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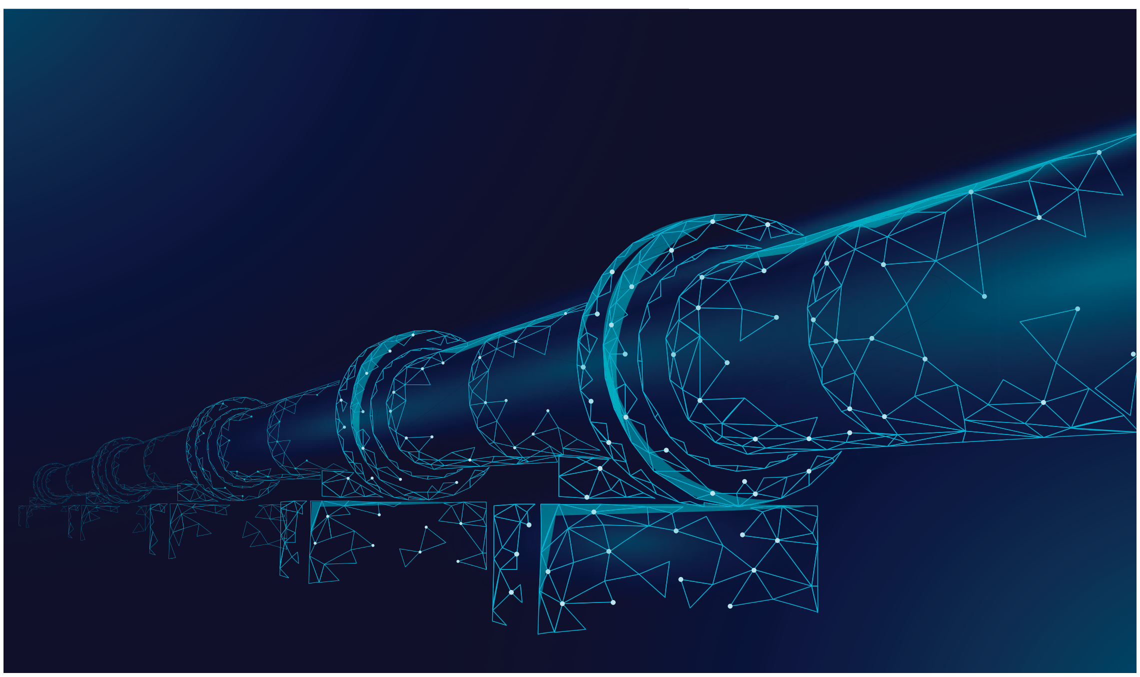
National Association of Regulatory Utility Commissioners

Artificial Intelligence for Natural Gas Utilities: A Primer

A Product of the U.S. Department of Energy-
National Association of Regulatory Utility Commissioners
Natural Gas Partnership



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Lead Authors

Hon. Diane X. Burman, Commissioner, New York State Public Service Commission, Chair, NARUC Committee on Gas, Chair of Natural Gas Infrastructure Modernization Partnership and its successor Natural Gas Partnership

Hon. D. Ethan Kimbrel, Commissioner, Illinois Commerce Commission

Hon. Tricia Pridemore, Commissioner, Georgia Public Service Commission

Andreas D. Thanos, Policy Specialist, Gas Division, Massachusetts Department of Public Utilities Chair, NARUC Staff Subcommittee on Gas

Kiera Zitelman, Senior Manager, NARUC Center for Partnerships & Innovation

About the Natural Gas Partnership

The Natural Gas Partnership (NGP) is a cooperative effort between the U.S. Department of Energy (DOE) and the National Association of Regulatory Utility Commissioners (NARUC), following the Natural Gas Infrastructure Modernization Partnership (NGIMP) between 2015 and 2020. The NGP convenes state regulators, federal agencies, and other natural gas stakeholders to facilitate the exchange of information among state regulators, federal agencies, and other natural gas stakeholders on emerging technologies and investments in natural gas for electricity generation and thermal load. This focus includes discussing natural gas pipeline leak detection and measurement tools and learning about new technologies and cost-effective practices for enhancing pipeline safety, reliability, resilience, affordability, and environmental stewardship. The NGP is chaired by Commissioner Diane X. Burman, of the New York State Public Service Commission, who also separately chairs the NARUC Committee on Gas.

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- **Jim Harmening**, Director, Cybersecurity and Risk Management, Illinois Commerce Commission
- **Wei Chen Lin**, Policy Advisor, Cybersecurity and Risk Management, Illinois Commerce Commission
- **Eric Lounsberry**, Director, Safety and Reliability Division, Illinois Commerce Commission
- **Casie Davidson**, Manager, Carbon Management and Fossil Energy, Pacific Northwest National Laboratory
- **Kevin Speicher**, Chief, Natural Gas and Hazardous Liquid Pipeline Safety, New York State Department of Public Service
- **Thomas Walker**, Deputy Director, Division of Reliability and Security, New Jersey Board of Public Utilities
- **Kimberly Denbow**, Engineering Services Director, American Gas Association
- **Benjamin Dierker**, Director of Public Policy, Alliance for Innovation and Infrastructure

- **Greer Johnson Gillis**, Vice President of System Development, Jacksonville Transit Authority, NARUC Commissioner Emeritus
- **Shannon Katcher**, R&D Manager, Energy Delivery, GTI
- **Sarah Magruder Lyle**, President and CEO, Common Ground Alliance
- **Brigham McCown**, President, Alyeska Pipeline Service Company
- **Richard Mroz**, Senior Advisor, State and Government Relations, Protect Our Power, NARUC Commissioner Emeritus
- **Kofi Woodley**, Operations & Engineering Services Manager, American Gas Association
- **Danielle Sass Byrnett**, Director, NARUC Center for Partnerships & Innovation

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Foreword

Hon. Diane X. Burman, New York State Public Service Commission
Chair, NARUC Committee on Gas
Chair, DOE-NARUC Natural Gas Partnership (formerly known as Natural Gas Infrastructure Modernization Partnership)

As Chair of the Natural Gas Partnership (NGP), a cooperative effort between the U.S. Department of Energy (DOE) and the National Association of Regulatory Utility Commissioners (NARUC), I am pleased to offer this educational primer to my fellow public utility commissioners, commission staff, and other relevant stakeholders. The NGP brings together public utility commissioners, DOE leaders, and other stakeholders directly involved in the nation's natural gas infrastructure. Building on the successes of the 2015 – 2020 Natural Gas Infrastructure Modernization Partnership (NGIMP), the NGP continues to convene technical workshops, organize infrastructure and innovation tours, produce handbooks and reports, and host other important gatherings to encourage collaboration and education on emerging technologies and practices in natural gas infrastructure modernization with the goal of further advancing safety, reliability, resilience, affordability, and environmental stewardship of our natural gas infrastructure.[1]

Purpose: During my leadership of the NGIMP and now NGP along with my concurrent tenure as chair of the NARUC Committee on Gas, artificial intelligence (AI) has been a frequent topic of interest among committee members. This primer is designed to assist regulators by defining AI and other relevant terms, offering substantive areas in which AI may be strategically used to continuously improve natural gas utility service, discussing challenges to successfully implementing AI, and positing areas in which prudent AI applications could be helpful in the near future. In addition to being an educational tool for regulators at multiple levels of familiarity with AI, this primer is a resource for utilities, consumer and environmental groups, and other critical stakeholders to understand how AI can further the safe, reliable, and affordable operation of natural gas infrastructure. This primer does not seek to endorse or recommend any particular AI solution, or AI as a general practice, but rather provide a common base of knowledge and increase the level of awareness regulators have towards AI. Overall, my goal is to ensure that regulators have the tools they need to evaluate utility investments fairly, accurately, and completely, regardless of the type of investment.

Contributors: I want to first recognize my fellow authors Commissioner D. Ethan Kimbrel of the Illinois Commerce Commission, co-vice chair of the Committee on Gas, and vice chair of the Subcommittee on Pipeline Safety; Commissioner Tricia Pridemore of the Georgia Public Service Commission; Andreas Thanos of the Massachusetts Department of Public Utilities and chair of the NARUC Staff Subcommittee for Gas; and Kiera Zitelman of the NARUC Center for Partnerships & Innovation for their collaborative leadership in jointly authoring this primer. I wish to also thank Commissioner Jay Balasbas of the Washington Utilities and Transportation Commission, chair of the NARUC Subcommittee on Pipeline Safety, and Commissioner Dianne Solomon of the New Jersey Board of Public Utilities for leading the expert team reviewing this primer. This handbook also benefited from the comments of several commissioners, commission staff, and other experts noted in the acknowledgments. I am grateful for their generosity in lending their time and expertise to improving this primer.

As regulators, utilities, and other stakeholders continue to collaborate in applying AI and other tools and practices to improve the safety, reliability, resilience, affordability, and environmental stewardship of our natural gas infrastructure, NARUC will continue to work closely with the U.S. DOE to foster the beneficial exchange of information among state regulators and other important stakeholders on critical natural gas subjects. It is my hope that state commissioners and other interested readers will find this primer both educational and useful.

Sincerely yours in dedicated public service,
Diane X. Burman, Esq.

1 As of July 1, 2020, the NGIMP concluded and the U.S. DOE and NARUC initiated a new five-year cooperative agreement, the Natural Gas Partnership (NGP). The NGP will continue the educational aims of the NGIMP, enabling NARUC to produce resources and engage commissioners and stakeholders on a broad range of natural gas regulatory issues.

Executive Summary

Modern natural gas utilities face numerous challenges and competing priorities from various stakeholders. Policymakers, customers, and advocacy groups want to see gas utilities improve performance on safety, reliability, resilience, affordability, and environmental stewardship. State utility regulators — public utility commissions — are responsible for overseeing utility performance, ensuring that ratepayer funds are being spent in the public interest, and aligning utility goals with public goals. The use of new technologies is critical to enabling cost-effective performance on these attributes.

