hughes	Composite Pipe	Fiberglass Tape	2-inch to 6-inch	750 to 2,250	5.17 to 15.51
	Thermoflex	Aramid Fiber	2-inch	275 to 2,000	1.90 to 13.79
			6-inch	275 to 750	1.90 to 5.17
FlexSteel	FlexSteel Line Pipe	Helical Steel Strips	3-inch to 8-inch	750	5.17
			2-inch to 8-inch	1,500	10.34
			2-inch to 8-inch	2,250	15.51
			2-inch to 6-inch	3,000	20.68
Future Pipe Industries	FlexStrong	Fiberglass Tape	3-inch to 6-inch	750 to 1,500	5.17 to 10.34
NOV Fiberglass Systems	Fiberspar	Glass Reinforced Epoxy	2-inch to 3-inch	750 to 3,500	5.17 to 24.13
			2-inch to 4-inch	750 to 2,250	5.17 to 15.51
			2-inch to 6-inch	750 to 1,500	5.17 to 10.34
	DuraFlex	Fiberglass Tape	3-inch to 6-inch	500	3.45
Primus Line	High Pressure	Aramid Fiber	6-inch	1,190	8.20
			10-inch	740	5.70
			14-inch	460	3.17
Shawcor	FlexPipe	Dry Fiberglass	2-inch to 5-inch	750	5.17
			2-inch to 5-inch	1,500	10.34
	FlexCord	Steel Wire	2-inch to 4-inch	2,250	15.51
Smart Pipe	SmartPipe Line Pipe	Liquid Crystal Polymer	4-inch to 16-inch	750 to 2,200	5.17 to 15.17
SoluForce	Classic	Fiberglass Tape	4-inch	1,639	11.30
			6-inch	1,305	9.00
	Heavy	Steel Wire	4-inch	6,527	45.00
			6-inch	5,627	38.80