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ISSUE BRIEF

A Review of the Safety Record of CO_2 Pipelines in the United States

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Introduction

Totaling over 5,000 miles, carbon dioxide (CO_2) pipelines have operated in various regions of the United States for decades, largely between natural sources of CO_2 and enhanced oil recovery fields. While estimates for the number of miles needed vary, deploying carbon capture technologies at power and industrial facilities to aid in the decarbonization of the US economy will necessitate an expansion of the nation's CO_2 pipeline network.[1]

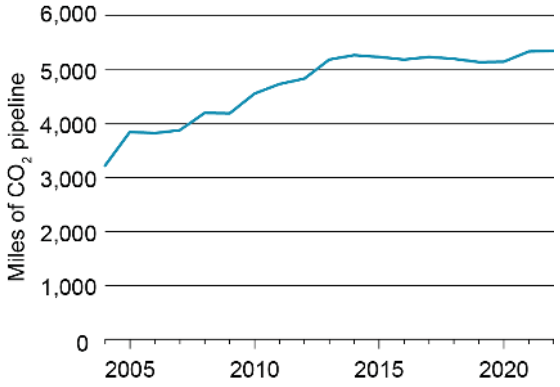
The Pipeline and Hazardous Materials Safety Administration (PHMSA), a federal agency under the US Department of Transportation, is responsible for developing and enforcing regulations related to the safe operation of pipeline infrastructure in the US, including supercritical CO_2 pipelines.[2]

This issue brief provides an overview of the historical accident record of CO_2 pipelines in the US. The brief aims to provide publicly available data reported by pipeline operators to PHMSA to understand a variety of aspects related to CO_2 pipeline safety in the US. For a more detailed review of CO_2 pipeline construction, operation, and oversight, see a recent report from the Global CCS Institute, which included collaboration with the Great Plains Institute.[3]

History of CO_2 pipelines in the united states

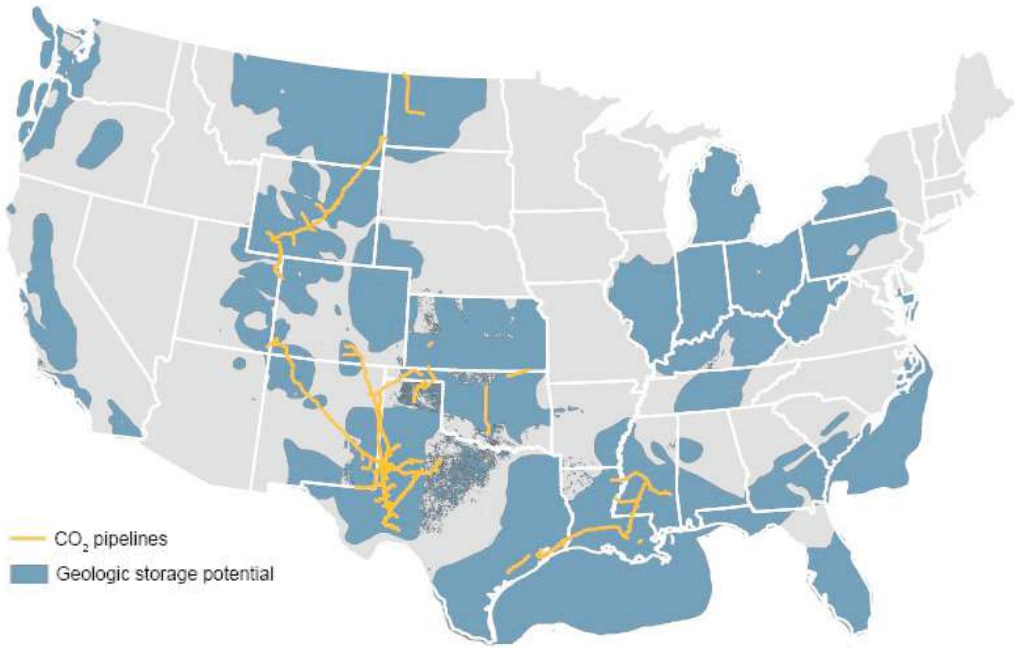
The first large-scale CO_2 pipelines were built in the 1970s for use during the enhanced oil recovery process in the Permian Basin in West Texas.[4] Growing to over 3,000 miles by the early 2000s, US CO_2 pipeline infrastructure has steadily climbed to over 5,000 miles in operation today (figure 1). CO_2 pipeline infrastructure is present in multiple regions of the US and includes natural and anthropogenic sources of CO_2, as well as oil reservoirs and saline geologic formations as storage locations (figure 2).

