U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Patty Murray
Chair, Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Chair Murray:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

The Report includes an assessment of the causes of pipeline failure and pipeline safety risks; identifies specific short-term and long-term research and development objectives that address pipeline safety risks and vulnerabilities; identifies specific research activities and how they relate to DOT research goals, agency objectives, and research programs; the roles and responsibilities of PHMSA, industry, academia and other Federal partners in advancing technological solutions that improve the overall safety and integrity of the nation's pipeline system through the execution of the proposed research and development activities; and reports on the implementation and execution of the prior year proposed annual research activities compared to the annual research plan and how such activities were co-funded with industry and/or academia consistent with subparagraph (b) of section 22 of Public Law 114-183.

I hope this information is helpful. Should you require further information or assistance, please feel free to call me or have your staff contact Samantha Keitt, PHMSA's Director of Governmental, International, and Public Affairs, by phone at (202) 934-2417 or by email at samantha.keitt@dot.gov.

A similar letter has been sent to the Vice Chair of the Senate Committee on Appropriations; the Chair and Ranking Member of the Senate Committee on Commerce, Science, and Transportation; the Chair and Ranking Member of the House Committee on Appropriations; the Chair and the Ranking Member of the House Committee on Energy and Commerce; and the Chair and the Ranking Member of the House Committee on Transportation and Infrastructure.

Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
Administration**

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Susan Collins
Vice Chair, Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Vice Chair Collins:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Rosa DeLauro
Ranking Member, Committee on Appropriations
U.S. House of Representatives
Washington, DC 20515

Dear Ranking Member DeLauro:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Kay Granger
Chairwoman, Committee on Appropriations
U.S. House of Representatives
Washington, DC 20515

Dear Chairwoman Granger:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
Administration**

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Maria Cantwell
Chair, Committee on Commerce, Science, and Transportation
United States Senate
Washington, DC 20510

Dear Chair Cantwell:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021 (Pub. L. 116-260), which requested the U.S. Department of Transportation (DOT) to submit an updated research plan report to Congress.

Pursuant to 49 Code of Federal Regulations (CFR) § 1.97(a)(1), the Secretary has delegated the authority to PHMSA to submit this Report. The Report includes an assessment of the causes of pipeline failure and pipeline safety risks; identifies specific short-term and long-term research and development objectives that address pipeline safety risks and vulnerabilities; identifies specific research activities and how they relate to DOT research goals, agency objectives, and research programs; the roles and responsibilities of PHMSA, industry, academia and other Federal partners in advancing technological solutions that improve the overall safety and integrity of the nation's pipeline system through the execution of the proposed research and development activities; reports on the implementation and execution of the prior year proposed annual research activities compared to the annual research plan and how such activities were co-funded with industry and/or academia consistent with subparagraph (b) of section 22 of Public Law 114-183.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
Administration**

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Senator Ted Cruz
Ranking Member
Committee on Commerce, Science, and Transportation
United States Senate
Washington, DC 20510

Dear Ranking Member Cruz:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Frank Pallone, Jr.
Ranking Member
House Committee on Energy and Commerce
U.S. House of Representatives
Washington, DC 20515

Dear Ranking Member Pallone:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Cathy McMorris Rodgers
Chair, House Committee on Energy and Commerce
U.S. House of Representatives
Washington, DC 20515

Dear Chair McMorris Rodgers:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
Administration**

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Rick Larsen
Ranking Member
Committee on Transportation and Infrastructure
U.S. House of Representatives
Washington, DC 20515

Dear Ranking Member Larsen:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department
of Transportation
Pipeline and Hazardous Materials Safety Administration

1200 New Jersey Avenue, SE
Washington, DC 20590

April 11, 2023

The Honorable Sam Graves
Chairman
Committee on Transportation and Infrastructure
U.S. House of Representatives
Washington, DC 20515

Dear Chairman Graves:

Enclosed please find the report titled, "Pipeline Safety Research and Development Updated Plan Fiscal Year (FY) 2021 and 2022," (Report) in fulfillment of the request in Congress' Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021, which requested the U.S. Department of Transportation (DOT) to submit a report to Congress that describes the DOT's Pipeline and Hazardous Materials Safety Administration (PHMSA) research and development program.

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Sincerely,

Tristan H. Brown
Deputy Administrator

Enclosure

U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

Office of Pipeline Safety

Research & Development Updated Plan

Fiscal Years 2021 – 2022

Report to Congress

Table of Contents

Abbreviations:

AI	Artificial Intelligence
ASME	American Society of Mechanical Engineers
BBL	Barrel of Crude Oil
Bcf	Billion Cubic Feet
BSEE	Bureau of Safety and Environmental Enforcement
CAAP	Competitive Academic Agreement Program
CFR	Code of Federal Regulations
CP	Cathodic Protection
CPM	Computational Pipeline Monitoring
Core	Core Research Program
CSM	Colorado School of Mines
DAS	Distributed Acoustic Sensing
DFOS	Distributed Fiber-Optic Sensing
DOC	Department of Commerce
DOI	Department of the Interior
DOT	Department of Transportation
EDF	Environmental Defense Fund
EDI	Edison Welding Institute
EMP	Electromagnetic Pulse
EPA	Environmental Protection Agency
FY	Fiscal Year
FBO	Federal Business Opportunities
FOCOS	Fiber-Optic Excavation Monitoring Sensor
GO	Government Organization
GHG	Greenhouse Gas
GMD	Geomagnetic Disturbance
GPS	Global Positioning System
GTI	Gas Technology Institute
HSE	United Kingdom Health and Safety Executive

IAA	Inter-Agency Agreement
INGAA	Interstate Natural Gas Association of America
KAI-MAP	Knowledge Guided Automation for Integrity Management of Aging Pipelines
LNG	Liquefied Natural Gas
MCF	Thousand Cubic Feet
MIT	Mechanical Integrity Tests
ML	Machine Learning
MMCF	Million Cubic Feet
MMCF/D	Million Cubic Feet per Day
NACE	National Association of Corrosion Engineers
NAPSR	National Association of Pipeline Safety Representatives
NDE	Nondestructive Examination
NDSU	North Dakota State University
NFPA	National Fire Protection Association
NGA	Northeast Gas Association
NGO	Non-government Organization
NIST	National Institute of Standards and Technology
NMP	Non-Metallic Pipe
OGPs	Oil and Gas Pipelines
OPS	Office of Pipeline Safety
OSHA	Occupational Safety and Health Administration
OTD	Operations Technology Development
PHMSA	Pipeline and Hazardous Materials Safety Administration
PIM	Pipeline Integrity Management
PIPES Act(s)	Protecting our Infrastructure of Pipelines and Enhancing Safety Acts of 2016 and 2020
PRCI	Pipeline Research Council International
PSRP	Pipeline Safety Research Program
PST	Pipeline Safety Trust
R&D	Research and Development

RD&T	Research, Development, and Technology
ROW	Right-of-Way
SCADA	Supervisory Control and Data Acquisition
SBIR	Small Business Innovative Research
SDO	Standards Developing Organizations
SWARMS	Smart Well Assessment and Reservoir Management System
TAP	Technical Advisory Panel
UNGS	Underground Natural Gas Storage
USDA	U.S. Department of Agriculture
VCI	Vapor Corrosion Inhibitor

1. Executive Summary

The mission of the U.S. Department of Transportation (DOT or Department) Pipeline and Hazardous Materials Safety Administration (PHMSA or Agency) is to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives. PHMSA funds research to advance and improve pipeline safety, protect the environment, support supply reliability, and improve business and government productivity. PHMSA pursues its pipeline research, development, and technology goals through its Office of Pipeline Safety (OPS) Pipeline Safety Research Program (PSRP). OPS's PSRP contains four major subprograms:

- Core Research (Core) Program;
- Competitive Academic Agreement Program (CAAP);
- Small Business Innovative Research (SBIR) Program; and
- Interagency Agreement (IAA).

Congress directed PHMSA to submit an updated research plan to the House and Senate Committees on Appropriations.[1] The report includes an assessment of the causes of pipeline failure and pipeline safety risks; identifies specific short-term and long-term research and development objectives that address pipeline safety risks and vulnerabilities; identifies specific research activities and how they relate to DOT research goals, agency objectives, and research programs; the roles and responsibilities of PHMSA, industry, academia and other Federal partners in advancing technological solutions that improve the overall safety and integrity of the nation's pipeline system through the execution of the proposed research and development activities; reports on the implementation and execution of the prior year proposed annual research activities compared to the annual research plan and how such activities were co-funded with industry and/or academia consistent with subparagraph (b) of section 22 of Public Law 114-183. The report also includes specific short-term and long-term research and development objectives that address pipeline safety risks and vulnerabilities; and description of fiscal year (FY) 2021 funded research projects. The PSRP analyzed incident data from 2011 to 2020 to better identify a set of high-value programmatic and research priorities and objectives, focusing on eight areas (See **Section 7**):

1. Preventing Pipeline Threats/Damage;
2. Improving Pipeline Leak Detection Systems;
3. Improving Anomaly Detection and Characterization;
4. Improving Anomaly Repair and Pipe Remediation and Rehabilitation;
5. Improving Design, Materials, and Welding/Joining;
6. Improving Safety Systems for Liquefied Natural Gas (LNG) Facilities;
7. Improving Safety Systems for Underground Natural Gas Storage (UNGS) Facilities; and
8. Climate Change Solutions/Hydrogen/CO_2.

[1] Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021 (Pub. L. 116-260).

Research in these eight focus areas align with DOT's Strategic Objectives of (1) Safety and (2) Climate and Sustainability by supporting the development of effective tools and technology to improve pipeline safety and best practice standards for the pipeline industry. This report also outlines detailed short and long-term goals for each research focus area, as well as specific research activities that will secure technology transfer (T2) into the market and drive innovation and safety. In addition, these research areas support rulemaking/decision-making. PHMSA promotes T2 in the pipeline industry through its research investments and stakeholder outreach and engagement initiatives. This report also describes PHMSA's strategy to accelerate and enhance the T2 process in pipeline safety transportation.

As shown in **Section 7,** the summary of Fiscal Year (FY) 2021 activities and the examples of Significant Research Activities indicate that PHMSA continues to successfully execute its mission as described in **Section 3** through innovative research investments. In addition, as discussed in **Section 8**, PHMSA engages with stakeholders and government agencies through partnerships with government organizations (GOs) and nongovernment organizations (NGOs)—providing opportunities to support ongoing successes through T2s, cost-shared research that addresses mutual safety challenges, and the elimination of duplicated effort. Also, as shown in **Sections 9 and 10**, the report provides details on research funded in FY 2021 and research projects awarded in FY 2022.

The outlook for FY 2023 and beyond illustrates the need for a significant investment into research for the safe transportation of hydrogen and carbon dioxide (CO_2) by pipeline. **Section 11** demonstrates that the PHMSA's research program comprehensively addresses the Biden Administration's central goals on clean energy and the environment through research.

2. Introduction

In the Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act of 2021 (Pub. L. 116-260), Congress directed PHMSA to submit an Updated Research Plan (Plan) to the House and Senate Committees on Appropriation. That updated plan is required to:

- Conduct an assessment of the causes of pipeline failure and pipeline safety risks;
- Identify specific short-term and long-term research and development objectives that address pipeline safety risks and vulnerabilities;
- Identify specific research activities and how they relate to DOT research goals, agency objectives, and research programs;
- Define the roles and responsibilities of PHMSA, industry, academia, and other federal partners in advancing technological solutions that improve the overall safety and integrity of the Nation's pipeline system through the execution of the proposed research and development activities; and
- Report on the implementation and execution of the prior year's proposed annual research activities compared to the annual research plan and how such activities were co-funded with industry and/or academia consistent with subparagraph (b) of Section 22 of the PIPES Act of 2016 (Public Law 114-183).[2]

[2] See footnote 1 on p.1.

The Plan details PHMSA's activities in FY 2021 and the awarded activities in FY 2022. Initiation of the next five-year research plan covering FY 2023 through 2027 is underway, in accordance with Section 12 of the Pipeline Safety Improvement Act of 2002 (49 U.S.C. 60101 note; Public Law 107-355), as amended.

3. Mission, Organization, and Authorities

As previously noted, PHMSA's mission is to protect people and the environment by advancing the safe transportation of energy and other hazardous materials that are essential to our daily lives. PHMSA establishes national policy, sets and enforces standards, educates, and conducts research to prevent incidents. PHMSA also assists the public and first responders through training, cooperation, and communication to manage pipeline emergencies in the event of an incident.

PHMSA operates in a dynamic and challenging environment in which changes in technology, manufacturing, and energy production affect transportation safety. It is anticipated that the scope and complexity of PHMSA's safety mission will continue to grow to protect the environment, serve environmental justice, and prepare our infrastructure for emerging and/or alternative fuel sources.

America's pipeline infrastructure includes more than 3.3 million miles subject to PHMSA's regulatory oversight. This complex pipeline infrastructure is used to transport nearly all of the natural gas and about two-thirds of the liquid petroleum energy products consumed domestically. According to the U.S. Energy Information Administration in 2021, liquid petroleum energy products furnish 36 percent of our energy, natural gas 32 percent, coal 11 percent, nuclear 8 percent, and renewables 12 percent. Adaptation of the existing pipeline infrastructure to support alternative energy sources and the need to better serve disadvantaged communities will drive the need for innovation in the coming decade.

Due to the significant contribution of energy and hazardous materials to our economy and standard of living, it is essential that PHMSA continues to fund research projects to enhance safety, address environmental impacts, and improve the resilience and performance of our transportation system. Research of this nature will enhance the security of our infrastructure, our economy, and our environment. In FY 2022, PHMSA pursued pipeline safety research, development, and technology (RD&T) goals through a variety of projects carried out by OPS.

Section 12 of the Pipeline Safety Improvement Act of 2002 (49 U.S.C. 60101 note; Public Law 107-355) mandated that DOT, the Department of Energy (DOE), and the Department of Commerce's (DOC) National Institute of Standards and Technology (NIST) "carry out a program of research, development, demonstration, and standardization to ensure the integrity of pipeline facilities." In response, OPS's PSRP and the associated program elements identified in the 2002 Act were subsequently established to help ensure the safety and integrity of hazardous liquid and natural gas pipeline systems through R&D activities that are designed to support identification, characterization, detection, and management of risks to the safety and integrity of these systems. The PSRP includes research, development, demonstration, and standardization activities related to the following:

"1. Materials inspection;
2. Stress and fracture analysis; detection of cracks, corrosion, abrasion, and other abnormalities inside pipelines that lead to pipeline failure; and development of new equipment or technologies that are inserted into pipelines to detect anomalies;
3. Internal inspection and leak detection technologies, including detection of leaks at very low volumes, and methods of analyzing the content of pipeline throughput;
4. Methods of analyzing content of pipeline throughput;
5. Pipeline security, including improving real-time monitoring, surveillance of pipeline rights-of-way; developing tools for evaluating and enhancing pipeline security and infrastructure; reducing natural, technological, and terrorist threats; and protecting first response units and persons near an incident;
6. Risk assessment methodology, including vulnerability assessment and reduction of third-party damage;
7. Communication, control, and information systems surety;
8. Fire safety of pipelines;
9. Improved excavation, construction, and repair technologies; and
10. Other appropriate elements." [3]

4. PHMSA R&D Program

OPS's PSRP funds innovative research to improve safety, protect the environment, and support reliable supplies of energy products and hazardous materials. The focus of the PSRP is to fill the gaps in research not conducted by industry and to partner with pipeline stakeholders to leverage private R&D investment that would enhance pipeline safety and protect the environment. PHMSA strives to avoid duplicating research and works closely with academia and pipeline stakeholders to fund and share the cost of critical research to develop new technologies, products, and knowledge, and to promote stakeholder engagement. In addition, the PSRP seeks to advance knowledge and technology that addresses the following FY 2022 through FY 2026 Department strategic goals:[4]

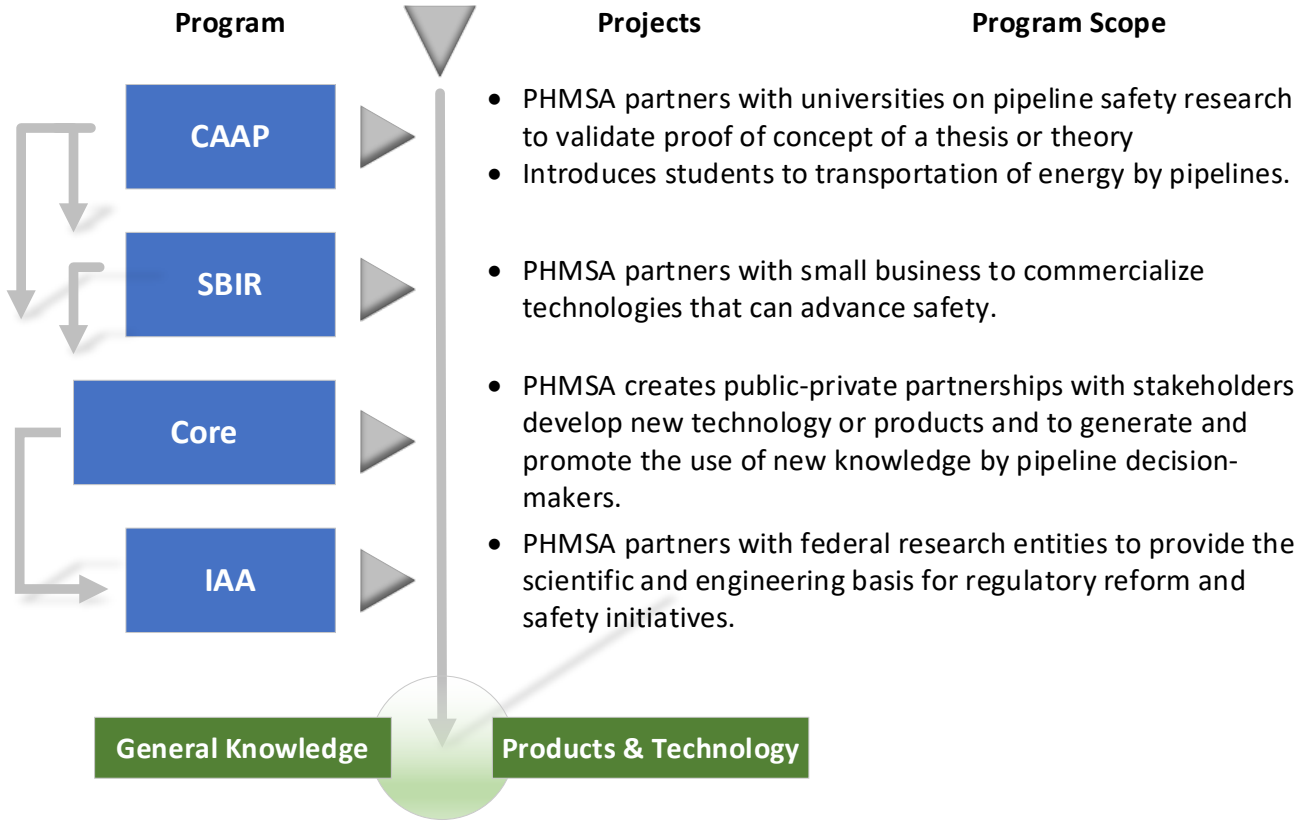
- Safety;
- Economic Strength and Global Competitiveness;
- Equity;
- Climate and Sustainability;
- Transformation; and
- Organizational Excellence

The PSRP executes research funding through four major subprograms: the CAAP, SBIR, Core, and IAAs. Each subprogram is designed to advance research concepts throughout their lifecycles, from initial conceptual stages to industry or government adoption, as depicted in **Figure 1** below:

Figure 1: Scope and Project Flows of PSRP Subprograms

[3] Section 12 of the Pipeline Safety Improvement Act of 2002 (49 U.S.C. 60101 note; Public Law 107-355). For additional clarification on items #8 and #9, see https://www.firemarshals.org/Pipeline-Emergencies and https://primis.phmsa.dot.gov/comm/FactSheets/FSExcavationDamage.htm, respectively.

[4] https://www.transportation.gov/sites/dot.gov/files/2022-04/US_DOT_FY2022-26_Strategic_Plan.pdf.



