R&D Strategy Report 2024

PG&E®

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Written in collaboration with Realize 2050

MESSAGE FROM THE CEO

At PG&E, we are actively building the carbon-free energy system of the future.

A system in which advanced automation refines our operations, predictive technologies prevent equipment failure, and personalized experiences benefit every customer.

All of this helps us provide energy that's **resilient**, **clean**, **affordable** and **safe**.

Last year, our Research and Development Strategy Report identified nearly 70 critical challenges we face in creating California's energy future.

Innovators from around the world heard our call, and they joined us in tackling these challenges. From over 600 proposals, we identified dozens of promising climate-tech solutions to test, integrate and deploy at scale.

This year, our refreshed 2024 R&D Strategy Report outlines **new and updated challenges that could be solved by artificial intelligence and other technologies**.

We're calling on innovators to join us in exploring how AI can shape the future of energy and amplify the incredible work of our dedicated workforce.

The future of energy is ours to imagine and create, and together, we will achieve extraordinary things.

Sincerely,

Patti Poppe
Chief Executive Officer
PG&E Corporation

MESSAGE FROM THE SENIOR DIRECTOR of Grid Research, Innovation and Development

Last year we embarked on a new chapter in PG&E's innovation journey.

We sought to embrace **breakthrough thinking and radical collaboration** by openly sharing our toughest technological challenges and inviting problem solvers from around the world to **help PG&E envision what the future could look like**.

From the Innovation Summit to the 2023 Pitch Fest, we were awed by the strength of the innovation community's response and its shared passion for building this better future together.

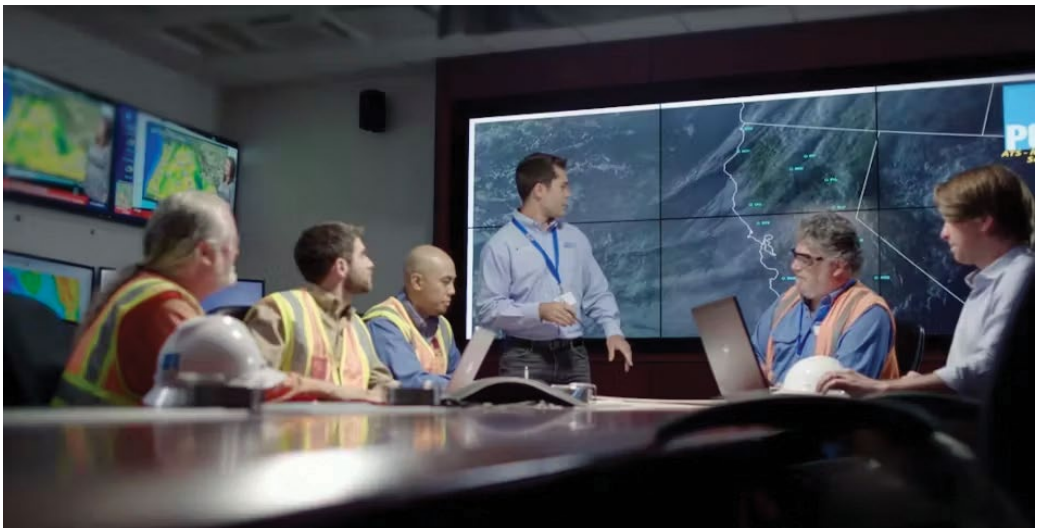
Throughout this report, we are excited to share the progress that we have made towards our True North Strategy and Climate Strategy goals as a result of collaborations with external innovation partners and the dedicated efforts of our coworkers.

While we have made meaningful strides over the last year, the world has inevitably continued to change, bringing new challenges and unlocking a new universe of potential solutions.

Our updated 2024 R&D Strategy not only highlights our evolving R&D needs but also explores the vast potential of artificial intelligence to revolutionize our energy system. At PG&E, we see **unbounded opportunity for AI** to drive advanced efficiencies and orchestration across our operations, unlock predictive capabilities to support the health of our assets, personalize interactions with our customers, and magnify the capabilities of our coworkers.

We look forward to partnering with you—innovators, regulators, educators, and peers—to co-create the solutions that will unlock a future that is cleaner, safer, more affordable, and more reliable for all Californians.

Quinn Nakayama
Senior Director
Grid Research, Innovation and Development



Reflections from 2023

Last year marked a bold shift in PG&E's approach to R&D and innovation. Our new strategy was born out of the recognition that the pace and scale of change across our energy system is too massive to tackle alone, as well as the understanding that the challenges posed by these evolving dynamics are not unique to PG&E.

