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

1200 New Jersey Avenue, SE
Washington, DC 20590

December 2, 2024

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, Fiscal Years 2021 and 2022 R&D Update Report to Congress on Pipeline Safety Research and Development. The report fulfills the mandate found in section 12 of the Pipeline Safety Improvement Act of 2002, Pub. L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90. The Act requires the Secretary of Transportation (Secretary) to submit reports updating Congress on the progress and implementation of the Pipeline Safety Research and Development (R&D) Five-Year Program Plan. The previous biennial update report covered Fiscal Years (FYs) 2019 and 2020 and is publicly available on the Pipeline and Hazardous Materials Safety Administration's (PHMSA) Pipeline Safety R&D Program website.[1]

This report also fulfills the requirement found in section 22 of the Protecting Our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act of 2016, Pub. L. 114-183. This Act requires the Secretary to submit a biennial update report to Congress that summarizes each research and development project awarded by PHMSA to federal and non-federal stakeholders and provides reviews of how each project affects pipeline safety. The previous biennial update report covered FYs 2019 and 2020 and is publicly available on PHMSA's Pipeline Safety R&D Program website.[2]

Should you require further information or assistance, please feel free to call me, or your staff may contact Matt Sonneborn, Director of Governmental, International, and Public Affairs, by phone at 202-366-4831 or by e-mail at matt.sonneborn@dot.gov. I hope this information is helpful.

[1] PHMSA Report to Congress FY 2019 and 2020 Update Report on the Pipeline Safety RD Five-Year Program Plan
[2] Pipeline Safety Research and Development Biennial Update Report Fiscal Years 2019 and 2020

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

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

December 2, 2024

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

Dear Ranking Member Cruz:

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1200 New Jersey Avenue, SE
Washington, DC 20590

December 2, 2024

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

Dear Chairman Graves:

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Sincerely,

Tristan H. Brown

Tristan H. Brown
Deputy Administrator

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U.S. Department
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**Pipeline and Hazardous
Materials Safety
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1200 New Jersey Avenue, SE
Washington, DC 20590

December 2, 2024

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

Dear Ranking Member Larsen:

Enclosed please find the report titled, Fiscal Years 2021 and 2022 R&D Update Report to Congress on Pipeline Safety Research and Development. The report fulfills the mandate found in section 12 of the Pipeline Safety Improvement Act of 2002, Pub. L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90. The Act requires the Secretary of Transportation (Secretary) to submit reports updating Congress on the progress and implementation of the Pipeline Safety Research and Development (R&D) Five-Year Program Plan. The previous biennial update report covered Fiscal Years (FYs) 2019 and 2020 and is publicly available on the Pipeline and Hazardous Materials Safety Administration's (PHMSA) Pipeline Safety R&D Program website.[1]

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

Sincerely,

Tristan H. Brown

Tristan H. Brown
Deputy Administrator

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U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
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1200 New Jersey Avenue, SE
Washington, DC 20590

December 2, 2024

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

Dear Chair Rodgers:

Enclosed please find the report titled, Fiscal Years 2021 and 2022 R&D Update Report to Congress on Pipeline Safety Research and Development. The report fulfills the mandate found in section 12 of the Pipeline Safety Improvement Act of 2002, Pub. L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90. The Act requires the Secretary of Transportation (Secretary) to submit reports updating Congress on the progress and implementation of the Pipeline Safety Research and Development (R&D) Five-Year Program Plan. The previous biennial update report covered Fiscal Years (FYs) 2019 and 2020 and is publicly available on the Pipeline and Hazardous Materials Safety Administration's (PHMSA) Pipeline Safety R&D Program website.[1]

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Tristan H. Brown
Deputy Administrator

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U.S. Department
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**Pipeline and Hazardous
Materials Safety
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1200 New Jersey Avenue, SE
Washington, DC 20590

December 2, 2024

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

Dear Ranking Member Pallone:

Enclosed please find the report titled, Fiscal Years 2021 and 2022 R&D Update Report to Congress on Pipeline Safety Research and Development. The report fulfills the mandate found in section 12 of the Pipeline Safety Improvement Act of 2002, Pub. L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90. The Act requires the Secretary of Transportation (Secretary) to submit reports updating Congress on the progress and implementation of the Pipeline Safety Research and Development (R&D) Five-Year Program Plan. The previous biennial update report covered Fiscal Years (FYs) 2019 and 2020 and is publicly available on the Pipeline and Hazardous Materials Safety Administration's (PHMSA) Pipeline Safety R&D Program website.[1]

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Tristan H. Brown

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Deputy Administrator

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U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration

Fiscal Years 2021 and 2022
R&D Update Report to Congress on
Pipeline Safety Research and Development

Pipeline Safety Research and Development

Contents

Abbreviations List

AGA	American Gas Association
AI	Artificial Intelligence
ANSI	American National Standards Institute
AOPL	Association of Oil Pipelines
API	American Petroleum Institute
APGA	American Public Gas Association
ASME	American Society of Mechanical Engineers
ASU	Arizona State University
AMPP	Association of Materials Protection and Performance (formerly National Association of Corrosion Engineers)
BSEE	Bureau of Safety and Environmental Enforcement
CAAP	Competitive Academic Agreement Program
CCUS	Carbon Capture and Underground Storage
CEC	California Energy Commission
CER	Canada Energy Regulator
CFD	Computational Fluid Dyna
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
CSU	Colorado State University
DNV	Det Norske Veritas
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
EMAT	Electromagnetic Acoustic Technology
EPA	Environmental Protection Agency
EPRG	European Pipeline Research Group

FECM	Fossil Energy and Carbon Management
G/L PAC	Gas/Liquid Pipeline Advisory Committee
GO	Governmental Organization
GTI	Gas Technology Institute
H_2	Hydrogen
HE	H_2 Embrittlement
ICCOPR	Interagency Coordinating Committee and Oil Pollution Research
ILI	In-Line Inspection
INGAA	Interstate Natural Gas Association of America
IPC	International Pipeline Conference
IVR	Integrated Voltage Regulator
LNG	Liquefied Natural Gas
ML	Machine Learning
NAPSR	National Association of Pipeline Safety Representatives
NDE	Nondestructive Examination
NETL	National Energy Technology Laboratory
NGA	Northeast Gas Association
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
NMP	Non-Metallic Pipe
NOFO	Notice of Funding Opportunity
NTL	National Transportation Library
OTD	Operations Technology Development
PDCA	Plan, Do, Check, Act
PHMSA	Pipeline and Hazardous Materials Safety Administration
PRCI	Pipeline Research Council International
R&D	Research and Development
ROSA-P	Repository & Open Science Access Portal

SBIR	Small Business Innovation Research
T2	Technology Transfer
USDA	Department of Agriculture
WVU	West Virginia University

1.0 Executive Summary

The Pipeline and Hazardous Materials Safety Administration's (PHMSA) mission is to protect people and the environment by advancing the safe transportation of energy products and other hazardous materials that are essential to our daily lives. PHMSA oversees the transportation of hazardous materials, including energy products, through all modes of the transportation industry. PHMSA operates in a dynamic and challenging environment in which changes in technology, manufacturing, and energy production affect transportation safety. The Agency anticipates the scope and complexity of its safety mission will continue to grow, requiring it to continuously evaluate how it uses information and technology to achieve the Department of Transportation's (DOT) safety goals. PHMSA partners with any stakeholder who shares the goal of developing new technology, products, and knowledge aimed at improving safety in all its research. PHMSA's research agenda adapts to address existing and future safety threats.

This report fulfills the mandate in section 12 of the Pipeline Safety Improvement Act of 2002, Pub. L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90 (the Act). This Act requires the Secretary of Transportation (Secretary) to transmit a report to Congress on the status and results-to-date of implementation of the five-year program plan required by the Act every two years. The biennial report includes a summary of research needs and priorities identified through the consultation requirements of paragraph (2) of the Act.

This report also fulfills the mandate in section 22, Pub. L. 114-183 of the Protecting Our Infrastructure of Pipelines and Enhancing Safety (PIPES) Act of 2016. Herein, PHMSA identifies the research and development (R&D) investments for Fiscal Years (FYs) 2021 and 2022, and summarizes the potential impact on pipeline safety. PHMSA developed a Pipeline Safety Research and Development Updated Plan (Plan) for FYs 2021 and 2022 to comply with the Joint Explanatory Statement accompanying Division L of the Consolidated Appropriations Act, 2021; that Plan serves as the basis for this report. PHMSA's current Pipeline Safety Research and Development (R&D) Five-Year Program Plan (Five-Year Plan) covers FYs 2023 through 2027.

The FYs 2021 and 2022 Plan focused research on the following eight program elements in response to consultation with stakeholders and identified subject areas:

- 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 Liquefied Natural Gas (LNG) Facilities

- Improving Safety Systems for Underground Natural Gas Storage (UNGS) Facilities
- Safe Transportation of Hydrogen (H_2)/Carbon Dioxide (CO_2)

In FY 2021, PHMSA funded 17 R&D projects, totaling $12,169,481; in FY 2022, it funded 23 R&D projects, totaling $13,696,428. Of these projects, 14 focused on developing new technologies, and the remaining 26 promoted and expanded the knowledge base for decision-makers. R&D in FYs 2021 and 2022 included a greater focus on UNGS facilities, methane detection, and LNG facilities due to changes in regulatory landscape and energy supply/demand. PHMSA's Competitive Academic Agreement Program (CAAP) continues to engage students from higher education institutions in pipeline safety-related research, providing a potential career pathway into the pipeline industry. Such engagement also illustrates that R&D carried out in academia, particularly in science and technology, contributes to American innovation, competitiveness, and economic growth.

PHMSA's research results in scholarly publications and commercially viable products to improve pipeline safety. This collaborative partnership with pipeline stakeholders has resulted in the development of several commercialized technology transfers. Since 2002, PHMSA's R&D Program has resulted in 35 commercialized technologies.

PHMSA is currently investing in more than 67 active research projects, totaling $46,361,350 ($62,059,668, including resource share), and will continue to evaluate research in new areas, such as H_2 and CO_2 pipeline safety, to support sustainable alternative fuels. The potential impact of these projects on safety are significant; however, full safety benefits of the technologies and knowledge created from these projects can only be realized after adoption by the pipeline industry and implementation in the field. These solutions impact safety on pipeline systems, UNGS facilities, and LNG facilities by providing operators of these systems and facilities with the tools and state-of-the-art knowledge to prevent accidents.

2.0 Introduction

Section 12 of the Pipeline Safety Improvement Act of 2002, P.L. 107-355, as amended by section 32 of the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, Pub. L. 112-90, requires the Secretary to submit reports updating Congress on the progress-to-date and implementation of PHMSA's Pipeline Safety R&D Five-Year Plan. This report provides a general overview of PHMSA's Pipeline R&D Program (R&D Program), highlights past successes, and recounts Plan activities for FYs 2021 and 2022, covered by the Pipeline Safety Research and Development Updated Plan FY 2021 and 2022, submitted to Congress in response to the Joint Explanatory Statement Accompanying Division L of the Consolidated Appropriations Act of 2021.

This report is also in compliance with section 22 of the PIPES Act of 2016 mandate that requires PHMSA to report on the R&D investments for FYs 2021 and 2022 and summarize the

potential impact on pipeline safety.

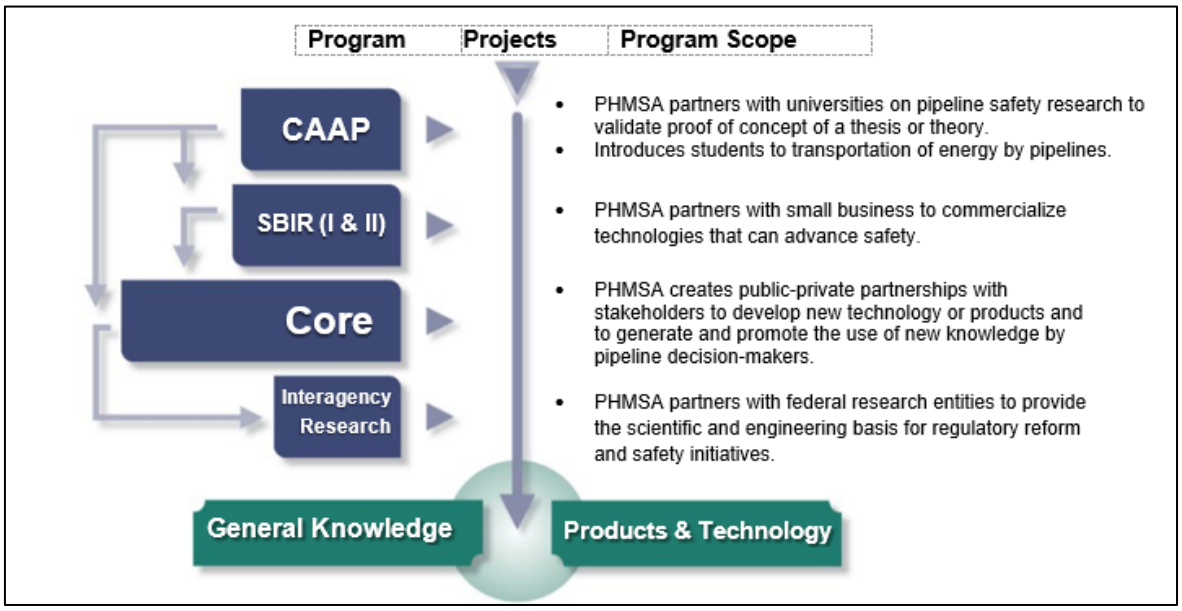
3.0 PHMSA Pipeline Safety Research Program

PHMSA's R&D Program will continue to pursue its R&D goals through four sub-programs: the CAAP; the Pipeline Core Research Program (Core); Small Business Innovative Research (SBIR); and Inter-Agency Agreements (IAAs). The sub-programs address different research requirements and are designed to develop concepts from their initial stages to industry or government adoption.

PHMSA uses public-private partnerships with stakeholders, academic institutions, small businesses, and intergovernmental agreements to conduct the PHMSA R&D Program. The program is executed through competitive awards, cost-sharing agreements, grants, and IAAs. These four approaches address different research requirements and are designed to develop research concepts from initial conceptual stages to industry or government adoption.

Figure 3-a shows the four different research requirements.

Figure 3-a. Developing a Research Program Strategy



PHMSA's R&D Program funds innovative research to improve safety, protect the environment, and support reliability of pipeline systems. The PHMSA R&D Program identifies and develops emerging technologies for the pipeline industry to adopt voluntarily, and provides scientific and engineering support for PHMSA's rulemaking and inspection and compliance efforts, among other things.

The focus of the PHMSA R&D Program is to identify and fill research gaps, and to partner

with pipeline stakeholders to leverage private R&D investment that would ensure public safety and protection of the environment. PHMSA strives to avoid duplicative research, and works closely with academia and pipeline stakeholders to fund and share the cost of critical research to develop new technology, products, and knowledge and promote stakeholder engagement.

On a biennial basis, a comprehensive research strategy is developed through R&D forums, research gap ideas submitted by the public, PHMSA's own initiatives, and collaboration with partners, as shown in Figure 3-b.

Figure 3-b. Developing a Research Program Strategy

4.0 Stakeholder Engagement and Research Needs and Priorities

PHMSA continually and transparently engages with the public and its stakeholders with the goal to advance technological solutions and knowledge that improve the overall safety, protection of the environment, and reliability of pipeline systems. PHMSA communicates with stakeholders through public meetings, requests for comments, website publications, and conferences.