4.1 Competitive Academic Agreement Program (CAAP)

The CAAP funds research through competitive agreements with colleges and universities. The CAAP is intended to spur innovation by enabling academic research focused on high-risk, high-reward solutions to address a wide range of pipeline safety challenges. This program also introduces students to the transportation of energy by pipelines to encourage career interests in the pipeline safety sector after graduation.

4.2 Small Business Innovative Research (SBIR)

The SBIR program was established under Executive Order 13329 in February 2004 to encourage innovation in manufacturing. The executive order assigns duties to the Small Business Administration, defines the duties of the agencies and departments participating in the SBIR program, and states that continued technological innovation is critical to the strength of the U.S. manufacturing sector. PHMSA uses the SBIR program to identify innovative small businesses providing novel concepts and prototype technologies that can later lead to commercialization. In addition, PHMSA's SBIR program collaborates with small businesses that can leverage successes in other economic sectors, such as medical or defense, toward resolving pipeline safety challenges.

"The SBIR Program is structured in three phases:[5]

Phase I. The objective of Phase I is to establish the technical merit, feasibility, and commercial potential of the proposed research efforts and to determine the quality of performance of the

[5] https://www.sbir.gov/about

small business awardee organization prior to providing further Federal support in Phase II. SBIR Phase I awards are generally $50,000 - $250,000 for 6 months.

Phase II. The objective of Phase II is to continue the research efforts initiated in Phase I. Funding is based on the results achieved in Phase I and the scientific and technical merit and commercial potential of the project proposed in Phase II. Typically, only Phase I awardees are eligible for a Phase II award. SBIR Phase II awards are generally $750,000 for 2 years.

Phase III. The objective of Phase III is for the small business to pursue commercialization objectives resulting from the Phase I/II research activities. The SBIR programs do not fund Phase III. At some Federal agencies, Phase III may involve follow-on non-SBIR funded research or production contracts for products, processes or services intended for use by the U.S. Government."

4.3 Core Research Program

OPS's PSRP is primarily executed through the Core Program. Under this program, the main activities focus on developing new technologies or products and conducting demonstrations to transfer technologies into commercialization. In addition, the Core Program promotes the use of new knowledge for decision-makers.

4.4 Inter-Agency Agreement (IAA)

PHMSA partners with government research organizations through IAAs to conduct technical research. PHMSA currently has IAAs with the DOT Volpe National Transportation Systems Center, Oak Ridge National Laboratory, Sandia National Laboratories, the NIST, and other federal entities. OPS's PSRP frequently enters into IAAs to utilize the expertise of federal labs to bring innovative solutions forward.

5. R&D Goals and Objectives

The PSRP achieves its goals through research partnerships with universities through CAAP; demonstrations, deployments, and commercialization through Core; innovative, small business-focused projects through SBIR; and expertise from federal agencies and national labs through IAAs. The PSRP's main objectives are to:

- Help advance a safe and reliable pipeline transportation system for the American public by providing the scientific and engineering basis for improved industry standards and rulemaking;
- Promote emerging technologies for pipeline industry adoption; and
- Identify and address pipeline safety challenges and research gaps and invest in research projects that address the Department's strategic goals.

Based on stakeholder input from R&D forums, responses to research solicitations, submissions on research gaps, and historical incident trends, PHMSA identifies a set of high-value programmatic objectives as the focal point for its research. The PSRP addresses these programmatic objectives each year; however, specific research projects and activity scopes may change to address emerging safety issues based on specific pipeline incidents, data analysis, and congressional mandates. The following eight programmatic objectives are based on congressional directives, stakeholder input, and pipeline incident data:

- Preventing Pipeline Threats/Damage;

- Improving Pipeline Leak Detection Systems;
- Improving Anomaly Detection and Characterization;
- Improving Anomaly Repair and Pipe Remediation and Rehabilitation;
- Improving Design, Materials, and Welding/Joining;
- Improving Safety Systems for LNG Facilities;
- Improving Safety Systems for Underground Natural Gas Storage (UNGS) Facilities; and
- Climate Change Solutions/Hydrogen/CO_2.

6. Background: PHMSA-Regulated Infrastructure and Incident Data Overview

PHMSA oversees a complex network of over 3.3 million miles of pipeline infrastructure, 168 LNG facilities, and 399 UNGS facilities.[6]

Table 1: Pipeline Infrastructure Mileage by System Type (2021)

System Type	Miles	% of Miles
Natural and Other Gas	**2,618,836**	**92%**
Gas Distribution	**2,300,287**	**88%**
Gas Transmission	**301,486**	**12%**
Natural Gas	298,396	99%
Hydrogen Gas	1,567	0.5%
Landfill and Other	1,523	0.5%
Gas Gathering[7]	**17,063**	**0.7%**
Hazardous Liquid	**230,002**	**8%**
Crude Oil	84,727	37%
Refined Petroleum products	64,307	28%
HVL	75,612	33%
Carbon Dioxide	5,339	2%
Biofuel	17	0%
Total Miles	**2,848,837**	

Total Miles is the summation of Natural and Other Gas and Hazardous Liquid system types.

Table 1 shows[8] PHMSA jurisdictional pipeline infrastructure mileage by system type and the predominant commodity type transported in pipelines. Currently, 92 percent of pipeline infrastructure consists of natural gas pipelines, with 88 percent of those being gas distribution lines.

[6] On November 15, 2021, PHMSA published a final rule (86 FR 63266) bringing approximately 400,000 miles of gas gathering (GG) pipelines that were previously unregulated under federal oversight. This brings the total miles of federally-regulated pipeline to approximately 3.3 million miles. However, the exact mileage will not be reported until PHMSA receives Annual Reports for all GG pipelines in 2023.

[7] As stated in Footnote 9, over 400,000 miles of GG pipelines that were previously not subject to federal safety oversight will be reported in 2023 once PHMSA receives Annual Reports for all GG pipelines.

[8] Source of infrastructure information used in this report is PHMSA Annual Reports for CY 2021, Data as of June 17, 2022.

PHMSA uses incident and accident data, infrastructure information, inspection and compliance data, and industry trends to continually evaluate and assess regulatory and other agency priorities, including R&D initiatives.[9] Part 191 of 49 Code of Federal Regulations (CFR), prescribes the incident reporting requirements for natural and other gas pipelines, including LNG and UNGS facilities, whereas Part 195 of 49 CFR prescribes accident reporting requirements for pipeline facilities used in the transportation of hazardous liquid and carbon dioxide.[10, 11] For ease of discussion in this report, the term "incident" will be used for reportable incidents involving natural and other gas pipelines and reportable accidents involving hazardous liquid and carbon dioxide pipelines. The reporting requirements for both natural gas and hazardous liquids have changed over time. **Table 2** details the incident reporting requirements during the most recent 10-year period (2012-2021), for which complete data is available and was used for incident data analysis for this report.[12]

Table 2: Reporting Criteria for 30-Day Written Reports (2012-2021)

Reporting Criteria in §191.3 for Natural and Other Gas[13]	Reporting Criteria in §195.50 for Hazardous Liquid or Carbon Dioxide
(1) An event that involves a release of gas from a pipeline, gas from a UNGS facility, liquefied natural gas, liquefied petroleum gas, refrigerant gas, or gas from an LNG facility, and that results in one or more of the following consequences: (i) A death, or personal injury necessitating in-patient hospitalization. (ii) Estimated property damage *of $50,000 or more until 2020 and then to* $122,000 or more, including loss to the operator and others, or both, but excluding the cost of gas lost. (iii) Unintentional estimated gas loss of three million cubic feet or more. (2) An event that results in an emergency shutdown of an LNG facility or a UNGS Facility. Activation of an emergency shutdown system for reasons other than an actual emergency within the facility does not constitute an incident. (3) An event that is significant in the judgment of the operator, even though it did not meet the criteria of paragraph (1) or (2) of this definition.	An accident report is required for each failure in a pipeline system subject to this part in which there is a release of the hazardous liquid or carbon dioxide transported resulting in any of the following: (a) Explosion or fire not intentionally set by the operator. (b) Release of 5 gallons (19 liters) or more of hazardous liquid or carbon dioxide. (c) Death of any person; (d) Personal injury necessitating hospitalization; (e) Estimated property damage, including cost of clean-up and recovery, value of lost product, and damage to the property of the operator or others, or both, exceeding $50,000.

All reported incidents fall into one of the following three categories: 1) "Serious incidents" that have human consequences in terms of fatality and injuries requiring in-patient hospitalization; 2) "Significant incidents," which may include human consequences; certain costs related to environmental and property damages through product releases in air, soil, and water; certain releases of hazardous liquids; and liquid releases resulting in an unintentional fire or

[9] Although Part 195 refers to hazardous liquid failures meeting reporting criteria as "accidents", and Part 191 defines them as "incidents," this report refers to all releases that meet the reporting criteria as "incident."

[10] https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-191

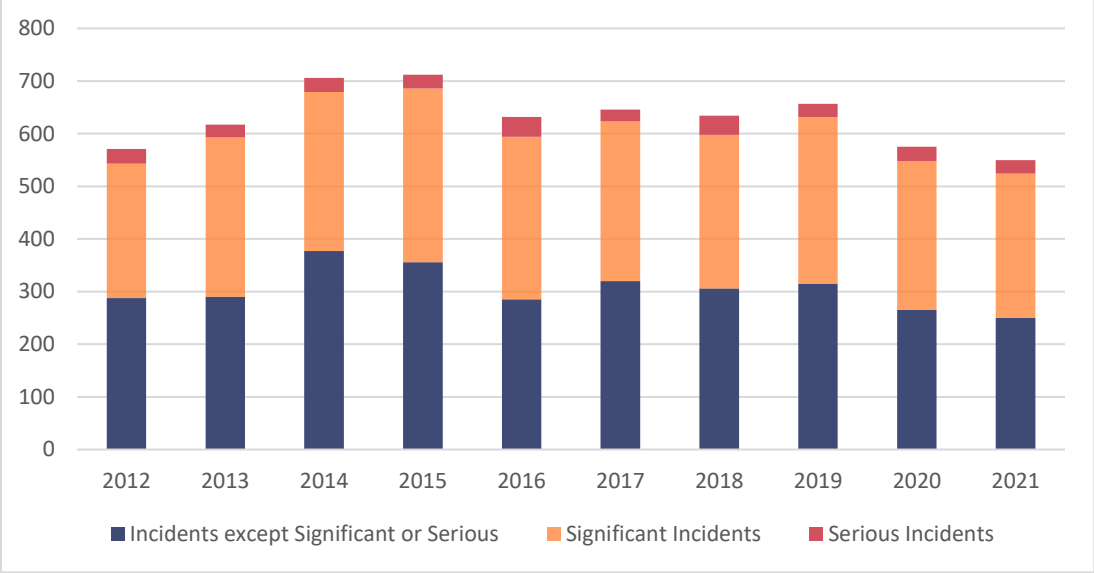
[11] https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-195

[12] https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2021-07/PHMSA%20Incident%20Report%20Criteria%20Change%20History%202021-01-11.docx?web=1

[13] Incident reports for Underground Storage facilities are available since 2017

explosion;[14] and 3) “Incidents Except for Significant or Serious” which meet the reporting criteria described in **Table 2**. PHMSA uses all incident reports to conduct detailed analyses to identify system-specific threats and consequences, and to support PHMSA’s short-term and long-term R&D objectives and programmatic priorities. As shown in **Figure 2** below, PHMSA received 6,300 incident reports between 2012 and 2021, of which 280 (4 percent) were Serious incidents and 2,968 (47 percent) were Significant incidents.[15]

Figure 2: Pipeline Serious Incidents with Context Measures



Source: PHMSA Incident Reports; Data as of 05/31/2021.[16]

Population growth, energy consumption, and pipeline infrastructure, a well as the trends in Serious incidents in the past 10 years in U.S. are shown in **Figure 3**.[17] As population increased, so did energy consumption and the associated pipeline infrastructure that transports natural gas and petroleum products to households, businesses, and industries throughout the U.S. Although the long-term trend in pipeline Serious incidents is declining, PHMSA is mindful of the dynamic and challenging ways in which technology, manufacturing, and fluctuations in energy production and consumption impact pipeline safety.

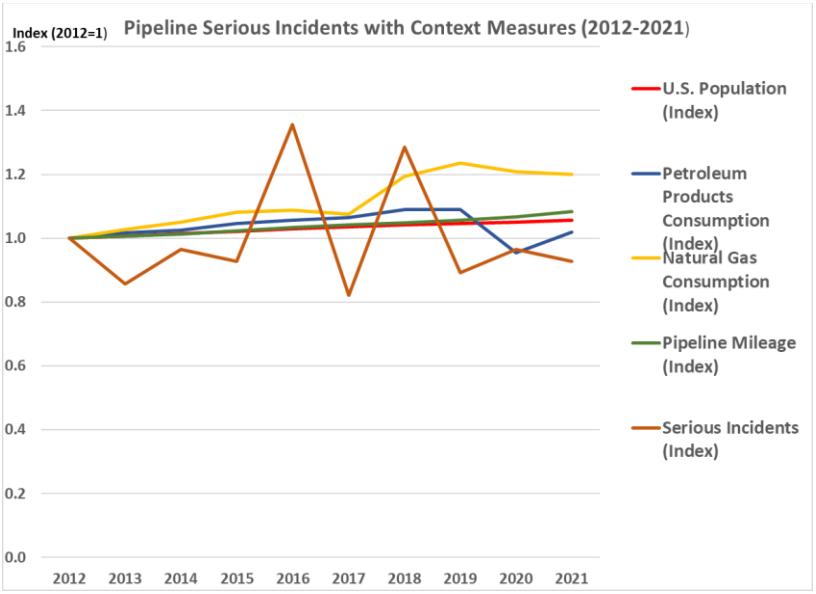
[14] Significant incidents are those including any of the following conditions, excluding gas distribution incidents caused by a nearby fire or explosion that impacted the pipeline system: 1) Fatality or injury requiring in-patient hospitalization, 2) estimated damages $50,000 or more until 2020 and then to $122,000 or more; 3) Highly volatile liquid releases of 5 barrels or more or other liquid releases of 50 barrels or more, and 4) Liquid releases resulting in an unintentional fire or explosion.

[15] All Serious incidents are Significant incidents.

[16] The Incident data analyzed in this report is sourced from PHMSA Accident and Incident reports, Data as of 05/31/2022.

[17] Serious incidents include a fatality or injury requiring in-patient hospitalization, excludes gas distribution incidents caused by a nearby fire or explosion that impact the pipeline system.

Figure 3: Pipeline Serious Incidents with Context Measures



Data Sources: Energy consumption from Energy Information Administration and US Population from Census Bureau, Mileage: PHMSA 2021 Gas and HL Annual Reports Data, Serious Incidents: PHMSA Incident Data
Energy consumptions have been used as a preliminary estimate for 2021.

Table 3 details the 6,300 reported incidents for both natural gas and hazardous liquid system types.

Table 3: Incidents Reports by System Type and Incident Categories (2012-2021)

System Type	All Reported	Significant Incidents	Serious
Natural and Other Gas	**2,318**	**1,419**	**264**
Gas Distribution	1,060	660	234
Gas Transmission	1,140	677	27
Gas Gathering	69	55	1
Liquefied Natural Gas	30	10	1
Underground Storage Facilities	19	17	1
Hazardous Liquid	**3,982**	**1,549**	**16**
Number of Incidents* (2012-2021)	**6,300**	**2,968**	**280**

*Number of Incidents is the summation of the following shown in Table 3:
Natural and Other Gas and Hazardous Liquid.

Between 2012 and 2021, there were a total of 280 Serious incidents resulting in 112 fatalities, 538 injuries, over $2 billion in property damages, and 116,180 barrels of hazardous liquid unintentionally spilled.[18] During this time, Significant incidents resulted in an additional $2.7

[18] PHMSA collects property damage data through its incident report forms. Property damages includes damages to both public and operator properties, repairs to the operator's properties, cost of emergency responses, cost

billion in property damage. The overall consequences of all 6,300 reported incidents during this period were 112 fatalities, 538 injuries, over $5.2 billion in property damage, and 848,200 barrels of unintentional hazardous liquid spilled.[19]

The following figures show the reported causes of all reported incidents, by type of incident, over the 2012-2021 period for all regulated pipelines (natural gas and hazardous liquids). Specifically, **Figure 4**, shows that for all reported incidents across all system types, Equipment Failure (37 percent) is the leading cause, followed by Corrosion (17 percent), and Incorrect Operation (12 percent). Of the 2,327 incidents involving Equipment Failures, 1,833 occurred in hazardous liquid pipeline systems (79 percent), followed by 414 in gas transmission systems (18 percent).[20]

Figure 4: Causes of All Reported Incidents (2012-2021)

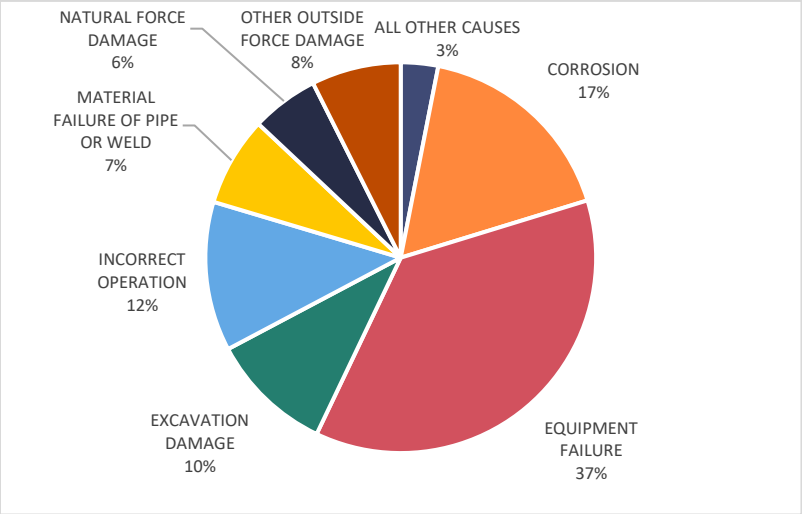


Figure 5 shows that for all reported incidents across all system types, 28 percent of the Serious incidents were caused by Other Outside Force Damage, predominantly damage to pipeline facilities caused by vehicles, while Excavation Damage caused 23 percent. The two other causes were Incorrect Operations (18 percent) and Material Failure of Pipe or Weld (11 percent).

of environmental remediations for hazardous liquid spills, and cost of the product lost during the incident. These costs are reported by the operators and collected in nominal.

[19] Serious incidents include a fatality or injury requiring in-patient hospitalization, excludes gas distribution incidents caused by a nearby fire or explosion that impact the pipeline system.

[20] The remaining 3 percent of Equipment Failure incidents (80) occurred on gas distribution (47 or 2%) , gas gathering (11 or 1%), LNG (14), and UNGS (8).