Artificial intelligence (AI) is a widely used term among utilities and regulators, but the term means different things to different stakeholders, and it is often used to describe data analytics approaches that fall short of the formal definition of AI, which is:

> *"…the ability of a machine to receive inputs and produce a behavior or reaction similar to that of an intelligent human being."*

AI (and related tools, techniques, and technologies) can help utilities solve current and emerging challenges. By combining customer and system data with analytical tools and technologies, AI can augment human decision-makers by assisting in identifying problems and events before they occur, enabling resources to be more efficiently directed across utility infrastructure.

The intended primary audience for this primer is state regulators, although utilities and other stakeholders might also find it useful and relevant to improve their awareness of AI. The objectives of this primer are to: (a) offer a set of broadly applicable definitions for AI and related terms, allowing regulators, utilities, and other stakeholders to speak the same language; (b) discuss how AI is currently being implemented in the gas utility sector; and (c) understand the challenges affecting AI solutions and how tools might be implemented in the future. This primer fits within NARUC's goals of providing impartial information to improve the ability of public utility commissions to regulate in the public interest. As such, this primer does not seek to recommend AI over any other investment, nor does it endorse any particular vendor, product, or approach. It does seek to prepare state regulators to oversee AI investments by sharing information about the current landscape of commercially available tools.

To these ends, the primer is organized as follows:

- **Section I** discusses the current environment in which natural gas utilities operate and how AI, when thoughtfully designed and implemented, can enable utilities to achieve performance goals.
- **Section II** offers definitions of AI and related terms within the data analytics discipline.
- **Section III** provides three current opportunities for which AI can offer solutions: replacing aging gas distribution infrastructure, preventing excavator damage to gas distribution infrastructure, and improving energy efficiency programs. This section discusses each problem statement in detail. Second, Section III includes a discussion of how costs and benefits of investments to solve each problem are measured. And third, this section offers real-world examples of utility implementation of AI solutions.
- **Section IV** discusses challenges with implementing AI, both from the perspective of utilities and regulators.
- **Section V** suggests areas in which AI could feasibly be implemented in the near future.
- Finally, **Section VI** offers concluding thoughts and areas for further research.

I. Introduction

Today's natural gas utilities face complex challenges. State policymakers are contemplating the role of natural gas in a clean energy portfolio. Gas utilities must address long-standing infrastructure challenges, including replacing aging pipeline infrastructure, while continuing to provide safe, reliable, and affordable service to customers. The natural gas delivery system must also be resilient to natural and human-made threats by preparing to absorb, respond to, and recover from high-impact, low-frequency events. Safety and environmental concerns around unintentional methane emissions from throughout the natural gas supply chain have resulted in increasing attention towards detecting, quantifying, and repairing leaks in distribution pipes.[2]

Gas utilities have more customer data available on their systems than ever before, enabled largely by advanced metering infrastructure (AMI) and Internet-connected devices. Across all types of U.S. utilities, acquiring and analyzing increased quantities of customer data is a top priority.[3] However, utilities face the challenge of how these data can be evaluated to take appropriate action. Understanding changing customer demands and system characteristics is a necessary condition for utilities to provide service that meets the goals of safety, reliability, resilience, affordability, and environmental stewardship. However, utilities face challenges in assessing how to invest in and act on available data.[4]

Combining data with analytical tools and technology can create opportunities to reduce emissions, increase safety, and deliver better outcomes for customers. To help unlock this potential, regulators and utilities benefit from understanding the role of artificial intelligence (AI) solutions and how AI can help gas utilities solve current and anticipated problems. In light of new challenges facing natural gas infrastructure, AI and associated analytical tools can be considered alongside traditional natural gas utility investments.

It is important to remember that as technology continues to evolve, states would do well to enable future innovation by focusing on desired outcomes rather than specific tools or approaches. Rather than require the use of a particular tool that may grow obsolete, regulation in the public interest can encourage competition and innovation through developing metrics for performance, setting appropriate goals for regulated entities, measuring progress in a transparent way, and incentivizing successful outcomes.

In the interest of aiding regulators in understanding the range of desirable outcomes that novel technologies can deliver, this primer is intended to provide a common set of terms and applications for artificial intelligence solutions for gas utilities. This document does not seek to make the case that AI solutions are preferable to other tools, nor that any one particular vendor's or utility's approach is preferable to any other. Pursuant to the mission of the DOE-NARUC Natural Gas Partnership and its predecessor Natural Gas Infrastructure Modernization Partnership, this primer aims to educate state regulators and other critical stakeholders on these issues and provide a foundation for future progress.

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2 D. Ethan Kimbrel et al., National Association of Regulatory Utility Commissioners, *Sampling of Methane Emissions Detection Technologies and Practices for Natural Gas Distribution Infrastructure: An Educational Handbook for State Regulators,* July 19, 2019. https://pubs.naruc.org/pub/0CA39FB4-A38C-C3BF-5B0A-FCD60A7B3098

3 SAS, *How Analytics Reveals New Utility Customer Value*, 2015, https://www.sas.com/content/dam/SAS/en_us/doc/whitepaper1/analytics-reveals-new-utility-customer-value-107575.pdf

4 Mark Wiranowski and Susan Bergles, *Big Data: Opportunities and Constraints for Gas Utilities*, Wilkinson Barker Knauer LLP, July 2015. http://www.wbklaw.com/uploads/Wiranowski%20and%20Bergles,%20%20AGA%20Paper%20%20Data%20and%20Gas%20Utilities%20Jul15.pdf

II. Definitions

Artificial intelligence (AI), a subset of computer science combining advanced computing and statistics, is the *ability of a machine to receive inputs and produce a behavior or reaction similar to that of an intelligent human being*. AI uses complex instruction sets to approach being indistinguishable from human-like intelligence. AI is powered by data and algorithms: sets of step-by-step computer instructions that can use data to build models that make predictions based on the data.[5] AI only extends up to the point prior to a decision; AI solutions do not replace humans, but improve the quantity and quality of information available to human decision-makers.

Understanding AI and its relationship to natural gas requires an understanding of related terms within the data science field:

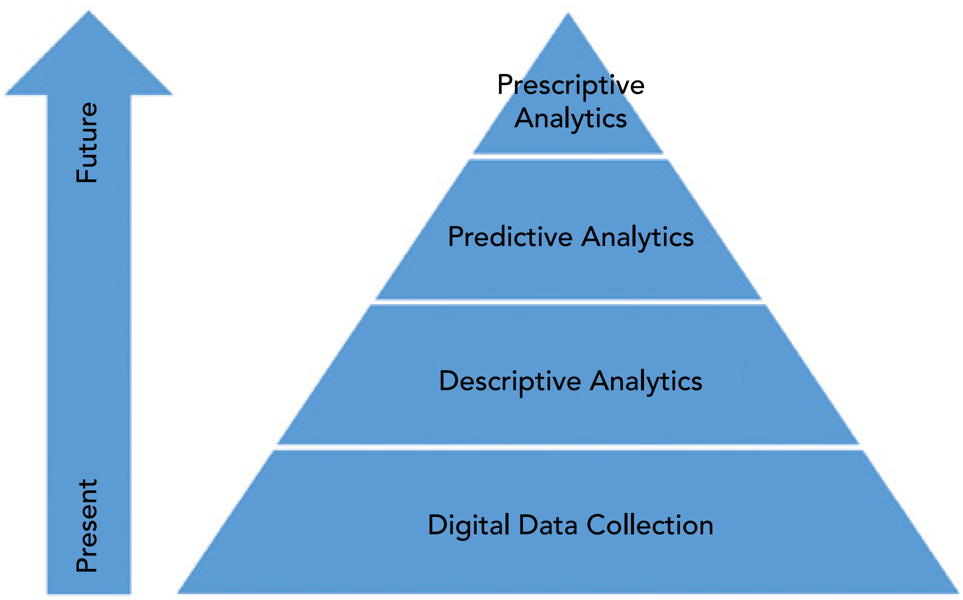
Data analytics — the process of drawing conclusions from data (*Figure 1*):

a. **Descriptive analytics** defines what has happened in the past up to the current state.

b. **Predictive analytics** defines what can happen in the future.

c. **Prescriptive analytics** advises what can be done in the context of what is predicted to happen in the future.[6]

Figure 1: Data Analytics



The data analytics field has spawned a number of AI-based applications and tools, which are useful to define here to provide readers with an understanding of the vast potential of AI for natural gas utilities.

a. **Machine learning (ML)**, a subset of AI, is the process of programming computers to use data and "learn" by identifying patterns to make decisions. ML learns by continuously updating models using new data and refining the algorithms to better understand the patterns through the process of training, testing, and verifying models against data.[7]

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5 Gene Wolf, "The Potential of AI for Utilities," T&D World, July 9, 2019. https://www.tdworld.com/grid-innovations/article/20972827/the-potential-of-ai-for-utilities

6 Shayle Kann, "The World Around Us," Medium, November 19, 2019. https://medium.com/energy-impact-partners/the-world-around-us-e554cd7f62bd

7 Gene Wolf, "A Virtual Environment with AI-Powered Digitization," T&D World, July 12, 2019. https://www.tdworld.com/grid-innovations/smart-grid/article/20972852/a-virtual-environment-with-aipowered-digitization.

b. **Deep learning (DL)**, a subset of machine learning, is the utilization of multiple layers of abstraction with demonstrated successful applications to fields such as computer vision and automatic speech recognition.[8] DL infers decisions based on data that may not yet be explicitly modeled; it does not have to be "told" in the same way ML does.

c. **Natural language processing (NLP)** uses ML techniques to extract human language semantics and syntax from machine-readable text.[9]