4.1 Stakeholder Engagement

PHMSA staff participate in various meetings and public events and note any research needs identified through the course of these activities. Throughout the year, PHMSA's R&D Program staff engage directly with stakeholders, including trade associations and the pipeline industry, on the research program and consult with them on individual projects that are within their sphere of expertise. For example, PHMSA participates in conferences with key industry sectors to understand technology needs and learn about successes and challenges in order to better inform its R&D Program. In addition, PHMSA encourages various stakeholders to partner with industry and government agencies to pilot new technologies and promote pipeline safety.

Partnerships with governmental organizations (GOs) and non-governmental organizations (NGOs) provide clear opportunities to leverage ongoing successes, cost-share on research with mutual safety challenges, and prevent duplication. Research collaboration partners—both GOs and NGOs—who cost-share research with PHMSA include, but are not limited to, those shown

in Table 4-a.

PHMSA's R&D Program technology transfer (T2) successes depend highly on the strategic partnerships PHMSA forms with the pipeline industry.

PHMSA will continue to collaborate with its stakeholders to promote transparency and collaboration between government and the public and provide near-term solutions to ensure the safe, reliable, and environmentally sound operation of the nation's pipeline system. In addition, PHMSA invites the public to join its Distribution List to stay informed of all R&D related activities.

Table 4-a shows research collaborators who partner with PHMSA.

Table 4-a. Research Collaboration Partners

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
Association of Oil Pipelines (AOPL)		X
California Energy Commission (CEC)	X	
Canada Energy Regulator (CER)	X	
Department of Agriculture (USDA)	X	
Department of Commerce (DOC): National Institute of Standards and Technology (NIST)	X	
Department of Energy (DOE)	X	
Department of the Interior (DOI): Bureau of Safety and Environmental Enforcement (BSEE)	X	
Environmental Protection Agency (EPA)	X	
Interstate Natural Gas Association of America (INGAA)		X
National Association of Pipeline Safety Representatives (NAPSR)	X	
Northeast Gas Association (NGA)/NYSEARCH		X
Operations Technology Development (OTD)		X
Pipeline Research Council International (PRCI)		X
United States Coast Guard (USCG)	X	

4.2 Interagency Engagement

PHMSA frequently enters IAAs with the U.S. Department of Energy (DOE), U.S. Department of Commerce (DOC), and U.S. Department of Interior (DOI) to conduct pipeline safety research. PHMSA engages with federal agencies beyond specific research projects to have federal partners participate in PHMSA's R&D related events. Additionally, PHMSA staff regularly participate in the initiatives of other federal agencies with a pipeline safety component. Periodic meetings are held with federal partners for knowledge-sharing and awareness on specific topics, such as emerging fuels like H_2 and CO_2. PHMSA also collaborates with the United Kingdom's Health and Safety Executive, which participates in numerous PHMSA R&D events.

In FYs 2021 and 2022, PHMSA participated in the following interagency H_2 and CO_2 initiatives:

- DOE
    - H_2 and Fuel Cell Technologies Office
        - National H_2 Strategy and Roadmap
        - Clean H_2 Joint Undertaking Expert Workshop on Environmental Impacts of H_2
        - Bulk Storage of Gaseous H_2 Workshop
    - FECM
        - Division of Methane Mitigation Technologies
        - Division of Carbon Transport and Storage
            - Front End Engineering and Design Peer Reviews
        - FECM and United States Energy Association Roundtable on Carbon Transport R&D Priorities for Existing Pipelines
        - Tulsa Carbon Interactive Workshop
- DOC/U.S.-India Strategic Partnership Forum
- PHMSA/NAPSR Gas Distribution Team and H_2/Biofuels Working Group

In FYs 2021 and 2022, PHMSA awarded the following IAAs:

- DOE, NETL: Detection of Buried Plastic Pipelines
- DOC, NIST: Determining Steel Weld Qualification and Performance for Hydrogen Pipelines

PHMSA will continue to work with federal agencies to accomplish the following:

- Develop and implement a periodic notification practice and/or system to notify stakeholders of new public materials and research data, including T2 and knowledge

metrics, as they become publicly available. Promoting research successes and project outcomes will not only encourage conversation and transparency among stakeholders but also create demand for pipeline research from the industry.

- Expand the publication of its reports beyond the PHMSA website and DOT Research Hub to the Research & Open Science Access Portal (ROSA-P) database, the NTL, and the Transportation Research Board's Transport Research International Documentation database.
- Coordinate research efforts with DOE, NIST, and ICCOPR—particularly on emerging fuels and oil spill prevention—to co-sponsor and collaborate on mutual priorities, reduce duplicative research, and maximize funding efficacy.

4.3 Consultation

Section 12 of the Pipeline Safety Improvement Act of 2002 and the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011 directs PHMSA to consult with various stakeholder groups in preparing the Five-Year Program Plan, selecting and prioritizing appropriate project proposals, and identifying research priorities and research needs.

One way PHMSA conducts consultation to determine research priority areas is through R&D forums, which are held on a biennial basis. These forums allow PHMSA to connect pipeline experts with researchers, government officials, pipeline operators, and the public to generate a national research agenda that fosters solutions for the various challenges associated with pipeline safety and protecting the environment. The forums provide a great opportunity to share ongoing research efforts, leverage resources, and strengthen research relationships and partnerships. The forums also allow PHMSA's stakeholders to develop recommendations on the technical gaps and challenges for future pipeline safety research.

The format typically includes a general session with speakers on topics of interest, poster sessions from CAAP projects, and interactive working groups. Working groups are charged with determining research gaps and needs within their focus areas, and then sharing their recommendations during a report out on the last day of the forum. PHMSA takes the identified research needs and recommendations to craft the research agenda for the coming fiscal years.

The research strategy for FYs 2021 and 2022 was derived, in part, from two research forums conducted in 2020 and 2021.

4.3.1 2020 R&D Forum

On February 19 and 20, 2020, PHMSA conducted a Pipeline R&D Forum attended by 240 stakeholders in Arlington, Virginia.[1] Attendees were from a wide spectrum of pipeline safety stakeholders, including trade industry associations, Canadian regulators, engineering consultants, research entities, classification societies, universities, national laboratories, energy companies, and other federal agencies. The forum provided an opportunity to discuss research gaps in the following focus areas:

1. Gas Gathering Pipelines
2. Preventing and Mitigating Geo-Forces on Pipelines and Facilities
3. Automation Solutions for Integrity Management Challenges
4. Underground Gas Storage Facilities
5. LNG

The first day of the forum featured presentations in which representatives from industry shared national perspectives and key technical challenges facing hazardous liquid, gas transmission, and gas distribution pipelines and LNG safety. Five working groups convened on the second day to identify research needs and develop recommendations. Each working group provided a report out presentation at the end of the forum.

Working Group #1, Gas Gathering, identified three areas of research for gas gathering pipelines, including nondestructive examination (NDE) tools suitable for composite pipe; fitness-for-service analysis; and a knowledge-based study on corrosion and erosion-corrosion mechanisms.

Working Group #2, Preventing and Mitigating Geo-Forces on Pipelines and Facilities, recommended research on the strain state and strain capacity of existing pipelines and data integration for geohazard monitoring.

Working Group #3, Automation Solutions for Integrity Management Challenges, found the need for research to develop a framework/guidance document to assist industry in utilizing probabilistic and artificial intelligence (AI) tools; a process for benchmarks applicable to validation tools and technologies; probability of detection (POD) for remote sensing technologies; and automation (e.g., robotics) for repairs.

Working Group #4, Underground Gas Storage Facilities, identified research needs related to wellhead seal design and monitoring; integration of fiber optics into wellbore design and monitoring; through tubing inspections; cement as a barrier; and cathodic protection (CP) for storage wells.

[1] Research & Development Program: Research & Development | Meetings/Events (dot.gov)

Working Group #5, LNG, identified five research needs, including developing guidelines for tank inspections; bench testing to validate cryogenic bolted join model behavior; evaluating full containment tank design; identifying performance-based standards for maintenance; and developing guidelines for fire protection evaluations.

These gaps were used to develop the priority research areas and research needs discussed in Section 4.4.

4.3.2 2021 Hydrogen and Emerging Fuels R&D Forum

From November 30–December 2, 2021, PHMSA conducted a Pipeline R&D Virtual Forum attended by approximately 500 stakeholders from trade associations, energy companies, national laboratories, pipeline safety advocates, standards bodies, technical societies, research entities, labor and environmental organizations, and other federal agencies.[2] With a focus on H_2 and emerging fuels, this forum assisted PHMSA in developing its FYs 2021 and 2022 R&D agenda to address one of DOT's strategic goals to develop climate solutions. The forum also provided an opportunity to discuss research gaps and had six working groups finalize research recommendations on the following topic areas:

1. Rehabilitation of Aging Cast Iron Pipelines
2. Integrity of Underground Natural Gas/Hydrogen Storage
3. Utilization of Inspection Tools on Hydrogen Pipelines
4. Hydrogen Network Components
5. Methane Mitigation – Construction and Operations
6. Breakout Tanks – Methods to Prevent Corrosion of Tank Bottoms

The first day of the forum consisted of a public meeting and general session focusing on two objectives: (1) the current state of PHMSA's pipeline safety R&D Program; and (2) the environmental and infrastructure impacts of a shift to clean emerging fuels. The second day consisted of six smaller, interactive workgroups to develop R&D topics for funding consideration by PHMSA. The final day included a report out on research recommendations from the workgroups to the general session and a public comment period.

Working Group #1, Rehabilitation of Aging Cast Iron Pipelines, identified three areas of research needs related to the development of rapid, cured in-place liners, a decision support tool, and structural liner materials.

Working Group #2, Integrity of Underground Natural Gas/Hydrogen Storage, identified four research needs in the field of H_2, including the study of microbial interactions in a H_2 rich environment; formation of a consortia for pilot studies; loss monitoring; and site suitability criteria for H_2 versus CO_2 storage.

[2] https://primis.phmsa.dot.gov/Meetings/MtgHome.mtg?mtg=153

Working Group #3, Utilization of Inspection Tools on Hydrogen Pipelines, identified five areas of needed research, including the unique threats of pure or blended H_2 compared to those in ASME B31.8S; leak detection for both pure H_2 and methane-H_2 blends; damage mechanisms specific to H_2; development of in-line inspection (ILI) tools suitable for service in H_2 pipelines; and the limitations of current ILI tools for detecting H_2 specific damage.

Working Group #4, Hydrogen Network Components, identified needed research for steel weld qualification and performance for both new and repurposed pipelines; modifications needed to safely repurpose existing infrastructure to carry pure H_2; and H_2 compatibility for equipment and leak detection technologies.

Working Group #5, Methane Mitigation – Construction and Operations, identified five gaps related to methane leak detection and quantification; in-situ repair and rehabilitation technologies; compressor station operations; best practices for methane mitigation from gathering to distribution; and development of codes and standards for CO_2 transportation via pipeline.

Working Group #6, Breakout Tanks – Methods to Prevent Corrosion of Tank Bottoms, identified research needs in the areas of corrosion monitoring and tank foundation/pad design, as well as two specifically related to vapor corrosion inhibitor (VCI) standardization and compatibility.

These gaps were used to develop the priority research areas and research needs discussed in Section 4.4.

4.3.3 Gap Submission Portal

The R&D Program maintains a portal on the program website where any stakeholder can submit a research gap or idea for a research project. In FY 2021 there were 13 ideas submitted to the portal and most focused on threat prevention. Other proposed research topics ranged from the safe transportation of ammonium nitrate to gas-coupled ultrasonic technology for ILI to novel, bio-based inhibitors for the mitigation of internal corrosion in oil pipelines. Submissions in FY 2022 focused more heavily on anomaly detection, design, and pipe remediation/rehabilitation with research ideas, including axial crack detection in natural gas facility lines, induced polarization measurements for rapid inspection, and analysis and guidance for the performance of automatic shutoff valves.

Each submission is reviewed by PHMSA and, if deemed viable, is incorporated into upcoming research announcements. For example, two gap ideas submitted in FY 2021 were incorporated into the CAAP FY 2023 Notice of Funding Opportunity (NOFO) as Topic 1: “Novel Bio-Based Inhibitors for the Mitigation of Internal Corrosion in Pipelines;” and Topic 2: “Develop Innovative Solutions to Supplement the Current Cathodic Protection Methodologies to Assess the Effectiveness of the Pipeline Cathodic Protection System.”

4.4 Priority Research Areas and Research Needs

Consultation conducted through a series of stakeholder engagement activities, including the research needs identified at R&D forums, led to developing the following list of research priority areas for FYs 2021 and 2022:

1. Ensuring Integrity and Safety of Gas Gathering Pipelines

This research priority recognizes the growing use of composite materials in gas gathering pipelines, and the need for improved methods to assess the integrity of these pipelines and those made from traditional materials. It emphasizes developing new and improved NDE tools for comprehensive damage detection; establishing minimum damage thresholds for safe operation; and gaining a deeper understanding of corrosion and erosion-corrosion mechanisms. The goal of this research focus area is to ensure the safe and reliable operation of gathering lines constructed from various materials by providing operators with better tools and knowledge to assess pipeline integrity and proactively address potential threats.

Based on the research needs developed under this priority area, the following project was solicited:

- Core FY 2021: Corrosion, Erosion-Corrosion, Material Compatibility, and Associated Design of Gas Gathering Pipelines

2. Enhancing Pipeline Risk Assessment for Proactive Pipeline Integrity Management

Proactively managing pipeline risk to ensure pipeline safety and integrity is of critical importance. Research in this priority area emphasizes the development of improved methods for assessing the strain state and strain capacity of existing pipelines, along with improved geohazard monitoring and data integration. The aim of this research is to equip pipeline operators with better tools and data to proactively identify potential threats to pipeline integrity before they lead to failures.

Based on the research needs developed under this priority area, the following project was solicited:

- Core FY 2021: Measuring Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines

3. Revolutionizing Pipeline Risk Management Through Advanced Analytics and Robotics

This research priority acknowledges the limitations of current pipeline risk assessment practices, and emphasizes the development and implementation of advance analytical tools and robotic technologies. It focuses on leveraging probabilistic methods, AI, and remote sensing for improved risk modeling, data analysis, and leak detection. Additionally, the research prioritizes the development of automated robotic systems for efficient and safe pipeline repair. The ultimate goal is to transform pipeline risk management from a reactive to a proactive approach, enabling data-driven decision making for enhanced pipeline safety and integrity.