Figure 5: Causes for Serious Incidents (2012-2021)

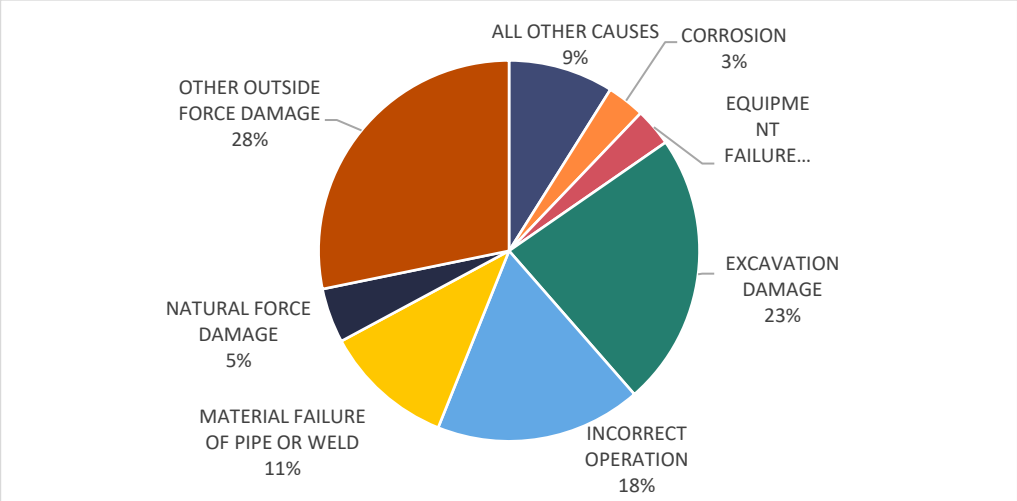
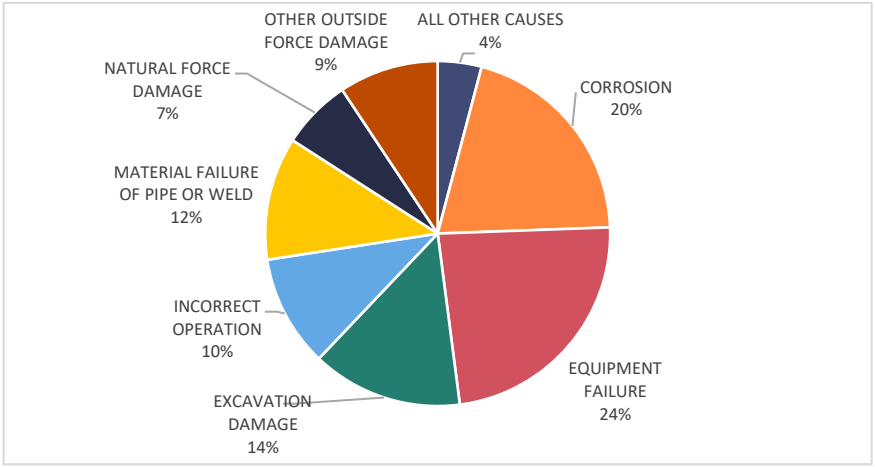


Figure 6 shows that for Significant incidents across all system types, Equipment Failure (24 percent) and Corrosion (20 percent) were the primary causes; Excavation Damage (14 percent) is the third leading cause of Significant incidents.

Figure 6: Causes for Significant Incidents (2012-2021)



In addition to cause, the incident data has been analyzed based on system type, locational information, pipeline characteristics (e.g., material, pipe diameter, and item failed), and consequence, among other factors, to help inform PHMSA's safety programs, including the PSRP.

7. PHMSA's Research Focus Areas

As noted earlier, the PSRP focuses on the following eight research areas based upon congressional directives, stakeholder input, pipeline incident data analysis of the causes and consequences, along with system type, locational information, and pipeline characteristics:

1. Preventing Pipeline Threats/Damage
2. Improving Pipeline Leak Detection Systems;
3. Improving Anomaly Detection and Characterization;
4. Improving Anomaly Repair and Pipe Remediation and Rehabilitation;

5. Improving Design, Materials, and Welding/Joining;
6. Improving Safety Systems for LNG Facilities;
7. Improving Safety Systems for UNGS Facilities; and
8. Climate Change Solutions/Hydrogen/CO_2.

7.1 Research Focus Area 1: Preventing Pipeline Threats/Damage

7.1.1 Overview

Activities under this focus area have historically included examining tools to notify operators of possible intrusions to pipeline rights-of-way (ROW) (e.g., excavation damage[21]), helping operators map the underground utility networks for existing pipelines, making new plastic pipelines locatable without the need for a separate tracer wire, and making existing unlocatable plastic pipelines locatable before excavation activities. Additional opportunities in this topic area include advancements in high-altitude imaging, machine learning (ML), and predictive analytics to prevent and mitigate integrity threats to pipeline infrastructure.

Table 4 summarizes the investment history and the documented success in this research focus area from 2002 through September 2022. The investments enable technology solutions to enter the marketplace and become available to pipeline stakeholders to prevent excavation damage.

Table 4: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
73	**$32.4 M**	**4/4**	**6**[22]

PHMSA's research investment continues to develop in this focus area, as Other Outside Force Damage (28 percent) and Excavation Damage (23 percent) remain the leading causes of all Serious reportable incidents (see **Figure 5**). However, as shown in **Table 5**, these threats primarily occur on gas distribution pipelines, indicating future research investment targets for PHMSA. Serious incidents caused by "Vehicle Not Engaged in Excavation" (i.e., vehicular crash impacting a gas facility) account for 57 percent of the incidents caused by outside force damage to pipelines. Therefore, PHMSA will continue coordinating with the industry, public advocacy groups, the National Association of Pipeline Safety Representatives (NAPSR), and the Common Ground Alliance (CGA) to develop potential safety solutions to address this incident cause.

[21] Excavation damage is defined as damage sustained to a pipeline or other underground infrastructure resulting from operation involving movement of earth, rock or other materials below existing grade or surface level. Excavation can include digging, blasting, boring, tunneling, and backfilling.

[22] https://www.phmsa.dot.gov/research-and-development/pipeline/technology-success-stories

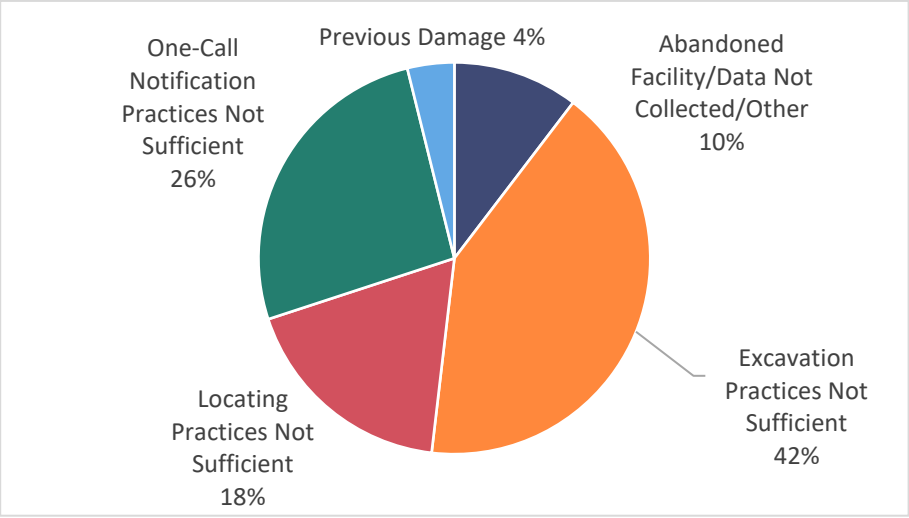
Table 5: Top Two Causes by System Type of Pipeline Serious Incidents (2012-2021)

Cause/System Type Serious Incidents (2012-2021)	Serious Incidents	Total Fatalities	Total Injuries
Other Outside Force Damage	***79***	***31***	***106***
Gas Distribution	71	25	93
Gas Transmission	5	2	10
Hazardous Liquid	3	4	3
Excavation Damage	***65***	***29***	***128***
Gas Distribution	56	17	98
Gas Transmission	5	5	19
Hazardous Liquid	4	7	11
Grand Total*	**144**	**60**	**234**

*All Tallies are the summation of the following Cause/System Type Serious Incidents: Excavation Damage; Other Outside Force Damage

For all Excavation Damage incidents, the leading root cause, as shown in **Figure 7** below, was determined to be "Excavation Practices Not Sufficient" (42 percent). This is attributed to excavators not complying with laws, rules or industry best practices. The second leading cause was "One-Call Notification Practices Not Sufficient" (26 percent), followed by "Locating Practices Not Sufficient" (18 percent). PHMSA is actively engaged in collaborative efforts with all stakeholders, including CGA's Technology Committee, Best Practices Committee, and other committees, to help address these areas. PHMSA continues to explore damage prevention programs and initiatives, such as those described in the 2017 Congressional report[23], through R&D investments.

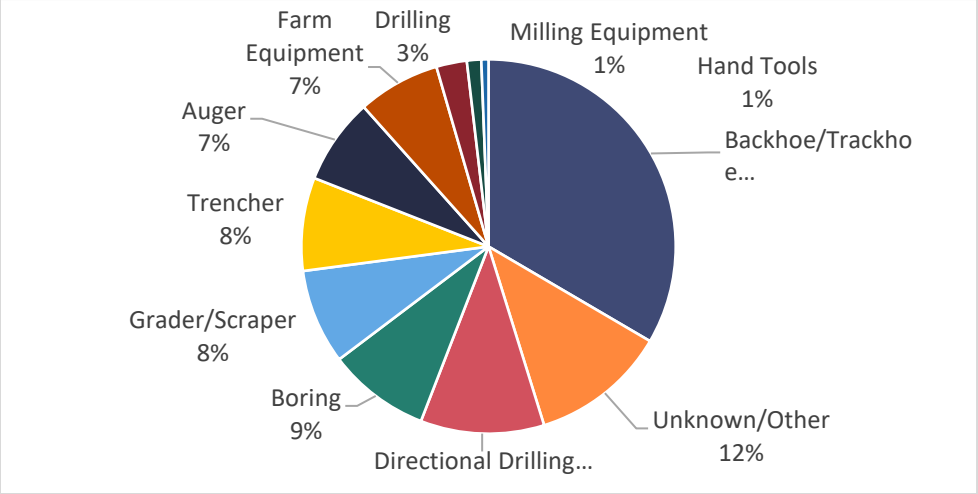
Figure 7: Root Causes for Excavation Damage Incidents, All System Types (2012-2021)



[23] https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/news/18351/reporttocongressonimprovingdamagepreventiontechnologyaug2017.pdf

As shown in **Figure 8**, incidents caused by Backhoes/Trackhoes, which are the predominant equipment used during excavation activities, account for 33 percent of reportable incidents across all system types. Prior research[24] funded by PHMSA on global positioning system (GPS) technologies has provided solutions to prevent excavators from digging in unauthorized areas. Other equipment, such as the ones used for directional drilling and boring, may be equipped with technologies, alerts, or sensors for safer excavation practices.

Figure 8: Equipment Used in Excavation Damage: All Reports, All System Types (2012-2021)



Figures 7 and 8 indicate that PHMSA's research strategy should include both knowledge-based and technological solutions that can reduce the likelihood of these incidents occurring. The data also indicates that focusing on removing challenges to better locate underground pipes and other utilities, and to safely excavate and prevent damage to existing pipeline infrastructure will help to reduce the number of incidents. PHMSA will continue to focus on improving federal and state regulatory effectiveness, support best practices, and coordinate with the industry, NAPSR, CGA, and other stakeholders to develop or enhance potential safety solutions and programs to address pipeline damage and excavation threats.

7.1.2 Department Strategic Alignment

Prioritizing research activities in this focus area supports the Department's strategic goals of *Safety* and *Climate* by developing new tools, technologies, and general knowledge/best practices that help alert: 1) Pipeline operators and communities to the presence and location of pipelines; and 2) Pipeline operators to possible pipeline ROW intrusions. Success in this research area could contribute to a reduction in the number of excavation-caused incidents and, in turn result in fewer gas or hazardous liquid releases, injuries, and fatalities.

Protecting pipeline systems from the threat of excavation damage is critical to supporting climate solutions and to building a stronger economy.

7.1.3 Short-Term Goals

Analysis of the incident data indicates that PHMSA should fund research under this focus area of Preventing Pipeline Threats/Damage to support the following short-term goals:

[24] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=249

1. *Improving Locating Practices* – Partner with organizations, such as the CGA, to develop knowledge-based solutions that integrate both tools and lessons learned into improved pipeline locating practices. Develop effective technology that clearly detects and maps underground pipelines of any material and possibly other utilities that can contribute to improving locating practices.

2. *Improving Awareness of Excavation Best Practices and State One-Call Laws* – PHMSA is partnering with CGA, NAPSR, the Occupational Safety and Health Administration (OSHA), and other safe excavation stakeholders to develop a professional excavator educational program, focused on safe digging/excavation and worker safety. This training will build upon existing federal and state laws, as well as CGA consensus best practices.

3. *Preventing/Mitigating Other Outside Force Damage* – Develop technology, tools, and best practices to prevent or mitigate pipeline damage through improved design for new pipelines and mitigation techniques for existing pipelines.

7.1.4 Long-Term Goal

Funding research to support the short-term goals will lead to solutions that could help reduce the frequency and consequence of pipeline damage incidents when deployed by organizations, such as pipeline operators and locating and excavation companies. Research outputs addressing this focus area will refine technology and knowledge-based solutions that: 1) Help pipeline operators monitor excavation activities around pipelines in real-time before significant damage results; 2) Help pipeline operators effectively locate existing pipelines and other underground utilities through improved tools and industry best practices; and 3) Help excavators work safely through improved tools in the market and best practices. Research outcomes resulting in technology transfer of improved tools into the marketplace will allow operators to utilize effective technologies to mitigate excavation damage to pipelines and to quickly detect and respond to pipeline damages and leaks. Research outcomes also include recommendations for new best practices for adoption by operators, locators and excavators, and organizations like CGA. The research will contribute to reducing incident frequency and consequence to ensure an effective, efficient, and reliable pipeline network and help reduce greenhouse gas (GHG) emissions caused by excavation damage to pipelines.

7.1.5 Significant Research Activities

PHMSA registered a technology transfer in FY 2022 for the project awarded to Gas Technology Institute (GTI) entitled “Improved Tools to Locate Buried Pipelines in a Congested Underground.”[25] The installation of utilities, such as electrical, natural gas, water, cable, and sewer lines, underground is a common practice that provides protection from surface activities, vehicles, and the weather. In accordance with state and federal laws, notification of excavations

[25] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=734

in close proximity to underground facilities must be provided by calling 811 so that the facility operators can mark the horizontal locations of those facilities for safe excavation. There are older plastic pipelines that are not easily located or are unlocatable due to lack of tracer wire and accurate records. GTI developed and commercialized a geospatial probe to locate and map existing buried pipelines that are not locatable. The probe, which can be inserted in a live gas pipeline, is able to accurately map underground pipeline locations to allow safe excavation around these facilities. The probe can be used to locate 2-inch and larger diameter pipes.

7.2 Research Focus Area 2: Improving Pipeline Leak Detection Systems

7.2.1 Overview

Activities under this focus area have historically included developing new or improved tools and technology solutions for locating, quantifying, and reducing the gas or liquid volumes released into the environment as a result of pipeline leaks and ruptures. Natural gas and hazardous liquid pipelines each have their own set of safety challenges when developing technology solutions. Field validation of research projects under realistic and variable conditions are key aspects that PHMSA addresses through research investments in this focus area. Research projects utilizing ML algorithms to analyze pipeline data will provide new solutions for pipeline safety. Leak detection thresholds can be improved through enhancing data analytics with ML for both hazardous liquid and natural gas releases.

Table 6 summarizes the investment history and resulting documented success in this research focus area from 2002 through September 2022. This investment enables technology solutions to enter the marketplace and become available to industry stakeholders to improve the detection of leaks.

Table 6: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
35	**$16.5 M**	**3/1**	**6**[26]

PHMSA's research investments will continue within this research focus area. **Table 7** presents incidents caused by leaks and ruptures from 2012-2021. This data shows that leaks have a higher frequency of occurrence than ruptures and on average release less product per leak than

[26] https://www.phmsa.dot.gov/research-and-development/pipeline/technology-success-stories

volume released per rupture; however, if leaks go undetected, they can release substantial volumes of hazardous liquid or natural gas cumulatively over time. The data indicates that research should continue to focus on preventing or mitigating pipeline leaks and ruptures.

Table 7: Releases by Type (2012-2021)

Release Type (2012-2021)	# of Incidents	Unintentional Release BBL	Average Release per Incident BBL	# of Incidents	Unintentional Release mcf	Average Release per Incident in mcf	# of Incidents	Unintentional Release mcf	Average Release per Incident mcf
	Hazardous Liquid			Gas Transmission			Gas Distribution		
Leak	3,153	316,640	100	453	2,579,561	5,694	332	478,203	1,490
Mechanical Puncture	119	189,911	1,596	112	890,282	7,949	351	857,494	2,485
Other	350	101,556	290	435	6,446,762	14,820	331	264,296	858
Overfill Or Overflow	272	16,708	61						
Rupture	87	223,331	2,567	140	6,451,974	46,086	47	106,788	2,321
Unknown	1	75	75						
Grand Total	3,982	848,221	213	1,140	16,368,578	14,358	1,061	1,706,781	1,673

A review of the data shows that the majority of failures were identified and reported by local operating personnel, emergency responders, the public, and others. Less than 10 percent of incidents were initially detected by computational pipeline monitoring (CPM) leak detection or supervisory control and data acquisition (SCADA) based systems. The majority of hazardous liquid and gas transmission systems involved in these incidents had an operational SCADA system in place, though these provided effective incident detection in a small number of cases. These incidents indicate the need for pipeline operators to incorporate more automation, such as through the application of ML to evaluate all collected leak data as part of their SCADA based systems. Increasing system automation through applying ML could support improvements to detecting both leaks and ruptures.

7.2.2 Department Strategic Alignment

Research investments in pipeline leak detection and quantification will assist with the early identification of leaks before they lead to catastrophic ruptures or remain undetected, causing ongoing environmental damage. These investments will improve public safety, reduce environmental threats, such as GHG emissions released during ruptures or undetected leaks of natural gas and hazardous liquid pipelines, and support the Department's *Safety* strategic goal by ensuring safe and reliable pipeline system infrastructure for all communities, including underserved and disadvantaged communities.

Furthermore, PHMSA is committed to encouraging pipeline operators to upgrade, replace, and repair aging, high-risk infrastructure. In addition to our work to enable current infrastructure to continue to safely supply energy to the public, we seek to position America to adopt the infrastructure of the future. This includes upgrading systems to transport hydrogen and other

renewables, which will support the Administration's climate and job creation priorities and the Department's *Climate and Sustainability* strategic goal.

7.2.3 Short-Term Goals

The incident data analysis indicates PHMSA should fund research under this focus area that supports the following short-term goal focused on pipeline leak detection and repair:

1. *Improving Pipeline Leak Detection/Mitigation* – Develop and validate technology that can detect and locate leaks in hazardous liquid and natural gas pipelines. Leak quantification will be a focus for natural gas pipelines. Automation through the comprehensive testing of ML algorithms will be employed so that they can improve CPM and SCADA-based systems to provide continuous leak detection monitoring and identification for both gas and hazardous liquid pipelines. Further develop leak detection systems for home monitoring of gas leaks at an affordable device cost and to identify ideal device placement within a home.

7.2.4 Long-Term Goal

In general, leak detection continues to be a challenge particularly for small leaks. Funding research in support of the short-term goal will enable a long-term goal of reducing the volumes of hazardous liquid or natural gas released into the environment. The research outputs will develop, test, and deploy advanced leak detection platforms (ground-based, aerial, and satellite) and protocols under real-time field conditions to provide pipeline operators with critical knowledge on gas migration and real-time data to help locate and quantify natural gas leaks. Outputs will also benefit from the increased application of ML to assess collected data which can be used to make confident and rapid pipeline shutdown decisions. Research outcomes will provide effective, validated technology solutions in the marketplace for pipeline operators to employ. Outcomes will also be standardized methodologies for integrating ML into CPM and SCADA-based systems. This safety improvement will ultimately help advance the Administration's strategic goal of tackling climate change by lowering the U.S. cumulative methane emissions.

7.2.5 Significant Research Activities

PHMSA registered a technology transfer in FY 2019 for the project completed by Physical Sciences, Inc. entitled "Natural Gas Pipeline Leak Rate Measurement System."[27]

Picture Courtesy: Heath Consultants, Inc.

[27] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=650

The project supported the development and validation of the Heath MobileGuard™ gas leak detection system, which consists of a methane/ethane analyzer, GPS, a sonic anemometer, and proprietary leak detection software that presents real-time geospatial maps of multiple gas concentrations. The software's sophisticated leak detection algorithm combines the system's measurements of gas concentrations (methane and ethane), local coordinates using GPS, and local wind velocity (sonic anemometer) to estimate the leak location. Readings are stored in the device and can be transmitted in real-time to “the cloud” for centralized monitoring. The MobileGuard™ laser-based sensor has a sensitivity and precision more than 3,000 times greater than legacy equipment. This enables the identification of leaks several hundred feet away from the source.