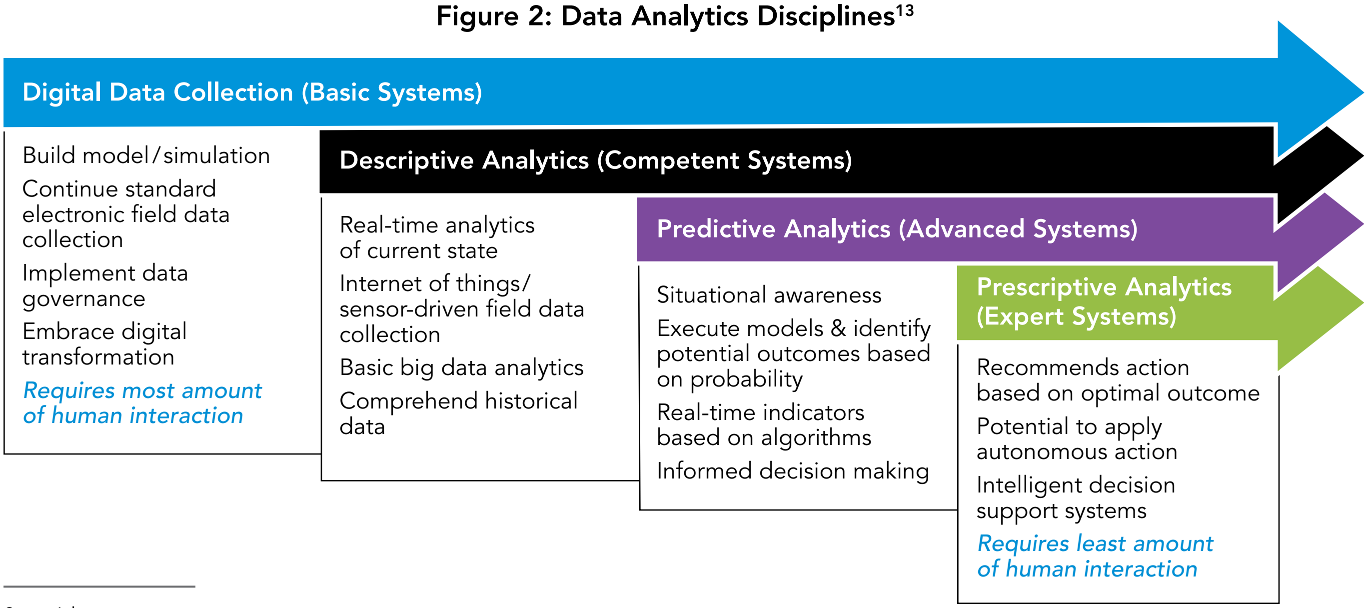
d. An **intelligent decision support system (IDSS)** uses AI to gather and analyze data, identify and diagnose problems, and propose and evaluate various courses of action, essentially behaving as a computerized consultant to a human decision-maker.[10]

e. **Generative adversarial networks (GANs)**[11] pit two models against each other in a game, teaching a model to generate entirely new, original data with similar attributes as a set of training data.[12]

Natural language processing, deep learning, machine learning, and AI are techniques used to achieve predictive and prescriptive analytics, but can even support analytics at a more basic level. To achieve any level of successful data analytics, one needs a substantial amount of machine-readable data. Historical data helps to train models, and continuous data being input into these systems helps refine the models. *Figure 2* summarizes the relationships among these disciplines.

Highly advanced AI can be prescriptive, with the most advanced systems having capabilities to make autonomous actions based on perceiving the environment (for example, closing a valve autonomously or deploying a field crew to a location because of a perceived risk in the system). For the most part, human decision-makers must still process the predictive information supplied by AI solutions and decide how to deploy limited resources to respond.

Figure 2: Data Analytics Disciplines[13]



8 Id.

9 Michael Garbade, "A Simple Introduction to Natural Language Processing," Becoming Human: Artificial Intelligence Magazine, October 15, 2018, https://becominghuman.ai/a-simple-introduction-to-natural-language-processing-ea66a1747b32

10 Gloria Phillips-Wren, "Intelligent Decision Support Systems," *Multicriteria Decision Aid and Artificial Intelligence*, February 2013, https://www.researchgate.net/publication/277703502_Intelligent_Decision_Support_Systems

11 An example of GANs in practice is the creation of fake images or videos of people, known as "deepfakes." The Defense Advanced Research Projects Agency (DARPA) operates a Media Forensics program that aims to use AI to counter the proliferation of deepfakes. See https://www.darpa.mil/program/media-forensics.

12 Ian Goodfellow et al., "Generative Adversarial Nets," Proceedings of the International Conference on Neural Information Processing Systems, 2014, https://papers.nips.cc/paper/5423-generative-adversarial-nets.pdf

13 Shannon Katcher, GTI.

With the progress of new analytical tools has also come the need to understand the conclusions being made. In many cases, there are layers of abstraction between the input data and the output content, where humans cannot comprehend (and therefore cannot trust) how conclusions were reached. Explainable AI (sometimes referred to as XAI) becomes important for humans to be able to trust the results that come out of the analytical models. This can be achieved by doing things like including explainable models and layers of probabilistic or Bayesian statistics — or even subject matter expertise — as validation.[14] For example, explainable AI may even help to prioritize specific datasets and data collection practices that would otherwise be unclear to human decision-makers. This type of information would not be transparent without an explainable model. Explainable AI can also help with exposing and avoiding biases within the data (see Section IV for more discussion).

14 David Gunning, "Explainable Artificial Intelligence (XAI)," Defense Advanced Research Projects Agency, November 2017 https://www.darpa.mil/program/explainable-artificial-intelligence

III. Current Opportunities

AI solutions are attracting attention from utilities looking to direct resources more efficiently. In particular, the potential for predictive and prescriptive analytics is attractive to utilities that dedicate substantial amounts of labor and funding to inspecting infrastructure and equipment. The analysis and recommendations that AI can provide enable utilities to act promptly on specific, identified assets, rather than rely solely on periodic inspections across the entire system.[15]

AI solutions can provide value to gas distribution utilities to help address a number of problems. This primer discusses how AI addresses three common challenges: (1) aging gas distribution infrastructure; (2) excavator damage; and (3) customer engagement and programs. These three categories do not encompass all the ways in which AI solutions are currently applied in the natural gas sector, but summarize current use cases across areas of particular concern to state regulators. AI solutions are highly likely to evolve to address other challenges in the future, particularly as emerging disciplines like NLP, IDSS, and GAN continue to mature. The following sections discuss each of these categories in more detail and offer case studies illustrating solutions in practice. These case studies should not be taken as an endorsement of any particular vendor, utility, or approach to addressing these issues, but are presented as informational examples of AI in practice.

In all three of these challenges, AI solutions would augment existing tools and practices. Utilities and regulators will need to collaborate on developing methodologies to estimate the incremental benefits of an AI investment to ultimately implement robust cost-benefit analysis. As stated above, the goal of this primer is not to promote AI investments over other alternatives, and elaborating on how to structure and conduct cost-benefit analysis is beyond the scope of this publication. However, in the interest of enabling regulators to consider the costs and benefits of the full scope of investment options, including emerging technologies like AI, a summary of how AI contributes to the safety, reliability, resilience, affordability, and environmental stewardship of the natural gas system is helpful.

A. Aging Gas Distribution Infrastructure

Gas utilities and state utility regulators work closely to replace aging cast iron and bare steel pipeline infrastructure. Aging pipes are more prone to gas leaks, which may lead to gas loss, property damage, and potential risks to health and safety. Aging pipelines lead to frequent repair by utility companies, which can result in service interruptions or distribution shutoffs. While states and utilities are making progress on replacing aging infrastructure nationwide, bare steel and cast iron pipeline infrastructure still accounts for 5.1% of main miles and 2.7% of service lines.[16] As NARUC discussed in a 2020 handbook on gas distribution infrastructure replacement and modernization,[17] distribution companies may lack incentive to pursue replacement aggressively because they often can only earn a return on investments on "used and useful" infrastructure. Investing in infrastructure upgrades does not always create infrastructure that is later determined to be used and useful, and the utility could be responsible for bearing those costs. The American Gas Association (AGA) has recognized the importance of infrastructure replacement as a component of pipeline safety while underscoring:

> *"Operators are supportive of accelerating risk reduction, but doing so will take both time and resources. It is incumbent upon operators and their state regulators to agree upon rate-making*

15 Utility Analytics Institute, "State of the Market: Addressing Challenges and Improving Performance through Analytics, Utility Market Data and Case Studies." November 14, 2018. https://img.en25.com/Web/PentonCEM/%7B2981eb64-20ca-43dd-a5b6-5968fe25640f%7D_Sensus_-_State_of_the_Market_Report_Final2.pdf?elqTrackId=76226d756ad84f2aa503970ad030dd91&elqaid=1380&elqat=2

16 U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. "Cast and Wrought Iron Inventory." March 17, 2020. https://www.phmsa.dot.gov/data-and-statistics/pipeline-replacement/cast-and-wrought-iron-inventory

17 Andreas Thanos and Kiera Zitelman, *Natural Gas Distribution Infrastructure Replacement and Modernization: A Review of State Programs*, National Association of Regulatory Utility Commissioners. January 2020, https://pubs.naruc.org/pub/45E90C1E-155D-0A36-31FE-A68E6BF430EE

mechanisms that support accelerated reduction of cast iron risk in a timeframe and at a cost that will not unduly burden the operator, their consumers, or the communities they serve."[18]

Replacing infrastructure can be costly and time-consuming for utilities and customers. Washington Gas & Light (WGL), a distribution utility serving customers in Washington, D.C., received approval from the District of Columbia Public Service Commission to spend up to $110 million over 40 years to replace 8,000 bare steel service segments and 38 miles of bare or unprotected steel and cast iron mains. In addition to spending money on the aging infrastructure replacement operations, WGL also dedicated funds to educating customers about the replacement program, providing avenues for customers to make complaints, and convening public meetings to gather community input to minimize disruptions to homes and businesses impacted by pipeline replacement work.[19] Still, infrastructure replacement is an essential task to assure a reliable, safe system and deliver broad customer and societal benefits.[20] State regulators and the Pipeline and Hazardous Materials Safety Administration (PHMSA) oversee gas industry investments in infrastructure replacement by auditing distribution integrity management program (DIMP) plans for optimal risk mitigation.[21] Such measures seek to ensure that incurred costs are prudent and effective.