Figure 1. Miles of pipeline in the United States classified as CO_2 from 2004 to 2022.



Source: Pipeline and Hazardous Materials Safety Administration, "Annual Report Mileage for Hazardous Liquid or Carbon Dioxide Systems."

Figure 2. CO_2 pipelines and geologic formations with CO_2 storage potential in the United States.



Sources: Bauer et al., "NATCARB."; Pipeline and Hazardous Materials Safety Administration, "Active CO_2 Pipelines in the NPMS."

1 Abramson, McFarlane, and Brown, *Transport Infrastructure for Carbon Capture and Storage*; Larson et al., *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*, 17; Wallace et al., "A Review of the CO_2 Pipeline Infrastructure in the U.S.," 12–30.
2 United States Code of Federal Regulations, "49 CFR Part 195 - Transportation of Hazardous Liquids by Pipeline."
3 Minervini et al., *Building Our Way to Net-Zero: Carbon Dioxide Pipelines in the United States.*
4 Wallace et al., "A Review of the CO_2 Pipeline Infrastructure in the US."

Review of accident record

Accidents in a CO_2 pipeline must be reported to PHMSA if any one of the following events occur:

a. Explosion or fire not intentionally set by the operator

b. Release of 5 gallons or more, or 5 barrels or more if release occurs during maintenance

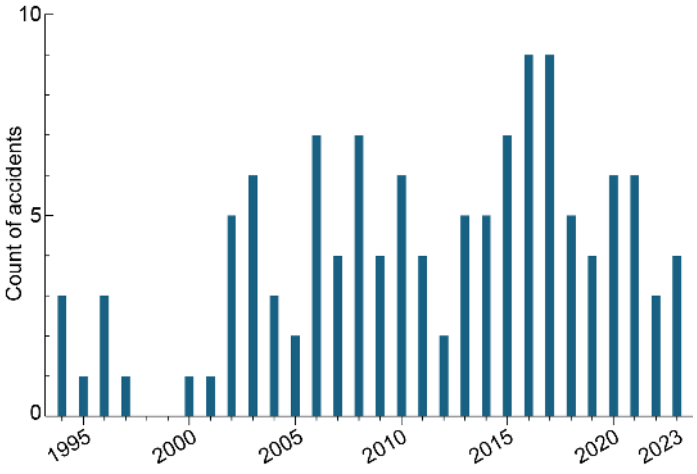
c. Injury requiring hospitalization or a death

d. Estimated total property damage exceeding $50,000 [5]

In the event of a reportable accident, an operator must submit an accident report to PHMSA within 30 days and may be required to notify the National Response Center within one hour if the accident meets certain criteria.

PHMSA publishes data from pipeline accident reports on its website, which are used in this analysis.[6] The first recorded CO_2 pipeline accident was in 1994, after PHMSA was authorized to enforce safety regulations related to CO_2 pipelines beginning in 1988. Since then, CO_2 pipelines have had an average of 4.1 accidents per year and have never had more than nine accidents in a single year (figure 3). From 2004 to 2022, CO_2 pipelines had an average accident rate of 0.001 per mile in operation per year.

Figure 3. Count of accidents by year.



Source: Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."