Based on the research needs developed under this priority area, the following project was solicited:

- CAAP FY 2021: Remote Monitoring Technology

4. Ensuring Safe and Reliable Underground Natural Gas Storage (UNGS)

This research priority focuses on the critical importance of ensuring the safety and integrity of UNGS wells throughout their life cycle, including the development and implementation of improved technologies and best practices for wellhead seal design and monitoring, wellbore integrity assessment, and corrosion mitigation. The goal of research conducted under this priority area is to minimize the risk of leaks and to ensure the safe operation of UNGS facilities.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2021: Developing Advanced Tubing Inspection Tools for UNGS
- Core FY 2021: Investigating Cement and Other Materials as a Barrier in UNGS Wells
- CAAP FY 2021: UNGS Leak Identification and Well Control Solutions

5. Enhancing the Safety and Efficiency of LNG Facilities

Recognizing the need for enhanced LNG safety, integrity, and operational efficiency, this research area prioritizes the development of a more comprehensive and flexible framework for LNG facility safety and management. This framework emphasizes improved industry guidelines, performance-based control system standards, and risk-informed fire protection strategies. This holistic approach aims to balance public safety and environmental protection with optimal facility performance.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2021: Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks
- Core FY 2021: Developing Performance Criteria for External Loading Factors on External Steel Shell Tanks
- Core FY 2021: Determining the Maximum Permissible Temperature Drops for Steel When Exposed to Cryogenic Liquid
- Core FY 2021: Evaluating/Demonstrating the Feasibility of LNG Storage Tank Operations Without Bottom Fill
- Core FY 2022: Determining the Maximum Permissible Temperature Drops for Steel When Exposed to Cryogenic Liquid Capabilities

6. Cost-Effective and Efficient Technologies for Pipeline Rehabilitation and Replacement

This research priority acknowledges the need for innovative solutions that address both infrastructure renewal and cost-effectiveness. This priority area emphasizes technologies that minimize downtime, optimize decision-making, and ultimately ensure a reliable and cost-efficient pipeline network.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2022: Rapid Cure Process for Cured-in-Place Liners
- Core FY 2022: Decision Support Tool for Replacement/Rehabilitation of Natural Gas Distribution Pipelines
- CAAP FY 2022: Development of Structural Liner Material

7. Comprehensive Understanding and Technical Framework for Safe, Efficient, and Environmentally Responsible Hydrogen Storage in Geological Formations

This area of research priority recognizes the significant potential for underground geologic storage of H_2 gas. Critical knowledge gaps exist pertaining to how H_2 can be stored safely, efficiently, and in an environmentally responsible manner. Research will focus on providing an understanding of microbially induced corrosion risk; conducting pilot field studies; developing robust site selection criteria for H_2 storage; and improving H_2 loss monitoring technologies. Under this priority area, the ultimate aim is to establish a comprehensive technical framework for safe and reliable H_2 storage, paving the way for large-scale H_2 deployment as a clean energy carrier.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2022: Solutions for Predicting/Monitoring Hydrogen Gas Loss

8. Robust Technical Framework for Ensuring the Integrity and Reliability of New and Re-purposed Pipelines for the Transportation Hydrogen and Hydrogen Blends

H_2 has emerged as a clean energy source critical to the success of transitioning to a low-carbon sustainable energy future. This priority area recognizes the critical need to ensure the safe and reliable transportation of H_2 and H_2-natural gas blends through both newly constructed pipelines and existing natural gas pipelines. Research under this priority area will emphasize developing a comprehensive framework that addresses potential H_2-specific threats to pipeline integrity; leak detection technologies optimized for H_2 service in both transmission and distribution lines; and robust inspection technologies suitable for a H_2-rich pipeline environment. The goal of research needs addressed under this priority area are to establish a strong technical foundation to facilitate the transition to a low carbon economy safely and responsibly.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2022: Validate Existing or Develop New Hydrogen Leak Detection and Quantification Technologies Compatible with Hydrogen-Blends
- Core FY 2022: Review of Integrity Threat Characterization Resulting from Hydrogen Gas Pipeline Service
- Core FY 2022: Determining the Required Modifications to Safely Repurpose Existing Pipelines to Transport Pure Hydrogen and Hydrogen-Blends
- CAAP FY 2022: Pipeline Infrastructure Modernization - Hydrogen Network
- IAA – NIST FY 2021: Determining Steel Weld Qualification and Performance for Hydrogen Pipelines

9. Comprehensive Strategies for Reducing Methane Emissions Throughout the Entire Natural Gas Life Cycle

Methane emissions persist as a major environmental concern and an economic loss for the natural gas industry and the consumers. This area of research priority emphasizes the need for developing more advanced leak detection technologies, the importance of infrastructure integrity, the standardization of best practices and operational improvements, and the transportation of CO_2 by pipeline. By addressing research needs in this priority area, PHMSA can provide the natural gas industry with tools to significantly reduce its overall methane footprint, which will contribute to environmental sustainability goals, reduce product loss, and enhance safety.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2022: Field Validation Demonstrations to Advance Pipeline Leak Detection Beyond Current Capabilities
- Core FY 2022: Determining How to Advance Methane Leak Detection Technology Deployed in Diverse Operating Areas/Environments Beyond Current Capabilities
- Core FY 2022: Pipeline Industry Best Purging Practices for Minimizing Methane Emissions in Transmission, Distribution, and Gathering Pipelines
- Core FY 2022: Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2
- CAAP FY 2022: Determination of Potential Impact Radius for CO_2 Pipelines

10. Ensuring the Long-Term Integrity of Breakout Tanks through Improved Corrosion Control Methods and Standards

This research priority area recognizes the importance of ensuring the long-term safety of breakout tanks by addressing limitations in corrosion control. It acknowledges the potential for new technologies, such as VCIs, and emphasizes the need for improved and more reliable monitoring, standardized practices, and optimized tank foundation designs.

Based on the research needs developed under this priority area, the following projects were solicited:

- Core FY 2022: Monitoring the Long-Term Compatibility of Vapor Corrosion Inhibitor (VCI) and Cathodic Protection (CP) Associated Components
- Core FY 2022: Developing Corrosion Control Monitoring Technology for Hazardous Liquid Breakout Tanks

5.0 Programmatic Objectives and Elements

Based on stakeholder input and historical and current accident trends, a set of high-value programmatic objectives were identified as the focal point of PHMSA's research for FYs 2021 and 2022. The specific research projects and scope of activities may change from year-to-year to address emerging challenges based on data analysis and industry needs, and in response to congressional mandates and specific pipeline incidents. Based on the Agency's analysis and stakeholder input, this report focused on the following eight selected research program elements.

5.1 Preventing Pipeline Threats/Damage

Activities in this topic area included examining tools to alert operators of possible intrusions to pipeline rights-of-way (ROWs) (e.g., excavation damage); 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 included advancements in high-altitude imaging, machine learning (ML), and predictive analytics to mitigate external threats to pipeline infrastructure.

5.2 Improving Pipeline Leak Detection Systems

Activities in this topic area developed new or improved tools and technology solutions for locating, quantifying, and reducing the gas or liquid volumes released into the environment because 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 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.

5.3 Improving Anomaly Detection and Characterization

Activities in this topic area were designed to support the pipeline industry in making integrity management decisions, and finding and removing critical defects or anomalies in the pipeline system. This research area supported both anomaly detection and characterization efforts within pipelines, and provides operators with effective instrumentation to enable accurate remediation measures.

5.4 Improving Anomaly Remediation and Repair and Rehabilitation

Activities in this topic area supported reliable methods for repairing damaged coatings and corrosion damage, which are major integrity management challenges for pipelines. Research activities addressed ways to improve the pipeline repair processes, and to improve standards or best practices for operators. Research activities also advanced 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 included 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.

5.5 Improving Design, Materials, and Welding/Joining

Activities in this topic area addressed improved pipeline materials and design that could mitigate or minimize integrity threats to both transmission and distribution piping. The welding and joining of transmission and distribution systems require automation and inspection capabilities that can safely improve the efficiency of construction activities. The development of 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 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.

5.6 Improving Safety Systems for Liquefied Natural Gas Facilities

Activities in this topic area addressed various LNG industry challenges related to LNG hazards, as well as fostering development of new technologies and alternative designs for LNG storage and piping systems. Additional initiatives in this research focus area addressed 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.

5.7 Improving Safety Systems for Underground Natural Gas Storage

Activities in this topic area included research to improve the safety of UNGS facilities for their

full life cycle. Research activities focused on reducing risks to the public, environment, and UNGS worker safety. Specific research areas included 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.

5.8 Advancing Safe Transportation of Hydrogen and Carbon Dioxide

Activities under this focus area addressed methods for improving the safety of H_2, a growing alternative fuel source, and CO_2 transportation via pipeline—which is required for carbon capture initiatives. The ability to safely transport these commodities by pipeline supports widespread movement of CO_2 from capture to storage, and allows H_2 to be more widely utilized in blending with natural gas or in lieu of natural gas as a fuel. Research activities assessed the suitability of current natural gas pipeline infrastructure for the future transportation of pure H_2 gas or blended H_2 with natural gas. Research also addressed the safe deployment of new pipelines and facilities needed to fill any new demand for the transportation and storage of these fuels.

The research provided an understanding of potential changes to material properties due to exposure to H_2—such as H_2 embrittlement (HE), changes to fatigue crack growth rate, and changes to material toughness—and their potential safety impacts. In addition, this research addressed required pipeline modifications to existing infrastructure and potential design modifications for new pipelines to ensure pipeline integrity.

Additionally, given the increase in, and recent federal incentives for, the use of carbon capture technologies, research activities also addressed the potential safety impacts of the transportation of supercritical CO_2, as well as any other pertinent phases of CO_2, via pipeline. Both research areas contributed to pipeline safety by providing critical data to responders in an emergency situation, and failure consequence knowledge as the U.S. increases its lower carbon energy portfolio.

6.0 Program Structure Funding Summary (FYs 2021 and 2022)

Between FY 2021 and FY 2022, the PHMSA R&D Program invested $28,010,135 in pipeline safety research across the four programs.

Core Research Program – $14,533,713

PHMSA's R&D Program is primarily executed through the Core program. Under Core, the main activities focus on developing new technologies or products and conducting demonstrations, and on transfer of technology for commercialization. In addition, Core promotes the use of new knowledge by decision makers.

- FY 2021 Awarded Projects: $6,990,826
- FY 2022 Awarded Projects: $7,542,887

CAAP – $6,652,978

PHMSA developed and launched CAAP in 2013, funding research awards to conduct innovative research made 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 a wide range of pipeline safety challenges.

- FY 2021 Awarded Projects: $1,859,424
- FY 2022 Awarded Projects: $4,793,554

Small Business Innovation Research Program – $4,259,318

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 that participate in the SBIR program; and states that continued technological innovation is critical to the strength of the U.S. economy's manufacturing sector.

- FY 2021 Awarded Projects: $3,959,331
- FY 2022 Awarded Projects: $299,987

Interagency and PHMSA-Conducted Research – $2,564,126

PHMSA partners with governmental 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, NIST, NETL, and other federal entities.

- FY 2021 Awarded Projects: $504,126
- FY 2022 Awarded Projects: $2,060,000

7.0 Communication of Program and Project Solicitation Activities

In FYs 2021 and 2022, PHMSA communicated its program and project funding opportunity requests for proposal activities through the following forms of media outlets:

SAM.gov

- Core Research Announcement #693JK321RA0001 in FY 2021
- Core Research Announcement #693JK322RA0001 in FY 2022

SBIR.gov/solicitations

- SBIR 6913G622QSBIR1 in FY 2022

Grants.gov

- CAAP NOFO #693JK321NF0005 in FY 2021
- CAAP NOFO #693JK322NF0001 in FY 2022

Website Post

- New research project pages posted in FY 2021
- New research project pages posted in FY 2022

When announcing public events, such as R&D forums, PHMSA posted information in the *Federal Register* and on Twitter/X, LinkedIn, and other social media. Other key R&D presentations were made at GPAC/LPAC meetings, and research portfolios were presented at industry conferences, such as the API Pipeline Conference, Control Room and Cybernetics Conference, AMPP Corrosion Conference and Expo, and the International Pipeline Conference (IPC). In each contract or agreement, PHMSA required several deliverables that the researcher provided to promote project results, such as information regarding the commercialization of the product. However, the knowledge or technology transfer often occurs long after the end of the contract, limiting PHMSA's ability to track them. To ensure researchers continue to provide status updates on their technology transfer after project closeouts, PHMSA is in the process of implementing additional measures for new awards that will encourage researcher to keep PHMSA informed. PHMSA has tried to ensure that awarded research promotes general knowledge to decision-makers by requiring awardees do the following during their contract period:

- Submit results at public conferences, forums, symposiums, workshops, or trade journals.
- Report any application for a U.S. patent and provide updates post contract end date.
- Conduct an output-focused final meeting with invited decision-makers and stakeholders.
- Collaborate at public events where ongoing work or results are discussed, such as research, development, and technology forums, and workshops.
- Participate in PHMSA's R&D Program peer reviews through technical advisory panels (TAPs), where knowledge from research is reviewed and shared.

Information about research projects awarded by PHMSA is made publicly available on the USDOT Research Hub, the NTL Digital Library, and PHMSA's website.[3]

[3] https://www.phmsa.dot.gov/

8.0 Research Objectives and Results to Date

8.1 Research Project Awards

This section presents a comprehensive summary of projects funded through the PHMSA R&D Program in FYs 2021 and 2022, organized by each research program element. Each project's objectives, anticipated outcomes, and potential safety impacts are detailed, and accompanied by links to their respective project pages on PHMSA's website. Most projects from FYs 2021 and 2022 are currently in active phases, with projected completion in 2024 and 2025.

8.1.1 Preventing Pipeline Threats/Damage

Description: The funding total for this Program Element is $6,421,574.

Activities in this topic area included examining tools to alert operators of possible intrusions to pipeline ROWs (e.g., excavation damage); 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 included advancements in high-altitude imaging, ML, and predictive analytics to mitigate external threats to pipeline infrastructure. Funded projects for FY 2021 and FY 2022 are listed in Table 8-a and Table 8-b, respectively; the tables are followed by project details, including descriptions, anticipated results, and potential impacts on safety.

Table 8-a documents the projects funded during FY 2021 for this programmatic element.

Table 8-a. FY 2021 Funded Projects – Preventing Pipeline Threats/Damage

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Detection of Buried Plastic Pipelines	$504,126 (IAA)	NETL	Morgantown	WV
2.	Development and Validation of a Probabilistic Method for Estimating Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines	$1,437,508 (Core)	GTI	Des Plaines	IL
3.	Design and Placement of Compact Service Regulators	$383,725 (Core)	GTI	Des Plaines	IL
4.	Development of Corrosion/Erosion Threat Assessment Methodologies and Enriched Preventive and Mitigative Measures to Promote Safety of Gas Gathering Pipelines	$377,830 (Core)	North Dakota State University	Fargo	ND
5.	Pipeline Risk Management Using Artificial Intelligence-Enabled Modeling and Decision Making	$349,328 (CAAP)	Rutgers, The State University	New Brunswick	NJ
6.	Easily Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity	$665,370 (CAAP)	Colorado School of Mines	Golden	CO
7.	Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard	$991,124 (SBIR)	Paulsson, Inc.	Van Nuys	CA
					FY 2021 Total: $4,709,011

Project 1: Detection of Buried Plastic Pipelines

Recipient: NETL

Project Description: This IAA with NETL will identify/develop methods that can locate buried plastic distribution pipelines—currently only locatable by ground penetrative radar when buried beneath resistive cover—and predict subsurface position and depth from the surface.

Anticipated Results: This project will conduct a comprehensive review of commercially available technology to identify gaps in existing technology and what new technology can be developed to advance the state of surface detection. Further investment then may be considered to develop new technology.

Potential Impact on Safety: The methods developed in this research project could be used to locate buried and difficult to locate plastic pipes more quickly and accurately, which could help prevent damage to pipes from excavation and other activities. Accurately locating pipelines also enables faster and more accurate leak detection, maintenance, and repair, and more informed emergency response during accidents.

Project 2: Development and Validation of a Probabilistic Method for Estimating Accumulated Strain and Assessing Strain Demand and Capacity on Existing Pipelines

Recipient: GTI

Project Description: This project aims to develop a comprehensive system for assessing the strain capacity of high-strength steel pipelines. It will combine historical data, real-time measurements (e.g., satellite ground movement data and in-field strain gauges), and advanced modeling techniques to estimate a pipeline's remaining strain capacity and identify potential weaknesses. This project will also recommend interventions to mitigate situations with insufficient strain reserve or modeling uncertainties.