While considering what AI can do for natural gas service, regulators must also consider how to quantify the costs and benefits of such investments. Quantifying the benefits of ***replacing a mile of aging infrastructure*** relies on having accurate data about the probability and impact of that pipe or excavation resulting in a damaging incident. A Stanford University study found that pipeline replacement programs can reduce the incidence of gas leaks by 90 percent in a comparison between cities that invested in accelerated pipeline replacement and cities that did not.[22] The American Gas Foundation found that "[t]he benefits of accelerated replacement efforts are compelling and include:

- Achievement of safety and reliability benefits more rapidly;
- Alignment and compliance with the requirements of a pipeline operator's Distribution System Integrity Management Plan, a risk-based assessment of an LDC's (local distribution company's) infrastructure that is mandated under pipeline safety laws;
- Cost savings resulting from increased scale through comprehensive planning, geographically focused replacement efforts and the efficient use of outside contractor services;
- Less disruption and improved coordination with affected municipalities; and
- Efficient deployment of capital for safety and reliability through a reduction in emergency repair efforts."[23]

AI can assist in identifying and prioritizing repair and replacement programs. AI can also reduce operational and maintenance expenditures and reduce greenhouse gas emissions by predicting infrastructure that is likely to develop a methane leak, enabling distribution utilities to act quickly to address the leak before or shortly after its development, depending on its severity and other characteristics.

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18 American Gas Association, *Managing the Reduction of the Nation's Cast Iron Inventory*, 2013. https://www.aga.org/sites/default/files/managing_the_nations_cast_iron_inventory.pdf

19 Washington Gas, a WGL Company, *Customer Education Plan: 2018 Annual Report*, December 2018, https://www.washingtongas.com//-/media/a059cc4fe8054d159b9b41e728bb8b04.pdf

20 Yardley Associates for the American Gas Foundation, *Gas Distribution Infrastructure: Pipeline Replacement and Upgrades, Cost Recovery Issues and Approaches*, July 2012, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/07-2012%20Gas%20Distribution%20Infrastructure%20-%20Pipeline%20Replacement%20and%20Upgrades.pdf

21 American Gas Association, *Managing the Reduction of the Nation's Cast Iron Inventory*, 2013, https://www.aga.org/sites/default/files/managing_the_nations_cast_iron_inventory.pdf.

22 Ker Than, "Stanford Study Proves Pipeline Replacement Programs Are Effective," September 9, 2015, https://news.stanford.edu/2015/09/09/methane-pipeline-replacement-090915/

23 Yardley Associates for the American Gas Foundation, *Gas Distribution Infrastructure: Pipeline Replacement and Upgrades, Cost Recovery Issues and Approaches*, July 2012, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/07-2012%20Gas%20Distribution%20Infrastructure%20-%20Pipeline%20Replacement%20and%20Upgrades.pdf

Emerging Examples

Methane Emissions Detection

Leaks of methane, the primary component of natural gas, occur throughout the gas supply chain. The U.S. distribution system is made up of 1.3 million miles of pipeline — many of which are underground and aging — that deliver gas to 62.1 million residential customers, 5.5 million commercial customers, and 200,000 industrial customers.[24] Regulators and utilities work collaboratively to facilitate the replacement of aging infrastructure[25] and deploy advanced technologies to detect, quantify, and fix methane leaks in the distribution system.[26]

Traditionally, gas utilities have detected methane leaks by equipping inspectors with handheld detectors. The detectors need as much as 45 minutes to calibrate to a particular site. The technician must then move slowly throughout the site while the detector tests the air periodically for methane. Detectors may miss leaks entirely or generate false positives. Results are entered manually, another time-consuming part of the process.[27] Advances in detection system technology have resulted in improvements to the speed and accuracy of the methane leak detection process.[28] Combining these emerging technologies with AI could result in further enhancements to leak detection and improved safety, reliability, resilience, affordability, and environmental stewardship of the natural gas delivery system.

The National Energy Technology Laboratory (NETL) has funded Southwest Research Institute's (SwRI) research into the Smart Leak Detection system (SLED) since 2016.[29] SLED deploys optical sensors throughout oil and gas infrastructure to provide images from across the system. Using algorithms, SLED processes the images to pinpoint small leaks before they become large enough to threaten human health and safety, the environment, or property.[30] Algorithms enable the system to differentiate between the chemical properties of various hydrocarbons and non-hazardous substances such as puddles of water.[31] SLED was initially developed and applied to detect leaks of diesel, mineral oil, gasoline, and crude oil in liquid pipelines, and later adapted to methane detection (SLED/M) in gas pipelines.[32]

In January 2019, NETL announced funding to adapt SLED/M into an airborne solution that would enable aerial sensing. Currently, SLED/M relies on stationary, land-based sensors. Applying SLED/M to aerial platforms or unmanned aerial vehicles (UAVs, commonly referred to as drones) would reduce the need to install stationary sensors throughout an entire pipeline system. Aerial sensors would be able to monitor entire sections of pipeline, including in hard-to-reach places. The increased upfront cost of a UAV could potentially be offset by the improved mobility and broadened reach of a methane detection device. Further, an aerial SLED/M system would offer autonomous, real-time sensing that would save operational and non-recurring costs, according to NETL Director Brian Anderson.[33] NETL's grant to support the project concluded on December 31, 2019. The aerial methane

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24 U.S. Energy Information Administration, "Number of Natural Gas Consumers," May 31, 2019, https://www.eia.gov/dnav/ng/ng_cons_num_dcu_nus_a.htm.

25 See note 17.

26 See note 2.

27 ABB Measurement & Analytics, AZO Materials, "Advanced Leak Detection with Novel Laser Technology," June 16, 2020. https://www.azom.com/article.aspx?ArticleID=19375

28 See note 2.

29 U.S. DOE, National Energy Technology Laboratory, "Cutting-Edge Methane Detection Technology to Go Airborne," January 30, 2019, https://www.netl.doe.gov/node/8139.

30 Southwest Research Institute, "SwRI Smart Leak Detection System Locates Hazardous Chemical Spills," November 27, 2017, https://www.swri.org/press-release/swri-smart-leak-detection-system-locates-hazardous-chemical-spills

31 Southwest Research Institute, "Methane Leak Detection," https://www.swri.org/industry/fluids-engineering-oil-gas-software-systems/methane-leak-detection

32 Southwest Research Institute, "SwRI Smart Leak Detection System Locates Hazardous Chemical Spills," November 27, 2017, https://www.swri.org/press-release/swri-smart-leak-detection-system-locates-hazardous-chemical-spills

33 See note 29.

detection algorithm was developed in August 2019.[34] As of May 2020, NETL had expanded its grant with SwRI to apply machine learning to the aerial SLED/M system, thereby providing "a substantial reduction in false positives."[35] Throughout 2020, SwRI plans to integrate a low-cost longwave infrared thermal imager and lightweight LiDAR (Light Detection and Ranging) system and further validate and improve the algorithm.

Asset Health and Management

Compiling and sharing current information on asset health throughout a utility is a major challenge. To that end, multiple AI vendors offer integrated asset management systems (AMS) offering end-to-end asset discovery and tracking featuring predictive maintenance, failure analysis, and asset health awareness programs.[36] Such systems typically present a single inventory view of all utility assets, enabling better decision-making for asset maintenance and replacement. AI can also leverage and build upon a "digital twin" of a physical asset, drawing data from the asset into a model and projecting into the future to understand what could happen to the asset given a change in the surrounding environment.[37] Building a digital twin requires a utility to invest in accurate, consistent, and reliable data collection; however, many utilities are already collecting the appropriate data to achieve this. The digital twin allows utilities to understand the impact of and adapt their activities by simulating situations before impacting the physical entity in the system. AI can then build on these data by deploying sensors and other streams of data to continuously update, validate, and train the existing model. This baseline data also allows for more advanced, mature analytics and visualizations (e.g., augmented reality visualizations of buried infrastructure with high geospatial accuracy).

IBM's Maximo Asset Performance Management (APM) system includes capabilities for asset health, asset monitoring, maintenance optimization, asset lifecycle, and asset strategy. By using AI as well as current and historical system data, APM can predict asset failure, enabling utilities to plan maintenance proactively rather than react once a problem has occurred. The APM can also optimize capital and operational expenditures, improve deferred maintenance decision-making, prioritize unplanned work, and improve capital planning strategies over the short and medium term.[38] Cohesive Solutions, Inc. implemented IBM Maximo to enable a gas distribution utility to comply with PHMSA requirements and improve its DIMP plan. The approach integrated geospatial and asset management information and applied AI to improve how the utility managed its asset maintenance program.[39]

In addition to improving information across an entire system, AI can augment existing data collection methods to detect pipeline leaks. Pipeline operators already have high-quality data on their systems, particularly as Internet-connected sensors have come down in cost and have been more widely deployed. Many operators have used real-time data analysis to monitor their pipelines, but are often faced with vast amounts of data. Machine learning can analyze patterns in these data to improve operators' ability to understand actual — and even predict potential — leaks.[40]

34 Heath Spidle, Southwest Research Institute, "Research Performance Progress Report: Smart Methane Emission Detection System Development," January 22, 2020, https://netl.doe.gov/sites/default/files/FE0029020-qpr-oct-dec-2019.pdf

35 U.S. DOE, National Energy Technology Laboratory, "NETL Project to Add Methane Emissions Quantification Capabilities," May 21, 2020, https://www.netl.doe.gov/node/9755

36 Gene Wolf, "The Potential of AI for Utilities," T&D World, July 9, 2019, https://www.tdworld.com/grid-innovations/article/20972827/the-potential-of-ai-for-utilities

37 U.S. Association for Energy Economics, "Artificial Intelligence (AI) in Energy: From Pipedream to Practical Applications," June 15, 2020, https://www.usaee.org/webinars/webinar-ai.aspx