While in some cases we may be ahead of the curve in realizing their impacts, these challenges will ultimately be shared broadly across the industry as we **transition to cleaner sources of supply, as electrification accelerates, and as the effects of global climate change continue to materialize**.

With last year's launch of PG&E's inaugural R&D Strategy Report, Innovation Summit, and Innovation Pitch Fest event, we shared our biggest challenges and invited problem solvers from all corners of the world to join us in building the energy system of the future, together.

By broadening our innovation efforts, we sought to bring together diverse perspectives to grapple with these thorny challenges, to imagine the possibilities for tomorrow's energy system, and to identify the most promising solutions for achieving our True North Strategy (TNS) and delivering a safe, clean, resilient, and affordable energy system.

We were excited and humbled to see the enthusiasm with which you responded to this call:

Over 3,000 in-person + virtual attendees of the inaugural Innovation Summit

Nearly 630 responses to our call for solutions across the 67 problem statements in our R&D Strategy Report

60 in-person pitches at our live Innovation Pitch Fest

This enthusiastic response also yielded real progress towards solving some of the most vexing innovation challenges we face in pursuit of our True North Strategy goals. **Through the 2023 Pitch Fest, we identified over a dozen potential vendor partners that offer breakthrough innovations that can advance our efforts to support our customers' growing electric demand** by maximizing the utilization of our electric system, addressing the complexities of multi-family EV charging, and managing increasing EV charging loads. Other promising Pitch Fest solutions that we are evaluating have the potential to transform our efforts to promote safety across our energy system by advancing our vegetation management capabilities and introducing a cutting-edge approach to undergrounding electric lines.

While Pitch Fest was instrumental in identifying a broad range of solutions that we believe can have game-changing impact across our operations, it is just one of the many avenues through which we identified and pursued breakthrough technologies in 2023. Later in the report we will share our plans for the 2024 Innovation Summit, where we will provide a comprehensive update on our R&D efforts over the last year and preview our strategy for what's to come.

This is just the beginning.

The evolving backdrop for innovation

In recent years, the accelerating forces of electrification, decarbonization, and climate change have brought about a paradigm shift in the operating environment for utilities globally, requiring a fundamental reimagining of the way we build, maintain, and operate our electric and gas systems.

California stands at the leading edge of many of these trends. With some of the nation's most forward-looking clean energy policies and leading rates of electrification, California is leading the way in the transition to a cleaner energy system.[1]

At PG&E, our vision for the future is similarly ambitious, and we are working resolutely to tackle the wide range of challenges necessary to make that future a reality for the customers and communities that we serve.

While rapidly evolving dynamics across the energy system have presented new challenges to our operations, the technologies available to potentially address these challenges have also been rapidly advancing in parallel. In particular, the advent of artificial intelligence (AI) and the rapid proliferation of diverse and far-ranging capabilities leveraging this powerful technology have unlocked an entirely new solution space that few had contemplated as a real possibility as recently as last year.

[1] California has passed a wide range of climate mandates and regulations, including Executive Order N-79-20, stipulating that all new passenger vehicles sold in the state must be zero-emission by 2035, and SB 100, mandating that all electric retail sales must come from renewable and/or zero-carbon sources by 2045.

The potential advances enabled by AI could equip us to not only better keep pace with the changes we are experiencing across our system today but also to proactively anticipate the challenges of tomorrow by reimagining our energy system to be resilient, decarbonized, and optimized to local and system needs, as well as adaptable to a wide range of potential futures.

PG&E has already embraced numerous applications of artificial intelligence that augment the efforts of our coworkers, including technologies that support our efforts to **quickly identify ignitions**, **inspect and maintain our assets**, and **optimally bundle and prioritize field work**.

We believe strongly in the transformative power of AI and have ambitious plans to build upon these early successes and extend the game-changing capabilities of AI broadly across our system. At the same time, we are committed to responsible, accurate, and reliable use of AI that includes human oversight as an essential component to guarantee safe and ethical operations and have implemented a rigorous framework to ensure that these values are prioritized in our use of AI. Later in the report, we will expand upon our vision for how an AI-enabled utility can deliver a tomorrow for our customers that is cleaner, safer, and resilient while also driving meaningful efficiencies that can amplify our ongoing efforts to deliver affordable energy and excellent customer experiences every day.