Anticipated Results: This project will result in improved strain capacity estimates by delivering a more accurate and data-driven method for estimating the strain capacity of pipelines. This will provide valuable insights for pipeline operators and allow them to make informed decisions regarding maintenance and safety procedures. By incorporating various threat models, the system will be able to identify and prioritize potential risks for pipeline failure—such as compressive buckling and tensile overload—for enhanced thread identification. Based on the strain capacity analysis, the project will recommend specific, targeted interventions to address situations where pipelines may be exceeding their safe operating limits. This could include pipeline repair, pressure reduction, or even replacement.

Potential Impact on Safety: This project can help prevent catastrophic failures caused by exceeding pipeline strain capacity by providing a more accurate assessment of pipeline health. The information on potential threats and recommended interventions will enable pipeline operators to implement proactive maintenance strategies, addressing issues before they become critical. The project will shift pipeline safety management from reactive to proactive, allowing operators to make data-driven decisions to ensure safe and reliable operation.

Project 3: Design and Placement of Compact Service Regulators

Recipient: GTI

Project Description: This project aims to expand safe natural gas service regulator installation options for utilities. By evaluating new "vent-limiting" regulators and comparing them to traditional models, the project will determine if these vents can be installed outdoors with reduced clearance requirements from buildings. This could provide gas utilities with more flexibility in meter and regulator placement.

Anticipated Results: This project will establish whether vent-limiting regulators can be safely installed outdoors with reduced clearance distances. This could provide utilities with more options for placing meters and regulators outside of buildings. Based on the testing and evaluation, the project will develop new guidelines and recommendations for the safe use of vent-limiting regulators, providing clear guidance for natural gas utilities considering these new technologies. The project's findings have the potential to influence industry standards and codes regarding service regulator installation, which could ultimately lead to wider adoption of vent-limiting regulators for safe outdoor placement.

Potential Impact on Safety: This project will establish clear guidelines for vent-limiting regulators and promote consistent safety practices across the natural gas industry. Gas leaks inside buildings can lead to explosions or carbon monoxide poisoning; moving regulators outdoors minimizes this risk. Additionally, regulators located outdoors might be easier to access for maintenance and inspection, potentially leading to earlier detection and repair of potential issues.

Project 4: Development of Corrosion/Erosion Threat Assessment Methodologies and Enriched Preventive and Mitigative Measures to Promote Safety of Gas Gathering Pipelines

Recipient: North Dakota State University

Project Description: This project involves gas gathering pipeline safety by developing a new, data-driven method to assess corrosion and erosion risks. The project will combine advanced computer modeling, experiments, and data analysis to create a unified approach for predicting the likelihood and severity of these threats. This will be used to develop improved preventive and mitigation measures for gas pipeline safety.

Anticipated Results: The project will deliver a probabilistic method for assessing the likelihood and severity of corrosion and erosion in gas gathering pipelines. This will provide a more data-driven and accurate picture of pipeline health compared to current methods. Based on the improved assessment method, the project will develop new and improved strategies to prevent and mitigate corrosion and erosion threats in gas pipelines, which could involve new maintenance activities, material selection techniques, or pipeline protection methods.

Potential Impact on Safety: The project can help prevent pipeline failures caused by corrosion and erosion, and will allow pipeline operators to take a more proactive approach to

managing pipeline health and safety. This can be accomplished by providing an improved and more accurate assessment of corrosion and erosion threats and mitigation strategies.

Project 5: Pipeline Risk Management Using Artificial Intelligence-Enabled Modeling and Decision Making

Recipient: Rutgers, The State University

Project Description: The project will develop AI-enabled tools to improve accuracy of probabilistic performance modeling, and support decision-making of inspection and repair actions in pipeline risk management.

Anticipated Results: The project is expected to develop AI-based solutions that can identify connections between pipeline safety datasets through data analytics; develop data-driven probabilistic prediction models of pipeline degradation using Bayesian[4] neural network; quantify probability of failure with uncertainties; and support decision-making of pipeline inspection and repair using an innovative reinforcement learning approach.

Potential Impact on Safety: The results of this project will allow operators to utilize AI for quantitative risk-based management and make better informed integrity management decisions.

Project 6: Easily Deployed Distributed Acoustic Sensing System for Remotely Assessing Potential and Existing Risks to Pipeline Integrity

Recipient: Colorado School of Mines

Project Description: The purpose of this project is to investigate the feasibility of using distributed acoustic sensing (DAS) with cable inside a pipeline to detect and locate the potential and existing risks to pipeline integrity from the vibration signals, and the effectiveness and robustness of risk assessment using different cable deployment methods, especially easily deployed cables inside the pipeline.

Anticipated Results: The project is expected to use DAS with cables inside the pipeline to detect and locate various risks through vibration signals.

Potential Impact on Safety: The DAS technology identified in this project could serve as a highly advanced tool for detecting a variety of pipeline threats in real time, including corrosion and dent/pipe deformation, liquid accumulation, and leaks.

Project 7: Fiber Optic Sensors for Direct Pipeline Monitoring Under Geohazard

Recipient: Paulsson, Inc.

Project Description: The goal of this project is to design and test a fiber optic system to monitor high-risk pipeline locations for geotechnical hazards, such as geological faults. The fiber optic system will measure strain, temperature, and acoustics to provide continuous

[4] https://en.wikipedia.org/wiki/Bayesian_statistics

monitoring to pipeline operators at these locations.

Anticipated Results: The project is expected to produce and test a prototype monitoring system at a laboratory scale. After laboratory testing, they will conduct a nine-month field test on an in-service pipeline at a geological fault. Field testing data will be analyzed and used to further refine the tool for commercial use.

Potential Impact on Safety: This project will reduce pipeline accidents caused by natural forces, such as earth movement. This monitoring equipment installed in high-risk areas will permit real-time monitoring of the location, and allow operators to assess risk more accurately and respond quicker to any hazardous conditions.

Table 8-b documents the projects funded during FY 2022 for this programmatic element.

Table 8-b. FY 2022 Funded Projects – Preventing Pipeline Threats/Damage

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Fiber-Optic Excavation Monitoring Sensor System	$149,997 (SBIR)	Intellisense Systems, Inc.	Torrance	CA
2.	Performance Evaluation and Risk Assessment of Excessive Cathodic Protection on Vintage Pipeline Coatings	$513,800 (CAAP)	The University of Akron	Akron	OH
3.	Dynamic Geohazard Risk and Decision Support Platform	$398,750 (Core)	Boston Geospatial, Inc.	Boston	MA
4.	Developing Corrosion Control Monitoring Technology for Hazardous Liquid Breakout Tanks	$250,001 (Core)	PRCI	Chantilly	VA
5.	Monitoring the Long-Term Compatibility of Vapor Corrosion Inhibitor and Cathodic Protection Associated Components	$400,015 (Core)	PRCI	Chantilly	VA
				FY 2022 Total: $1,712,563	

Project 1: Fiber-Optic Excavation Monitoring Sensor System

Recipient: Intellisense Systems, Inc.

Project Description: This Phase I project sought to develop a new fiber-optic monitoring and ML system to provide vibration detection with high spatial resolution, long sensing distance, threat localization, low false alarms, and immunity to electromagnetic interference.

Anticipated Results: The Phase I project served as an initial proof-of-concept for technology. The contractor designed and tested a prototype system at a laboratory scale. This testing proved the ability of the system to carry, detect, and locate a vibration signal along the fiber optic. Based on the successful Phase I results, this project moved to a Phase II in 2023 with the aim of developing a field-deployable system.

Potential Impact on Safety: These project results may help reduce damage to pipelines caused by third parties, such as excavators. The system will allow real-time detection of threats, such as machinery operating near the pipeline, enabling operators to respond quicker to hazardous conditions.

Project 2: Performance Evaluation and Risk Assessment of Excessive Cathodic Protection on Vintage Pipeline Coatings

Recipient: The University of Akron

Project Description: This project aims to develop a model to predict coating disbondment in vintage pipelines under CP. The experimental testing, numerical analysis, and resulting coating performance data will be used to develop a probabilistic degradation model that operators can use to determine pipeline sections in need of coating remediation and recoating times.

Anticipated Results: The project is expected to result in: (1) a better understanding of coating cathodic disbondment mechanism; (2) industry-ready probabilistic prediction models for coating degradation; (3) a crucial body of knowledge of coating performance under CP; and (4) better knowledge of the propagation and quantification of prevailing uncertainties in prediction models for the quantitative risk management of pipelines.

Potential Impact on Safety: This study will help pipeline operators identify critical sections and schedule optimal recoating times, enhancing safety and cost-effectiveness through data-driven decision making.

Project 3: Dynamic Geohazard Risk and Decision Support Platform

Recipient: Boston Geospatial, Inc.

Project Description: This project aims to develop a web-based decision support tool for pipeline operators. Leveraging geographic information system (GIS) technology, this tool will identify and assess the impact of geohazards on both cast iron and non-cast iron oil and gas pipelines. The tool will consider established industry standards and best practices for pipeline design and geohazard management, and will incorporate satellite-based radar technology to detect and monitor ground movement—a key indicator of potential geohazards. The tool will be cloud-based, allowing for easy access and scalability for pipeline systems of any size.

Anticipated Results: The proposed project will create a web-based, GIS tool that helps operators identify areas impacted by geohazards based on previous events or forecasted hazards using satellite radar-based ground motion insights as well as other geospatial data. In consulting with mechanical design code, geotechnical engineering, geohazards, and costing subject matter experts and academic leaders, this tool will incorporate best practices and best-in-class geospatial technologies to aid operators in avoiding geohazard incidents and make recommendations on remediation. The project team intends to fully commercialize this tool by co-marketing with its channel partners and selling tool access to operators.

Potential Impact on Safety: The proposed project will improve pipeline safety and operations by providing operators with the ability to overlap past geohazard risks with forecasted future ones. With this capability, better choices can be made with regards to rehabilitation, replacement, or triage of existing cast iron and non-cast iron pipelines. It will also lead to a reduction in casualties and property damage, as well as a decrease in the environmental impact that oil and gas systems have on our communities.

Project 4: Developing Corrosion Control Monitoring Technology for Hazardous Liquid Breakout Tanks

Recipient: PRCI

Project Description: This project tackles a critical challenge in oil and gas storage infrastructure—corrosion under breakout tanks—and aims to achieve two key goals. First, through research and evaluation, the project will identify and validate reliable technologies for monitoring corrosion conditions beneath breakout tanks, which will provide operators with effective tools to assess the health of their tanks. Second, the project will go beyond identifying technologies, and will develop practical and efficient monitoring programs that can be readily implemented by tank operators. These programs will provide clear guidance for effective corrosion monitoring. The project will provide tank operators with the information needed to evaluate and monitor the effectiveness of existing corrosion control measures (e.g., tank pads or coatings); identify trends in the corrosivity of the tank pad allowing for proactive maintenance; and determine if additional corrosion control measures (e.g., VCIs) are necessary to prevent future problems.

Anticipated Results: This project aims to identify and validate reliable methods for monitoring corrosion beneath aboveground storage tanks (ASTs), which will provide operators with effective tools to assess the health of their tanks. The project will go beyond identifying technologies by establishing clear and efficient monitoring programs that tank operators can readily use, and will outline how to use the validated technologies for effective corrosion control. By implementing the monitoring programs, the project will provide valuable data on the corrosivity of the tank pad material over time, and will allow operators to anticipate potential issues and take proactive maintenance measures. The project will also assess the effectiveness of existing corrosion control methods, such as CP systems, and assist operators in determining if additional corrosion control measures, such as VCIs, are warranted. The project will also determine the optimal dispersion range and reapplication interval for VCIs to increase

efficacy.

Potential Impact on Safety: This project can help prevent leaks from occurring initially by providing reliable methods for monitoring corrosion and evaluating the effectiveness of existing corrosion control measure. Leaks can pose a safety risk due to a potential fire hazard and environmental contamination. Early detection of corrosion allows for timeline maintenance and repairs, preventing further deterioration and potential failures that could lead to leaks and safety incidents. The project's findings on VCI use and the need for additional controls can help operators implement more targeted and effective corrosion mitigation strategies, which will minimize the risk of corrosion reaching a critical stage and causing a leak. Effective monitoring and corrosion control practices can extend the lifespan and improve the overall integrity of ASTs, reducing the risk of tank failure and associated safety hazards.

Project 5: Monitoring the Long-Term Compatibility of VCI and CP Associated Components

Recipient: PRCI

Project Description: This project will research and identify technologies that can detect and quantify the interaction between VCI- and CP-associated components. Additionally, the project will provide an in-depth understanding of the VCI technology operating parameters, including delivery methods, coverage, dosages, monitoring, reinjection, and interaction with CP and associated components, such as anodes. This project will provide aboveground storage tank (AST) operators with a deeper understanding of how VCIs and CP work together, allowing them to optimize VCI use, and improve the overall safety and lifespan of their ASTs.

Anticipated Results: The major project outcome will be an in-depth understanding of the VCI technology's operating parameters, such as delivery methods, coverage, dosages, monitoring, reinjection, and its interaction with the CP and associated components, such as the anodes. Most importantly, the project will result in generation of knowledge and in-depth understanding of the VCI technology that operators can directly use in field implementation, and, thereby, improve life-cycle performance of the AST bottoms.

Potential Impact on Safety: The VCI technology identified in this project can be used as an alternative corrosion control tool to CP, and can be used as standalone or in combination with CP. This project will help operators understand the complex interaction between VCIs and CP. The widespread usage of VCI technology will help the tank operators improve mitigation of soil-side corrosion, and thus, improve safety plus reduce the AST operational life-cycle cost. Corrosion induced integrity breaches of the breakout tank bottoms result in the release of hazardous liquids that can migrate into the biosphere if secondary containment is not functional or is compromised; leakage of the hazardous liquids into the biosphere could have an adverse effect on public health and safety.

8.1.2 Improving Pipeline Leak Detection Systems

Description: The funding total for this Program Element is $1,927,342

Activities in this topic area developed new or improved tools and technology solutions for locating, quantifying, and reducing the gas or liquid volumes released into the environment because 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 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. In 2021 no topics solicited fell into this safety priority area, therefore, no projects are listed below for FY 2021. In 2022, this was a focused safety priority area; funded projects through the solicitation processes for FY 2022 are listed in Table 8-c followed by project details, including description, anticipated results, and potential impact on safety.

Table 8-c documents the projects funded during FY 2022 for this programmatic element.

Table 8-c. FY 2022 Funded Projects – Improving Pipeline Leak Detection Systems

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Advancing H_2 Leak Detection and Quantification Technologies Compatible with H_2 Blends	$749,446 (Core)	Gas Technology Institute	Des Plains	IL
2.	Accelerating Pipeline Leak Detection Quantification Solutions Through Transparent and Rigorous Scientific Validation	$600,000 (Core)	Colorado State University	Fort Collins	CO
3.	Innovative Leak Detection Methods for Gas and Liquid Pipelines	$384,268 (Core)	PRCI	Chantilly	VA
4.	Field Validation Demonstrations to Advance Pipeline Leak Detection Beyond Current Capabilities	$193,628 (Core)	Siemens Energy, Inc.	Orlando	FL
					FY 2022 Total: $1,927,342

Project 1: **Advancing H_2 Leak Detection and Quantification Technologies Compatible with H_2 Blends**

Recipient: GTI

Project Description: The goal of this project is to advance leak detection as H_2 is introduced into natural gas infrastructure by investigating the impact of H_2 injection on leak dynamics and

the effect of H_2 on existing leak detection equipment. To accomplish this, the project team will evaluate leak detection equipment currently being used by natural gas pipeline operators; provide guidance on new/altered usage protocols; map out any threshold of H_2 blending above which these devices become not effective; and quantitatively map out the impact of varying amounts of H_2 on the calibration and analytics of this equipment. Where gaps are identified, the project will develop a proof-of-concept H_2 detection scheme to fill those gaps.