7.3 Research Focus Area 3: Improving Anomaly Detection and Characterization

7.3.1 Overview

Activities under this focus area have historically supported improvements in pipeline integrity management decisions that include finding and removing critical defects or anomalies in pipeline systems, such as metal loss due to corrosion. This research area will support both anomaly detection and characterization efforts within pipelines and provide operators with effective instrumentation to enable accurate remediation measures.

Table 8 summarizes the investment history and documented success in this research focus area from 2002 through September 2022. The investment is enabling technology solutions to become available for improving anomaly detection and characterization activities.

Table 8: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
128	**$58.3 M**	**26/14**	**18**

PHMSA continues to invest in this research focus area due to the need to detect and evaluate integrity threats, such as corrosion, in aging pipeline infrastructure. As shown in **Table 9**, approximately 50 percent of hazardous liquid and natural gas transmission pipelines were installed before 1970, prior to promulgation of the federal pipeline safety regulations. Modern steel pipe manufacturing requirements, external coatings, welding examination practices, and construction inspection procedures were not required prior to the federal pipeline safety regulations. PHMSA is focused on systemic approaches in pipeline integrity management, such as technologies and practices to identify critical defects, to enhance pipeline safety, and ultimately reduce the number of pipeline incidents.

Table 9: Miles of Hazardous Liquid and Gas Transmission Pipes by Decade Installed

2021 Miles by Decade Installed	Pre-1940 or Unknown	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2019	2020-2029	Total Miles
Hazardous Liquid	11,599	14,839	33,155	33,785	30,026	17,876	18,727	16,766	46,571	6,658	**230,002**
Gas Transmission	10,292	19,981	64,004	67,937	29,542	24,378	29,948	29,013	22,760	3,628	**301,484**

As shown in **Figure 9**, corrosion failure progressively becomes the leading cause of incidents as hazardous liquid pipelines age. Material failure of a pipe or weld becomes the secondary leading cause. **Figure 10** illustrates that the threat of external corrosion significantly surpasses that of internal corrosion based upon the pipe's age and, therefore, should be a focus of research for hazardous liquid pipelines.

Figure 9: Hazardous Liquid Incidents in Onshore and Offshore Pipelines, Including Valve Sites by Age of the Items Failed (2012-2021)

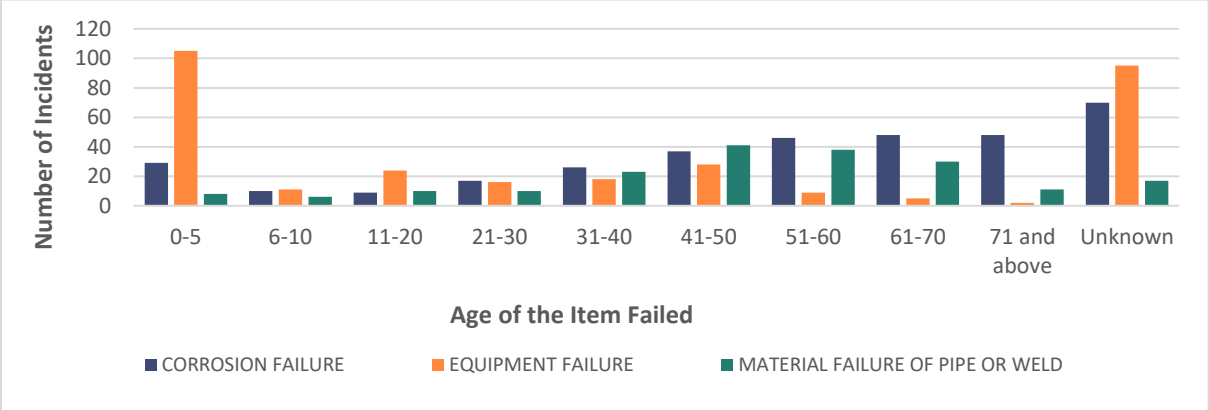
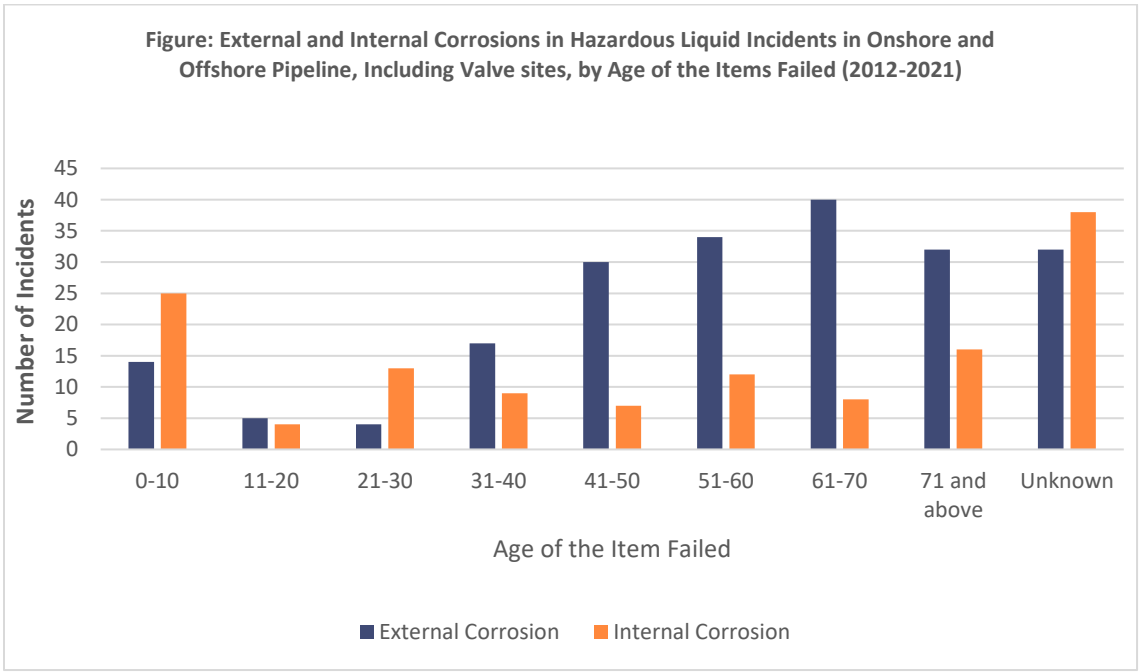


Figure 10: External and Internal Corrosion Hazardous Liquid incidents in Onshore and Offshore Pipelines, Including Valve Sites by Age of the Items Failed (2012-2021)



As shown in **Figure 11,** corrosion and material failure of pipe or weld pipelines are the leading causes of incidents for natural gas transmission pipelines. Research should be pursued in support of these pipeline threats. **Figure 12** illustrates that external and internal corrosion both cause incidents. External corrosion threats grow over time for both natural gas transmission and hazardous liquid pipelines. Research in this focus area should concentrate on external and internal corrosion, specifically the manufacturing process utilized or coating type applied to the pipe.

Figure 11: Gas Transmission Incidents in Onshore and Offshore Pipelines, Including Valve Sites by Age of Item Failed

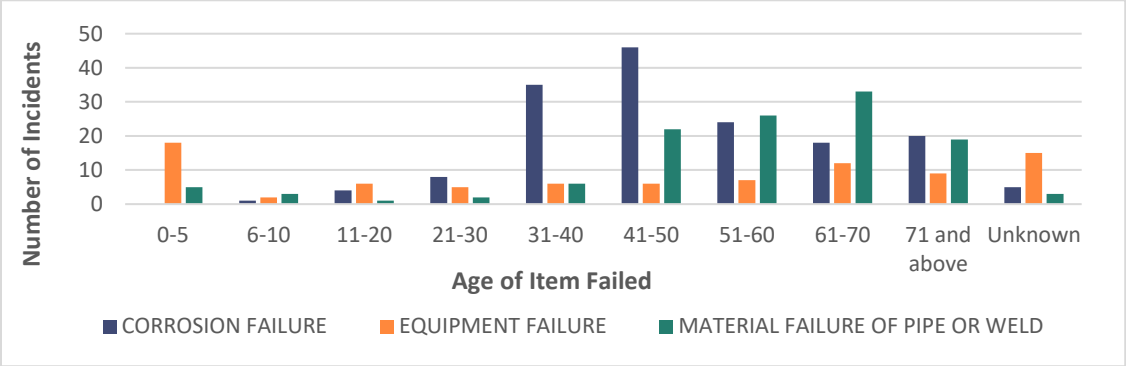
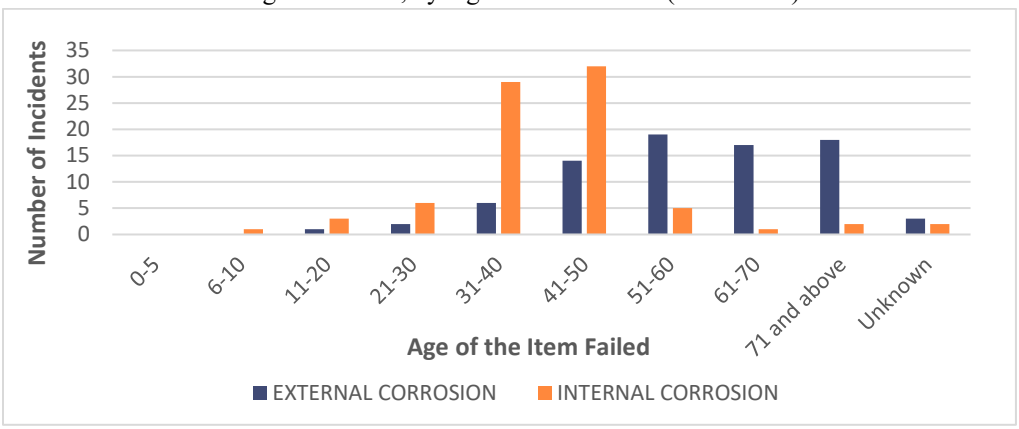


Figure 12: External and Internal Corrosion in Gas Transmission Incidents in Onshore and Offshore Pipeline, Including Valve sites, by Age of Items Failed (2012-2021)



Incidents caused by material failure of a pipe or weld are further detailed in **Table 10** for hazardous liquid and natural gas transmission pipelines. In general, the data shows that hazardous liquid pipelines are experiencing more incidents due to material failure than gas transmission pipelines. Research should assess best practices for construction, installation, and fabrication activities and processes. In addition, research should target an improved ability to detect and characterize such defects so that these defects can be repaired before a pipeline fails.

Table 10: Material Failure of Pipe or Weld (2012-2021)

Material Failure of Pipe or Weld by Detailed Cause	# of Incidents	# of Incidents
	Hazardous Liquid	***Gas Transmission***
Construction-, Installation-, or Fabrication-Related	145	77
Environmental Cracking-Related	29	25
Original Manufacturing-Related (Not Girth Weld or Other Welds Formed in the Field)	83	28
Grand Total	257	130

7.3.2 Department Strategic Alignment

Research investments in anomaly detection and characterization will improve the capability to identify and locate critical pipeline defects and to characterize the severity or interacting nature of these defects. These investments will also improve public safety, reduce environmental threats, such as GHG emissions released during leaks and/or ruptures of natural gas or hazardous liquid pipelines, and support the Department's *Safety* strategic goal by promoting safer and more reliable pipeline infrastructure system for all communities, including underserved and disadvantaged communities.

Furthermore, PHMSA is committed to encouraging pipeline operators to upgrade, replace, and repair aging, high-risk infrastructure. In addition to our work to enable current infrastructure to continue to safely supply energy to the public, we seek to position America to adopt the infrastructure of the future. This includes upgrading systems to transport hydrogen and other renewables, which will support the Administration's climate and job creation priorities and the Department's *Climate and Sustainability* strategic goal.

7.3.3 Short-Term Goals

The incident data analysis indicates that PHMSA should fund research under this focus area that supports the following short-term goals:

1. Improved Detection and Characterization of Corrosion Defects:

   Internal Corrosion – Develop and validate technology and models that can better detect, map the defect profile, and quantify the significance of internal corrosion defects in all its forms with an emphasis on application to natural gas transmission pipelines and secondary applications to hazardous liquid pipelines.

   External Corrosion – Develop and validate technology and models that can better detect, map the defect profile, and quantify the significance of external corrosion defects in all its

forms with an emphasis on application to hazardous liquid pipelines and secondary applications to natural gas transmission pipelines. The technology research will be focused on developing tools deployed from inside or outside of the pipe to better detect disbonded coatings.

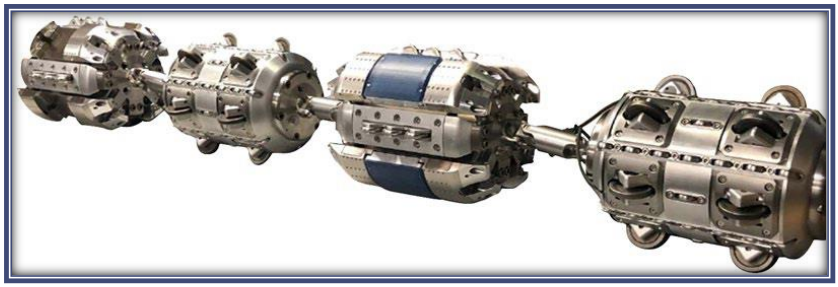
2. *Improved Detection and Characterization of Material Failure of Pipe or Weld Defects* - Develop and validate technology and models that can better detect, map the defect profile, and quantify the significance of cracking in either the pipe or the pipe weld.

7.3.4 Long-Term Goal

As indicated by the incident data presented earlier, internal and external corrosion continue to be challenges for pipeline safety. Funding research in support of the short-term goals will enable achieving the long-term goal of improving safety and reducing the volume of hazardous liquid or natural gas released into the environment. Research outputs in this area are designed to identify critical corrosion defects or anomalies within pipelines and provide pipeline operators with effective instrumentation and methodologies to find, assess, and evaluate manufacturing defects and cracking and in-service corrosion anomalies in the pipe. Research outcomes will better inform PHMSA and pipeline operators to make integrity management decisions on steel and composite pipeline systems, support safer operations, and aid in determining a pipeline's fitness for service. Furthermore, the research results should provide pipeline operators with effective commercial tools and services, allowing for accurate remediation measures that reduce the likelihood of pipeline failures harming the public or the environment.

7.3.5 Significant Research Activities

PHMSA registered a technology transfer in FY 2022 for the project completed by Physical Sciences, Inc. entitled "Electro Magnetic Acoustic Transducer (EMAT) Sensor for Small Diameter and Unpiggable Pipes; Prototype and Testing."[28] The project demonstrated the ability of the EMAT crack tool to detect tight/closed cracks down to 2 millimeters deep for 8-inch diameter pipes in traditionally difficult-to-inspect pipelines. The EMAT Crack In-Line Inspection tool is now being offered for operators' use.



Picture Courtesy: Baker Hughes/Qi2 Elements

[28] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=653

7.4 Research Focus Area 4: Improving Anomaly Repair and Pipe Remediation and Rehabilitation

7.4.1 Overview

Activities under this research focus area have historically supported reliable methods for repairing damaged coatings and corrosion damage, which are major integrity management challenges for pipelines. Research activities address ways to improve the pipeline repair processes and to improve standards or best practices for operators. Testing is needed for composite materials—the most common materials used for pipeline repairs—to understand its integrity under complex loading and over long-term operational and environmental conditions. Research activities will also advance repair materials, techniques, processes, tools, and/or technology designed to decrease system downtime and quickly bring pipeline systems back online. Research activities for pipe remediation and rehabilitation include developing and validating effective extruded or cured-in-place liner material so that cast iron and bare steel natural gas distribution systems can safely operate without leaks.

Table 11 summarizes the investment history and resulting success documented for this research focus area from 2002 through September 2022. Although to date this investment has not generated any technology transfer into the marketplace, it has produced significant knowledge generation and supports informed decision-making about repair options and tradeoffs.

Table 11: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
24	**$8.1 M**	**0/0**	**0**

PHMSA does not intend to pursue research on repairing damage to localized sections of gas transmission and hazardous liquid pipelines at this time because the DOE's Advanced Research Projects Agency - Energy is currently advancing repair solutions to address locally identified damage that are being closely coordinated with PHMSA. Furthermore, compared to the other challenges identified in this report, a review of incident data to assess the integrity of repairs on natural gas transmission and hazardous liquid pipelines does not indicate that a focus is warranted. **Table 12** below shows that pipelines have a low frequency of leak incidents after repairs have been made.

Table 12: Leaks from Repaired Pipelines (2012-2021)

Gas Transmission Pipelines			Hazardous Liquid Pipelines	
# of Incidents	**Unintentional Release** Mcf	**Year**	**# of Incidents**	**Unintentional Release** BBL
1	131	**2012**	0	0
1	250	**2013**	3	2.29
0	0	**2014**	1	0.2
2	635	**2015**	1	0.02
0	0	**2016**	0	0
0	0	**2017**	2	2.34
0	0	**2018**	2	13
0	0	**2019**	5	37.77
0	0	**2020**	1	0.3
2	587	**2021**	4	42.73
6	1,603	**Total**	19	98.65

Although the pipeline industry has replaced tens of thousands of miles of leak prone cast iron pipe since 2005, approximately 19,900 miles of cast iron gas distribution mains remained[29] at the end of 2020. Additional research is needed to support effective solutions to rehabilitate these systems with technological solutions, such as liners. These solutions will either temporarily return a pipe to safe service while a replacement is scheduled or, in some cases and as appropriate, allow a pipe to return to safe service after a liner is installed. PHMSA research investment continues to assess and develop integrity solutions for aging cast iron pipes.

PHMSA may pursue future research topics to investigate the risk profiles and location of aging cast iron pipeline systems throughout the country and advance technological solutions to rehabilitate aging cast iron pipelines in urban areas with higher percentages of cast iron main lines.

7.4.2 Department Strategic Alignment

Research investments in pipeline repair and internal liner materials for legacy pipelines contribute to the safe operation of pipeline infrastructure. A pipeline can extend its useful life when an effective repair solution is applied to the damaged pipe, supporting the Department's strategic goals of Safety, Equity, and Climate and Sustainability by repairing leak-prone pipes.

7.4.3 Short-Term Goals

The data analysis indicates that PHMSA should fund research under this focus area to support the following short-term goals:

1. *Enable a Risk Informed and Equitable Replacement Strategy* – Develop and validate pipeline replacement models that can review all pipeline related operational data sets

[29] PHMSA's new Natural Gas Distribution Infrastructure Safety and Modernization Grant program will assist in reducing this mileage by offering nearly $200 million in grants annually over the next five years to improve the safety of high-risk, leak-prone natural gas distribution pipelines. However, additional efforts are needed to reduce the remaining miles of leak-prone pipes.

and provide a risk informed, data-driven strategy that incorporates the goals of *Safety*, *Equity*, and *Climate and Sustainability* within urban areas.

2. *Deploy High Integrity Liner Solutions for Cast Iron Pipe* – Develop and validate new liner materials and processes that can effectively rehabilitate cast iron pipelines in situ (or in place). The goal of such new materials and processes is to enhance the safety of cast iron mains. PHMSA will also coordinate efforts in this area with other Federal agencies.

7.4.4 Long-Term Goal

Funding research in support of the short-term goals will enable the long-term goals of improving safety and reducing the volume of natural gas released into the environment. Research outputs will provide models allowing pipeline operators to make equitable and risk informed decisions about legacy pipe repair or replacement strategies and develop liners that can be effectively installed to rehabilitate critical pipelines in urban areas and, in some cases, fully replace this aging infrastructure. Research outcomes will provide validated and safe commercial solutions to rehabilitate and replace cast iron pipe and rapidly return them to service. Impacts from these research investments will help address leaking pipelines that have been the source of fatalities and serious injury, reduce economic losses and customer inconvenience, and advance technological solutions that improve performance to help advance the Administration's strategic goals of *Safety*, *Equity*, and tackling *Climate Change*.

7.4.5 Significant Research Activities

In FY 2022, PHMSA awarded new research funding to support solutions to rehabilitate cast iron gas distribution pipes, which are primarily located in urban and underserved rural areas. The research topic will address the "Rehabilitation of Aging Cast Iron Pipelines." The research investments will develop and validate a next-generation cured adhesive and curing method which yields a faster cure, adheres to the host gas pipe, and facilitates a more precise and repeatable installation process.