38 IBM, "IBM Maximo: Optimizing E&U Assets with AI-Powered Technology," 2020, https://www.ibm.com/downloads/cas/6GJJDY1Z

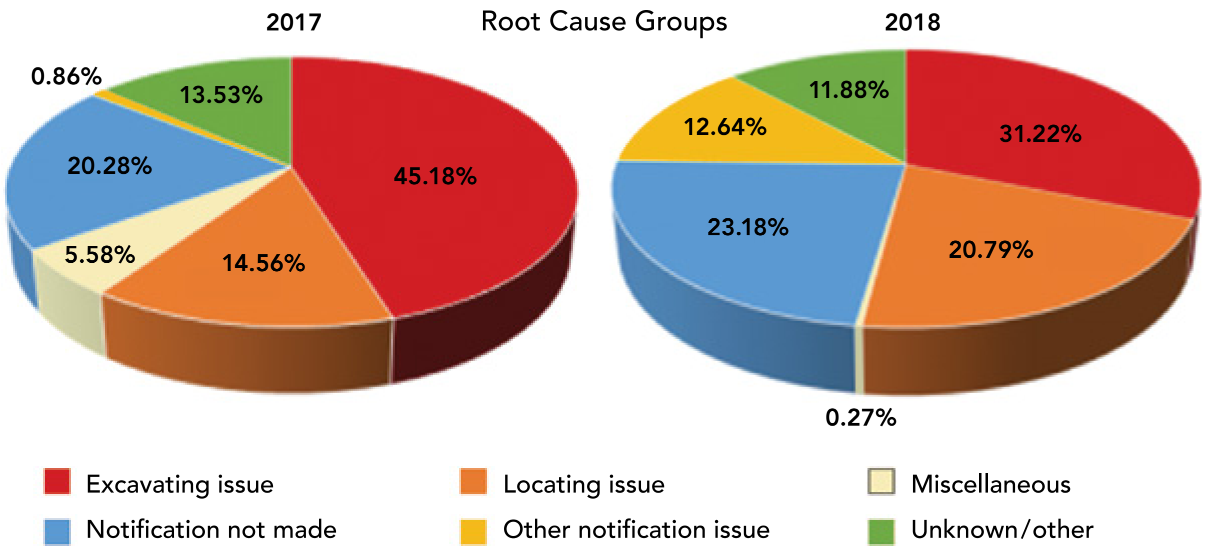
39 Cohesive Solutions, "Cohesive Solutions Enhances Regulatory Compliance and Asset Integrity," https://cdn2.hubspot.net/hubfs/2186475/Infographics/Infographic%20Case%20Studies/Regional%20Gas%20Utility%20Case%20Study%202018-1.pdf

40 Jyoti Prakash, ARC Advisory Group, "Artificial Intelligence and Machine Learning Reshaping Today's Pipeline Leak Detection Systems," November 20, 2018, https://www.arcweb.com/blog/artificial-intelligence-machine-learning-reshaping-todays-pipeline-leak-detection-systems

B. Excavator Damage

Third-party excavation is the leading cause of damage to gas distribution pipes, causing $1.5 billion in costs to utilities every year.[41] States encourage excavators to call 811 before they dig to receive current information on gas lines and underground telecommunications, electric, water, and other infrastructure. However, compliance with pre-excavation 811 calls is not universal. Further, 811 system data can, in some cases, be incomplete or inaccurate. More than 330,000 unique damage incidents in the U.S. were reported in 2018 to the voluntary Damage Information Reporting Tool (DIRT) system, with 85,993 of these impacting natural gas infrastructure. Of these incidents, the root cause of almost 90% were listed as either excavation issues, locating issues, or lack of notification (no notification made to One Call Center or 811).[42] While notifying 811 is the simplest and most effective way to reduce or eliminate underground damages,[43] location and excavation issues will require attention as well (*Figure 3*).

Figure 3: Damage Cause Analysis[44]



In response to the Protecting our Infrastructure of Pipelines and Enhancing Safety Act ("PIPES Act") of 2016,[45] PHMSA issued A Study on Improving Damage Prevention Technology that considered how to address increasing location and excavation damages. The study offered multiple recommendations, including one on predictive analytics:

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41 Common Ground Alliance, *Damage Information Reporting Tool 2016 Analysis & Recommendations*, August 2017. https://commongroundalliance.com/sites/default/files/publications/DIRT%202016%20Annual%20Report_081017_FINAL_Updated_09.20.17.pdf

42 Common Ground Alliance, *Damage Information Reporting Tool 2018 Analysis & Recommendations*, September 2019. Table 6, https://commongroundalliance.com/sites/default/files/publications/2018%20DIRT%20Report%20Final_100419.pdf

43 To reduce the number of incidents stemming from a lack of 811 notification, the Common Ground Alliance aids damage prevention stakeholders in increasing public awareness of 811 and conducting outreach to excavators. See Common Ground Alliance, *CGA White Paper: Data-Informed Insights and Recommendations for More Effective Excavator Outreach*, April 2019. https://commongroundalliance.com/Portals/0/Library/2020/White%20Papers/CGA%20White%20Paper%202019%20-%20FINAL.pdf?ver=2020-08-14-125534-127

44 Common Ground Alliance, *Damage Information Reporting Tool 2018 Analysis & Recommendations*, September 2019. https://commongroundalliance.com/sites/default/files/publications/2018%20DIRT%20Report%20Final_100419.pdf.

45 On August 6, 2020 the U.S. Senate passed S.2299, PIPES Act of 2020, reauthorizing the U.S. Department of Transportation's pipeline safety programs for fiscal years 2020 through 2023. As of publication, the U.S. House of Representatives had yet to pass the bill. See Congress.gov, "S.2299 — PIPES Act of 2020, 116th Congress (2019 – 2020), https://www.congress.gov/bill/116th-congress/senate-bill/2299; and PHMSA, "U.S. Transportation Secretary Elaine L. Chao Announces 2019 Pipeline Safety Legislative Proposal," June 3, 2017. https://www.phmsa.dot.gov/news/pipeline-safety-reauthorization

"These tools use data to identify and manage high-risk excavation tickets. These technologies have been implemented with success to reduce damage rates, and as such are considered technically, operationally, and economically feasible for at least some stakeholder groups. Additionally, these technologies could be enhanced by incorporation into one-call center processes."[46]

Similarly brought about through the PIPES Act of 2016, PHMSA's Voluntary Information-Sharing System Working Group (VIS WG)[47] released a report to the Secretary of Transportation in April 2019. The report recognized the need:

"…to continuously improve system knowledge and pipeline-specific data to analyze and mitigate pipeline safety risks. The industry lacks a comprehensive, systematic, and integrated way to gather, evaluate, quantify, and share critical pipeline safety data and recommended remediation measures or lessons learned of all types to operators across the various industry segments (hazardous liquid transmission, gas transmission, gas distribution) in an efficient and confidential manner."[48]

The benefits of preventing ***excavation damage*** to distribution infrastructure include the avoided costs of replacing damaged infrastructure, avoided threats to human health and safety, and avoided damages to surrounding buildings. PHMSA measures the cost of significant incidents[49] on the gas distribution system at more than $10 billion total from 2000 – 2019.[50] Benefits of avoiding incidents also accrue to the operators and customers of other underground infrastructure such as electricity, telecommunications, and water, who may experience service interruptions from the same excavation that damages gas infrastructure.

AI can offer value by improving the information state government entities (including regulators and pipeline safety agencies), utilities, and excavators have about underground infrastructure and pipeline safety risks. According to the VIS WG, American Petroleum Institute's Recommended Practice 1173 (API RP 1173) "provides an excellent framework for gathering, evaluating, prioritizing, remediating, and measuring the results of programmatic pipeline safety improvement solutions."[51] The VIS WG recommends that pipeline safety be further enhanced by increasing the adoption of API RP 1173 and leveraging various modern techniques and tools, including machine learning, to store, analyze, and distribute data.[52]

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46 U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, *A Study on Improving Damage Prevention Technology*, August 2017, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/news/18351/reporttocongressonimprovingdamagepreventiontechnologyaug2017.pdf

47 The PIPES Act created two vehicles through which state regulators and PHMSA can collaborate toward the shared mission of pipeline safety. These include: the Gas Pipeline Advisory Committee (https://www.phmsa.dot.gov/standards-rulemaking/pipeline/gas-pipeline-advisory-committee-gpac-committee-roster-and-biographies) and the Voluntary Information-Sharing System Working Group (https://www.phmsa.dot.gov/standards-rulemaking/pipeline/voluntary-information-sharing-system-working-group). Multiple representatives of state public utility commissions sit on both groups. Commissioner Diane X. Burman, New York State Public Service Commission; Chairman David Danner, Washington Utilities and Transportation Commission; and Peter Chace, Public Utilities Commission of Ohio, serve as members of the Gas Pipeline Advisory Committee. Commissioner Burman; Joe Subsits, Washington Utilities and Transportation Commission; and Michelle Thebert, Georgia Public Service Commission, serve on the Voluntary Information-Sharing System Working Group.

48 Voluntary Information-Sharing System Working Group Federal Advisory Committee, *Pipeline Safety Voluntary Information-Sharing System Recommendation Report*, April 2019, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/standards-rulemaking/pipeline/71576/vis-recommendation-report-and-chair-letter-06-10-19.pdf

49 PHMSA defines "significant incidents" as those including any of the following conditions: 1. Fatality or injury requiring in-patient hospitalization; 2. $50,000 or more in total costs, measured in 1984 dollars; 3. Highly volatile liquid releases of 5 barrels or more or other liquid releases of 50 barrels or more; 4. Liquid releases resulting in an unintentional fire or explosion. Gas distribution incidents caused by a nearby fire or explosion that impacted the pipeline system are excluded. See https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends

50 PHMSA, "Significant Incidents," June 26, 2020, Update URL to: https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends

51 See note 48.

52 See note 48. See Appendix XVII: Implementation Patterns for discussion of cloud services for data storage and analytics and Appendix XVIII: Paradigms of Data Processing for additional discussion of database structures.