Anticipated Results: This project will develop new leak detection sensing schemes for H_2 and natural gas/H_2 blends. The results will also produce important information on required sensing specifications and detection procedures. This will be from extensive literature review, laboratory testing, and field testing of existing commercially available and newly developed sensing technologies and detection methodologies.

Potential Impact on Safety: The findings of this project are important for advancing our understanding of H_2 and natural gas/H_2 blend leaks. In addition, the project will ensure that any leaks can be detected quickly and efficiently; reduce potential safety impacts caused by undetected leaks; and, most importantly, minimize misinterpreted leak detection results causing an underestimation of the size and potential safety hazard of a leak.

Project 2: Accelerating Pipeline Leak Detection Quantification Solutions Through Transparent and Rigorous Scientific Validation

Recipient: Colorado State University

Project Description: This project seeks to enhance leak detection capabilities for pipelines in difficult conditions by examining and recording the methodologies employed by existing technology service providers for leak detection and quantification, assessing their suitability for complex pipeline environments rather than focusing solely on specific technologies. The project will identify potential improvements to methods for better performance and conduct comprehensive, multi-solution, controlled field testing, including testing multiple pipeline types (e.g., flow and gathering lines), complex environments (e.g., aerodynamics, topography, and accessibility), and varying operating conditions. Through testing and analysis, the project will deliver practical improvements to leak detection protocols that can be readily adopted by operators and guide future technology development.

Anticipated Results: The project is expected to provide valuable insights for enhancing existing leak detection protocols used in complex pipeline environments. The project will also deliver practical recommendations for improving leak detection practices, helping pipeline operators to better identify and address leaks. Additionally, the findings on leak detection method enhancements will inform the development of future leak detection solutions for pipelines operating in challenging conditions.

Potential Impact on Safety: The project's findings can be used to enhance routine monitoring practices, allowing operators to tailor leak detection strategies for specific pipelines and environments. Ultimately, this project has the potential to significantly improve pipeline safety

through earlier leak detection, better monitoring, and the development of more advanced leak detection technologies. By improving leak detection methods, especially in difficult environments, this project can lead to faster leak identification and repair, reducing environmental damage and safety risks.

Project 3: Innovative Leak Detection Methods for Gas and Liquid Pipelines

Recipient: PRCI

Project Description: This project aims to improve leak detection by enhancing computational pipeline monitoring (CPM) methods. The project will develop better algorithms for estimating inventory levels; improve zone balancing calculations for leak identification; and create troubleshooting techniques for high-error situations. Additionally, the project will develop methods to recognize leak patterns and differentiate them from measurement errors. These advancements aim to reduce flow uncertainty, simplify inventory management, and ultimately enable earlier and more precise leak detection.

Anticipated Results: This project will develop advanced algorithms for pipeline leak detection using CPM. The project will achieve this through improving flow measurement and accuracy, including zone balancing, which will allow for detection of smaller leaks that might be missed by current systems. It will also develop simplified and user-friendly methods for handling changes in pipeline inventory. The developed technology will be tested on simulated systems followed by validation on a gas or liquid hydrocarbon pipeline system.

Potential Impact on Safety: The project methods will allow for the detection of smaller leaks and/or less time to reliably detect larger leaks than can currently be performed with existing leak detection systems. In any combination of size/response time, less product is lost from the pipeline using the methods to be developed here, which will minimize the risk associated with leaks, such as explosions, and reduce environmental impacts.

Project 4: Field Validation Demonstrations to Advance Pipeline Leak Detection Beyond Current Capabilities

Recipient: Siemens Energy, Inc.

Project Description: This project aims to validate the capabilities of Siemens' Spontaneous Leak Detection System (SLDS) through controlled testing. The project will simulate pipeline ruptures of various sizes by opening valves at different locations along the pipeline. These tests will assess the ability of the SLDS to detect and identify the negative pressure wave generated by the simulated leak, and measure the propagation time of the pressure wave to determine the precise location of the leak using global positioning system coordinates.

Anticipated Results: This project will confirm whether the SLDS can effectively detect leaks of varying sizes by identifying the negative pressure wave they create. The tests will also evaluate the accuracy of the SLDS in pinpointing the leak location based on analysis of the

propagation time of the negative pressure wave.

Potential Impact on Safety: The validation of the SLDS in this project can enable quicker response compared to traditional methods relying on pressure loss volume by detecting leaks within seconds based on pressure changes and without false positives. Faster leak detection can minimize the amount of product lost through a leak, reducing economic impact and potential environmental damage. Precise leak location data from the SLDS can help operators pinpoint the leak source for faster and more targeted repair efforts.

8.1.3 Improving Anomaly Detection and Characterization

Description: The funding total for this Program Element is $2,962,244

Activities in this topic area were designed to support the pipeline industry in making integrity management decisions, and finding and removing critical defects or anomalies in the pipeline system. This research area supported both anomaly detection and characterization efforts within pipelines, and provides operators with effective instrumentation to enable accurate remediation measures. Table 8-d shows funded projects for FY 2021; the table is followed by project details, including description, anticipated results, and potential impacts on safety. As this was a focused research area in 2021, no further topics were solicited in 2022.

Table 8-d documents the projects funded during FY 2021 for this programmatic element.

Table 8-d. FY 2021 Funded Projects – Improving Anomaly Detection and Characterization

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Assessment of Nondestructive Examination (NDE) and Condition Monitoring Technologies for Defect Detection in Non-Metallic Pipe (NMP)	$992,483 (Core)	Edison Welding Institute, Inc. (EWI)	Columbus	OH
2.	Robust, Field-Ready, Inline Tool for the Accurate Measurement of Pipe Bending Stresses and Crack Detection	$984,396 (SBIR)	Creare, LLC	Hanover	NH
3.	Meandering Winding Magnetometer Array Bending Stress and Crack Detection In-Line Inspection (ILI) Module	$985,365 (SBIR)	JENTEK Sensors Inc.	Marlborough	MA
				FY 2021 Total: $2,962,244	

Project 1: Assessment of Nondestructive Examination (NDE) and Condition Monitoring Technologies for Defect Detection in Non-Metallic Pipe (NMP)

Recipient: EWI

Project Description: This project will evaluate several NDE methods for detecting flaws, damage, and anomalies in non-metallic pipe (NMP); establish detection and sizing thresholds; and develop inspection guidelines for in-plant quality assurance (QA), quality control (QC), and field applications. Demand for spoolable composite pipe and reinforced thermoplastic pipe is increasing in many onshore and offshore oil and gas applications supporting production, gathering, transmission and distribution operations. However, limited capability currently exists for NDE of these pipes either as a manufacturing QC tool or to assess in-service condition. This presents a significant gap in the development and implementation of robust engineering assessment methodologies, and limits expanding use of these types of NMP. Completion of this research effort will provide a critical foundation for the development of robust safety and integrity assessment methods for NMP.

Anticipated Results: The deliverables from this project will include NDE procedures for in-plant QA/QC inspection, a guidance document for selecting NDE methods for inspection of NMP, a guide for requirements for in-service NMP inspection, a series of written reports quantifying the detection and sizing of various NDE methods, a virtual workshop to support transfer of the technology to industry, and conference papers.

Potential Impact on Safety: The project will enhance quality control during manufacturing, ensure safer operation through effective in-service inspection, and pave the way for broader use of NMP in the oil and gas industry.

Project 2: Robust, Field-Ready, Inline Tool for the Accurate Measurement of Pipe Bending Stresses and Crack Detection

Recipient: Creare, LLC

Project Description: This project aimed to develop a multimodal ILI tool capable of measuring bending stresses, dents and deformation, metal loss, and cracking on in-service pipelines. The three modes include magnetic flux leakage sensors to detect cracks and metal loss; a magnetic Barkhausen Noise[5] sensor to measure bending stresses; and a laser scanner to detect dents and deformation.

[5] https://en.wikipedia.org/wiki/Barkhausen_effect

Anticipated Results: The project included developing and testing three sensing modules and conducting an in-pipe simulation test. A technical demonstration, including the in-pipe simulation test, was held in New York in June 2023 and attended by PHMSA. This project has been approved for a Phase IIB SBIR, starting in 2024, to complete development and commercialization of the bending stress tool.

Potential Impact on Safety: The project will improve the ability of pipeline operators to measure and classify bending stress in pipelines and respond appropriately. Bending of pipelines due to geotechnical hazards, such as landslides, is currently difficult for operators to properly assess.

Project 3: Meandering Winding Magnetometer Array Bending Stress and Crack Detection In-Line Inspection (ILI) Module

Recipient: JENTEK Sensors, Inc.

Project Description: This project aims to develop an ILI tool to measure bending stress and detect cracks in steel pipelines. Bending stresses will be measured by magnetic permeability of the steel, while cracks can be detected with eddy current technology.

Anticipated Results: The project will test and correlate magnetic permeability readings into bending load estimates; conduct validation testing with bend test apparatus; and complete development of a prototype tool.

Potential Impact on Safety: The project will improve the ability of pipeline operators to measure and classify bending stress in pipelines and respond appropriately. Geotechnical hazards, such as earth movement, can make it difficult to detect bending hazards on buried pipelines. This technology will allow these hazards to be detected and quantified.

8.1.4 Improving Anomaly Remediation and Repair

Description: The funding total for this Program Element is $3,318,075

Activities in this topic area supported reliable methods for repairing damaged coatings and corrosion damage, which are major integrity management challenges for pipelines. Research activities addressed ways to improve the pipeline repair processes and improve standards or best practices for operators. Based on the research conducted, testing is needed for composite materials—which are the most common materials used for pipeline repairs—and to understand their integrity under complex loading and over long-term operational and environmental conditions. Research activities also advanced 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 included developing and validating effective extruded or cured-in-place lining (CIPL) material so that cast iron and bare steel natural gas distribution systems can safely operate without leaks. Table 8-e and

Table 8-f show funded projects for FY 2021 and FY 2022, respectively; the tables are followed by project details, including description, anticipated results, and potential impacts on safety.

Table 8-e documents the projects funded during FY 2021 for this programmatic element.

Table 8-e. FY 2021 Funded Projects – Improving Anomaly Remediation and Repair

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	No-Dig Point Repair Technology for Steel Oil and Gas Pipelines	$998,447 (SBIR)	QuakeWrap, Inc	Tucson	AZ
					FY 2021 Total: $998,447

Project 1: No-Dig Point Repair Technology for Steel Oil and Gas Pipelines

Recipient: QuakeWrap, Inc.

Project Description: This project aimed to create a tool capable of repairing pipeline defects from inside the pipe without requiring excavation. The tool enters the line from an existing access point and deploys a carbon fiber sleeve to the internal pipe surface.

Anticipated Results: The project, completed in February 2024, included developing the tool apparatus, testing and refining the carbon fiber sleeve, and conducting a technology demonstration in December 2023 where a sleeve was deployed in a test pipeline.

Potential Impact on Safety: This project allowed quicker repair to pipelines in difficult to excavate areas, such as under river and highway crossings, as well as reduced the risks to personnel presented when excavating pipelines.

Table 8-f documents the projects funded during FY 2022 for this programmatic element.

Table 8-f. FY 2022 Funded Projects – Improving Anomaly Remediation and Repair

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Risk-Based Decision Support for Rehabilitation of Natural Gas Distribution Pipelines	$400,000 (Core)	GTI	Des Plains	IL
2.	Rapid Ultraviolet (UV) Cured Adhesive for Gas Main Cured-in-Place Lining (CIPL)	$919,628 (Core)	Progressive Pipeline Management	Wenonah	NJ

No.	Project Title	PHMSA Funding Total	Recipient	City	State
3.	All-in-One Multifunctional Cured-In-Place Structural Liner for Rehabilitating of Aging Cast Iron Pipelines	$1,000,000 (CAAP)	North Dakota State University	Fargo	ND
					FY 2022 Total: $998,447

Project 1: Risk-Based Decision Support for Rehabilitation of Natural Gas Distribution Pipelines

Recipient: GTI

Project Description: First, this project will evaluate and rank the threats on aged cast iron and bare steel gas distribution pipelines. Second, it will establish a risk-based approach that provides the acceptable deformations and strain limits of pipeline segments, and recommend actions for their monitoring, rehabilitating, or replacement options. Segments that are deemed suitable for rehabilitation will be evaluated for trenchless repair, such as CIPL, based on pipeline attributes, site conditions, and cost of installation in comparison with other alternatives, such as open trench replacement. A web-based user interface tool will provide the risk levels of the selected segments in a GIS platform. The risk analysis will be based on the probabilities of corrosion and ground movement threats and associated pipe deformations in a Bayesian analysis approach.

Anticipated Results: The project will provide a web program to gas distribution utilities for a decision-support of pipeline replacement and rehabilitation considerations. The reliability of the program will be evaluated against operational data in existing utilities rehabilitated segments.

Potential Impact on Safety: The risk-based decision support system in this project will provide a selection tool and procedures for replacement and rehabilitation options of aged infrastructure. It will increase safety and reduce gas emissions from high-risk cast iron and bare steel pipes in the infrastructure. The risk-based approach will address the gas distribution integrity management program (IMP) requirements to establish effective rehabilitation and replacement programs to prevent leaks and breakage of aged pipelines.

Project 2: Rapid Ultraviolet (UV) Cured Adhesive for Gas Main Cured-in-Place-Lining (CIPL)

Recipient: Progressive Pipeline Management

Project Description: The project will develop a next-generation UV-cured adhesive and curing method that yields a faster cure, adheres to the host gas main, and facilitates a more precise and repeatable installation process. The resulting commercialized product will enable a one-day return to service and be suitable for gas mains up to 48 inches in diameter. Additionally, a well-designed and optimized UV-cured adhesive will reduce working time, reduce construction footprint, eliminate resin pot life obstacles, and enable a fully monitored curing process from within the pipe.

Anticipated Results: The project will deliver a rapid cured UV adhesive for CIPL that is suitable for the full range of degrading gas main pipes in North America. Ultimately, this CIPL technology will reduce the environmental and safety impact of the communities wherein this rehabilitative work is performed.

Potential Impact on Safety: The rapid cured UV adhesive for gas main CIPL identified in this project will reduce construction footprint and site time, as well as alleviate installation risks associated with complex pot-life restrictions of traditional CIPL adhesives.

Project 3: All-in-One Multifunctional Cured-In-Place Structural Liner for Rehabilitating of Aging Cast Iron Pipelines

Recipient: North Dakota State University

Project Description: The intention of this project is to develop an all-in-one, self-healing, self-sensing, high-performance, cured-in-place pipe (CIPP) liner for cast iron pipelines, aiming to enhance sustainability, reliability, and safety through improved performance and risk assessment.

Anticipated Results: The project is expected to develop a new structural liner that will be highly paid off for next-generation lifetime protection of aging, legacy pipelines in terms of self-sensing, self-healing, high-damage tolerance capability.

Potential Impact on Safety: This research project will enhance sustainability and reliability of CIPP technology through self-repair, improved performance, and proactive risk assessment, ultimately contributing to safer and longer-lasting cast iron pipelines.

8.1.5 Improving Design, Materials, and Welding/Joining

Description: The funding total for this Program Element is $3,005,270.