Picture Courtesy: Advantage Reline

7.5 Research Focus Area 5: Improving Design, Materials, and Welding/Joining

7.5.1 Overview

Activities under this focus area have historically supported improved pipeline materials and design, which can mitigate or minimize integrity threats to both transmission and distribution piping. The investment into welding and joining of transmission and distribution pipelines has addressed automation and inspection capabilities that can safely improve the efficiency and

quality of construction activities. Developing guidelines to improve construction-related quality management issues can reduce the likelihood of girth weld failures shortly after welding, during installation, during hydrostatic testing, and when in service. Research activities will improve the industry's ability to design and construct safe, long-lasting pipelines using the most appropriate materials and welding/joining procedures for a given operating environment. Developing effective pipeline coatings is also addressed under this focus area, where academia has played a strong role. Strong partnerships have been established between universities[30] engaged in applied research and coating manufacturers through PHMSA's research investments in coatings.

Table 13 summarizes the investment history and resulting success documented for this research focus area from 2002 through September 2022. Although the investment to date has not generated a large number of technology transfers into the marketplace, significant knowledge generation and transfer is supporting and informing decision-makers on improving the design, materials, and welding/joining of pipeline facilities.

Table 13: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
77	**$38.3 M**	**8/6**	**2**

PHMSA's research investments continue within this focus area on coatings due to external corrosion threats and the data analysis described in **Section 7.3**. Pipeline coatings are the primary cathodic protection system against the threat of external corrosion. Research into more effective coatings, both those that are applied at the pipe mill during manufacturing and those applied in the field, is warranted to reduce incidents caused by external corrosion.

Table 14 indicates that material failure of a pipe or weld accounted for 83 percent of all the incidents experienced by natural gas transmission and hazardous liquid pipelines between 2012 and 2021. The material failure of a pipe or weld is attributed to the manufacturing, transportation, and installation processes and procedures implemented during pipeline construction. This indicates that research should focus on quality management on each step of the manufacturing, transportation, and construction phase of a pipeline project.

Incidents caused by material failure of pipe or weld involving natural gas distribution pipelines resulted in the most fatalities and injuries during the 2012-2021 period as shown in **Table 14**. **Figure 14** provides further detail on where the failures occurred on the natural gas distribution pipeline system.

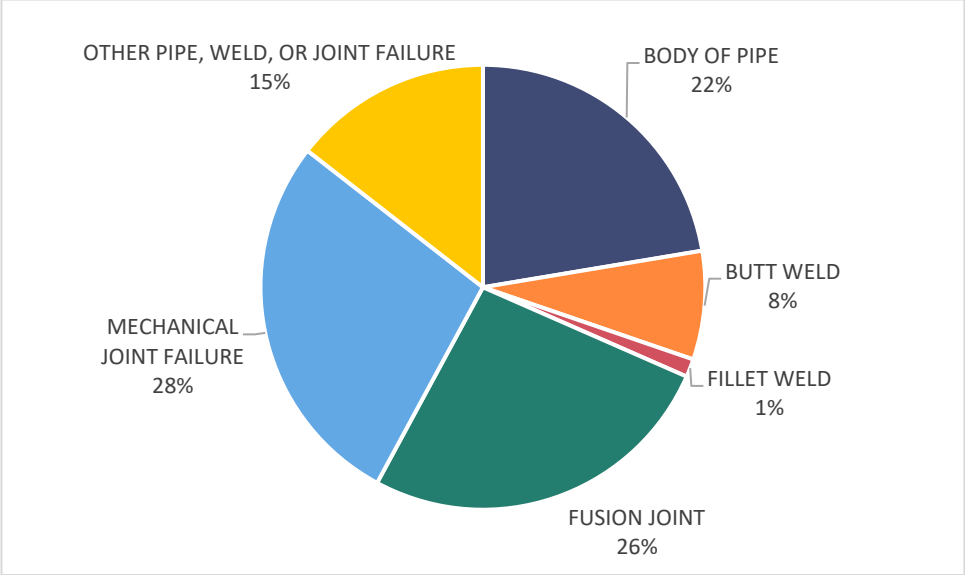
[30] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=568

Table 14: Material Failures of Pipe or Weld (2012-2021)

Material Failure of Pipe or Weld (2012-2021)	# of Incidents	Fatalities	Injuries	Property Damages	Unintentional Spill BBL	Release Intentional Gas mcf	Release Unintentional Gas mcf
Gas Distribution	76	5	42	33,248,794	-	-	216,679
Gas Gathering	2	0	0	887,529	-	10,241	9,682
Gas Transmission	130	0	0	95,331,101	-	823,083	2,958,707
Hazardous Liquid	257	1	1	471,606,631	194,811	-	-
Liquefied Natural Gas	1	0	0	205,155	-	-	-
Total	466	6	43	601,279,210	194,811	833,324	3,185,067

For natural gas distribution incidents where there is loss of product containment, Mechanical Joint Failure, through ductile fracture or brittle fracture of the pipe material at the joint, accounted for 28 percent of the incidents; followed closely (26 percent) by Fusion Joint Failure, which is the delamination/separation at the joint of two plastic pipe segments. Further research should be conducted on these two failure-types with a focus on improved procedures to reduce possible safety threats. This investment can contribute to lowering the number of fatalities and injuries.

Figure 14: Material Failure of Pipe or Weld or Joint in Gas Distribution Incidents (2012-2021)



7.5.2 Department Strategic Alignment

Well-designed pipeline systems, comprised of newer materials, including composite materials, and properly installed and maintained pipelines, can reduce future incidents. Effective welding/joining methods and materials will support longer operational life cycles of pipelines. Research investments in this area will contribute to improved public safety, reduce environmental threats, such as GHG emissions from natural gas and hazardous liquid pipelines, and support the Administration's *Safety* and *Climate and Sustainability* strategic goals.

7.5.3 Short-Term Goals

The incident data analysis indicates PHMSA should fund research under this focus area that supports the following short-term goals:

1. *Improve Coating Performance* – Develop and test new pipeline coating materials that provide superior protection against external corrosion threats to natural gas transmission and hazardous liquid pipelines. This goal provides an opportunity for universities that receive CAAP R&D funding to partner with coating manufacturers to develop and test new materials that can provide advancements to both mill and field applied coatings. Federal labs may also be employed to develop and advance solutions.

2. *Improve Coating Application Procedures* – Analyze current coating application procedures to identify steps where quality could be negatively impacted leading to coating damage or a disbondment, which is an unintentional gap between the coating and pipe surface. Develop effective procedures to prevent lapses in quality through the coating application process either at the mill or in the field and then work with standards bodies to issue a nationally recognized recommended practice.

3. *Advance Automation into Pipe Welding/Joining Inspection* – Develop and validate inspection tools that confidently detect flaws in the root of the weld of steel pipes and delamination or gaps between joined plastic pipes. Automation will be integrated into such a system using ML algorithms to analyze inspection data. This approach may lower the detection threshold of flaws below current capabilities, ensuring higher integrity of welds/joints.

4. *Improve Plastic Pipe Materials* – Develop and test new innovative pipe materials that will improve the ability to design and construct safer, longer-lasting pipelines with the most appropriate materials for a given operating environment. This is another opportunity for universities to partner with manufacturers and enable solutions to mitigate or prevent threats of ductile fracture or brittle fracture in these new materials. Federal labs may also be employed to develop and advance solutions.

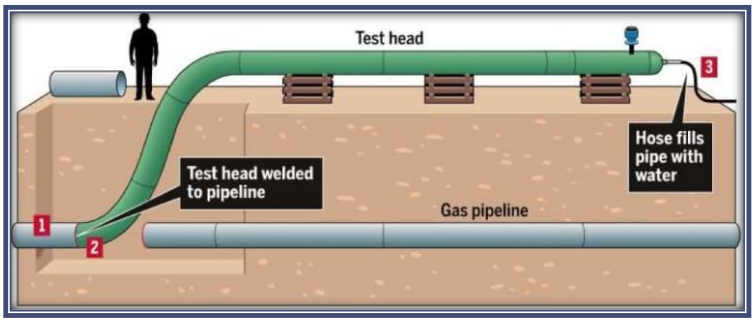
7.5.4 Long-Term Goal

Funding research in support of the short-term goals will help reduce external corrosion incidents due to pipe coating issues over the long-term. Strong partnerships between academia, Federal labs, and pipe and coating manufacturers provide new materials that could be further validated through research. Research outputs will be knowledge and improved procedures about effective material use in mitigating or preventing threats. Outcomes will be new innovative coatings and pipe materials and inspection technology utilizing the benefits of ML. Acceptable new materials adopted into industry standards are also potential outcomes from investments in this focus area. The impact will be fewer incidents caused by external corrosion due to ineffective coatings and application procedures. Improved pipe materials and inspection of welding/joining processes will result in safely constructing pipeline systems that are long-lasting and less failure-prone.

7.5.5 Significant Research Activities

PHMSA awarded research funding in FY 2020 to the Engineering Mechanics Corporation of Columbus to explore material impacts resulting from hydrotesting a pipeline. The project entitled

"Hydrostatic Retesting Optimization for Older Liquid Pipelines,"[31] will investigate the hydrotest pressure level used on lower pressure hazardous liquid pipelines and review the hydrotest pressure to optimize repairs, while still maintaining adequate fatigue life for liquid pipelines that experience pressure cycling. For older pipelines, high hydrotest pressure could induce many leaks during the hydrotest that is costly and potentially dangerous in a more populated area. Hydrotesting of liquid pipelines can be better optimized to avoid having unnecessary repairs for liquid lines that experience pressure cycling. The project goal is to determine the minimum number of pressure cycles after a hydrotest so that any surviving postulated surface crack will not become a rupture. The project was awarded in September 2020 and is expected to be completed by November 2023.



Picture Courtesy: Pepco Pipe Services

7.6 Research Focus Area 6: Improving Safety Systems for Liquefied Natural Gas (LNG) Facilities

7.6.1 Overview

Activities under this focus area have historically supported addressing challenges related to LNG safety, as well as fostering development of new technologies and alternative designs for LNG storage and piping systems. Additional initiatives in this research focus area will address early leak detection technologies; personnel and worker safety; and performance-based risk reduction during siting, design, construction, operations, maintenance, and fire protection activities, as well as process safety management principles and engineering best practices to address congressional mandates.[32]

Table 15 summarizes the investment history for this research focus area from 2002 through September 2022. Although this investment to date has not seen technology transfer into the marketplace or knowledge transfer into industry standards, significant knowledge generation and transfer is supporting and informing decision-makers about LNG safety.

[31] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=924

[32] See Section 27(b) of the PIPES Act of 2016 (Public Law 114-183) (mandating updated safety standards for small-scale LNG facilities) and Section 110 of the PIPES Act of 2020 (Public Law 116-260) (mandating updated safety standards for large-scale LNG facilities).

Table 15: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
14	**$5.7 M**	**0/0**	**0**

PHMSA began a major focus on LNG research in 2015. Research investment continues within this focus area to build a diverse portfolio to support several policy issues. **Table 16** presents the number and types of LNG plants currently operating in the United States.

Table 16: Type of LNG Plants (2021)

Type of LNG Plants (2021)	Number of In-Service LNG Plants	Maximum Liquefaction Rate mmcf/d	Number of Vaporizers	Maximum Vaporization Capacity	Number of LNG Tanks	Total Capacity BBL
Peak Shaving	70	367	203	10,117	102	21,974,665
Base Load	26	11,977	150	17,232	73	36,171,584
Satellite	23	18	49	574	36	564,583
Mobile/Temporary	40	4	34	116	19	4,428
Other	9	69	5	216	12	809,139
Grand Total	**168**	**12,435**	**441**	**28,254**	**242**	**59,524,399**

Note: Peak shaving plants are used for storing natural gas for use during peak demand periods, such as winter. Base load plants operate throughout the year to provide gas supply as LNG or natural gas. Satellite plants do not include process equipment to convert natural gas to LNG and instead have LNG delivered by truck for storage onsite and later injection (in gaseous form) into distribution pipeline systems. Mobile/temporary LNG plants are those not characterized as permanent infrastructure that are designed to be easily moved (e.g., skid-mounted or trailer-mounted). Other plants may include vehicular fueling facilities.

LNG operators reported 30 incidents between 2012 and 2021, with the primary causes listed as Equipment Failure and Incorrect Operation. To reduce the number of incidents involving these causes, PHMSA will pursue research to evaluate performance-based principles to identify requirements and methodologies for design, construction, operations, maintenance, and fire protection activities. Proper operation, inspection, and maintenance of LNG equipment with quality control/assurance programs would help to decrease the likelihood of failure. Additionally, early leak detection and appropriate actions (i.e., equipment shutdown and isolation) is critical in LNG operations and would help minimize the risks to plant personnel and the public and cascading damage to equipment in the event of an incident. As a result, PHMSA will pursue research to improve detection technologies and mitigation measures from the release of toxic or flammable gases. Both research topics will be expanded to a third research area to improve plant personnel protection by developing procedures and technologies for use during the performance of operations and maintenance activities.

Table 17: LNG Incidents and Cause (2012-2021)

Cause of the Failure (2012-2021)	LNG Incident Reports Received	Total Volume Released (Intentional plus Unintentional) in mcf	Average Volume Released per Incident in mcf
Corrosion Failure	1	202	202
Equipment Failure	14	17,634	1,260
Incorrect Operation	7	171,099	24,443
Material Failure of Pipe or Weld	1	185	185
Natural Force Damage	2	8,244	4,122
Other Incident Cause	4	1	0
Other Outside Force Damage	1	-	-
Grand Total	**30**	**197,364**	**6,579**

7.6.2 Department Strategic Alignment

Research investments in LNG will improve the safety and global competitiveness of domestic LNG facilities and its employees as well as help mitigate climate change impacts associated with LNG production. These research investments will address safety risks and operational challenges from LNG facilities, as well as foster and develop new technologies and alternative designs for LNG storage and piping systems. The *Safety, Global Competitiveness and Economic Strength,* and *Climate and Sustainability* strategic goals are addressed through this research investment.

7.6.3 Short-Term Goal

The incident data analysis supports PHMSA's funding of research under this focus area that supports the following short-term goals:

1. *Evaluate LNG Facility Hazards* – Conduct research to improve detection technologies and mitigation measures from the release of toxic or flammable gases and hazardous fluids. Research will minimize the potential impacts on plant personnel and the public and cascading damage to equipment.
2. *Develop Risk-Based Approaches for Performance-Based Standards* – Evaluate performance-based principles to identify requirements and methodologies for design, construction, operations, maintenance, and fire protection activities. Develop innovative or new approaches that provide demonstrably equivalent or improved safety via risk analyses.
3. *Improve LNG Personnel/Worker Safety* – Develop effective procedures and recommend technologies to improve plant personnel protection during operations and maintenance activities. In the event of equipment failure, they should also incorporate early leak detection and appropriate actions that facility personnel and workers can take to minimize the risks to plant personnel.

Additional industry performance data over time is required to conduct an analysis equivalent to those completed for the other research focus areas in **Section 7**.

7.6.4 Long-Term Goal

Due to the increased role of LNG in the global market, and the need to ensure the safe operation of LNG facilities, PHMSA will continue to invest in LNG safety research to address the safety risks and operational challenges from LNG facilities, as well as foster development of new technologies and alternative designs for LNG storage and piping systems. As an example, there are currently no suitable industry standards that identify best practices or establish minimum acceptable inspection requirements for cryogenic storage tanks. Research outputs will yield recommendations on optimal inspection intervals and identify best practices to improve the inspection and testing of aboveground cryogenic LNG storage tanks. Outcomes from the research may lead to changes in federal regulations or industry standards, providing immediate benefit in terms of inspection standardization for LNG tanks to limit operational safety risks to employees and the public. The LNG research can provide a consistent and systematic methodology for improving the safety and integrity of LNG facilities, including storage tanks.

7.6.5 Significant Research Activities

PHMSA awarded a research project to Blue Engineering and Consulting in FY 2019 entitled "Develop a Risk-Based Approach and Criteria for Hazard Detection Layout"[33] that looked at LNG facilities. This research was to fill a gap in the current methodology on developing hazard detection layouts as well as to evaluate existing hazard detection layouts at different LNG facility types. The researcher expanded on the methodology in the International Society of Automation (ISA) 84.00.07 *Guidance on the Evaluation of Fire, Combustible Gas and Toxic Gas System Effectiveness* for LNG-specific plant layouts. The project developed a performance-based approach that incorporated risk tolerance and harm criteria. The project found that flame detector layouts, which are established to detect active flames resulting from a leak and subsequent ignition, are best designed by ensuring adequate geographic coverage. It also found that gas detector layouts, which are established to detect flammable or toxic gas clouds resulting from a leak, are best designed by evaluating and modeling potential leak scenarios and placing detectors where flammable clouds from the scenario modeling are likely to develop in LNG plants.

7.7 Research Focus Area 7: Improving Safety Systems for Underground Natural Gas Storage (UNGS) Facilities

7.7.1 Overview

Activities under this focus area have historically supported improving the safety of UNGS facilities through their full life cycle. Research activities will focus on reducing risks to the public, the environment, and UNGS worker safety. Specific research areas include design and reliability improvements to UNGS equipment, such as tubing, packers, and subsurface safety valves, as well as knowledge enhancement on associated maintenance practices for UNGS wells.

[33] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=852

Table 18 summarizes the investment history for this research focus area from 2002 through September 2022. Although this investment to date has not seen technology transfer into the marketplace or knowledge transfer into industry standards, significant knowledge generation and transfer is supporting and informing decision-makers about UNGS safety.

Table 18: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
7	**$3.3 M**	**0/0**	**0**

After the 2015 Aliso Canyon natural gas leak (largest methane leak from a natural gas storage facility in U.S. history) in California of approximately 5.7 billion cubic feet (Bcf) of natural gas into the atmosphere, PHMSA gained additional regulatory authority through the Protecting our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act of 2016 and began collecting data in 2017 of incidents involving underground natural gas storage facilities. PHMSA research investment, which began in 2018, continues to build a diverse portfolio of projects around the various safety and environmental challenges facing UNGS facilities. The initial research projects funded were to address the recommendations noted by the Interagency Task Force on Natural Gas Storage Safety.[34]

Table 19 shows the 19 reported incidents during the 2017-2021 period involving UNGS or caverns, resulting in one injury, over one million cubic feet (mmcf) of natural gas unintentionally released, and over $17 million in property damages resulting from all reportable incidents.

[34] https://www.energy.gov/fact-sheet-ensuring-safe-and-reliable-underground-natural-gas-storage

Table 19: Underground Storage Incidents (2017-2021)

Underground Storage Incidents (2017-2021)	Number of Reports	Injury	Fatality	Intentional Release mcf	Unintentional Release mcf	Property Damages $
Underground Gas Storage or Cavern	**12**	**1**		**6,156**	**1,026,765**	**15,470,232**
Corrosion Failure	2				334,806	1,676,143
Equipment Failure	4				94,719	2,858,277
Incorrect Operation	2	1		2,025	41,524	280,757
Other Incident Cause	4			4,131	555,716	10,655,055
Dehydrator/Drier/Treater/Scrubber	**1**				**800**	**844,980**
Equipment Failure	1				800	844,980
Other	**3**			**95**	**12,330**	**960,307**
Equipment Failure	1			90	5	10,297
Incorrect Operation	1				12,324	698,999
Other Outside Force Damage	1			5	1	251,011
Regulator/Control Valve	**1**			**10**	**4**	**300,063**
Equipment Failure	1			10	4	300,063
Valve	**2**				**45,236**	**184,647**
Equipment Failure	1				28,216	69,008
Other Outside Force Damage	1				17,020	115,639
Grand Total	**19**	**1**		**6,260**	**1,085,135**	**17,760,229**

In 2017, PHMSA began collecting infrastructure information on UNGS through its annual report submission requirements. There are 399 UNGS facilities with 453 UNGS reservoirs and 16,722 wells, of which 13,786 are injection and/or withdrawal wells and 2,936 are monitoring and/or observation wells. **Table 20** shows the number of wells by the reservoir type and well maintenance information.