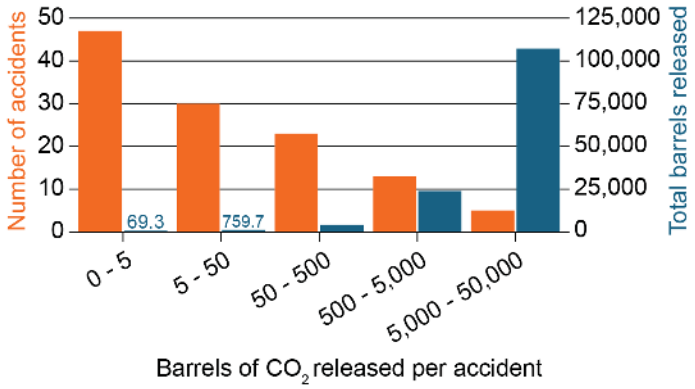
Unintentional releases of CO_2

Accidents have ranged in size from 0.1 (i.e., 5 gallons, the minimum amount required to be reported) to 41,177 barrels of CO_2 unintentionally released, with an average unintentional release of 1,150 barrels and a median release amount of 20 barrels.

In total, CO_2 pipeline accidents have resulted in roughly 135,000 barrels of CO_2 being unintentionally released, an average of 4,500 barrels per year. The density of CO_2 is affected by temperature and pressure, but a barrel of CO_2 is roughly between 0.13 and 0.16 metric tons of CO_2 at pipeline operating conditions. Current CO_2 pipeline infrastructure transports over 66 million metric tons of CO_2 per year,[7] equating to 0.001 percent of transported CO_2 being lost to unintentional releases from CO_2 pipeline accidents in an average year.

Most releases (65.3 percent) have resulted in 50 barrels or less released, while the five releases with a volume greater than 5,000 barrels have accounted for 79 percent of all unintentionally released CO_2 from pipeline accidents (figure 4).

Figure 4. Number of accidents and total barrels released by size of release, per accident.



Note: Orange bars indicate the number of accidents of a given size, blue bars indicate total barrels of CO_2 released for all accidents of the given size range. Five accidents did not report amount of CO_2 released and are not included.

Source: Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."

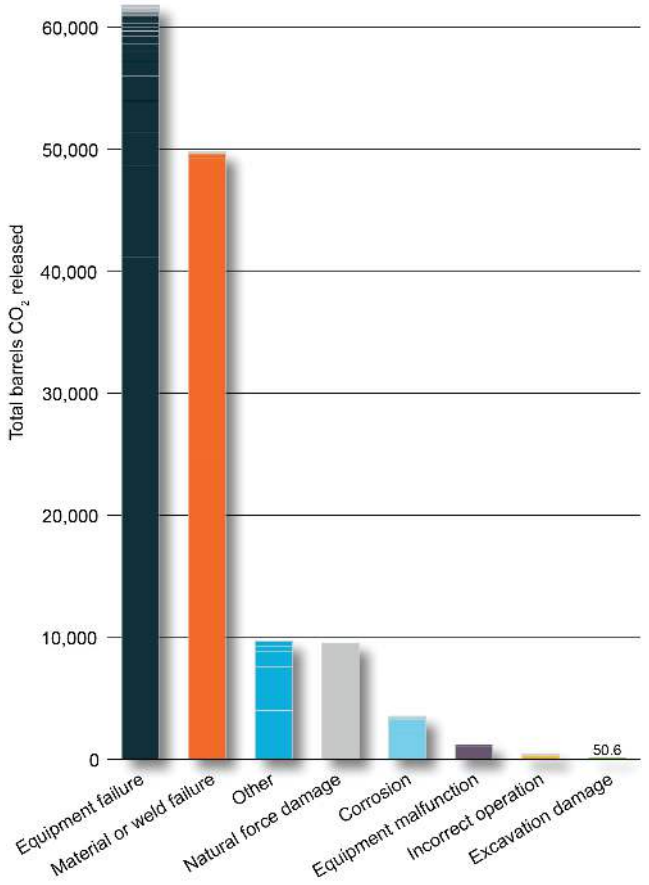
5 United States Code of Federal Regulations, "49 CFR Part 195 - Transportation of Hazardous Liquids by Pipeline."

6 Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data." The reported data fields and naming conventions used by PHMSA have changed over time. This analysis has aggregated the data fields presented, with an explanation of crosswalks included as an appendix.