Activities in this topic area address improved pipeline materials and designs that could mitigate or minimize integrity threats to both transmission and distribution piping. The welding and joining of transmission and distribution systems require automation and inspection capabilities that can safely improve the efficiency of construction activities. The development of 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 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. Funded projects are listed in Table 8-g for FY 2021 and Table 8-h for FY 2022, and are followed by project details, including description, anticipated results, and potential impact on safety.

Table 8-g documents the projects funded during FY 2021 for this programmatic element.

Table 8-g. FY 2021 Funded Projects – Improving Design, Materials, and Welding/Joining

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Feasibility of Using Alternative Steel and Composite Material in Gas and Hazardous Liquid Pipeline Systems	$945,270 (Core)	GTI	Des Plaines	IL
					FY 2021 Total: $945,270

Project 1: Feasibility of Using Alternative Steel and Composite Material in Gas and Hazardous Liquid Pipeline Systems

Recipient: GTI

Project Description: The project objective is to identify and address the gaps in implementing qualification process for non-steel and alternative steel composites similar to the ones currently used for steel pipes. The project is designed to map the requirements under 49 CFR Parts 192 and 195, and the special permits issued under 49 CFR § 190.341.

Anticipated Results: The project will provide a framework of the feasibility and requirements for the installation, inspection, and integrity management of alternative steel and non-steel composite systems in natural gas and hazardous liquid gathering and transmission pipelines. The project will establish design qualifications, requirements, inspection procedures, and a roadmap for using alternative steel and non-steel composite systems.

Potential Impact on Safety: The project will establish clear guidelines for the use of alternative materials and will encourage the adoption of their use in a safe and reliable manner.

Table 8-h documents the projects funded during FY 2022 for this programmatic element.

Table 8-h. FY 2022 Funded Projects – Improving Design, Materials, and Welding/Joining

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Determining Steel Weld Qualification and Performance for H_2 Pipelines	$2,060,000 (IAA)	NIST	Boulder	CO
					FY 2022 Total: $2,060,000

Project 1: Determining Steel Weld Qualification and Performance for H_2 Pipelines

Recipient: NIST

Project Description: This project, initiated through a 2019 IAA with NIST, aims to address gaps in current codes and standards for welds in pipelines designed for H_2 transportation. The project will establish new weld qualification procedures for critical welds in H_2 pipelines. This includes seam welds (longitudinal welds made during pipe manufacturing), girth welds (welds connecting pipe sections), and repair welds. These procedures will ensure that welds meet the specific demands of H_2 service. The project will evaluate the performance of various modern steel grades used in pipeline construction when exposed to H_2. This will involve testing these steels under simulated operating conditions to assess their suitability for H_2 transportation. The project will develop methods for evaluating the integrity of existing and pre-code (built before current standards) pipelines for potential H_2 conversion. This will involve establishing assessment parameters to determine if these pipelines can be safely repurposed for H_2 service.

Anticipated Results: The project will deliver new weld qualification requirements for H_2 pipelines and ensure that welds meet the specific challenges of H_2 transportation. This will contribute to the development of safer and more reliable H_2 pipeline infrastructure. Valuable data on the performance of modern steel grades in H_2 environments will also be generated; this information will be crucial for selecting appropriate materials for future H_2 pipelines. The project will also establish methods for evaluating the suitability of existing pipelines for H_2 service, which could potentially extend the lifespan of existing infrastructure and facilitate a smoother transition to H_2 transportation.

Potential Impact on Safety: This project may enhance the safety of H_2 pipelines in several ways. First, the development of robust weld qualification procedures will minimize the risk of weld failures in H_2 pipelines, which, in turn, will help prevent leaks, explosions, and potential

environmental damage. Second, by evaluating the performance of modern steels, this project will contribute to the selection of safer and more reliable materials for H_2 pipelines, reducing the risk of material degradation and pipeline failures. Lastly, this project will develop methods for assessing existing pipelines that will allow for the safe repurposing of existing infrastructure for H_2 transport, which could potentially expedite the adoption of H_2 as a clean energy source.

8.1.6 Improving Safety Systems for Liquefied Natural Gas Facilities

Description: The funding total for this Program Element is $1,271,772.

Activities in this topic area addressed various LNG industry challenges related to LNG hazards, as well as fostered development of new technologies and alternative designs for LNG storage and piping systems. Additional initiatives in this research focus area addressed 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. Table 8-i and Table 8-j show funded projects for FY 2021 and FY 2022, respectively; the tables are followed by project details, including description, anticipated results, and potential impacts on safety.

Table 8-i documents the projects funded during FY 2021 for this programmatic element.

Table 8-i. FY 2021 Funded Projects – Improving Safety Systems for LNG Facilities

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Developing Performance Criteria for External Loading Factors on External Steel Shell Tanks	$424,429 (Core)	Simpson Gumpertz & Heger	Waltham	MA
2.	Liquefied Natural Gas Tanks Without Bottom Fill	$331,760 (Core)	Blue Engineering and Consulting Company	Ellicott	MD
3.	Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks	$165,000 (Core)	PEMY Consulting	Martinez	CA
					FY 2021 Total: $921,189

Project 1: Developing Performance Criteria for External Loading Factors on External Steel Shell Tanks

Recipient: Simpson Gumpertz & Heger

Project Description: The objectives of this project are to evaluate external steel shell tanks subject to external and internal accidental loads, since the resistance of external steel tanks to blast loads, fire radiation and flame impingement, and projectiles have not been studied in detail for full containment LNG tank applications. Mitigation recommendations will be suggested for external steel tanks in order that they provide comparable protection to concrete secondary containment.

Anticipated Results: The project will provide a better understanding of the ultimate capacity and resilience of a nine percent nickel steel secondary container subjected to accidental loads, including blast, fire, projectile impact, and thermal shock. Detailed finite element models (FEMs) of both small and large capacity LNG tanks with steel secondary steel container will be developed for the assessment. Performance criteria will be developed based on consensus standards. Results of the analyses will be checked against the performance criteria to evaluate structural integrity and leak tightness, and compare the response of steel tanks with that of a concrete tank. Fragility analyses will be performed to compare the degrees of safety margin for LNG tanks with steel and concrete secondary containers.

Potential Impact on Safety: The project will provide an enhanced basis of comparing the efficacy of the two secondary containment types against accidental loads. This will provide PHMSA with research to determine whether a metal secondary container provides an adequate level of safety and operational integrity comparable to that of an alternative concrete secondary container.

Project 2: Liquefied Natural Gas Tanks Without Bottom Fill

Recipient: Blue Engineering and Consulting Company

Project Description: This project will review typical design and operating conditions of flat-bottomed LNG storage tanks of different capacity and for different types of facilities to define ranges of conditions for which top filling of the tanks can safely be performed. The project will rely on experience and expertise from tank manufacturers, designers, and plant operators to identify the process means (e.g., operating parameters, instrumentation, control systems) that can mitigate LNG stratification inside the tank and allow the safe operation of LNG tanks without bottom fill capabilities. The limits of operation for top-filled LNG tanks then will be demonstrated quantitatively by means of computational fluid dynamics (CFD) modeling by evaluating two case studies, including a large, export-scale tank (e.g., 160,000 m^3) and a smaller, peakshaver-scale tank (e.g., 40,000 m^3).

Anticipated Results: This project will identify process means that could be used to mitigate LNG stratification inside an LNG tank, in the absence of bottom-fill capabilities, in order to satisfy the requirement in National Fire Protection Association (NFPA) 59A. This 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. It will also define requirements and safe limits of operation for LNG tanks without bottom fill.

Potential Impact on Safety: The operation requirements identified in this project will mitigate LNG stratification inside an LNG tank, in the absence of bottom-fill capabilities, to satisfy the requirement in NFPA 59A. NFPA 59A requires that all LNG tank systems be designed for both top and bottom filling unless other process means are provided to mitigate stratification. The purpose of this requirement is to provide LNG plant operators with the flexibility to introduce LNG at either location, to preserve stable stratification, and to minimize the potential for rollover of the LNG column inside the tank.

Project 3: Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks

Recipient: PEMY Consulting

Project Description: This project will develop a set of inspection recommendations that is based on industry experience, reinforced by sound domain knowledge, supported by stakeholders, and reflective of current state of the art and best available technologies. The recommendations could be included in federal regulations or industry standards.

Anticipated Results: This project will result in the development of an LNG tank inspection guideline and checklist for consideration. The guidelines for the inspection of LNG tanks will develop far enough that they can either be used directly by an owner/operator with some further detailing or they can be further developed by a standards development organization (SDO), such as the API, to write specific, detailed standards or recommended practices. The project includes a detailed checklist as part of the tank inspection guidelines. The conclusions and recommendations are primarily aimed at the regulatory industries, as well as the SDOs that will take this project as an input to the process of developing publicly available American National Standards Institute accredited and recommended practices, guidelines, and standards.

Potential Impact on Safety: The guidelines identified in this project may provide immediate benefit in terms of standardization. Over time, well-written recommendations will foster a strong, healthy market for cryogenic tank inspections and public confidence in the safe and environmentally sound operation of cryogenic tanks.

Table 8-j documents the projects funded during FY 2022 for this programmatic element.

Table 8-j. FY 2022 Funded Projects –Improving Safety Systems for Liquefied Natural Gas Facilities

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Determine the Maximum Permissible Temperature Drops for Steel When Exposed to Cryogenic Liquid	$350,574 (Core)	Simpson Gumpertz & Heger	Waltham	MA
					FY 2022 Total: $350,574

Project 1: Determine the Maximum Permissible Temperature Drops for Steel When Exposed to Cryogenic Liquid

Recipient: Simpson Gumpertz & Heger

Project Description: The project will investigate, test, and determine the maximum permissible rate of temperature changes for various types of steel when exposed to cryogenic liquid. Representative tank and pipe configurations and LNG spill scenarios will be selected from our team's extensive project database. Detailed FEMs will be developed for analyses and tests to be performed. An API 579 fitness-for-service assessment of typical containment tank and pipe-in-pipe systems will be performed at various temperatures based on toughness testing results.

Anticipated Results: The project will determine the maximum permissible rate of temperature changes for various representative alternative types of steel when exposed to cryogenic liquid to inform DOT/PHMSA about the risks and mitigation methods to increase the safety of LNG production in the U.S. The project results will fill the knowledge gaps in terms of material properties for manufactured steel components at cryogenic temperatures and will provide mitigation recommendations to reduce brittle fracture risks due to cryogenic liquid exposure. The findings will be presented at conferences and code committee meetings to inform the industry.

Potential Impact on Safety: This project will increase awareness and inform the industry about potential failure risks due to cryogenic exposure of commonly used steel types and details at LNG plants. Informing the key stakeholders about the behavior of steel and manufactured components at low temperatures, which are not fully covered in the design codes, is expected to reduce component failure risks**.**

8.1.7 Improving Safety Systems for Underground Natural Gas Storage

Description: The funding total for this Program Element is $1,236,584.

Activities in this topic area included research to improve the safety of UNGS facilities for their full life cycle. Research activities focused on reducing risks to the public and environment, and improving UNGS worker safety. Specific research areas included 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. Table 8-k and Table 8-l show funded projects for FY 20211 and FY 2022, respectively; the tables are followed by project details, including description, anticipated results, and potential impacts on safety.

Table 8-k documents the projects funded during FY 2021 for this programmatic element.

Table 8-k. FY 2021 Funded Projects – Improving Safety Systems for UNGS

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Advancement of Through-Tubing Casing Inspection for Underground Storage Wells	$788,594 (Core)	PRCI	Chantilly	VA
					FY 2021 Total: $788,594

Project 1: Advancement of Through-Tubing Casing Inspection for Underground Storage Wells

Recipient: PRCI

Project Description: This project will advance the current state of through-tubing casing inspection technology for underground storage wells. A fit-for-purpose lab test program, including multiple rounds of full-scale physical tests, will assist logging tool vendors to improve their commercial through-tubing logging tools. Specially designed artificial metal loss features installed in representative casing configurations in a lab test well will be used to quantitatively assess the tool performance to provide directional guidance for tool improvement. A reliability-based assessment methodology will be developed to inform the use and interpretation of through-tubing logs for casing corrosion management. A field trial will be conducted to validate vendor tool performance and demonstrate the new assessment methodology.

Anticipated Results: The expected outcome of this project is to establish a workflow that provides operators with improved efficiency in casing corrosion management, using through-tubing inspection technology with reduced cost and well entry risk which is defendable to regulators.

Potential Impact on Safety: This project will provide a more accurate and reliable casing inspection data, improved decision-making for corrosion management with potentially reduced costs and risks, and a defendable approach for regulatory compliance.

Table 8-l documents the projects funded during FY 2022 for this programmatic element.

Table 8-l. FY 2022 Funded Projects – Improving Safety Systems for UNGS

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Smart Well Assessment and Reservoir Management System (SWARMS)	$149,990 (SBIR)	Oceanit Laboratories, Inc.	Honolulu	HI
2.	Expanding H_2 Storage to Porous Rock Formations: A Framework for Estimating Feasibility and Operational Considerations	$298,000 (Core)	GTI	Des Plaines	IL
					FY 2022 Total: $447,990

Project 1: Smart Well Assessment and Reservoir Management System (SWARMS)

Recipient: Oceanit Laboratories, Inc.

Project Description: This project aims to create an innovative method for leak repair in UNGS reservoirs. The system will use engineered particles to dynamically plug leaks.

Anticipated Results: This Phase I project served as a proof of concept for the project and closed in 2022. The project used artificial intelligence and high-fidelity physics modeling to predict likely leak paths in UNGS reservoirs, and then modeled particle sizes that would be most likely to cause a plug in the predicted leak paths. A Phase II project was initiated in 2023 to begin creating and testing actual particles.

Potential Impact on Safety: This project will improve the ability of UNGS operators to repair leaks when they occur by creating particles engineered to cause plugs in leak channels.

Project 2: Expanding H_2 Storage to Porous Rock Formations: A Framework for Estimating Feasibility and Operational Considerations

Recipient: GTI

Project Description: This project will create a set of guidelines to inform gas utilities, storage facilities, and regulatory agencies to assess potential H_2 movement and loss that is based on the formation type, caprock sealing and containment, geochemical reactions, and multiphase H_2 flow with formation fluids. This project will also define the operational considerations needed to address geomechanical reservoir impacts from repeated injection-reproduction cycles on stress fields. This framework accelerates underground H_2 storage (UHS) site screening characterizations and operational considerations for most U.S. porous rock UHS reservoirs.

Anticipated Results: The results of this project will inform a set of guidelines to help gas utilities, storage facilities, and regulatory agencies assess potential H_2 movement and loss, which is based on the formation type, caprock sealing and containment, geochemical reactions, and multiphase H_2 flow with formation fluids. It will also define the operational considerations needed to address geomechanical reservoir impacts from repeated injection-reproduction cycles on stress fields. This framework accelerates UHS site screening characterizations and operational considerations for most U.S. porous rock UHS reservoirs.

Potential Impact on Safety: The framework identified in this project will help identify the most viable candidates for safely storing and recovering H_2 in these types of formations. Porous rock basins for UHS are currently situated in areas of higher power demand that could facilitate ease of access, thus reducing or eliminating added pipeline cost and associated transmission losses.

8.1.8 Advancing Safe Transportation of H_2 and CO_2

Description: The funding total for this Program Element is $5,733,057.