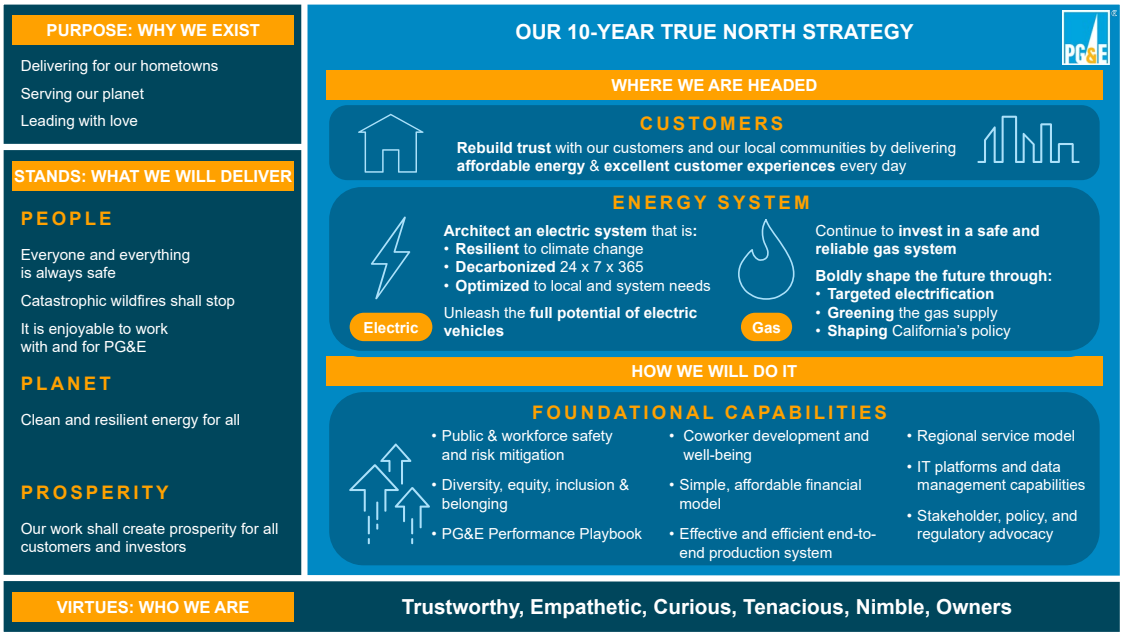
Our 10-year True North Strategy charts a path for our transformation journey and serves as the compass for our innovation efforts. AI can act as an accelerant to achieving our TNS and, while it does not change where we are going, it can act as a critical enabler to achieving our TNS goals.

Our True North Strategy

PG&E's **True North Strategy** is our 10-year enterprise transformation strategy, guiding us toward a future where we play a pivotal role in California's transition to a net zero emissions, climate-resilient future.

Our strategy is rooted in the belief that **PG&E has a responsibility to build a safer, better future, contributing to both environmental sustainability and community prosperity**.

TNS directs the entire company to fulfill our commitments to people, planet, and prosperity. It focuses on three key areas: rebuilding trust by delivering affordable energy and excellent service to customers; designing a decarbonized, safe, and reliable energy system; and building strong foundational capabilities to enable these outcomes. Now in its third year, TNS drives long-term strategic thinking while maintaining a sharp focus on near-term priorities across Customers, Energy System, and Foundational Capabilities.



As part of our broader R&D strategy, the Grid Research, Innovation, and Development (GRiD) team leads an annual initiative to support TNS. This involves reviewing progress from the previous year, updating our R&D Strategy report to stay in lockstep TNS and the evolving technology landscape, socializing our needs with external stakeholders, and pursuing new projects with the greatest potential to advance our TNS. Many of our projects aim for long-term, catalytic breakthroughs, guided by the question: **What will the future look like in 2, 5, and 10 years, and how can technology help us get there?**

This year's report shines a spotlight on the growing potential of AI to enable these TNS outcomes across our energy system. AI, particularly the emergence of generative AI, presents opportunities across our business. Key questions include:

- How can the growth of AI accelerate PG&E's progress toward our TNS?
- What opportunities does AI create to improve our energy system and build trust with customers?
- How will PG&E integrate AI into our broader investment in foundational capabilities?
- What challenges may AI and related technologies pose to the society we serve and the energy systems we lead, and how can we ensure our procedures reflect an awareness of and responsiveness to those challenges?

Within PG&E, the responsible use of AI is already beginning to transform our operations, notably in reducing wildfire risk and enhancing our climate resilience. As we continue to leverage AI, it will become a foundational capability in our overall strategy. Externally, we are responding to growing energy demands driven by AI-powered data centers and adjusting our strategy to support these evolving customer needs. This report outlines how our TNS positions us to navigate these complex questions.

What remains unchanged from year to year is that realizing the vision of our TNS requires transformational change. Achieving this vision will equip PG&E to meet the demands of today, anticipate the needs of tomorrow, and adapt to the challenges that lie ahead.