7 National Petroleum Council, *Meeting the Dual Challenge. A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage. Volume III, Chapter Six - CO_2 Transport.*

A variety of causes for pipeline accidents have been reported, with the primary causes of CO_2 pipeline accidents related to equipment and material or weld failure in both the number of accidents and the total volume released (figure 5). Accidents due to equipment failures have typically involved various valve, O-ring, gasket, or seal failures and have resulted in a wide range of releases.

Figure 5. Total barrels CO_2 released by cause of accident.



Note: Each colored bar indicates a cause of release, each bar within a color indicates a separate accident.

Source: Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."

Material or weld failures also have a wide range of total barrels released, though most involved releases of less than 1,000 barrels of CO_2. Many of these accidents involved small cracks, typically a few inches long, that resulted in slow but noticeable releases of CO_2. Repairs related to material or weld failures typically involve replacing 5 to 10 feet around the failed location, though some accidents reported replacing up to 70 feet of affected pipeline.

Intentional releases of CO_2

In some cases, an intentional release of CO_2 may be required while remediating a CO_2 pipeline after an accident. In these instances, the operator releases CO_2 to depressurize the pipeline prior to repair, often referred to as blowdown, in a controlled manner that does not pose a risk to the area or the public.[8]

PHMSA began requiring operators to include intentionally released CO_2 in 2010. Since then, accidents involving intentional releases have had an average intentional release amount of 7,735 barrels and a median release amount of 923. A total of 278,000 barrels of CO_2 have been intentionally released due to reportable pipeline accidents, with 90 percent of the intentionally released CO_2 resulting from the ten largest intentional releases.

High consequence areas

Pipeline operators must create an integrity management program to ensure the ongoing safe operation and maintenance of their pipelines.[9] During the development of the integrity management program, a pipeline segment or facility may be identified as one that could affect a high consequence area (HCA) in the event of an accident. PHMSA defines HCAs as urbanized or high population areas (defined by the Census Bureau), commercially navigable waterways, and unusually sensitive areas.[10] If a pipeline segment or facility could affect an HCA, the operator is required to include the pipeline segment or facility in its integrity management program, which may require additional safety measures and assessments. If a pipeline segment is identified as one that could affect an HCA as new information becomes available (e.g., new Census data), the operator must add the pipeline section to its integrity management program.[11]

Over the past ten years, an average of 565 miles of CO_2 pipeline has been identified as capable of affecting an HCA in the event of an accident. Ten accidents have occurred where CO_2 released during an accident reached an HCA. Seven of those accidents had identified the segment of pipeline as having the potential to reach an HCA, while three of the accidents where CO_2 reached an HCA had not identified an HCA along the pipeline segment affected by the accident. An additional four accidents were identified as potentially impacting an HCA in the event of an accident, but no CO_2 reached an HCA due to the reported accident.

8 Pipeline and Hazardous Materials Safety Administration, "Instructions for Form PHMSA F 7000-1."
9 Pipeline and Hazardous Materials Safety Administration, Pipeline Integrity Management.
10 United States Code of Federal Regulations, "49 CFR Part 195 - Transportation of Hazardous Liquids by Pipeline."
11 Pipeline and Hazardous Materials Safety Administration, "Implementing Integrity Management - Final Rule (as Amended)."

Impacts of CO_2 pipeline accidents

Operators must report any injuries, fatalities, and/or damage to property and additional costs associated with a pipeline accident. Property damage includes damage to operator, public, and non-operator property, the value of the CO_2 lost upon release during the accident, costs associated with repairs to the pipeline segment or facility, emergency response, environmental remediation, and other costs related to a pipeline accident.[12]

CO_2 pipelines have not had a reported fatality since reporting began in 1988 and have only had one reported injury, which was a contracted worker during an excavation.[13] While only one accident has reached the threshold for a reportable accident, which requires overnight hospitalization, it is important to note that a serious accident occurred involving natural force damage to a CO_2 pipeline in Satartia, Mississippi. As a result of this accident, 200 residents near the rupture location were evacuated, and 45 people were taken to the hospital.[14]