Activities under this focus area addressed methods for improving the safety of H_2, a growing alternative fuel source, and CO_2 transportation via pipeline. The ability to safely transport these commodities by pipeline supports widespread movement of CO_2 from capture to storage and allows H_2 to be more widely utilized in blending with natural gas or in lieu of natural gas as a fuel. Research activities assessed the suitability of current natural gas pipeline infrastructure for the future transportation of pure H_2 gas or blended H_2 with natural gas. Research also addressed the safe deployment of new pipelines and facilities needed to fill any new demand for these fuels. Table 8-m and Table 8-n show funded projects for FY 2021 and FY 2022, respectively; the tables are followed by project details, including description, anticipated results, and potential impacts on safety.

The H_2 specific research activities provided in this focus area give an understanding of potential changes to material properties due to exposure to H_2, such as HE, changes to fatigue crack growth rate, and changes to material toughness, and their potential safety impacts. In addition, this research addressed required pipeline modifications to existing infrastructure and potential design modifications for new pipelines to ensure pipeline integrity.

The CO_2 research activities in this focus area addressed the potential safety impacts of the transportation of supercritical CO_2, as well as other pertinent phases of CO_2, via pipeline. Both research areas contributed to pipeline safety and failure consequence knowledge as the U.S. increases its lower carbon energy portfolio.

Table 8-m documents the projects funded during FY 2021 for this programmatic element.

Table 8-m. FY 2021 Funded Projects – Advancing Climate Change Solutions – H_2 and CO_2

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Knowledge-Guided Automation for Integrity Management of Aging Pipelines (KAI-MAP) for H_2 Transport	$844,726 (CAAP)	Arizona State University (ASU)	Tempe	AZ
					FY 2021 Total: $844,726

Project 1: Knowledge-Guided Automation for Integrity Management of Aging Pipelines (KAI-MAP) for H_2 Transport

Recipient: ASU

Project Description: This project seeks to develop an AI-powered automation framework for managing the integrity of emerging fuel pipelines similar to those used for H_2 through automated data collection, inspection, quality assurance, and risk-based maintenance optimization.

Anticipated Results: The project is expected to develop an AI-enabled framework that automatically extracts safety data from various sources, proposes automated inspection methods for H_2-specific defects, ensures data quality for accurate decision-making, and optimizes maintenance based on risk assessment.

Potential Impact on Safety: This study will improve efficiency, accuracy, and safety in pipeline integrity management for emerging fuels.

Table 8-n documents the projects funded during FY 2022 for this programmatic element.

Table 8-n. FY 2022 Funded Projects – Advancing Climate Change Solutions – H_2 and CO_2

No.	Project Title	PHMSA Funding Total	Recipient	City	State
1.	Determining the Required Modifications to Safely Repurpose Existing Pipelines to Transport Pure H_2 and H_2-Blends	$800,000 (Core)	Engineering Mechanics Corporation of Columbus (EMC^2)	Columbus	OH
2.	Best Purging Practices for Minimizing Methane Emissions	$358,577 (Core)	GTI	Des Plaines	IL
3.	Review of Integrity Threat Characterization Resulting from H_2 Gas Pipeline Service	$240,000 (Core)	EMC^2	Columbus	OH
4.	Development of Compatibility Assessment Model for Existing Pipelines for Handling H_2-Containing Natural Gas	$1,000,000 (CAAP)	University of Oklahoma	Norman	OK
5.	Accelerating Transition Towards Sustainable, Precise, Reliable H_2 Infrastructure (Super H_2): Holistic Risk Assessment, Mitigation Measures, and Decision Support Platforms	$1,000,000 (CAAP)	North Dakota State University	Fargo	ND
6.	Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2	$1,200,000 (Core)	BMT Fleet Technology Limited	Kanata	ON (Canada)
7.	Determination of Potential Impact Radius for CO_2 Pipelines using Machine Learning Approach	$279,754 (CAAP)	Texas A&M Engineering Experiment Station	College Station	TX
				FY 2022 Total: $4,878,331	

Project 1: Determining the Required Modifications to Safely Repurpose Existing Pipelines to Transport Pure H_2 and H_2-Blends

Recipient: EMC[2]

Project Description: The purpose of this project is to determine practical methods for optimizing or repurposing existing pipeline networks for the safe transport of pure H_2 or H_2 blends, and to provide insight into which existing gas transmission pipeline components and associated facilities may need modifications to safely introduce H_2 gas or natural gas/H_2 blends.

Anticipated Results: This research will provide insight into which components of existing gas transmission pipelines and the associated gas compression facilities may need modification so that H_2 gas or natural gas/H_2 blends can be safely introduced. Knowledge from prior work and pilot projects will be collected through a literature review, with focus on both metallic and non-metallic components. Assessment procedures then will be developed to determine the options for reuse, repair, or replacement ("three R" methodology) for components with identified anomalies. This will include a description of procedures for determining acceptable flaw sizes for ILI of pipelines repurposed for H_2 service. The impact of findings on regulatory safety requirements will be reviewed, and suggestions for necessary operator actions will be provided.

Potential Impact on Safety: This project will enable safe and efficient repurposing of existing pipelines for H_2 transport, reducing environmental risks, supporting public safety, and accelerating the H_2 economy transition.

Project 2: Best Purging Practices for Minimizing Methane Emissions

Recipient: GTI

Project Description: The objective of this project is to establish best purging practices for the elimination or avoidance of methane emissions during pipeline construction, commissioning, and maintenance. This will include a literature survey and examination of prior work in these areas related to different methods of avoiding and/or eliminating methane emissions.

Anticipated Results: The deliverables of this project will be a comprehensive literature survey that identifies and details various methods to reduce and/or eliminate methane emissions due to purging and/or blowdown procedures. The technology survey will focus on already existing methods, improvements to these methods, and new technologies and techniques. In addition to a detailed review of commercially available equipment and techniques, a final report will also include operational recommendations and guidance to determine the best practices associated with each technique and method. The review of potential alternatives will also include economic examples and methane emissions avoidance quantification calculations to provide context for comparing the feasibility and benefits of different methods.

Potential Impact on Safety: This project will enhance efforts to minimize methane emissions. Methane releases and emissions can occur in transmission, distribution, and gathering pipelines at any point across the system. Avoidance of methane emissions from purging operations have both economic benefits for operators and environmental benefits for the community. Using alternatives to venting natural gas into the atmosphere also increases public trust in the natural gas industry and provides a safer work environment for pipeline and gathering system operators.

Project 3: Review of Integrity Threat Characterization Resulting from H_2 Gas Pipeline Service

Recipient: EMC[2]

Project Description: The objective of this project is to identify the differences between existing integrity threats and possible new threats resulting from the presence of H_2. H_2 pipeline safety depends on proven methods to collect system integrity information. Each operator's IMP is designed to prevent and mitigate identified and characterized integrity threats. The threat assessment process is necessary for a comprehensive IMP as required by 49 CFR Part 192 for gas transmission pipeline systems. PHMSA incorporates the ASME B31.8S methodology by reference. The operator's IMPs must be updated to incorporate integrity threats during transportation of H_2 or H_2-blends.

Anticipated Results: This research will define a list of possible changes to the ASME B31.8S threat assessment process for H_2 or H_2/natural gas blended service in new or existing pipelines. The results will inform whether a need for any changes to the threat process charts exists with a focus on time-dependent threats, and to the methods used to determine integrity assessment/reassessment intervals. Such methods can include threat algorithms, tool selection to inspect for features, and repair criteria and acceptance limits for identified flaws.

Potential Impact on Safety: This project will provide an updated threat assessment process for pipelines in H_2 gas service and will allow for better understanding of factors influencing the risks for pipeline rupture or leaks. Improved burst pressure predictions are essential for the betterment of safety because overpredictions suggest a false sense of low risk of failure, while underpredictions will require excessively conservative integrity management measures to be implemented. Improving leak predictions by establishing critical flaw sizes will help reduce environmental impact of gas escaping a pipeline, which is beneficial to both the pipeline industry and the general public.

Project 4: Development of Compatibility Assessment Model for Existing Pipelines for Handling H_2-Containing Natural Gas

Recipient: University of Oklahoma

Project Description: The intension of this project is to develop a data-driven software tool to assess the compatibility of existing pipelines for transporting blended and pure H_2 gas, considering HE, and suggesting necessary modifications for safe operation.

Anticipated Results: The project is expected to develop a data analytics-based compatibility assessment model that will leverage existing and new experimental data on HE, evaluate different data analytics methods for HE prediction, and incorporate these methods into a comprehensive model.

Potential Impact on Safety: This study will develop a publicly available software tool for pipeline operators to assess compatibility for blended/pure H_2, and identify necessary modifications for safe transport (e.g., gas processing, HE inhibitors).

Project 5: Accelerating Transition Towards Sustainable, Precise, Reliable H_2 Infrastructure (Super H_2): Holistic Risk Assessment, Mitigation Measures, and Decision Support Platforms

Recipient: North Dakota State University

Project Description: The intention of this project is to develop an AI-powered platform ("Super H_2") to accelerate the safe transition of existing gas pipelines for H_2 transport, including decision support tools for risk mitigation and best practices for the pipeline industry.

Anticipated Results: The project is expected to develop the Super-H_2 platform, featuring:

- AI-powered decision inference: analyzes data and suggests optimal strategies for pipeline conversion;
- Goal-oriented optimization: customizes solutions based on specific pipeline characteristics and desired outcomes; and
- Context-driven recommender engine: identifies potential risks and suggests mitigation measures.

Potential Impact on Safety: This study will provide data-driven insights for safe H_2 pipeline operation and offer valuable recommendations for the pipeline industry.

Project 6: Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2

Recipient: BMT Fleet Technology Limited

Project Description: This research project will apply engineering learnings and methodologies to realistically assess the impact of CO_2 on pipeline integrity, and the impact of

bursts and leaks on the public adjacent to the ROW, and then develop design criteria, welding requirements, and material testing specifications needed to qualify new and existing pipelines for transporting CO_2 safely. The work will identify safety gaps and requirements to support best practices for both gaseous, dense phase, and liquid systems, beyond the requirements of 49 CFR Part 195 for CO_2 pipeline transportation.

Anticipated Results: This project will conduct a comprehensive review, compare existing knowledge with operational needs, and identify gaps to define performance-based safety targets for various CO_2 pipeline states (i.e., gas, dense phase, liquid). This project will provide clear safety targets for CO_2 pipelines, considering unique properties and potential public risks that hinder safe transportation and require improved regulations and practices.

Potential Impact on Safety: This project will support the protection of people and the environment by advancing the safe transportation of impure CO_2, at both low pressure (gas phase) and high pressure (supercritical and dense phase) by defining the state of knowledge and how it can be applied in CO_2 pipeline design, operation, and maintenance. The information developed in this project will support the development of future designs and the assessment of existing pipeline conditions and performance, and, if required, will help define the root cause of failures. CO_2 pipeline standards committees and regulators will be able to employ the information developed to advance their work.

Project 7: Determination of Potential Impact Radius for CO_2 Pipelines Using Machine Learning Approach

Recipient: Texas A&M Engineering Experiment Station

Project Description: The intention of this research project is to develop an ML tool to predict the consequences and risks of accidental CO_2 dispersion from ruptured pipelines, using CFD simulations and scenario analysis.

Anticipated Results: The project is expected to develop an ML tool/quantitative property consequence relationship using CFD simulations and scenario analysis to predict CO_2 dispersion and consequences.

Potential Impact on Safety: This study will enable rapid risk assessment, improve safety by informing planning and emergency response, and provide a universally applicable tool for diverse pipeline scenarios.

8.2 Impacts on Standards and Publications

8.2.1 Standards

Many regulators, including PHMSA, incorporate consensus standards into regulation. The goal is to strengthen and streamline regulations with a less prescriptive approach that allows

performance to drive how regulations are met. Collaborative research that targets consensus standards feeds new knowledge into the process of keeping standards relevant to their purpose. The PHMSA R&D Program regularly funds research that will strengthen the scope and expand the applicability of pipeline standards. PHMSA measures the research benefit of projects addressing standards and to date has impacted standards from many organizations as shown in Table 8-o.[6]

Table 8-o shows the standards that have been impacted by PHMSA directed research.

Table 8-o. Impact on Participating Standards Developing Organizations

No.	Organization Name	Standards Addressed by Projects	Projects Addressing Standards [A]	PHMSA [A]
1.	ASME	7	21	$9.32M
2.	API	10	26	$11.41M
3.	AMPP	14	27	$6.37M
4.	NFPA	1	6	$2.48M
5.	American Society for Testing and Materials	6	7	$3.39M
6.	DNV	1	1	$ 0.17M
7.	American Welding Society	3	3	$1.36M
8.	Society for Protective Coatings	1	1	$0.14M

A. One project may impact multiple standards; thus, the count shown here can and will be different from more-detailed counts.

There is additional focus on transportation of hydrogen by pipeline. In response, standards that currently exist for natural gas pipelines, such as API 1104, "Welding Pipelines and Related Facilities," are being revised to include H_2. Other standards that apply directly to H_2 pipelines, such as ASME B31.12, are also being updated as new research produces critical data regarding the impact of H_2 on pipeline materials. PHMSA has historically funded research to strengthen consensus standards and continues to do so, including projects that impact standards related to emerging fuels.

A working group at the 2021 Emerging Fuels R&D Forum identified the need for weld qualification requirements for new and existing assets transporting H_2 or H_2-natural gas blends. A comprehensive statement of work was developed, and this project was funded as an interagency agreement between PHMSA and the National Institute of Technology and Standards. "Determining Steel Weld Qualification and Performance for Hydrogen Pipelines"

[6] https://primis.phmsa.dot.gov/rd/performance_cs.htm

began in August of 2022 with research scheduled to conclude at the end of 2024.[7]

The scope for this project includes a comprehensive review of current codes and standards for gaps in qualification requirements for welds in pipelines intended for H_2 transportation and to provide: (1) weld qualification requirements for new steel pipeline assets, including seam, girth, and repair welds; (2) performance evaluations for varying modern steel grades; and (3) assessment parameters for evaluating the integrity of existing and vintage (pre-code) assets.

This work is intended to contribute to possible modifications of industry codes, such as ASME B31.12, and standards, such as API 1104, and will include a comparison of existing codes and standards with regulations for pipelines carrying natural gas under 49 CFR Part 192. The project team shared their findings at the 2024 API/AGA Joint Committee on Pipeline Welding Practices and with the API 1104 H_2 Task Group. Revisions to ASME B31.12 currently are underway and the results from this project are being incorporated.