Emerging Examples

National Grid and NiSource, two Northeastern gas distribution utilities, have used predictive analytics to decrease third-party excavation damages by implementing Opvantek's Optimain system, now under the Urbint Lens for Damage Prevention suite.[53] The Lens for Damage Prevention predicts the 811 tickets that are likely to result in excavation damages. Using available ticket data, such as street names, towns, map grids, company names, locator information, and type of work being performed, Optimain applies a proprietary statistical analysis methodology to identify high-risk tickets, efficiently directing resources to intervene on risky excavations, and prevent damages from occurring. With 57 percent of damage incidents occurring on just 10 percent of 811 tickets, Optimain created a risk algorithm that supplies a locate request risk score to each ticket that could impact National Grid's assets. Between 2015 and 2017, as the system was implemented, damages declined by 22 percent, 35 percent, and 33 percent in Upstate New York, Long Island, and New York City, respectively. Opvantek estimates that Optimain avoided 235 of 745 expected damage incidents within National Grid's territory.[54] Opvantek also applied its AI system to reduce excavation damages for NiSource. Similar to National Grid, 10 percent of 811 tickets accounted for 45 percent of damage incidents. Employing predictive analytics and mitigating high-risk tickets reduced damage rates from the previous year.[55] Currently, Optimain processes nearly 7.4 million one-call center location requests and has prevented an estimated 12,303 damage incidents.[56]

Urbint's Lens for Damage Prevention, which now includes Opvantek's offerings, has also been implemented by Southern Company Gas in its Chattanooga service territory. Urbint combined internal utility infrastructure data with risk variables such as weather, contractor history, and work type to generate risk rankings for excavation tickets. Using this approach, Urbint identified nearly 50 percent of damages occurring on 5 percent of excavation tickets, helping the company decrease third party damage rates by more than 30 percent.[57]

Gas Technology Institute[58] (GTI) has developed an Excavation Encroachment Notification System that deploys a custom-built device in the cab of construction equipment to alert equipment operators and other stakeholders when digging is occurring close to the natural gas system. The device includes an embedded processor, cellular communication, Global Navigation Satellite System (GNSS) device, and Nine Degrees of Freedom inertial measurement unit (IMU) containing a 3-axis accelerometer, gyroscope, and magnetometer. Data from the device are streamed in real-time to a cloud-based geographic information system (GIS), where machine learning methods were used to train algorithms to characterize the movements of the construction equipment. The system continually compares spatial location data and the construction equipment movements, using artificial intelligence to alert and notify stakeholders when digging occurs near a gas pipeline. Alerts, notifications, and buffered boundaries built around the gas system are customizable to provide varying levels of information. They account for varying degrees of risk based on the accuracy of the GIS data and attributes of the construction equipment.

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53 Opvantek was acquired by Urbint in October 2019. See https://www.globenewswire.com/news-release/2019/10/28/1936330/0/en/Urbint-Acquires-Opvantek-to-Advance-AI-Technology-for-Enhanced-Pipeline-Risk-Management.html

54 Opvantek, "Preventing Damages Before They Happen Using a Risk Model." April 2018.

55 Opvantek, "Using Predictive Analytics to Guide Daily Damage Prevention Activities," April 2018. https://www.opvantek.com/app/uploads/2018/04/UsingPredictiveAnalytics-SessionPresentation.pdf

56 Urbint, "Urbint Lens for Damage Prevention," https://urbint.com/solutions/urbint-lens-for-damage-prevention

57 Case Study: Southern Company Gas Damage Prevention," https://urbint.com/case-studies/southern-company-gas-damage-prevention

58 GTI hosts virtual training events and webinars on safe excavation systems and other natural gas technologies at https://www.gti.energy/training-events/

C. Customer Engagement and Energy Efficiency Programs

Many gas utilities or third parties offer energy efficiency programs to customers. Annual spending from natural gas utilities on efficiency programs reached $1.37 billion in 2017, saving 449 million therms of gas.[59] New, more efficient gas appliances, including gas furnaces and boilers, water heaters, clothes washers, dishwashers, showerheads, faucets, and industrial process equipment, continue to enter the market.[60] Gas efficiency programs can offer home energy assessments to identify older, less efficient appliances and recommend replacements. Programs may also offer rebates for the purchase of new appliances. Additionally, gas efficiency can target residential space heating, water heating, and weatherization measures and/or commercial space heating and control and envelope measures. With the substantial amount of ratepayer funds provided to administer energy efficiency offerings, program administrators should ensure that energy savings are realized at least cost.

Measuring the benefits of ***natural gas energy efficiency programs*** relies on established cost-benefit analysis methods developed for electricity energy efficiency programs. Benefits include avoided energy, capacity, and distribution costs as well as participant benefits (e.g., lower energy bills) and societal benefits (e.g., lower energy-related carbon dioxide emissions).[61] States have selected different methodologies to assess efficiency programs. The societal cost test, total resource cost test, and utility cost (also called program administrators cost) test are three of the most common.[62] Comparing the cost of saved energy to retail cost is a useful metric. In a 2020 study of utility energy efficiency programs for natural gas between 2012 and 2017, Lawrence Berkeley National Laboratory found that energy savings cost program administrators 40 cents per therm, compared to an average retail price of approximately $1 per therm.[63]

AI can identify candidate customers for appliance replacement, weatherization, or other measures and suggest ways to target program advertising to increase program participation. By increasing the effectiveness of each dollar allocated to program implementation, AI can deliver more benefits from utility investments in demand side management and energy efficiency programs. AI systems can deliver personalized recommendations that take energy use and other customer characteristics into consideration.

Emerging Examples

AI applications can improve customer engagement and participation in energy efficiency and other programs. By leveraging customer data, survey design, and behavioral economics, utilities can improve how their customer-facing programs are designed and advertised and achieve program objectives more efficiently.

WGL used AI to improve its energy efficiency and awareness programs. The utility began offering Home Energy Conservation Kits to its residential customers in Virginia. WGL worked with Uplight to design and market the kits, which included efficiency and weatherization equipment that could be easily installed in a home. Uplight designed an online survey on home energy use to offer home energy profiles — personalized recommendations and savings estimates to customers — driving participation in the Home Energy Conservation

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59 Consortium for Energy Efficiency, *2018 State of the Efficiency Program Industry: Budgets, Expenditures, and Impacts*, July 31, 2019, https://www.aga.org/contentassets/b1c7804ce34146d7bcc493b436a4ba3c/final---cee-2018-annual-industry-report.pdf

60 Steven Nadel, Natural Gas Energy-Efficiency: Progress and Opportunities, American Council for an Energy Efficient Economy, July 2017, https://www.aceee.org/sites/default/files/publications/researchreports/u1708.pdf

61 Maggie Molina, *The Best Value for America's Energy Dollar: A National Review of the Cost of Utility Energy Efficiency Programs*, American Council for an Energy-Efficient Economy, March 2014, https://www.aceee.org/sites/default/files/publications/researchreports/u1402.pdf

62 Katherine Friedrich et al., *Saving Energy Cost-Effectively: A National Review of the Cost of Energy Saved through Utility-Sector Energy Efficiency Programs*, American Council for an Energy-Efficient Economy, September 2009, https://www.aceee.org/sites/default/files/publications/researchreports/U092.pdf

63 Steve Schiller et al., *Cost of Saving Natural Gas through Efficiency Programs Funded by Utility Customers: 2012–2017*, Lawrence Berkeley National Laboratory, May 2020, https://eta-publications.lbl.gov/sites/default/files/cose_natural_gas_final_report_20200513.pdf

Kit program. Insights from behavioral science and data analysis were used to drive a high rate of survey responses (90 percent of those who visited the program website) and deliver quality recommendations that led to high rates of program participation. Participation also led to further investments in energy efficiency. In a follow-up survey, 69 percent of residents who had received a kit installed additional efficiency measures outside of the kit, without receiving a rebate.[64] The success of WGL's efficiency program is one of multiple case studies for Uplight. As of Q2 2019, Uplight has sent 144 million profiles, called Home Energy Reports, to North American residential customers, driving an additional 178,000 customers to enroll in demand-side management programs.[65]

Bidgely's gas disaggregation program offers another example of AI improving customer-facing programs. Gas disaggregation takes appliance-level data from heating, cooking, water heating, and dryers and creates personalized recommendations and program delivery options for gas distribution utilities. Bidgely's offering relies on gas meter data. Using a machine learning algorithm, Bidgely can identify appliance fingerprints and compile a portrait of gas use for various services. Using AI, Bidgely can also develop gas usage insights and recommendations for customers on how to manage their gas use. Utilities can leverage the data and insights to build customized demand side management and energy efficiency recommendations that are more likely to be implemented.[66]

For instance, Southern California Gas Company (SoCal Gas) successfully deployed Bidgely's UtilityAI-driven Home Energy Report (HER) program in less than four months and immediately exceeded their program's energy efficiency goals, with 286,540 therms saved between December 2019 and February 2020. Beyond demonstrating measurable gains in program participation, HER 2.0 yielded an overall boost to customer satisfaction and engagement. Over the course of thousands of emails disseminated to the utility's gas customers, email open rates averaged 50 percent — double the utility industry norm. Email recipients also gave the email communications they received 81 percent "likes" via thumbs up and thumbs down voting buttons included with every message.[67] Knowing precisely where the savings opportunities are on an appliance-level basis improves the outcomes of demand side management programs traditionally thought to be less effective at delivering results.

64 Uplight, "Empowering Residential Customers to Improve Energy Efficiency." April 2019. https://uplight.com/wp-content/uploads/2019/10/U_Case_Study_WAG_ImproveEE.pdf

65 Uplight, "Behavioral Energy Efficiency," https://uplight.com/solutions/behavioral-energy-efficiency/

66 Bidgely, "AI-Powered Solutions for Gas Utilities and Energy Retailers," https://www.bidgely.com/solutions/gas-disaggregation/

67 Bidgely, "Southern California Gas Company Case Study with Bidgely," https://go.bidgely.com/SoCalGas-CaseStudy.html

IV. Implementation Challenges

Utilities and regulators face multiple challenges in pursuing AI solutions. First, utilities and regulators need to attract and retain skilled workers to design, procure, implement, and evaluate AI solutions. Second, the regulatory treatment of AI costs can deter utility investments. Third, AI will require the development of institutional practices for data access, quality, and governance. Fourth, AI underscores the need for comprehensive cybersecurity programs. And finally, AI should be thoughtfully implemented to identify and remove the unintentional amplification of pre-existing biases.