In addition to incident data, PHMSA plans to analyze other information, such as the year gas storage wells were drilled and results from our inspections, to further aid in understanding the safety and environmental challenges for UNGS facilities and the need for further research.

Table 20: Number of UNGS Wells (2021)

Underground Natural Gas Storage	Reservoir Type				
Number of Wells	Aquifer	Hydrocarbon	Bedded Salt Cavern	Salt Cavern	Grand Total
Injection and/or Withdrawal Wells	1,703	11,958	11	114	13,786
Monitoring and/or observation Wells	774	2,134	0	28	2,936
with Surface Safety Valve	237	1,378	11	113	1,739
with Subsurface Safety Valves	163	405	0	0	568
Maintenance During the CY, Number of Wells					
New Production Tubing Installed	57	199	0	4	260
New Production Casing, New Liner, or Repairs to Casing or Liner	14	110	0	2	126
Wellhead Remediation or Repair	57	423	0	6	486
Casing, Wellhead, or Tubing Leaks	8	103	0	2	113
Pressure Test Mechanical Integrity Tests (MIT)	151	541	0	34	726
Logged for Corrosion/Wall Loss MIT	383	1,273	0	29	1,685
MIT Other than Pressure Test or Logged for corrosion/wall loss	10	1,879	11	21	1,921

7.7.2 Department Strategic Alignment

Lessons learned resulting from the Aliso Canyon incident identify that a research focus on down hole operational integrity and effectiveness can prevent accidental releases and protect local populations from related safety and environmental threats. Research investigation into various equipment used down hole for well operations address the *Safety*, *Equity*, and *Global Competitiveness and Economic Strength* strategic goals. Energy supply via UNGS facilities is a critical component of domestic energy security.

7.7.3 Short-Term Goal

The incident data analysis indicates that PHMSA should fund research under this focus area to support the following short-term goal:

1. *Prevent/Mitigate Integrity Challenges for UNGS Facilities* – Develop new knowledge to better understand the technical issues involved with the reported corrosion, equipment failures, incorrect operation, and other incident causes of UNGS facility failures.

Additional industry performance data over time and lessons learned from facility inspections and audits conducted over the past few years will assist PHMSA to better identify research gaps in UNGS.

7.7.4 Long-Term Goal

Funding research in support of the short-term goal will enable improved knowledge of safety challenges for UNGS facilities, from which PHMSA will identify focused research areas to develop solutions. PHMSA will continue funding research to improve the safety of UNGS facilities over their full lifecycle, focusing on design and reliability improvements to storage well equipment and maintenance practices. Research outputs from UNGS projects will provide reliability-based methodologies focused on well integrity management and corrosion protection practices while evaluating the effectiveness of real-time, continuous pressure monitoring systems for well surveillance and leak monitoring. Research project outcomes can be incorporated into industry standards or best practices as minimum requirements and/or guidance for storage well casing integrity management. Furthermore, the research outcomes will improve operators' efficiency in managing casing corrosion, thereby potentially reducing well casing incidents. The results from UNGS research will support new policy development on the safe operation of these facilities and reduce uncontrolled releases of natural gas into the atmosphere.

7.7.5 Significant Research Activities

PHMSA awarded an SBIR Phase 1 project in FY 2022 to Oceanit Laboratories, Inc. entitled "Smart Well Assessment and Reservoir Management System (SWARMS)."[35] The project will model and test the plugging of gaps within geologic and physical systems by injecting microparticles. The project may receive a SBIR Phase 2 award contingent on the success of the Phase 1 project and available funding at that time.

Picture Courtesy: Asset Optimization

[35] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=975

7.8 Research Focus Area 8: Climate Change Solutions/Hydrogen/CO_2

7.8.1 Overview

Activities under this focus area will address methods for improving the safety of hydrogen, a growing alternative fuel source, and carbon dioxide (CO_2) transportation via pipeline, which is required for carbon capture initiatives, to support the Administration's goals for climate solutions and decarbonization. The ability to safely transport these commodities by pipeline will support widespread movement of CO_2 from capture to storage and allow hydrogen to be more widely utilized in lieu of natural gas as a fuel. Research activities will assess the suitability of current natural gas pipeline infrastructure for the future transportation of pure hydrogen gas or blended hydrogen with natural gas. Research will also address the safe deployment of new pipelines and facilities needed to fill any new demand for these fuels.

The research will provide an understanding of potential changes to material properties due to exposure to hydrogen, such as hydrogen embrittlement, changes to fatigue crack growth rate, and changes to material toughness, and their potential safety impacts. In addition, this research will address required pipeline modifications to existing infrastructure and potential design modifications for new pipelines ensure pipeline integrity.

Also, given the increase in and new federal incentives for the use of carbon capture technologies, research activities will also address the potential safety impacts of the transportation of supercritical carbon dioxide,[36] as well as any other pertinent phases of carbon dioxide, via pipeline. Both research areas will contribute to pipeline safety and failure consequence knowledge as the U.S. increases its lower carbon energy portfolio.

Table 21 summarizes the investment history for this research focus area from 2002 through September 2022. This represents the initial investment into climate change challenges so future knowledge and technology transfer will be recorded at a later time. This investment will support the safe transportation of hydrogen and CO_2 by pipelines.

Table 21: Investment and Success History

Awarded Projects	PHMSA Funding	U.S./Other Patent Activity (Applied/Granted)	Technology Transfer
8	**$7.3 M**	**0/0**	**0**

PHMSA's annual report data for 2021 shows a total of just over 5,300 miles of supercritical (fluid) carbon dioxide pipelines and just over 1,500 miles of hydrogen gas transmission pipelines in the U.S.

From 2012 to 2021, there were 56 accidents on CO_2 pipelines with no fatalities or injuries requiring in-patient hospitalization. The relatively large and high visibility 2020 Denbury Gulf Coast Pipeline's CO_2 accident in Satartia, Mississippi resulted in 45 individuals going to the hospital–all of whom were treated and released. On May 26, 2022, as a result of PHMSA's

[36] Carbon dioxide held above its critical temperature and pressure.

investigation into the CO_2 pipeline failure in Satartia, PHMSA announced that it would work to strengthen CO_2 pipeline safety.[37] Activities include initiating a new rulemaking to update standards for CO_2 pipelines, and requirements related to emergency preparedness and response, as well as pursuing research to strengthen the safety of CO_2 pipelines.

Since 2010, there have been a total of five reportable incidents on hydrogen gas pipelines, none of which involved injuries or fatalities.

7.8.2 Department Strategic Alignment

To support PHMSA's pipeline safety mission and to support Administration goals regarding climate change mitigation and decarbonization, PHMSA is planning to establish comprehensive regulatory programs for the safe transportation of carbon dioxide and gaseous hydrogen by pipeline, including new, repurposed, and converted service pipelines. Research in this area will help inform the development of updated regulations.

7.8.3 Short-Term Goal

The 2021 Environmental Protection Agency (EPA) Inventory of U.S. Greenhouse Gas Emissions and Sinks data reports that natural gas transmission and distribution pipelines account for 23 percent of total methane emissions, while LNG and UNGS account for 9 percent.[38] Significant research investments at the federal and international level have been conducted on alternative renewable fuels including hydrogen and/or hydrogen blends. PHMSA will help to address climate change by funding research projects that could reduce methane emissions on its regulated infrastructure, which will be done in coordination with its stakeholders and interagency partners. PHMSA plans to identify research gaps for hydrogen gas and/or various hydrogen blends in natural gas pipeline facilities. These include gas transmission or gas distribution systems, compressor stations, and gas storage facilities reflecting current projections for future pipeline systems and storage use.

7.8.4 Long-Term Goal

PHMSA will continue to invest in research initiatives to promote the Administration's strategic goals related to climate change solutions and decarbonization. Research outputs would provide solutions to safely store hydrogen gas and/or hydrogen gas blended with natural gas in underground storage facilities and determine practical methods to optimize or repurpose existing pipeline networks to safely transport pure hydrogen or hydrogen-blends. Additional research outputs would provide knowledge on the impact of hydrogen and hydrogen-blend concentrations on inline inspection tools to characterize the integrity of an operator's pipeline system. Research outcomes in this focus area will work to remove technical and safety barriers to transporting emerging fuels, such as hydrogen, by pipelines. Hydrogen can serve as a sustainable power generating fuel and could reduce GHG emissions by blending hydrogen into natural gas pipelines. Impacts from research investments in this focus area would expand the development and safe transportation by pipeline of gaseous hydrogen and supercritical carbon dioxide. Both are integral to increasing the production of green hydrogen, which is developed

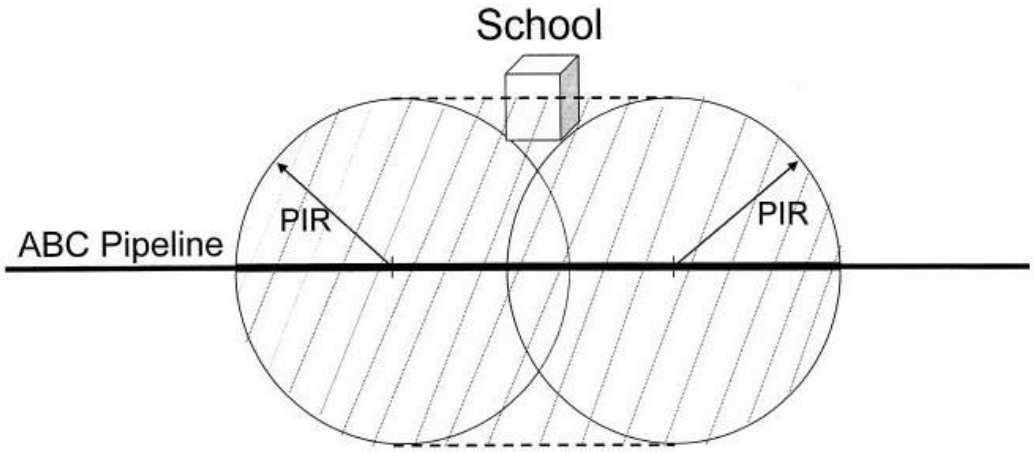
[37] https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures

[38] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

from renewable fuels, and blue hydrogen, where the climate impact is decreased through carbon dioxide capture and storage or utilization.

7.8.5 Significant Research Activities

In FY 2022, PHMSA invested in climate change research addressing both hydrogen and CO_2 related challenges. One research topic addresses the "Determination of Potential Impact Radius for CO_2 Pipelines." The research will establish a computation fluid dynamics model to simulate the release and dispersion of supercritical CO_2 from pipeline ruptures. It will also develop a rapid, universally applicable tool to assess the consequences of accidental CO_2 dispersion from high-pressure pipelines. This type of research is important to develop an understanding of the potential health and safety implications of a rupture from a CO_2 pipeline as activities, such as carbon capture, and the need to transport CO_2 by pipeline becomes more common.



Picture Courtesy: 49 CFR § 192.903

8. Collaborative Partnerships and Stakeholder Engagement

8.1 Collaborative Partnerships

Partnerships with government organizations (GOs) and non-government organizations (NGOs) provide clear opportunities to leverage ongoing successes, co-fund research on mutual safety challenges, and remove duplication. Throughout the year, PHMSA shares information with trade associations, public advocacy groups, academia, the pipeline industry, and pipeline service providers on its research programs and consults with subject matter experts from these organizations on focused projects and topics. **Table 22** identifies both GO and NGO research partners that collaborate and co-fund research with PHMSA.

In March 2019, PHMSA released an ongoing special notice titled, "Identifying Pipeline Safety Research Ideas," in the Federal Business Opportunities (FBOs) portal that is open year-round and now posted on SAM.gov. This special notice, which is revised as needed to reflect new PHMSA or Administration safety initiatives, invites stakeholders to submit ideas for future research. A web-based portal was also created to support and manage this effort.[39]

[39] https://primis.phmsa.dot.gov/rd/gapsuggestions.htm

Table 22: Collaborative Partnerships

Organization Name	GO	NGO
American Gas Association (AGA)		X
American Petroleum Institute (API)		X
American Public Gas Association (APGA)		X
American Society of Mechanical Engineers (ASME)		X
California Energy Commission (CEC)	X	
Canada Energy Regulator (CER)	X	
Environmental Defense Fund (EDF)		X
United Kingdom Health and Safety Executive (HSE)	X	
Interstate Natural Gas Association of America (INGAA)		X
Liquid Energy Pipeline Association (LEPE)		X
National Association of Corrosion Engineers (NACE) International		X
National Association of Pipeline Safety Representatives (NAPSR)	X	
National Fire Protection Association (NFPA)		X
Northeast Gas Association (NGA)/NYSEARCH		X
Operations Technology Development (OTD)		X
Pipeline Research Council International (PRCI)		X
Pipeline Safety Trust (PST)		X
U.S. Department of Agriculture (USDA)	X	
U.S. Department of Commerce (DOC) – National Institute of Standards and Technology (NIST)	X	
U.S. Department of Energy (DOE)*	X	
U.S. Department of the Interior (DOI) Bureau of Safety and Environmental Enforcement (BSEE)	X	
U.S. Environmental Protection Agency (EPA)	X	

*Includes multiple DOE agencies and labs.

8.1 Engagement

PHMSA remains focused on collaborating with stakeholders to improve data transparency and remove research duplication. PHMSA engages academia, industry, states, and other federal partners to fund and co-fund critical research that develops new technology, products, and knowledge to improve pipeline safety and protect the environment.

PHMSA interacts with hundreds of public and private stakeholders through R&D forums to identify safety gaps and generate research topics. This process creates stakeholder-based support for federal investment on nationally recognized pipeline safety challenges.

PHMSA has a responsibility to continually communicate, in a transparent manner, with the public and its stakeholders. Communication efforts are performed through public meetings, requests for comments, website publications, and conferences with the goals to advance technological solutions and knowledge that improve the overall safety and reliability of pipeline systems. PHMSA's research is published in the DOT Research Hub and Digital Library.[40]

[40] https://researchhub.bts.gov

Additionally, projects that have successfully led to product commercialization are available to the public on PHMSA's Technology Research & Development: Success Stories webpage.[41] PHMSA will continue to collaborate with its partners and stakeholders to promote transparency and collaboration between government and the public.

In March 2019, PHMSA's Office of Pipeline Safety sought to expand stakeholder engagement in general by releasing a Special Notice for "Identifying Pipeline Safety Research Ideas" in the beta.SAM.gov portal. The Special Notice invites any interested stakeholder to submit ideas for future research. This notice is open year-round and revised as needed to reflect initiatives from PHMSA or the Administration. PHMSA launched this measure to widen participation in formulating its future research strategy. A web-based portal was created to support and manage this action.[42]

8.2 Industry

PHMSA engages with a wide range of industry partners who share the same objectives in developing technology or generating and promoting new knowledge among decision makers to advance pipeline safety. Throughout a given year, research program staff attend meetings and conferences to provide information on PHMSA's R&D program and inform industry stakeholders on ongoing research efforts to ensure information and data are timely shared, particularly the research projects and potential technology and knowledge that can be used to meet or exceed regulatory safety requirements.

Presentations by researchers at the completion of their projects also target regulated companies, providing yet another pathway to the produced technology and knowledge.

8.3 Academia

As described earlier, PHMSA partners with academic institutions through CAAP. Academia has also participated in the Core research program either as the main recipient of R&D awards or as part of the research team when other organizations are awarded. PHMSA continues to explore ways to expand awareness of research opportunities.

Additionally, PHMSA is expanding its communication of CAAP funding opportunities to Minority Serving Institutions (MSIs), such as Historically Black Colleges and Universities (HBCUs); Hispanic-Serving Institutions (HSIs; and Asian-American, Native American, and Pacific Island-Serving Institutions (AANAPISIs) to ensure they are aware of opportunities.

On February 28, 2022, PHMSA issued its FY 2022 Notice of Funding Opportunity (NOFO) for CAAP through Grants.gov.[43] The NOFO closed on April 29, 2022, with PHMSA receiving 18 applications submitted by 12 applicants. None of the applicants were identified as being MSIs, HSIs, HBCUs or AANAPISIs even though PHMSA strongly encouraged universities to partner with MSIs in their grant proposals. PHMSA will continue to plan, assess, and execute strategies to increase research partnerships and collaboration with MSIs; increase awareness, capacity, and interest in pipeline safety research and careers; and introduce science, technology,

41 https://phmsa.dot.gov/research-and-development/pipeline/technology-success-stories

42 https://primis.phmsa.dot.gov/rd/gapsuggestions.htm

43 https://www.grants.gov/web/grants/search grants.html?keywords=Competitive%20Academic%20Agreement%20Program

engineering, and math (STEM) curriculum and learning through CAAP research partnerships. In March 2022, PHMSA conducted two informational sessions on CAAP with HBCUs and HSIs to encourage proposals for the FY 2022 CAAP NOFO.

8.4 Interagency

PHMSA frequently enters into IAAs with DOE, DOC, and DOI to conduct research. Beyond interaction within IAAs, periodic interagency coordination meetings are held to share information about interagency and other research activities. These meetings have directly led to increased interagency participation and collaboration for future IAAs. In FY 2021 and FY 2022, PHMSA participated in the following interagency hydrogen and carbon dioxide clean energy initiatives:

- **DOE**
  - Hydrogen and Fuel Cell Technologies Office
    - DOE's National Hydrogen Strategy and Roadmap
    - Clean Hydrogen Joint Undertaking Expert Workshop on Environmental Impacts of Hydrogen
  - Fossil Energy & Carbon Management
    - Division of Methane Mitigation Technologies
    - Division of Carbon Transport and Storage
- **U.S. Dept of Commerce/U.S.-India Strategic Partnership Forum**
- **PHMSA/NAPSR Gas Distribution Team and Hydrogen/Biofuels Working Group**

8.5 Other Stakeholders

PHMSA continuously monitors the pipeline sector for emerging issues, including seeking input and data from state pipeline safety offices, NGO stakeholder organizations, and pipeline technical committees. This information is vital to PHMSA for developing new or modifying current programs, research focus areas, and practices to increase efficiency and effectiveness of the R&D program. PHMSA outreach efforts include reaching out to other stakeholders, such as standards developing organizations (SDOs) and advocacy organizations (AOs).

Research solicitations (pre-award) and agreements (post-award) include requirements for researchers to include relevant SDOs on their Technical Advisory Panels (TAPs) for research projects. This requirement facilitates knowledge transfer and integration of the research results into standards. Several standards, some incorporated by reference in PHMSA's regulations, are directly informed by research results.

Ongoing coordination with AOs, such as with the PST and EDF, not only provides awareness of program and project activities, but also assists PHMSA's development of research topics and funding strategies. Participation also occurs by AOs in the pre-award review of submitted research proposals, which supports integrating diverse perspectives into how safety and environmental research is funded and executed.

9. Program Level Funding Summary: FY 2021

This section summarizes OPS's PSRP research awards obligated by program in FY 2021 utilizing appropriations from multiple fiscal years.

The PSRP's investments in FY 2021 were based on proposals received and available funding. The FY 2021 research topics were designed to provide solutions to strategic technical challenges and gaps affecting pipeline, UNGS, LNG, and breakout tank facilities while advancing the Administration's agenda on methane mitigation, emerging fuels, and equity.

PHMSA conducted a review of the FY 2021 annual plan comparing it to the implementation and execution of the FY 2021 annual research activities as shown in **Table 23**.

Table 23: FY 2021 Awards by Program Area

Research Program Area (Goal)	Planned	Awarded
Preventing Pipeline Threats/Damage	$1,300,000	$6,061,737
Leak Detection	1,255,000	-
Anomaly Detection and Characterization	1,545,000	2,698,211
Anomaly Remediation and Repair	-	998,447
Safety Systems for Liquefied Natural Gas Facilities	1,000,000	921,189
Design, Materials and Welding/Joining	-	873,320
Safety Systems for Underground Natural Gas Storage	900,000	788,594
Competitive Academic Agreement Program*	2,000,000	-
Transportation Technology Center	4,000,000	-
Total**:	$12,000,000	$12,341,498

*In FY 2021, PHMSA awarded $1,859,424 on three CAAP projects in the Research Focus Area on Preventing Pipeline Threats/Damages.
**FY 2021 research awards were obligated utilizing funding availability from FY 2019, FY 2020, and FY 2021 appropriations.