While our TNS encompasses a range of important goals, stabilizing bills for our customers and reducing rates is an urgent near-term priority. We are working across multiple fronts to drive progress and remain fiercely dedicated to eliminating waste across the organization and deploying cutting-edge solutions to ensure that we can architect an energy system that delivers affordable energy and excellent customer experiences every day.

PG&E's commitment to stabilizing customer bills

Energy is a vital resource that fuels our local economies and powers our customers' daily activities. The expansion of transportation and building electrification, remote work, and increased virtual communication have made reliable energy critical to successfully navigating everyday life.

At PG&E, helping all of our customers to prosper and thrive is central to our mission. Our efforts to create prosperity within the communities we serve take many forms across our operations. From ensuring that our customers can reliably power their daily lives and work, to safeguarding the future of our hometowns against catastrophic wildfires, to supporting local growth through providing new businesses and homes with timely access to power, PG&E strives every day to support all of our customers in their pursuit of prosperity.

We understand that customers are frustrated with higher costs of living, including energy bills, and we are committed to delivering safe, reliable, and climate-resilient energy at the lowest possible cost to our customers. We are taking actions to keep average annual combined gas and electric customer bill increases within two to four percent through our current General Rate Case which ends in 2026. This includes adopting company-wide savings initiatives to reduce our costs and limit unnecessary expenses.

In 2023, we saved $510 million in operating and capital costs through our waste elimination efforts. **This year, we are working to save up to $1 billion in costs** by managing over 200 initiatives to reduce materials, labor, and other costs and to more efficiently plan, execute, and automate our work to deliver for our customers.

Beyond efforts to drive efficiency across our operations, we are pursuing numerous other avenues to reduce costs for customers.

- We worked with consumer advocates on an alternative to commercial insurance, saving customers up to $1.8 billion over four years.
- We are working to reduce our financing costs by applying for Department of Energy grants and lower-cost loans that may save customers hundreds of millions of dollars in interest expense over the life of the loan.
- In August, the Department of Energy awarded a $600 million grant to a consortium including PG&E for a project to bring more clean energy online, while lowering customer costs.

Key components of PG&E customer bills

PG&E customer energy bills are made up of several key components:

Energy generation and purchasing costs: The cost of purchasing and producing energy to serve customers. PG&E does not control market prices for natural gas and electricity, and like other utilities, does not mark up the cost of the gas and electricity that we purchase on behalf of customers.

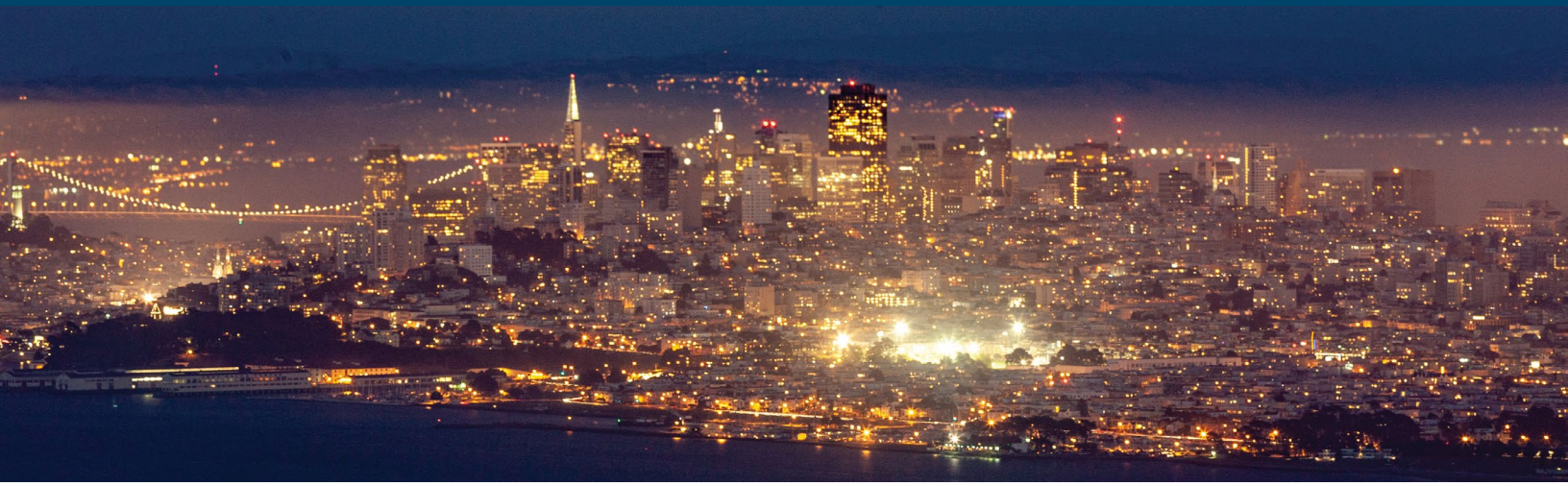
Operations, maintenance, and upgrades: The cost of delivering energy to customers, which includes operating, maintaining, and upgrading the natural gas and electric systems' infrastructure.