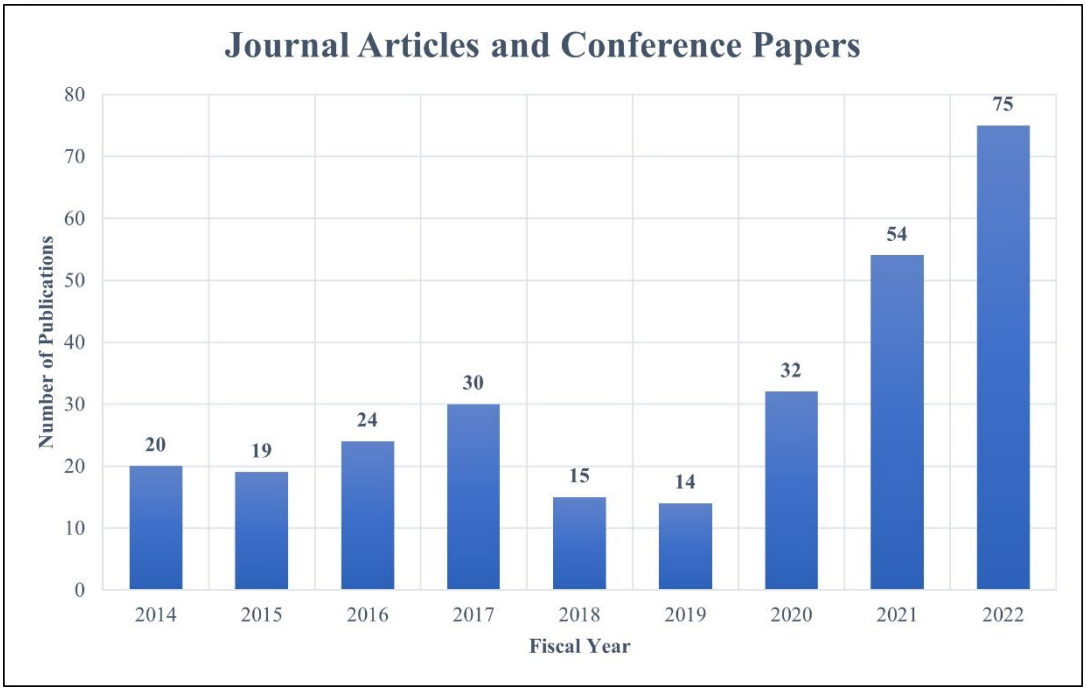
[7] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=976

8.2.2 Publications

Publications of PHMSA-funded research increased significantly in FYs 2021 and 2022 over the previous two FYs (see Figure 8-a).

Figure 8-a shows publications in journals and conferences stemming from PHMSA-funded research.

Figure 8-a. Publications of PHMSA-Funded Research



In FY 2021, PHMSA-funded R&D projects resulted in a total of 54 publications in such journals as *Process Safety and Environmental Protection* and the *Journal of Pipeline Science and Engineering* ,and conference papers from such events as the ASME 2020 15th International Manufacturing Science and Engineering Conference.

The research team at Colorado School of Mines published three journal articles and one conference paper in FY 2021, sharing the findings of their project, "Tools for Predicting Gas Migration and Mitigating its Occurrence/Consequence."[8] Results were shared at the 2021 PRCI Virtual Research Exchange and in the journals *Elementa* and *Environmental Pollution*. This project resulted in a more comprehensive understanding of leak response operational practices, specifically regarding gas migration from underground pipeline leakage. Also, influence of the subsurface and surface environment linked to variability in atmospheric

[8] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=748

conditions was identified and further investigated by field experiments and numerical modeling.

In FY 2022, PHMSA-funded R&D projects resulted in 34 articles in journals, such as the *Journal of Petroleum Science and Engineering* and the *Journal of Remote Sensing*. PHMSA-funded researchers also had a strong presence at conferences post-COVID lockdown, presenting40 papers at conferences, such as the 2022 14th International Pipeline Conference and the American Society of Civil Engineers Pipelines 2022 Conference.

PHMSA research had international exposure with a presentation on "X-Ray Computed Tomography for Characterizing Crack-Link Defects" at the 23rd Joint Technical Meeting of the European Pipeline Research Group (EPRG)-PRCI-APGA, held in Edinburgh, Scotland, in June of 2022. [9,10] As pipeline infrastructure worldwide continues to age, NDE technology, such as X-ray computed tomography, has emerged as a tool that could address the need for more reliable and accurate inspection techniques.

Through the end of FY 2022, PHMSA-funded R&D projects have resulted in a total of 360 journal articles and conference paper publications.

9.0 Performance Management

PHMSA manages the planning, implementation, and reporting of the research, development, and testing projects through internal systems. PHMSA maintains close relationships with research partners throughout a project to ensure the project remains on track and is on-pace to achieve its intended results. PHMSA sends out periodic e-mails to researchers to inquire about the status of patent technologies and commercialization status. PHMSA uses project management best practices to track and evaluate project progress in meeting defined objectives, to ensure milestones and commitments are on track, to monitor and control project risks, and to monitor funds to ensure they are expended properly and in a timely manner. PHMSA tracks projects through performance metrics, such as technology demonstrations, patent applications, commercialized technologies, T2 success rate, and knowledge transfer activities (i.e., the frequency of each completed research project resulting in commercialization).

[9] https://primis.phmsa.dot.gov/matrix/FilGet.rdm?fil=17058
[10] https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=853

9.1 Technology Transfer

Table 9-a provides the metrics that PHMSA uses to measure the development of new technologies during a reporting period.

Table 9-a. Technology Development Metrics

Technology Metric	Performance Definition	FY 2021	FY 2022
New Technology Development Projects	PHMSA tracks the number of new technology research projects that may yield future safety solutions into the market. This metric represents the total number of newly awarded technology projects.	6	8
Technology Demonstrations	PHMSA tracks the number of technology demonstrations occurring within research projects. This metric tracks the exposure PHMSA-funded new technology projects receive, which could increase the likelihood new technology will be commercialized.	14	9
Patents Granted (U.S. or Other)	PHMSA tracks the level of patent activity that resulted from awarded projects both via patent applications and patents granted. This metric indicates the level of activity to protect intellectual property and growth of innovation from PHMSA's program.	2	1
Other Technology Notifications	PHMSA reviews the "granted with no objection" Other Technology Notifications to document if PHMSA funded T2 is being used by the regulated community to demonstrate compliance.	23	40
Commercialized Technology	PHMSA tracks the number of projects bringing new technology to market. PHMSA uses this metric as an overall success rate for T2.	1 Table 9-b	2 Table 9-c
Net Safety Improvement due to T2	PHMSA documents the net safety improvement of T2 on a project-by-project basis. This information is publicly available from project pages where T2 has occurred.	Table 9-b	Table 9-c

Pipeline research has promising advancements. However, translating these innovations into practical solutions requires a focus on commercialization. Fortunately, research projects yielded commercially viable technology that became actively deployed to the field in FY 2021. Table 9-b and Table 9-c highlight these industry-ready solutions, which enhance pipeline safety.

Table 9-b highlights the technologies through PHMSA funded research that were commercialized in FY 2021.

Table 9-b. Highlights of FY 2021 Technology Transfer Activities

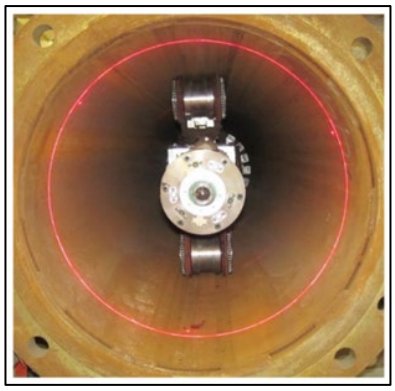
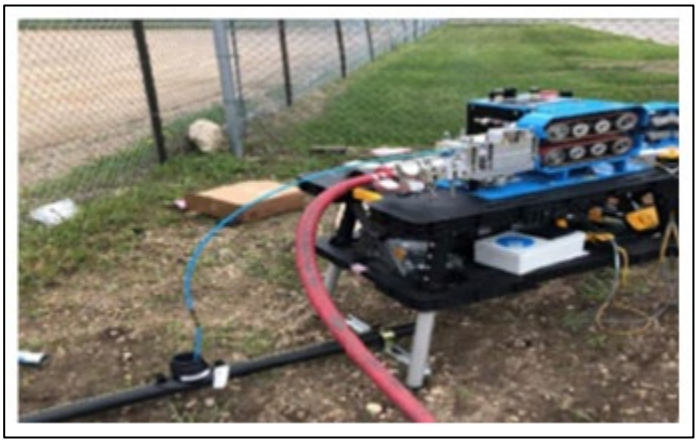
Programmatic Element	Project Title	Technology Transfer Outcome
FY 2021		
Improving Anomaly Detection and Characterization	Develop Field Testing and Commercialization of a Crack and Mechanical Damage Sensor for Unpiggable Natural Gas Transmission Pipeline	The research supported the launch of the laser deformation sensor (LDS) on the Explorer line of robotic inspection tools. The LDS is a laser-based sensor that allows the identification of any mechanical damage or ovality issues in a hard to inspect or unpiggable natural gas transmission pipeline. Unlike its traditional caliper-based mechanical damage sensors found on smart pigs, this sensor has no moving parts, requires minimal power to operate; is very light and occupies very little space. These are all important attributes for effectively operating in traditionally unpiggable systems. It identifies mechanical damage or ovality issues at an accuracy level comparable to or better than traditional calipers.  Photo Courtesy: NYSEARCH  Photo Courtesy: NYSEARCH

Table 9-c highlights the T2 that occurred during FY 2022.

Table 9-c. Highlights of FY 2022 Technology Transfer Activities

Programmatic Element	Project Title	Technology Transfer Outcome
FY 2022		
Preventing Pipeline Threats/Damage	Improved Tools to Locate Buried Pipelines in a Congested Underground	The project developed and validated a geospatial probe to map existing buried utilities through insertion into live gas pipelines. The resulting technology transfer led to the Live Gas Mapper (LGM-2) tool by REDUCT. The LGM-2 can map buried live gas pipes with an internal diameter range of 50 mm (2 inches) up to 100 mm (4 inches). From a single hot tap entry point, it can map a gas pipe up to 300 m (1,000 feet) in length in each direction, thus capturing data and the geographical location of 600 m (2,000 feet) of live gas pipe.  Prototype Testing of Pneumatically Driven Duct Rod Pusher Propelling Duct Rod into a Pipeline *Photo Courtesy: GTI*  *Photos Courtesy: Reduct*

Programmatic Element	Project Title	Technology Transfer Outcome
FY 2022		
Improving Anomaly Detection and Characterization	Electro Magnetic Acoustic Transducer (EMAT) Sensor for Small Diameter and Unpiggable Pipes; Prototype and Testing	The project developed and then demonstrated the ability of the EMAT crack tool to detect tight/closed cracks down to 2MM deep for 8-inch diameter pipes in traditionally difficult to inspect pipelines. The intellectual property from this research and from the prior research project under PHMSA Contract # DTPH56-13-T-000007 evolved into a free-swimming tool that operates at 2 m/s, navigates 1.5 diameter bends, and can be pressurized to 2,200 psi. The EMAT Crack ILI tool is now being offered by Baker Hughes/Qi2 Elements.  Photo Courtesy: Operation Technology Development

9.2 Knowledge Transfer

Table 9-d provides the metrics that PHMSA uses to measure knowledge generated and promoted by its R&D activities during a reporting period.

Table 9-d. Knowledge Metrics

Knowledge Metric	Performance Definition	FY 2021	FY 2022
New Knowledge Promotion Projects	PHMSA tracks the number of knowledge generation research projects that can be promoted to relevant end users.	11	15
Publicly Available Final Reports	PHMSA tracks the number of new final reports made available to the public for utilization in pipeline safety efforts.	26	13
Special Permits	PHMSA reviews approved special permit[8] applications to document if PHMSA funded research results were used by the applicant as part of their application request and if PHMSA staff have used research results to develop conditions included in the special permit approval.	11	23
Conference/Journal Papers	PHMSA tracks the publication/presentation of research results in peer reviewed conferences, journals, and magazines. Publication provides an additional form of peer review and disseminates knowledge out to a wide audience.	18	17
Public Events Held	PHMSA tracks the number of public events held that facilitate dissemination of research project information and results out to a wide audience. This metric is an indication of the level of stakeholder communication.	1	0
Stakeholders Reached at Events	PHMSA tracks the number of stakeholders attending all public events held. This metric is an indication of the level of stakeholder communication and interest in this program.	784	0
Website Visits	PHMSA tracks the number of visits to its research program portal and project pages. This metric is an indication of the level of stakeholder interaction and interest in this program.	758,980	1,047,430
Files Downloaded	PHMSA tracks the number of files downloaded from its research program and project pages. This metric is an indication of the level of stakeholder interaction and interest and level of use of research results.	190,468	146,580

Table 9-e summarizes the knowledge transferred on funded FY 2021 projects completed.

Table 9-e. Highlights of FY 2021 Knowledge Transferred

Programmatic Element Goal	Project Title	Knowledge Transfer Outcome
FY 2021		
Preventing Pipeline Threats/Damage	Design and Placement of Compact Service Regulators	Based on testing, developed and provided new guidelines and recommendations to reduce the minimum clearance distances for vent limiting service regulators, therefore improving the ability of the regulator to be safely installed outside. Gas leaks inside buildings can lead to explosions or carbon monoxide poisoning; moving regulators outdoors minimizes this risk. Additionally, regulators located outdoors might be easier to access for maintenance and inspection, potentially leading to earlier detection and repair of potential issues. Establishing clear guidelines for vent-limiting regulators can also promote consistent safety practices across the natural gas industry.
Improving Safety Systems for LNG Facilities	Developing Performance Criteria for External Loading Factors on External Steel Shell Tanks	Mitigation recommendations were determined for external steel tanks so that they provide comparable protection to concrete secondary containment. LNG tank design gaps were identified, and implementation recommendations presented. This will provide PHMSA with research to determine whether a metal secondary container provides an adequate level of safety and operational integrity comparable to that of an alternative concrete secondary container.
Improving Safety Systems for LNG Facilities	Developing Periodic External/Internal Inspection Requirements to Assess Low Temperature and Cryogenic Storage Tanks	Developed a set of inspection recommendations based on industry experience, underpinned by sound domain knowledge, and supported by stakeholders, and that reflect current state-of-the-art and best available technologies. The regulations and standards these results could be incorporated into or influenced will provide immediate benefit in terms of standardization. Over time, well written recommendations will foster a strong, healthy market for cryogenic tank inspections, and increase public confidence in the safe and environmentally sound operation of cryogenic tanks.

The Table 9-f summarizes the knowledge transferred on funded FY 2022 projects completed.

Table 9-f. Highlights of FY 2022 Knowledge Transferred

Programmatic Element	Project Title	Knowledge Transfer Outcome
FY 2022		
Climate Change Solutions/ H_2/CO_2	Best Purging Practices for Minimizing Methane Emissions	Detailed purging alternatives (pressure reduction prior to purging, cross compression, flaring, etc.) and details about some of the specific equipment being used in the field today. Included were the best practices and lessons learned for implementing and performing purging alternatives (pressure reduction prior to purging, cross compression, flaring, etc.). The impact on safety and climate is that methane releases and emissions can occur in transmission, distribution, and gathering pipelines at any point across the system. To achieve decarbonization and climate change goals, the government and the natural gas industry are working to minimize methane emissions. Avoidance of methane emissions from purging operations have both economic benefits for operators and environmental benefits for the community. Use of alternatives to venting natural gas into the atmosphere also increases public trust in the natural gas industry and provides a safer work environment for pipeline and gathering system operators.

10.0 R&D Program Websites

- R&D Program Alerts Distribution List
  https://service.govdelivery.com/accounts/USDOTPHMSA/subscriber/new
- R&D Program main webpage
  https://www.phmsa.dot.gov/research-and-development/pipeline/about-pipeline-research-development
- Sortable list of awarded research projects
  https://primis.phmsa.dot.gov/matrix/
- Submit a research gap suggestion
  https://primis.phmsa.dot.gov/rd/gapsuggestions.htm
- R&D workshops, forums, and briefings
  https://primis.phmsa.dot.gov/rd/workshops.htm
- Other key PHMSA public events
  https://primis.phmsa.dot.gov/meetings/
- Department of Transportation Small Business Innovative Research Program
  https://www.volpe.dot.gov/work-with-us/small-business innovation-research
- Pipeline Leak Detection, Leak Repair, and Methane Emission Reductions Public Meeting
  https://primis.phmsa.dot.gov/meetings/MtgHome.mtg?mtg=152
- Grants and Competitive Academic Agreement Program
  Search Grants | www.grants.gov

11.0 Contacts

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