CO_2 pipeline accidents are typically smaller in scale than pipeline accidents involving hazardous liquids and have a different makeup of the associated property damage costs. At the time of this report, CO_2 pipeline accidents have resulted in $9.2 million (2023$) in property damage.[15]

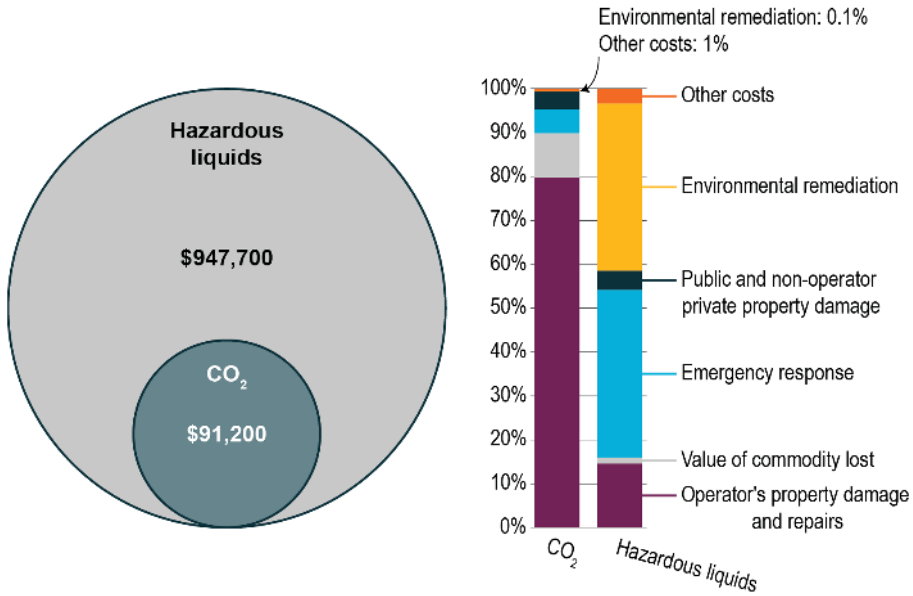
Nearly half of the reported total property damage resulted from one accident involving natural force damage to a CO_2 pipeline. Since 2010, CO_2 pipeline accidents have had an average total property damage of $91,200 (2023$), compared to an average total property damage of $947,700 for pipeline accidents involving hazardous liquids. Over 80 percent of the property damage associated with CO_2 pipeline accidents has been related to damage to an operator's property. In contrast, other types of hazardous liquid pipeline accidents have a much higher portion of the overall costs to property damage associated with emergency response and environmental remediation since 2010 (figure 6).

Conclusion

The safe operation of CO_2 pipelines is paramount to the effective deployment of carbon capture technologies to decarbonize the power and industrial sectors of the US. This issue brief provides a review of the safety record of CO_2 pipelines in the US, highlighting the quantity, size, and general cause of CO_2 pipeline accidents since PHMSA began regulating them in 1988.

CO_2 pipelines have a strong overall safety record, as evidenced in this issue brief, but serious accidents are still possible, necessitating continued advancement of safety standards and oversight by PHMSA.

Figure 6. Property damage associated with CO_2 and hazardous liquid pipeline accidents since 2010.



Note: Left circles show the average total property damage of CO_2 and hazardous liquid pipeline accidents (2023$, not to scale). Right bars show the average percent cost by damage type.

Source: Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."

12 Pipeline and Hazardous Materials Safety Administration, "Instructions for Form PHMSA F 7000-1."
13 Pipeline and Hazardous Materials Safety Administration, *Background for Regulating the Transportation of Carbon Dioxide in a Gaseous State*; Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."
14 Pipeline and Hazardous Materials Safety Administration, *Failure Investigation Report - Denbury Gulf Coast Pipelines, LLC - Pipeline Rupture/Natural Force Damage.*
15 Pipeline and Hazardous Materials Safety Administration, "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data."