Expertise. First and foremost, both utilities and regulators may need to acquire staff with sufficient expertise to evaluate, manage, and assess AI systems. Lack of trained staff and data scientists was identified as the primary challenge to utilizing data analytics in a Utility Analytics Institute survey.[68] As noted in Section II, AI systems do not make decisions, but ultimately deliver data and insights to human decision-makers who will then need to act. Additionally, AI and other advanced technologies that can automate tasks have the potential to displace human workers in manufacturing-intensive fields: "It is likely that artificial intelligence will soon replace jobs involving repetitive or basic problem-solving tasks, and even go beyond current human capability."[69] On the other hand, AI can also increase efficiency and productivity, generate revenue, and create additional jobs, particularly in service sectors like the energy industry.[70] Ernst & Young appropriately captures the upside of AI: "Far from replacing human ingenuity, AI complements it, while removing the tedium that would otherwise accompany data mining and the pursuit of valuable information."[71]

Cost recovery. Another major challenge is the lack of alignment between AI investments and cost recovery. In general, public utility regulation allows capital expenditures to be passed on to ratepayers. The utility receives reimbursement for capital expenditures through its rate base, as well as an allowable rate of return, approved by the regulator and passed through to shareholders. Operating expenditures are distinct from capital expenditures and are not treated in the same manner, with regulated utilities generally able to receive reimbursement for the expense, and in some cases performance incentives, but not a standard rate of return.[72] Investments in "services" rather than physical equipment are treated as operating expenditures, not capital expenditures, and are therefore less attractive to utility shareholders, particularly if such operational expenditures defer or replace capital investments.[73]

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68 Utility Analytics Institute, *State of the Market: Addressing Challenges and Improving Performance through Analytics, Utility Market Data and Case Studies*, November 14, 2018, https://img.en25.com/Web/PentonCEM/%7B2981eb64-20ca-43dd-a5b6-5968fe25640f%7D_Sensus_-_State_of_the_Market_Report_Final2.pdf?elqTrackId=76226d756ad84f2aa503970ad030dd91&elqaid=1380&elqat=2

69 Vishal Marria, "The Future of Artificial Intelligence in the Workplace," Forbes, January 11, 2019, https://www.forbes.com/sites/vishalmarria/2019/01/11/the-future-of-artificial-intelligence-in-the-workplace/#7e8316da73d4

70 MIT Technology Review, "The Growing Impact of AI on Business," April 30, 2018, https://www.technologyreview.com/2018/04/30/143136/the-growing-impact-of-ai-on-business/

71 Thierry Mortier, "How Human-Centered AI Can Help Transform the Energy Industry," Ernst & Young, January 29, 2019, https://www.ey.com/en_gl/power-utilities/how-human-centered-ai-can-help-transform-the-energy-industry

72 Dan Cross-Call et al., Rocky Mountain Institute, *Reimagining the Utility: Evolving the Functions and Business Model of Utilities to Achieve a Low-Carbon Grid*, January 2018, https://rmi.org/wp-content/uploads/2018/01/reimagining_the_utility_report.pdf

73 Advanced Energy Economy, "Optimizing Capital and Service Expenditures: Providing Utilities with Financial Incentives for a Changing Grid," June 5, 2018, https://info.aee.net/hubfs/PDF/Opex-Capex.pdf

New York offers an example of performance metrics in practice. Programs associated with AMI-enabled methane detection,[74] pipeline safety management systems, leak detection devices for first responders, and GIS mapping to verify locations of high-pressure gas lines are funded through rate cases with performance metrics, in which the utility can earn incentives to reward good performance or liabilities in response to poor performance. Regulatory liabilities are used to fund programs that benefit ratepayers by increasing safety.

A regulated utility could purchase legacy hardware and on-premise software rather than paying a third party for its services, but such an approach is unlikely to be the most cost-effective approach for customers. In addition, such a model may ignore better technology supplied by third parties, conflict with industry best practices, and miss the opportunity to take advantage of lessons learned through numerous deployments.

In recognition of this problem, NARUC passed a resolution in November 2016 calling for state regulators to consider leveling the playing field between cloud computing and on-premise solutions by allowing utilities to capitalize and earn a rate of return on software investments, regardless of the delivery method or payment model.[75] Many AI offerings make use of cloud computing, and are offered under a "software-as-a-service (SaaS)" model. The utility industry, while advancing the use of cloud computing and AI, has not yet accepted a consistent approach to the accounting of the investments into either capital expenditures or normal expenses. Commissions are encouraged to utilize NARUC resources[76] and enter a dialogue with their regulated companies to advance solutions in this area.

Data quality, access, and governance. Employing AI solutions also raises data governance, sharing, storage, and privacy issues. Data must be accessible and accurate. Often, utilities restrict data access to a certain department, and differences in formatting and storing data can inhibit sharing across an organization. Quality control and data validation can be costly and time-intensive.[77] Additionally, standards for data interoperability — transferring data between software systems or suppliers — are lacking and in need of attention from the industry.[78] Other state agencies, such as attorneys general or consumer protection offices, may play a role in developing standards.

The Electric Power Research Institute (EPRI) defines "responsible AI" as AI that is accountable, sustainable, and governable. People should be accountable for the AI models they create. The interpretation of AI results should be objective and explainable. Sustainable AI frameworks should be maintained and developed to respond to new data, policies, and regulations. In terms of data governance, EPRI outlines four objectives (*Figure 4*):

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74 Consolidated Edison of New York (Con Edison) provides an example of a successful pilot program demonstrating the performance of a new technology. Based on a pilot in which Con Edison installed 9,000 AMI-enabled natural gas detectors at the point where gas service lines enter buildings, the utility received approval from the New York State Public Service Commission to install 376,000 detectors inside buildings throughout its natural gas service territory in New York City and Westchester County. The detectors sense natural gas leaks and automatically issue an alarm, voice warning, and notification to the utility and local first responders, decreasing the likelihood of an explosion. Installation will happen through 2025 at a cost of $130 million, but at no additional charge to customers receiving AMI-enabled natural gas detectors. See Consolidated Edison Company of New York, "Con Edison Providing Smart Gas Detectors in Major Breakthrough for Customer Safety," September 28, 2020. https://www.prnewswire.com/news-releases/con-edison-providing-smart-gas-detectors-in-major-breakthrough-for-customer-safety-301139027.html

75 National Association of Regulatory Utility Commissioners, "Resolution Encouraging State Utility Commissions to Consider Improving the Regulatory Treatment of Cloud Computing Arrangements," November 16, 2016, https://www.naruc.org/resolutions-index/

76 NARUC hosted a webinar on cloud computing on September 24, 2020. The webinar was moderated by Commissioner Diane Burman and featured as speakers Joseph Santamaria, Amazon Web Services; Rick Cutter, Cloud for Utilities; and Danny Waggoner, Advanced Energy Economy. A recording is available at https://www.youtube.com/watch?v=tro8L9rZKH8 and slides at https://pubs.naruc.org/pub/8929ED7E-155D-0A36-317C-08848BB4DCFD. Discussion focused on the scalability and elasticity benefits of cloud computing for utilities, cybersecurity and compliance concerns, reasons for slower cloud adoption in the utility industry compared to other industries, and impacts of cloud computing on utility earnings.

77 Utility Analytics Institute, *State of the Market: Addressing Challenges and Improving Performance through Analytics, Utility Market Data and Case Studies,* November 14, 2018. https://img.en25.com/Web/PentonCEM/%7B2981eb64-20ca-43dd-a5b6-5968fe25640f%7D_Sensus_-_State_of_the_Market_Report_Final2.pdf?elqTrackId=76226d756ad84f2aa503970ad030dd91&elqaid=1380&elqat=2

78 Electric Power Research Institute, *A Primer on Data Governance Issues for Responsible Artificial Intelligence in the Power Industry,* January 2020, https://www.epri.com/research/products/000000003002017792

- Data integrity: preserving the accuracy, consistency, and quality of data across different systems
- Data lineage: describing the path of the data to its current location as well as any alterations
- Data security: preserving the data from unauthorized or inappropriate access or change
- Data loss prevention: identifying and monitoring sensitive data to ensure it is not misused, leaked, or accessed by unauthorized users

Figure 4: Components of Data Governance

Utilities will need to put in place comprehensive data governance protocols that comply with any relevant regulations and policies. To date, the utility industry lacks industry-wide standards and policies for responsible AI as defined by EPRI, and approaches to data governance may vary widely across the industry.

Cybersecurity. Cybersecurity presents both a challenge and an opportunity for AI. AI solutions can automate data protection and detect intrusions, although case studies are limited. Unfortunately, hackers are also shifting into AI and automating attacks, necessitating a shift to developing machine-on-machine cybersecurity defenses.[79] Further, AI's reliance on connected devices and storing customer data at a utility or third-party site can create potential targets for cyberattacks.[80] Before seeking approval from regulators, gas utilities must address the cybersecurity issues of any proposed AI investments.[81]

Bias. In the interest of providing fair, accessible service to all customers, AI solutions must be evaluated for potential bias. The Brookings Institution observes:

> *"[B]ecause machines can treat similarly-situated people and objects differently, research is starting to reveal some troubling examples in which the reality of algorithmic decision-making falls short of our expectations. Given this, some algorithms run the risk of replicating and even amplifying human biases, particularly those affecting protected groups... With algorithms appearing in a variety of applications, we argue that operators and other concerned stakeholders must be diligent in proactively addressing factors which contribute to bias."*[82]

Addressing and removing bias is a critical task with responsibility shared among utilities, regulators, and other stakeholders. Racial bias is particularly important for those in the energy sector to comprehend. At the time of publication, there is an ongoing public debate over the impacts of racial bias on health[83] and criminal

79 Nektaria Kaloudi and Jingyue Li, "The AI-Based Cyber Threat Landscape: A Survey," ACM Computing Surveys, February 2020, https://dl.acm.org/doi/fullHtml/10.1145/3372823

80 Herman Trabish, "In the 'Cat and Mouse' Game of Utility Cyberattacks, AI and Machine Learning Show Promise, Limits," Utility Dive, November 7, 2019, https://www.utilitydive.com/news/artificial-intelligence-and-machine-learning-face-off-with-new-cybersecurit/566499/

81 Mark Wiranowski and Susan Bergles, *Big Data: Opportunities and Constraints for Gas Utilities*, Wilkinson Barker Knauer LLP, July 2015. http://www.wbklaw.com/uploads/Wiranowski%20and%20Bergles,%20%20AGA%20Paper%20%20Data%20and%20Gas%20Utilities%20Jul15.pdf

82 Nicol Turner Lee, Paul Resnick, and Genie Barton, *Algorithmic Bias Detection and Mitigation: Best Practices and Policies to Reduce Consumer Harms*, The Brookings Institution, May 22, 2019, https://www.brookings.edu/research/algorithmic-bias-detection-and-mitigation-best-practices-and-policies-to-reduce-consumer-harms/