10. Research Activity Level Objectives and Outputs: FY 2021

This section identifies PHMSA's safety goals for each research project to address various programmatic elements, describes each project's objectives to meet those goals on providing solutions to improve pipeline safety and the protection of the environment. For FY 2021, PHMSA's goals include six of the eight focus areas, as described in **Section 7**.

Goal

Preventing Pipeline Threats/Damage ($6,061,737)

Objective 1a: Development and Validation of a Probabilistic Method for Estimating Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines (Core: $1,437,508)

The project will develop an estimate of the reserve strain capacity of a steel pipeline and a set of recommended interventions for mitigating situations where it is determined that there is insufficient strain reserve, lack of data, and/or inconsistency in the modeling process. The models will combine historic and new data with interacting threat models that address knowledge gaps in estimating compressive buckling and tensile overload risks that will be prioritized for intervention.

Objective 1b: Design and Placement of Compact Gas Service Regulators (Core: $383,725)

The project will review current regulatory requirements and evaluate vent limiting gas regulators to develop guidelines and recommendations on how these regulators can be installed outside where limited space exists. This project will allow the design solution to meet regulatory requirements and addresses National Transportation Safety Board recommendations. It is uncertain if regulatory changes will be required based on this work.

Objective 1c: Development of Corrosion/Erosion Threat Assessment Methodologies and Enriched Preventive and Mitigative Measures to Promote Safety of Gas Gathering Pipelines (Core: $377,830)

The project will develop a unified method to assess the likelihood and severity of corrosion/erosion damage and provide enriched preventative and mitigative measures for corrosion/erosion prevention and mitigation. These measures will provide a tool for operators to better predict and prevent future failures resulting from internal corrosion and erosion pipeline threats.

Objective 1d: Knowledge-guided Automation for Integrity Management of Aging Pipelines (KAI-MAP) for Hydrogen Transport (CAAP: $844,726)

The main objective of this project is to develop an artificial intelligence (AI) framework for pipeline integrity management for emerging fuels, such as hydrogen. The AI framework will include data entry algorithms to collect pipeline safety information from relevant sources, machine learning models to process pipeline inspection data, and a data quality assurance framework to reflect pipeline conditions more accurately. Arizona State University has partnered with GTI, Edison Welding Institute (EWI), and Pipeline Research Council International (PRCI) to form a TAP. The TAP will provide guidance to ensure the feasibility and suitability of the proposed research, share available databases with the university, and provide feedback and evaluation.

Objective 1e: Pipeline Risk Management Using Artificial Intelligence-Enabled Modeling and Decision Making (CAAP: $349,328)

The main objective of this project is to develop AI-enabled tools to improve accuracy of probabilistic performance modeling. Furthermore, the tools will support decision-making of inspection and repair actions in pipeline risk management. The researcher will develop the AI tools by identifying connections between pipeline safety datasets through machine learning approaches. Rutgers has partnered with Public Service Electric and Gas, a natural gas operator, and Burns & McDonnell, pipeline service consultant, to provide pipeline safety expertise.

Objective 1f: Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity (CAAP: $665,370)

The project's objective is to investigate the feasibility of using distributed fiber-optic sensing cables, specifically, the sensing cable's distributed acoustic sensing (DAS) capabilities to detect and locate pipeline integrity risks based on vibration. Furthermore, the feasibility study will consider the effectiveness and robustness of using different cable deployment methods, especially easily deployed cables inside the pipeline. This research effort will

focus on internal cables, rather than the cost prohibitive installation of externally mounted cables, which would require significant excavation. The researcher will test the capabilities of the internal cables alongside two externally mounted cables for reference.

Objective 1g: Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard (SBIR: $991,124)

This SBIR Phase 2 project will develop and test materials and techniques for cost-effective, secure, and permanent attachment of sensors to pipelines. The researcher will work with domestic fiber-optic cable companies to manufacture a tightly coupled fiber-optic cable with a predicted lifetime over 30 years that accurately measures strain, temperature, and acoustics on pipelines.

Objective 1h: Detection of Buried Plastic Pipelines (IAA: $504,126)

This project under the IAA with the National Energy Technology Laboratory will identify/develop methods that can locate buried plastic distribution pipelines and predict subsurface position and depth from the surface. The initial results will be based on a review of commercially available technology to identify what new technology can be developed to advance the state of surface detection. Further investment will then be considered to develop new technology.

Objective 1i: Ensuring Oil and Gas Pipeline Safety Following a Geomagnetic Disturbance event Pipeline Safety Research Project (IAA: $508,000)

U.S. oil and gas pipelines (OGPs) are potentially vulnerable to a geomagnetic disturbance (GMD). This project under the IAA with Sandia National Laboratories is intended to evaluate the ability of OGPs and associated infrastructure to maintain a safe state and, if needed, to safely shut down following a GMD event. GMD vulnerability assessments (VAs) of OGPs will be conducted to evaluate initial response actions as well as the potential long-term loss of power due to both types of electromagnetic disturbances. This project will support GMD VAs for PHMSA in response to Executive Order (EO) 13865 “Coordinating National Resilience to Electromagnetic Pulses.”

Table 24: Research Project Outputs (Objective 1)

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Objective 1a: Development and Validation of a Probabilistic Method for Estimating Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines						
Output 1: Estimate the current strain state of a pipeline.	Gas Technology Institute (GTI)		X			

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 2: Fuse current strain state with information pertaining to steel composition, pipe manufacturing process, installation methods, geologic, thermal, and operating history in the context of strain accumulation.	GTI		X			
Output 3: Measure strain as it accumulates over time.	GTI		X	X	X	
Output 4: Merge current state of threats acting on the pipeline with knowledge of the current strain state to estimate the expected value of segment risk with credible bounds for estimating.	GTI		X	X	X	
Output 5: Combine the previous outputs to develop a risk assessment model for a pipeline segment given its strain history and anticipated future ground-movement threats as well as associated documentation and dissemination workshops. Develop a final report that will detail the project with a description of the results.	GTI				X	
Objective 1b: Design and Placement of Compact Service Regulators						
Output 1: Initial kickoff and project scoping with PHMSA, GTI, and the TAP	GTI		X			

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 2: Conduct a product search of regulators with vent limiting capabilities currently available in the U.S. market and generate an associated report.	GTI		X			
Output 3: Identify and review service regulator installation procedure documentation provided by manufacturers and clearance requirements by governing bodies, various standards, and gas utilities.	GTI		X			
Output 4: Evaluate regulators focusing on both the volume of gas emitted from the regulator vent and the concentration and dispersion of methane at various distances from the vent port.	GTI			X		
Output 5: Develop best practice guidelines using the data generated from the previous output.	GTI			X		
Output 6: Develop a final report that will detail the project with a description of the results.	GTI			X		
Objective 1c: Development of Corrosion/Erosion Threat Assessment Methodologies and Enriched Preventive and Mitigative Measures to Promote Safety of Gas Gathering Pipelines						

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 1: Report detailing root causes and interacting mechanisms, as well as critical factors affecting the likelihood and severity of corrosion/erosion damage in gas gathering pipelines.	North Dakota State University (NDSU)		X			
Output 2: Report detailing knowledge gaps for corrosion/erosion assessment methodologies and best practices of measures used in the pipeline industry.	NDSU		X			
Output 3: Investigate mechanisms of corrosion, erosion, and corrosion-erosion interaction behaviors in gathering pipelines using integrated experimental, simulation, and analytical methods.	NDSU			X		
Output 4: Develop and implement a Bayesian-based probabilistic assessment method to assess likelihood and severity of corrosion/erosion damage.	NDSU			X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 5: Develop enriched preventive and mitigative measures for corrosion, erosion, and interacting corrosion/erosion threats. Develop a final report that will detail the project with a description of the results.	NDSU			X		
Objective 1d: Knowledge-guided Automation for Integrity Management of Aging Pipelines (KAI-MAP) for Hydrogen Transport						
Output 1: Develop an algorithm to extract useful information from historical data using AI-automated techniques to understand the risk of common failure modes as well as the potential risk of hydrogen transportation.	Arizona State University (ASU)		X	X		
Output 2: Develop a transfer learning technique to understand the temporal failure dynamic of the reuse of existing gas pipelines for the transportation of hydrogen.	ASU			X	X	
Output 3: Develop non-destructive environment/in-line investigation methodologies aided with a deep learning framework to provide a platform for real-time inspection of pipelines where hydrogen is transported.	ASU		X	X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 4: Apply machine learning as an automated method for data analysis.	ASU			X	X	
Output 5: Perform data quality assurance to ensure that the collected data can represent the pipeline condition accurately and effectively.	ASU		X	X	X	
Output 6: Develop a risk-based maintenance optimization framework to support the decision making on pipeline integrity management using data collected from the previous tasks. Develop a final report that will detail the project with a description of the results.	ASU				X	
Objective 1e: Pipeline Risk Management Using Artificial Intelligence-Enabled Modeling and Decision Making						
Output 1: Perform literature review on topics related to the research.	Rutgers University		X			
Output 2: Collect field inspection records from direct assessment, in-line investigation, and indirect survey/examination data from existing literature and industry partners for data analytics.	Rutgers University		X			
Output 3: Develop data-driven probabilistic modeling of pipeline defect generation and growth.	Rutgers University		X	X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 4: Quantify failure probability using reliability analysis for different pipeline failure modes based on pipeline degradation.	Rutgers University			X	X	
Output 5: Incorporate AI-based reinforcement learning for pipeline maintenance planning while ensuring a certain level of reliability in pipeline risk management.	Rutgers University				X	
Output 6: Develop a final report that will detail the project with a description of the results. Disseminate research findings at related pipeline conferences and PHMSA R&D forum.	Rutgers University				X	
Objective 1f: Easy Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity						
Output 1: Investigate and report the capability of DAS to identify liquid accumulation spots in a pipeline and its sensitivity for different deployment methods.	Colorado School of Mines (CSM)		X			
Output 2: Investigate and report the capability of DAS to identify and characterize the dynamic behavior of intermittent structures in a gas-dominant slightly inclined pipeline.	CSM			X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 3: Investigate and report the detectability of DAS for internal corrosion with various cable deployment methods under four different pipeline installation conditions.	CSM		X	X		
Output 4: Investigate and report the capability of DAS to identify and locate dents using vortex detection and beamforming methods.	CSM			X		
Output 5: Investigate and report the capability of DAS to monitor infrastructure damage.	CSM			X	X	
Output 6: Develop a final report that will detail the project with a description of the results.	CSM				X	
Objective 1g: Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard						
Output 1: Perform material and equipment research.	Paulsson, Inc.		X			
Output 2: Design, acquire, and perform functionality test on prototype fiber optic cables for strain, temperature, and acoustic monitoring for pipelines using 20-ft metal strips. Manufacture optical strain, temperature, and acoustic cables for vibrational sensors for large scale laboratory testing at DOE and industry labs. Provide a	Paulsson, Inc.		X			

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
summary report of test results.						
Output 3: Conduct strain, temperature, acoustic, and leak tests on pipeline samples. Manufacture field optical sensor systems. Provide a summary report of test results.	Paulsson, Inc.		X	X		
Output 4: Install fiber optic cable on pipeline and monitor for a period of nine months. Process data and issue a summary report on pipeline sensing system results.	Paulsson, Inc.			X		
Output 5: Develop a final report that will detail the project with a description of the results.	Paulsson, Inc.			X		
Objective 1h: Detection of Buried Plastic Pipelines						
Output 1: Perform a technical analysis of how different tunnel detection techniques may be scaled to detect buried plastic piping incorporating various models, methods, and costs.	National Energy Technology Lab (NETL)		X	X		
Output 2: Develop and field test down-selected methods for locating plastic pipes.	NETL		X	X		
Output 3: Introduce best performing technologies to regulators and the private sector.	NETL			X		
Output 4: Develop a final report that will detail the	NETL			X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
project with a description of the results.						
Objective 1i: Ensuring Oil and Gas Pipeline Safety Following a Geomagnetic Disturbance event Pipeline Safety Research Project						
Output 1: Determine the critical components of subsystems vulnerable to a GMD or an electromagnetic pulse (EMP).	Sandia National Labs		X			
Output 2: Develop coupling methods and perform coupling calculations to estimate GMD and EMP environments as seen at components to determine impacts to pipelines from GMD and EMP events. Provide memos and supporting documentation detailing results.	Sandia National Labs		X			
Output 3: Develop a final report that will detail the project with a description of the results.	Sandia National Labs		X			

Goal

Improving Anomaly Detection and Characterization ($2,698,211)

Objective 2a: Assessment of Nondestructive Examination (NDE) and Condition Monitoring Technologies for Defect Detection in Non-Metallic Pipe (Core: $728,450)

The objective of the program is to quantify the ability of several NDE methods for detecting, sizing, and characterization of defects, damage, and anomalies that may occur in non-metallic pipe (NMP), and to characterize the erosion performance of the inner liners and the potential to detect liner erosion wall loss externally. This program will develop critically important guidance on methods to quantify the condition of NMP for use as a manufacturing plant quality-control tool and field inspection tool.

Objective 2b: Robust, Field-Ready, Inline Tool for the Accurate Measurement of Pipe Bending Stresses and Crack Detection (SBIR: $984,396)

This SBIR Phase 2 project will demonstrate a developed prototype, evaluate its performance in several representative environments, and ready sensors for robotic platform integration. Ultimately, the sensor platform will comprise key components of a comprehensive ILI system capable of identifying bending stresses, something currently not achievable with current technology.

Objective 2c: Meandering Winding Magnetometer Array Bending Stress and Crack Detection In-Line Inspection Module (SBIR: $985,365)

This SBIR Phase 2 project will improve upon the prior Phase 1 project success with a focus on improving the use of directional magnetic steel permeability measurements to estimate strains in the pipe (with a focus on bending strains). The improvement will be independent of temperature, magnetization, and other error sources. At the end of the project, the bending load and crack detection capabilities will be demonstrated using JENTEK's 12-inch diameter prototype in-line inspection tool.

Table 25: Research Project Outputs (Objective 1)

Output	Collaborator	Fiscal Year					
		2021	2022	2023	2024	2025	2026
Objective 2a: Assessment of Nondestructive Examination (NDE) and Condition Monitoring Technologies for Defect Detection in Non-Metallic Pipe							
Output 1: Task report summarizing the outcome of a literature review.	Edison Welding Institute (EWI)		X				
Output 2: Develop a comprehensive pipe sample matrix.	EWI		X				
Output 3: Develop a set of laboratory NDE procedures for use in the project.	EWI		X				
Output 4: Task report summarizing the results of the NDE trials.	EWI		X	X			
Output 5: Task report documenting detection and sizing performance of each NDE method for the various defects and damage mechanisms.	EWI			X			
Output 6: Task report documenting erosion performance and detection of erosion.	EWI		X	X			

Output	Collaborator	Fiscal Year					
		2021	2022	2023	2024	2025	2026
Output 7: Develop a guidance document for performing in-plant inspections.	EWI			X			
Output 8: Develop a guidance document outlining requirements for field inspection.	EWI			X			
Output 9: Conduct a virtual training seminar presenting the results of the program.	EWI			X			
Output 10: Develop a final report that will detail the project with a description of the results.	EWI			X	X		
Objective 2b: Robust, Field-Ready, Inline Tool for the Accurate Measurement of Pipe Bending Stresses and Crack Detection							
Output 1: Develop prototype devices.	Creare, LLC		X	X			
Output 2: Perform system testing and validation.	Creare, LLC		X	X			
Output 3: Performing a pilot study evaluating device inline performance.	Creare, LLC			X			
Output 4: Lay foundations for technology transition.	Creare, LLC			X			
Output 5: Develop plan and design for the next generation prototype.	Creare, LLC			X			
Output 6: Develop a final report that will detail the project with a description of the results.	Creare, LLC		X	X			
Objective 2c: Meandering Winding Magnetometer Array Bending Stress and Crack Detection In-Line Inspection Module							
Output 1: Develop requirements for the Phase 2 and final deployment of the inspection module.	JENTEK Sensors, Inc.		X				
Output 2: Obtain and/or fabricate samples to support testing and demonstration of the inspection module.	JENTEK Sensors, Inc.		X				
Output 3: Fabricate sensors for use in the inspection module.	JENTEK Sensors, Inc.		X				

Output	Collaborator	Fiscal Year					
		2021	2022	2023	2024	2025	2026
Output 4: Perform benchmarking testing for circumferential crack detection.	JENTEK Sensors, Inc.		X				
Output 5: Improve the bending load estimation algorithm that converts magnetic permeability estimates into bending load estimates.	JENTEK Sensors, Inc.		X				
Output 6: Upgrade the 6-inch bend facility to allow for continued testing using tools developed during SBIR Phase 1 of this project.	JENTEK Sensors, Inc.		X				
Output 7: Build the 12-inch pipe bend and pull test facility to test the 12-inch inspection module.	JENTEK Sensors, Inc.			X			
Output 8: Performing demonstrations of bending stress estimation.	JENTEK Sensors, Inc.			X			
Output 9: Develop a transition plan to transition the technology into a commercially available tool.	JENTEK Sensors, Inc.			X			
Output 10: Develop a final report that will detail the project with a description of the results.	JENTEK Sensors, Inc.			X			

Goal

Improving Anomaly Remediation and Repair ($998,447) Objective 3a: No-Dig Point Repair Technology for Steel Oil & Gas Pipelines (SBIR: $998,447)

This SBIR Phase 2 project will conduct a pilot installation in a steel gas transmission pipe. To meet that objective the following tasks will be implemented: 1) deploy the repair system with a customized pipe crawler and packer in an experimental pipe setup; 2) conduct third-party pressure tests on steel pipes with various defects repaired with the composite material; 3) improve the design method per the test results and computation modeling; and 4) develop a commercialization strategy.

Goal

Improving Safety Systems for Liquefied Natural Gas Facilities ($921,189)

Objective 4a: Developing Performance Criteria for External Loading Factors on External Steel Shell Tanks (Core: $424,429)

The project will evaluate external steel-shell tanks subject to external and internal accidental loads, and resistance of external steel tanks to blast loads, fire, radiation, flame impingement, and projectiles. These hazards have not been studied in detail for LNG tank applications with outer steel tank walls. The project will provide mitigation recommendations for external steel tanks to ensure the designs are comparable to concrete secondary containment and provide adequate protection. Gaps in current LNG tank design will be identified and mitigation recommendations provided.

Objective 4b: Liquefied Natural Gas Tanks Without Bottom Fill (Core: $331,760)

The project will evaluate the operation of LNG tanks without bottom fill capabilities and determine the process means that will allow such operation to be performed safely. The safety evaluation of tanks without bottom fill will be performed using computational fluid dynamics tools and will be demonstrated separately for two case studies consistent with typical U.S. LNG tank installations. The output will provide new knowledge on the integrity challenges and guidelines for safe operations for these tank configurations.

Objective 4c: Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks (Core: $165,000)

The project will outline the current best practices associated with inspection and testing to ensure the integrity of aboveground cryogenic storage tanks. It will produce recommendations on inspection strategies for these tanks, which may also identify requirements for new technological solutions. The project will organize the information in a useful format, allowing tank owners, operators, and industry organizations to use this information to reduce the potential for incidents through inspection and testing.