References

Abramson, Elizabeth, Dane McFarlane, and Jeff Brown. *Transport Infrastructure for Carbon Capture and Storage*. Great Plains Institute, 2020. https://www.betterenergy.org/wp-content/uploads/2020/06/GPI_RegionalCO2Whitepaper.pdf.

Larson, Eric, Chris Greig, Jesse Jenkins, Erin Mayfield, Andrew Pascale, Chuan Zhang, Joshua Drossman, et al. *Net-Zero America: Potential Pathways, Infrastructure, and Impacts*. Princeton University, 2021. https://netzeroamerica.princeton.edu/img/Princeton%20NZA%20FINAL%20REPORT%20SUMMARY%20(29Oct2021).pdf.

Minervini, Joey, Jamie Burrows, Errol Pinto, and Hugh Barlow. *Building Our Way to Net-Zero: Carbon Dioxide Pipelines in the United States*. Global CCS Institute, 2024. https://www.globalccsinstitute.com/wp-content/uploads/2024/05/Building-Our-Way-to-Net-Zero-Carbon-Dioxide-Pipelines-in-the-United-States.pdf.

National Petroleum Council. *Meeting the Dual Challenge. A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage. Volume III, Chapter Six - CO_2 Transport*, 2021. https://dualchallenge.npc.org/files/CCUS-Chap_6-030521.pdf.

Pipeline and Hazardous Materials Safety Administration. *Background for Regulating the Transportation of Carbon Dioxide in a Gaseous State*, 2015. https://downloads.regulations.gov/PHMSA-2016-0049-0001/attachment_2.pdf.

———. "Distribution, Transmission & Gathering, LNG, and Liquid Accident and Incident Data," May 6, 2024. https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data.

———. *Failure Investigation Report - Denbury Gulf Coast Pipelines, LLC - Pipeline Rupture/Natural Force Damage*, 2022. https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2022-05/Failure%20Investigation%20Report%20-%20Denbury%20Gulf%20Coast%20Pipeline.pdf.

———. "Implementing Integrity Management - Final Rule (as Amended)," July 17, 2007. https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/technical-resources/pipeline/hazardous-liquid-integrity-management/61846/finalruleamended.pdf.

———. "Instructions for Form PHMSA F 7000-1," April 2023. https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2023-06/Current_HL_Accident_Instructions_PHMSA%20F%207000-1_2023-04%20and%20Beyond.pdf.

———. Pipeline Integrity Management, 49 CFR 195.452-195.454 § (n.d.). https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-195/subpart-F/subject-group-ECFRbe0c227f191b36d.

United States Code of Federal Regulations. "49 CFR Part 195 - Transportation of Hazardous Liquids by Pipeline." Accessed July 1, 2024. https://www.ecfr.gov/current/title-49/subtitle-B/chapter-I/subchapter-D/part-195.

Wallace, Matthew, Lessly Goudarzi, Kara Callahan, and Robert Wallace. "A Review of the CO_2 Pipeline Infrastructure in the U.S." National Energy Technology Laboratory, April 21, 2015. https://www.energy.gov/policy/articles/review-co2-pipeline-infrastructure-us.

Appendix

Value	1986 to 2001	2002 to 2009	2010 to present
Year	IDATE	IYEAR	IYEAR
Unintentional barrels released	LOSS	SPILLED*	UNINTENTIONAL_RELEASE_BBLS
Intentional barrels released**	N/A	N/A	INTENTIONAL_RELEASE_BBLS
Total property damage***	PRPTY	PRPTY	PRPTY
Cause of accident	CAUS	GEN_CAUSE_TXT	CAUSE

*From 2002 to 2009, accident report data included "SPUNIT_TXT," which identifies whether the reported volume is in gallons or barrels. Accidents with volumes reported in gallons have been converted to barrels at a conversion rate of 42 gallons per barrel.

**PHMSA did not begin requiring the reporting of intentional barrels released until 2010. All barrels reported released prior to 2010 are assumed to be unintentional in this issue brief.

***Property damage values have been converted to 2023$ using the GNP Implicit Price Deflator, annual average.