83 U.S. Centers for Disease Control and Prevention, *COVID-19 in Racial and Ethnic Minority Groups*, June 25, 2020, https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/racial-ethnic-minorities.html

justice outcomes,[84] brought about by the disproportionate impacts of the novel coronavirus (COVID-19) on racial and ethnic minority groups and multiple instances of excessive force used by law enforcement against African-American citizens. Racial minorities also experience differences in utility services compared to Caucasian customers. A working paper from the University of California, Berkeley found that African-American renters and homeowners paid $273 and $408 more per year for utilities, respectively, than white renters and homeowners, even when controlling for income, household size, city of residence, and other characteristics.[85] The National Association for the Advancement of Colored People found that some water utility shutoff practices disproportionately targeted Black and low-income neighborhoods.[86] Such findings provide no evidence of and make no claims toward intentional racial bias on the part of utilities, regulators, or other stakeholders, but underscore the need to understand how differences among racial and ethnic groups intersect with regulatory decisions and utility practices. As AI solutions are deployed in the utility industry, it will be essential to analyze any disproportionate impacts on minority communities and address the underlying issues to deliver equal outcomes to all customers.[87]

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84 Radley Balko, "There's Overwhelming Evidence That the Criminal Justice System is Racist. Here's the Proof," *The Washington Post*, June 10, 2020, https://www.washingtonpost.com/graphics/2020/opinions/systemic-racism-police-evidence-criminal-justice-system/

85 Eva Lyubichs, *The Race Gap in Energy Expenditures*, Energy Institute at Haas, June 2020, https://haas.berkeley.edu/wp-content/uploads/WP306.pdf

86 Coty Montag, *Water/Color: A Study of Race & the Water Affordability Crisis in America's Cities*, Thurgood Marshall Institute at the NAACP Legal Defense and Educational Fund, Inc., 2019, https://www.naacpldf.org/wp-content/uploads/Water_Report_FULL_5_31_19_FINAL_OPT.pdf

87 Google offers an example of how unintentional bias in AI can result in different results across races. Its "Vision AI" offers automated image labeling. An experiment found that the service was delivering different results for images of individuals of different races. See https://algorithmwatch.org/en/story/google-vision-racism/. Additionally, a study from the National Institute of Standards and Technology found that most AI-powered facial recognition systems performed worse on non-white faces than white faces. See https://www.technologyreview.com/2019/12/20/79/ai-face-recognition-racist-us-government-nist-study/

V. Forthcoming Opportunities

In addition to addressing challenges with distribution infrastructure modernization, excavator damage, and customer engagement, AI could feasibly solve two other issues faced by gas distribution companies: hydrogen transportation and virtual white lining.

Hydrogen transportation. Hydrogen can serve as a transportation fuel, source of heat for industrial processes, and the key ingredient for fuel cell systems. When burned, hydrogen emits only water vapor, making it an attractive option for decarbonization. Generating hydrogen requires energy from coal, natural gas, or renewable sources.[88] Natural gas-fired steam methane reforming (SMR) is projected to remain the dominant method of large-scale hydrogen production well into the future, according to the International Energy Agency.[89] Transporting hydrogen from source to end user requires either new infrastructure or the reallocation of existing infrastructure, including natural gas pipelines. Based on analysis from the National Renewable Energy Lab, hydrogen can be blended with natural gas in concentrations of up to 15% and used to power end-use devices without impacting safety or reliability. Additional study is needed to determine how existing gas infrastructure could handle differing blends. Hydrogen can also be separated from natural gas and extracted from the pipeline network for end uses requiring pure hydrogen.[90] AI could play a constructive role in enabling hydrogen use in two ways: (1) setting the appropriate blend concentration given real-time data on pipeline characteristics and natural gas compositions, and (2) optimizing locations to inject and withdraw pure hydrogen from natural gas pipelines.

The U.S. Department of Energy Is Investing in AI

Multiple offices within the U.S. Department of Energy are funding research that could unlock new capabilities for AI. In September 2019, DOE created the Artificial Intelligence and Technology Office (AITO) to accelerate AI capabilities, scale the development and impact of AI, and align AI activities with DOE priorities.[91, 92] In March 2020, AITO announced a $40 million funding opportunity to support research in data, AI, and machine learning over the next three years.[93] Other offices across DOE share AITO's goals. In November 2019, DOE's Advanced Research Projects Agency-Energy (ARPA-E) announced $15 million worth of funding for 23 projects under the Design Intelligence Fostering Formidable Energy Reduction (and) Enabling Novel Totally Impactful Advanced Technology Enhancements (DIFFERENTIATE) program. The projects will incorporate machine learning and AI into energy technology and product design processes.[94] ARPA-E's Rapid Encapsulation of Pipelines Avoiding Intensive Replacement (REPAIR) program "seeks to reduce natural gas

88 Sina Faizollahzadeh Ardabili et al., "Computational Intelligence Approach for Modeling Hydrogen Production: A Review," *Engineering Applications of Computational Fluid Mechanics*, Vol. 12, Issue 1; March 28, 2018. https://www.tandfonline.com/doi/full/10.1080/19942060.2018.1452296

89 International Energy Agency, *The Future of Hydrogen: Seizing Today's Opportunities,* June 2019, https://www.iea.org/reports/the-future-of-hydrogen

90 M.W. Melaina, O. Antonia, and M. Penev. *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues,* National Renewable Energy Lab. March 2013. https://www.nrel.gov/docs/fy13osti/51995.pdf. U.S. DOE, Artificial Intelligence and Technology Office, "About the Artificial Intelligence and Technology Office," https://www.energy.gov/science-innovation/artificial-intelligence-and-technology-office.

91 U.S. DOE, Artificial Intelligence and Technology Office, "About the Artificial Intelligence and Technology Office," https://www.energy.gov/science-innovation/artificial-intelligence-and-technology-office

92 U.S. DOE, Artificial Intelligence and Technology Office, "Cheryl Ingstad Sworn in as Director of DOE's Artificial Intelligence & Technology Office," February 6, 2020, https://www.energy.gov/node/4065537/articles/cheryl-ingstad-sworn-director-doe-s-artificial-intelligence-technology-office

93 U.S. DOE, "Department of Energy to Provide $40 Million for Artificial Intelligence Research at DOE Scientific User Facilities," March 9, 2020, https://www.energy.gov/articles/department-energy-provide-40-million-artificial-intelligence-research-doe-scientific-user

94 U.S. DOE, "Department of Energy Announces $15 Million for Development of Artificial Intelligence and Machine Learning Tools," November 19, 2019, https://www.energy.gov/articles/department-energy-announces-15-million-development-artificial-intelligence-and-machine

leaks from these pipes by developing a suite of technologies to enable the automated construction of new pipe inside existing pipe… incorporating smart functionality into structural coating materials and developing new integrity/inspection tools…[creating] three-dimensional (3D) maps that integrate natural gas pipelines and adjacent underground infrastructure geospatial information with integrity, leak, and coating deposition data." The technologies and practices that result from the REPAIR program can leverage AI tools to further improve pipeline safety and achieve cost-effective modernization of natural gas infrastructure.[95] In March 2020, the Office of Electricity (OE) announced $6.7 million for four university-led research projects to improve the integration of Internet of Things (IoT)" technologies in energy infrastructure by developing machine learning and algorithms to enhance coordination between system operators/utilities and distributed energy resource owners.[96]

Virtual white lining. Building from experience implementing AI for excavator damage prevention, and leveraging cutting-edge mapping technology and information-sharing practices, AI can enable substantial improvements in underground mapping and safe excavation. AI can be used as a quality control tool to protect against striking mismarked underground facilities prior to excavation now, and translate the data gathered through machine learning into accurate maps of underground facilities in the future. Virtual white lining is a growing practice in which excavation sites are marked virtually and depicted on a map using GPS coordinates. Combined with enhanced positive response (EPR), the practice of providing comprehensive site information to the excavator, including digital markings of the location of underground facilities, current and past worksites with overlapping GPS coordinates could be compared against each other to flag for inconsistencies in the marked location of underground facilities.[97] From here, AI and machine learning can compare all maps with overlaying GPS coordinates, and over time zero in more specifically on facilities' locations by revising and reconciling the maps for future locate and excavate projects, eliminating outliers. This approach would make the excavation process safer and more efficient. First, it would reduce the need for in-person visits to apply paint denoting underground infrastructure. Second, by ensuring that locators and excavators have access to reliable, accurate data, EPR can reduce damage rates up to 67 percent.[98]

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95 ARPA-E, "REPAIR," February 18, 2020, https://arpa-e.energy.gov/technologies/programs/repair

96 U.S. DOE, "Department of Energy Announces $6.7 Million for IoT Integration Research," February 25, 2020, https://www.energy.gov/articles/department-energy-announces-67-million-iot-integration-research

97 Personal communication, Brigham McCown, Alyeska Pipeline Service Company, and Benjamin Dierker, Alliance for Innovation and Infrastructure.

98 U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, *A Study on Improving Damage Prevention Technology,* August 2017, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/docs/news/18351/reporttocongressonimprovingdamagepreventiontechnologyaug2017.pdf

VI. Conclusion

AI has a broad range of current and potential applications for natural gas utilities, as discussed in Sections III and V. However, using these capabilities to provide valuable, actionable insights to utilities and benefit customers requires attention and action from regulators and utilities, as well as proactive collaboration to address the data privacy, data governance, equity, cybersecurity, staffing, and other challenges that AI presents to regulated utilities. AI is a transformative technology with vast potential in the natural gas industry. The DOE-NARUC NGP encourages continued communication and collaboration among regulators, gas utilities, and other stakeholders to pilot, evaluate, and improve the deployment of responsible AI innovations for natural gas utilities. In the future, as offerings continue to grow and utilities learn lessons from implementation, NARUC will continue to highlight successful approaches and offer educational opportunities to regulators and other stakeholders.

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National Association of Regulatory Utility Commissioners

1101 Vermont Ave, NW • Suite 200 • Washington, DC 20005
www.naruc.org • (202) 898-2200