Table 26: Research Project Outputs (Objective 1)

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Objective 1a: Development and Validation of a Probabilistic Method for Estimating Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines						
Output 1: Estimate the current strain state of a pipeline.	Gas Technology Institute (GTI)		X			

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 2: Fuse current strain state with information pertaining to steel composition, pipe manufacturing process, installation methods, geologic, thermal, and operating history in the context of strain accumulation.	GTI		X			
Output 3: Measure strain as it accumulates over time.	GTI		X	X	X	
Output 4: Merge current state of threats acting on the pipeline with knowledge of the current strain state to estimate the expected value of segment risk with credible bounds for estimating.	GTI		X	X	X	
Output 5: Combine the previous outputs to develop a risk assessment model for a pipeline segment given its strain history and anticipated future ground-movement threats as well as associated documentation and dissemination workshops. Develop a final report that will detail the project with a description of the results.	GTI				X	
Objective 1b: Design and Placement of Compact Service Regulators						
Output 1: Initial kickoff and project scoping with PHMSA, GTI, and the TAP	GTI		X			
Output 2: Conduct a product search of regulators with vent limiting capabilities currently available in the U.S. market and generate an associated report.	GTI		X			
Output 3: Identify and review service regulator installation procedure documentation provided by manufacturers and clearance requirements by governing bodies, various standards, and gas utilities.	GTI		X			
Output 4: Evaluate regulators focusing on both the volume of gas emitted from the regulator vent and the concentration and dispersion of methane at various distances from the vent port.	GTI			X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 5: Develop best practice guidelines using the data generated from the previous output.	GTI			X		
Output 6: Develop a final report that will detail the project with a description of the results.	GTI			X		
Objective 1c: Development of Corrosion/Erosion Threat Assessment Methodologies and Enriched Preventive and Mitigative Measures to Promote Safety of Gas Gathering Pipelines						
Output 1: Report detailing root causes and interacting mechanisms, as well as critical factors affecting the likelihood and severity of corrosion/erosion damage in gas gathering pipelines.	North Dakota State University (NDSU)		X			
Output 2: Report detailing knowledge gaps for corrosion/erosion assessment methodologies and best practices of measures used in the pipeline industry.	NDSU		X			
Output 3: Investigate mechanisms of corrosion, erosion, and corrosion-erosion interaction behaviors in gathering pipelines using integrated experimental, simulation, and analytical methods.	NDSU			X		
Output 4: Develop and implement a Bayesian-based probabilistic assessment method to assess likelihood and severity of corrosion/erosion damage.	NDSU			X		
Output 5: Develop enriched preventive and mitigative measures for corrosion, erosion, and interacting corrosion/erosion threats. Develop a final report that will detail the project with a description of the results.	NDSU			X		
Objective 1d: Knowledge-guided Automation for Integrity Management of Aging Pipelines (KAI-MAP) for Hydrogen Transport						
Output 1: Develop an algorithm to extract useful information from historical data using AI-automated techniques to understand the risk of common failure modes as well as the potential risk of hydrogen transportation.	Arizona State University (ASU)		X	X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 2: Develop a transfer learning technique to understand the temporal failure dynamic of the reuse of existing gas pipelines for the transportation of hydrogen.	ASU			X	X	
Output 3: Develop non-destructive environment/in-line investigation methodologies aided with a deep learning framework to provide a platform for real-time inspection of pipelines where hydrogen is transported.	ASU		X	X		
Output 4: Apply machine learning as an automated method for data analysis.	ASU			X	X	
Output 5: Perform data quality assurance to ensure that the collected data can represent the pipeline condition accurately and effectively.	ASU		X	X	X	
Output 6: Develop a risk-based maintenance optimization framework to support the decision making on pipeline integrity management using data collected from the previous tasks. Develop a final report that will detail the project with a description of the results.	ASU				X	
Objective 1e: Pipeline Risk Management Using Artificial Intelligence-Enabled Modeling and Decision Making						
Output 1: Perform literature review on topics related to the research.	Rutgers University		X			
Output 2: Collect field inspection records from direct assessment, in-line investigation, and indirect survey/examination data from existing literature and industry partners for data analytics.	Rutgers University		X			
Output 3: Develop data-driven probabilistic modeling of pipeline defect generation and growth.	Rutgers University		X	X		
Output 4: Quantify failure probability using reliability analysis for different pipeline failure modes based on pipeline degradation.	Rutgers University			X	X	

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 5: Incorporate AI-based reinforcement learning for pipeline maintenance planning while ensuring a certain level of reliability in pipeline risk management.	Rutgers University				X	
Output 6: Develop a final report that will detail the project with a description of the results. Disseminate research findings at related pipeline conferences and PHMSA R&D forum.	Rutgers University				X	
Output 1: Investigate and report the capability of DAS to identify liquid accumulation spots in a pipeline and its sensitivity for different deployment methods.	Colorado School of Mines (CSM)		X			
Output 2: Investigate and report the capability of DAS to identify and characterize the dynamic behavior of intermittent structures in a gas-dominant slightly inclined pipeline.	CSM			X		
Output 3: Investigate and report the detectability of DAS for internal corrosion with various cable deployment methods under four different pipeline installation conditions.	CSM		X	X		
Output 4: Investigate and report the capability of DAS to identify and locate dents using vortex detection and beamforming methods.	CSM			X		
Output 5: Investigate and report the capability of DAS to monitor infrastructure damage.	CSM			X	X	
Output 6: Develop a final report that will detail the project with a description of the results.	CSM				X	
Objective 1g: Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard						
Output 1: Perform material and equipment research.	Paulsson, Inc.		X			
Output 2: Design, acquire, and perform functionality test on prototype fiber optic cables for strain, temperature, and acoustic monitoring for pipelines using	Paulsson, Inc.		X			

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
20-ft metal strips. Manufacture optical strain, temperature, and acoustic cables for vibrational sensors for large scale laboratory testing at NREL and ADV. Provide a summary report of test results.						
Output 3: Conduct strain, temperature, acoustic, and leak tests on pipeline samples. Manufacture field optical sensor systems. Provide a summary report of test results.	Paulsson, Inc.		X	X		

Goal

Improving Design, Materials and Welding/Joining ($873,320)

Objective 5a: Feasibility of Using Alternative-Steel and Composite Material in Gas and Hazardous Liquid Pipeline Systems (Core: $873,320)

The project will establish design qualifications, requirements, inspection procedures, and a roadmap for using alternative steel and non-steel composite systems. As part of the scope, the project will review PHMSA's requirements under 49 CFR Parts 192 and 195 and the special permits issued under 49 CFR Part 190.341. This regulatory and special permit review will assist PHMSA and the industry's ability to develop engineering-based integrity inspection requirements that mitigate risk and support safe operations.

Table 27: Research Project Outputs (Objective 1)

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Objective 5a: Feasibility of Using Alternative-Steel and Composite Material in Gas and Hazardous Liquid Pipeline Systems						
Output 1: Perform evaluation of material properties and testing procedures.	GTI		X			
Output 2: Develop a design for maximum allowable operating pressure	GTI		X	X		
Output 3: Perform assessment of construction damage and quality assurance in trenchless and open trench installations.	GTI			X		
Output 4: Perform assessment of corrosion and erosion damage.	GTI			X		

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 5: Perform assessment of other integrity threats.	GTI			X		
Output 6: Evaluate the degradation of composite material properties due to varying service conditions.	GTI			X	X	
Output 7: Perform field inspection and monitoring for integrity management.	GTI				X	
Output 8: Review code requirements and map the existing CFR aspects and relevant American Society of Mechanical Engineers standards.	GTI				X	
Output 9: Develop a final report that will detail the project with a description of the results.	GTI				X	

Goal

Improving Safety Systems for Underground Natural Gas Storage ($788,594)

Objective 6a: Advancement of Through-Tubing Casing Inspection for Underground Storage Wells (Core: $788,594)

The project will review and test the capability and limitations of corrosion-logging technology used to inspect well casing through the production tubing used in UNGS wells. It will also develop a reliability-based assessment framework to better inform decision making about casing corrosion management.

Table 28: Research Project Outputs (Objective 1)

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Objective 6a: Advancement of Through-Tubing Casing Inspection for Underground Storage Wells						
Output 1: Perform engineering review and assessment.	Pipeline Research Council International (PRCI)		X			
Output 2: Perform logging tool development and testing.	PRCI		X	X	X	
Output 3: Develop a reliability-based assessment methodology.	PRCI			X	X	

Output	Collaborator	Fiscal Year				
		2021	2022	2023	2024	2025
Output 4: Perform field trial and demonstration.	PRCI			X	X	
Output 5: Develop a final report that will detail the project with a description of the results.	PRCI					X

11. Program Summary: FY 2022

OPS's RD&T FY 2022 initiatives are addressing ongoing safety and environmental risks and challenges. OPS's comprehensive research strategy into future fiscal years will be developed systematically through R&D forums, research gap ideas submitted by stakeholders, PHMSA initiatives, and collaborative partnerships with government and non-governmental organizations. OPS will coordinate and collaborate through workgroups, conferences, and meetings with international partners and other federal and state agencies.

11.1 Research Area Development

As described above, PHMSA uses its own pipeline data and the information gained from its Pipeline RD&T public forums to establish future fiscal year research funding agendas and solicitations. From November 30 to December 2, 2021, OPS hosted a virtual public meeting and forum to develop its PSRP agenda and identify research gaps and topics for research in FY 2022 and FY 2023 to address the Administration's strategic goals on *Safety* and *Climate and Sustainability* solutions. The goals of the RD&T public forum were to:

- Inform OPS's R&D agenda for the next two years.
- Elicit public feedback related to the repair, rehabilitation, and/or replacement of leak-prone and legacy pipelines and storage systems.
- Inform stakeholders and PHMSA of challenges and opportunities as the market transitions to newer fuels and begins to account for economic externalities.

Over 500 participants attended the forum, including several from Canada and the United Kingdom, and more than 60 presentations were given over three days. The public meeting and forum helped identify over 25 research gaps in the following areas:

- Repair, rehabilitation, or replacement of leak prone, legacy cast iron pipelines.
- Integrity of underground fuel storage, including hydrogen.
- Utilization of inspection tools and network components on hydrogen pipeline facilities.
- Integrity management of natural gas and hazardous liquid pipelines to include carbon dioxide lines.
- Methane mitigation from pipeline infrastructure.

PHMSA reviewed these gaps and prioritized them for research in FY 2022 and FY 2023. The PSRP's investments in FY 2022 were based on received proposals and available funding. For FY 2023, the PSRP will evaluate which research activities should be funded through PHMSA's Core Program, CAAP, SBIR, or an IAA.

11.2 Expected Outputs/Products

Research investments into pipeline, LNG, or UNGS-related challenges may result in analytical outcome publications, small-scale tests, and, in some cases, full-scale demonstration projects leading to new pipeline safety-improving technology and scientific methods. Final reports including each completed project's results are shared publicly on PHMSA's website and/or the National Transportation Library. Researchers also disseminate their findings through presentations and publications at conferences or in peer-reviewed journals. Completed technology development projects may result in new patents or products for commercialized adoption. PHMSA will continue tracking each project's performance using metrics that monitor the progress of the research and the readiness of the technology for commercial or government adoption.

From FY 2021 through June 2022, PHMSA invested in 7 projects developing new technologies ($5.9 M) and 12 projects promoting knowledge ($6.1 M) for decision-makers. The R&D investments in FY 2022 included a continued focus on pipeline safety, methane mitigation, UNGS facilities, and LNG facilities to reflect changes in the regulatory landscape and energy supply/demand. During FY 2022 to date, PHMSA's R&D investments have resulted in one patent application ($299 K), 31 published papers ($12.7 M), and three commercialized technologies ($1.5 M).

11.3 Core Research Program

A full and open competitive research announcement released in FY 2022 solicited proposals for thirteen research topics within the following safety priority areas:

- Rehabilitation of Aging Cast Iron Pipelines
- Underground Natural Gas/Hydrogen Storage
- Utilization of Inspection Tools on Hydrogen Pipelines
- Hydrogen Pipeline Network Components
- Methane/CO_2 Mitigation – Construction through Operations
- Breakout Tanks – Preventing Corrosion of Tank Bottoms
- LNG

OPS's FY 2022 Core Program focused on research and development consistent with Executive Order 13985, Advancing Racial Equity and Support for Underserved Communities Through the Federal Government and Executive Order 14008, Tackling the Climate Crisis at Home and Abroad.

OPS included and developed twelve specific research topics on pipeline safety and environmental challenges, as well as the Administration's key priorities, addressed in the 2021 RD&T public forum. The thirteenth topic regarding LNG was included as a second attempt to successfully fund research that was initially awarded in September 2021.[44] The initial funding was canceled at the awardee's request in January 2022. In FY 2022, OPS made multiple awards totaling $7.5 million.

[44] PHMSA Safety Research Announcement #693JK3211RA0001

The topics chosen for the research announcement were most suitably funded through the Core Program, as the research topics were at a more advanced stage of practical application and more likely to lead to the development of new technologies for commercialization.

Table 29: FY2022 Core Program Priorities, Awarded Amounts, and Project Durations

Core Program Safety Priority Area/Topic	Award Amount	Project Duration
Rehabilitation of Aging Cast Iron Pipelines		
Rapid Ultraviolet Cured Adhesive for Gas Main Cured-in-Place-Lining	$919 K	36 Months
Dynamic Geohazard Risk and Decision Support Platform	$398 K	25 Months
Risk-Based Decision Support for Rehabilitation of Natural Gas Distribution Pipelines	$400 K	36 Months
Underground Natural Gas/Hydrogen Storage		
Expanding Hydrogen Storage to Porous Rock Formations: A Framework for Estimating Feasibility & Operational Considerations	$298 K	24 Months
Utilization of Inspection Tools on Hydrogen Pipelines		
Review of Integrity Threat Characterization Resulting from Hydrogen Gas Pipeline Service	$240 K	24 Months
Hydrogen Pipeline Network Components		
Determining the Required Modifications to Safely Repurpose Existing Pipelines to Transport Pure Hydrogen and Hydrogen-Blends	$800 K	36 Months
Advancing Hydrogen Leak Detection and Quantification Technologies Compatible with Hydrogen Blends	$749 K	36 Months
Methane/CO_2 Mitigation – Construction through Operations		
Best Purging Practices for Minimizing Methane Emissions	$358 K	15 Months
Field Validation Demonstrations to Advance Pipeline Leak Detection Beyond Current Capabilities	$193 K	36 Months
Accelerating Pipeline Leak Detection Quantification Solutions Through Transparent and Rigorous Scientific Validation	$600 K	24 Months
Innovative Leak Detection Methods for Gas and Liquid Pipelines	$384 K	36 Months
Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2	$1.2 M	24 Months

Breakout Tanks – Preventing Corrosion of Tank Bottoms		
Developing Corrosion Control Monitoring Technology for Hazardous Liquid Breakout Tanks	$250 K	25 Months
Monitoring the Long-Term Compatibility of Vapor Corrosion Inhibitor (VCI) and Cathodic Protection (CP) Associated Components	$400 K	36 Months
LNG		
Determine the Maximum Permissible Temperature Drops for Steel when Exposed to Cryogenic Liquid	$350 K	15 Months
Total	**$7.5 M**	

11.4 Competitive Academic Agreement Program (CAAP)

CAAP awards funding to eligible entities, thereby generating research on new technologies and promoting commercialization of those technologies. Based on the availability of funds, PHMSA awarded $4.7 million in CAAP funding for FY 2022. The amount of federal funding did not exceed $1 million per award.

The competitive research announcement focused on the following topics:

Table 30: FY2022 CAAP Priorities, Awarded Amounts, and Project Durations

CAAP Safety Priority Area/Topic	Award Amount	Project Duration
Selection and Development of Safer Polymer and Composite Pipeline Liners through Microstructural and Macroscopic Study of Materials and Designs	$1 M	36 Months
All-in-One Multifunctional Cured-In-Place Structural Liner for Rehabilitating of Aging Cast Iron Pipelines	$1 M	36 Months
Development of Compatibility Assessment Model for Existing Pipelines for Handling Hydrogen-Containing Natural Gas	$1 M	36 Months
Accelerating Transition towards Sustainable, Precise, Reliable Hydrogen Infrastructure (Super-H_2): Holistic Risk Assessment, Mitigation Measures, and Decision Support Platforms	$1 M	36 Months
Performance Evaluation and Risk Assessment of Excessive Cathodic Protection on Vintage Pipeline Coatings	$513 K	36 Months
Determination of Potential Impact Radius for CO_2 Pipelines using Machine Learning Approach	$279 K	24 Months
Total	**$4.7 M**	

A summary of past CAAP awards may be found at: https://primis.phmsa.dot.gov/rd/UniversityPartners.htm.

CAAP offered special consideration to rural communities and projects located in Qualified Opportunity Zones designated pursuant to 26 U.S.C. § 1400Z-1. These cooperative agreement grants help fulfill the needs for promoting pipeline safety through developing and implementing advanced technologies in rural communities.

11.5 Small Business Innovative Research (SBIR)

The PSRP frequently participates in DOT's SBIR program to engage with small businesses who normally operate in sectors of the economy other than energy (i.e., such as medical and defense). In FY 2022, PSRP funded the following two Phase 1 projects. The focus of a Phase 1 project is to establish the technical merit, feasibility, and commercial potential of the proposed idea. If successful, the Phase 1 project may be further funded for a Phase 2 project, where the focus is to begin validating the proof of concept completed under the Phase 1 project. The first project is investigating how a Fiber-Optic Excavation Monitoring Sensor (FOCOS) system, based on phase-sensitive optical time-domain reflectometry, ML algorithms, and Internet of Things[45] communication can detect and locate threats and leaks along a pipeline. The second project is investigating an innovative approach for UNGS facilities to detect down hole leaks and methods to plug them via micro particles.

Table 31: FY2022 SBIR Program Priorities, Awarded Amounts, and Project Durations

SBIR Safety Priority Area/Topic	Award Amount	Project Duration
Fiber-Optic Excavation Monitoring Sensor (FOCOS) System	$149 K	6 Months
Smart Well Assessment and Reservoir Management System (SWARMS)	$149 K	6 Months
SBIR	**$299 K**	

11.6 Inter-Agency Agreements (IAAs)

PHMSA frequently enters into IAAs to leverage the expertise that federal labs can contribute to developing solutions through research. Several IAAs have been created with multiple agencies within the Federal Government. In the fall of FY 2022, the PSRP anticipates funding a hydrogen-related research topic taken from the 2021 RD&T public forum that will advance knowledge about the effects of hydrogen on steel and weld properties. The work will directly impact ASME's B31.12 standard and will be highly coordinated with related DOE efforts.

Table 32: FY2022 IAA Priorities, Awarded Amounts, and Project Durations

IAA Safety Priority Area/Topic	Award Amount	Project Duration
Determining Steel Weld Qualification and Performance for Hydrogen Pipelines	$2 M	24 Months
Total	**$2 M**	

[45] A definition of the term "Internet of Things" can be found via https://en.wikipedia.org/wiki/Internet_of_things.

11.7 Focus Area: Hydrogen and Emerging Fuels

In support of the Administration's climate change initiative, PHMSA funded $7,627,200 in FY 2022 on research to advance the safe transportation of carbon dioxide and hydrogen in pipelines and the safe operation of hydrogen gas storage. These research investments will also address safety gaps for underground storage and for research related to new construction, conversions, or repurposing of service pipelines that transport carbon dioxide and hydrogen.

Table 33: Funding-Level of Hydrogen and Emerging Fuel Focus Area

Funding Type	Funding Level
FY 2022 H_2 Funding Obligations	**$6.1 M**
FY 2022 CO_2 Funding Obligations	**$1.5 M**
Total Funding	**$7.6 M**

11.8 Conclusion

PHMSA will continue strengthening its research partnerships with universities, industry, and safety organizations, and continue implementation of its MSI outreach and engagement initiatives. Increased collaboration with stakeholders and interagency partners will also continue to ensure research outcomes result in technology transfer and adoption of innovative concepts and methods that will enhance pipeline safety, environmental protection, and performance of pipeline, LNG, and UNGS facilities.

OPS's FY 2023 PSRP will continue to address critical pipeline safety challenges with a portfolio of strategic solutions tailored to support the Biden Administration's central goals on energy and the environment. The program's forward-facing focus is designed with input from diverse stakeholders and experts to reduce near-term pipeline safety risks while preparing for tomorrow's threats. The projects funded will not only mitigate known risks directly affecting safety, but also explore new opportunities with unique challenges as novel resources are assessed for their suitability as energy products.

Advancing the Administration's strategic goals requires that pipeline and environmental safety measures be proactive and forward looking. Gaining a more practical understanding of the transportation and storage characteristics of resources, such as hydrogen, is a time sensitive priority that could influence energy policy decisions for decades. PHMSA's goal to mitigate and reduce methane releases from pipeline infrastructure will need to be bolstered by new understanding and tools. This emphasis on addressing emerging fuels and climate challenges, such as methane, does not remove the program's attention from traditional pipeline safety issues, such as tackling aging infrastructure and corrosion.