State policies and programs: The cost of certain programs, called Public Purpose Program charges, required by the state that support societal programs like low-income customer financial assistance and energy efficiency programs.

The evolving dynamics of electrification, decarbonization, and climate change have fundamentally altered the environment in which PG&E operates, and in turn have had an impact on several of these key drivers of customer bills. In response to these systemic changes, PG&E seeks to balance a complex equation of priorities, all of which are central to providing safe, reliable, and clean energy to our customers at the lowest cost possible.

Simultaneously delivering across all of these critical dimensions requires not only ongoing and historically unprecedented levels of investment across our energy system, but also an unwavering and vigilant commitment to increasing the efficiency of our operations.

In addition to these factors, the volume of energy delivered across our system also affects customer bills. New electric load can be a key enabler to lowering the unit cost of electricity, by spreading costs over more customers. By capitalizing on this opportunity, we see a pathway where electrification can deliver a decarbonized energy future at a lower societal cost.



Driving operational progress

PG&E is making significant investments in engineering and building an energy system that is decarbonized, safe, and resilient to the impacts of climate change.

These investments are delivering meaningful results for customers every day. Our layers of wildfire protection have significantly reduced wildfire risk from our equipment across our service area, and our gas operations' performance is among the utility industry's best in class. Our investments in the electric grid have also enhanced safety and reliability for our customers and paved the way for widespread EV adoption across our service area.

Wildfire safety: Our safety measures prevented any major fires from our equipment in 2023, and EPSS-enabled power lines reduced reportable ignitions by 72% compared to the 2018–2020 average. We are planning to bury 10,000 miles of power lines—about eight percent of our total distribution line miles—in our highest fire-risk areas, with approximately 690 miles completed so far. We're installing strong poles and covered power lines; revolutionizing our system inspections using cutting-edge drone and high-resolution image technology; and making Public Safety Power Shutoffs (PSPS) and Enhanced Powerline Safety Settings (EPSS) less impactful to customers and communities.

Gas safety: Our programs include system inspections; strength-testing and replacing gas pipelines; and using mobile leak detection technology to quickly find and fix gas leaks and improve safety and reduce methane emissions.

Electric reliability and safety: We're enhancing our storm, wildfire, and other natural disaster emergency response capabilities; increasing electric security and protection of the grid; expanding electric capacity to support growing demand and the state's transportation electrification, affordable housing and economic development goals; supporting widespread adoption of electric vehicles to reduce climate impacts and improve air quality; exploring technologies to use electric vehicle batteries and other energy storage and microgrids to improve grid resilience during extreme weather conditions.

Load growth and grid optimization: helping reduce customer costs

One primary driver of change across our energy system is accelerating forecasts of load growth over the next 15 years. Our current estimates indicate that these trends will drive an unprecedented **doubling of electric load by 2040**. While new infrastructure investments will be necessary in some cases to meet this forecasted demand, this growth also presents a significant opportunity to reduce costs by directing load growth to areas with existing transmission and distribution capacity. To capture these stabilizing effects, it is **critical to ensure that we are investing prudently to support load growth by prioritizing increased utilization of the existing system through the optimization of grid operations and effective management of customer load**.

The pursuit and deployment of innovative technologies will be central to our efforts to fully capitalize on the stabilizing potential of load growth and to advancing our work to further automate and optimize our work to operate, maintain, and upgrade our energy system. Through our R&D Strategy, Electric Program Investment Charge (EPIC) program, and numerous other innovation channels, PG&E is pursuing breakthrough solutions that have the potential to improve the efficiency of our operations and deliver meaningful savings for our customers on an ongoing basis.

In our 2023 EPIC Annual Report, we highlight several of these projects, including the deployment of predictive maintenance capabilities and advanced distributed energy resource management system (DERMS) functionality, that are estimated to save customers millions of dollars per year.

Our R&D Strategy aims to further these efforts, focusing on the challenges where research and development can have the most outsized impact on reducing rates and delivering for our customers, our communities, and the planet.

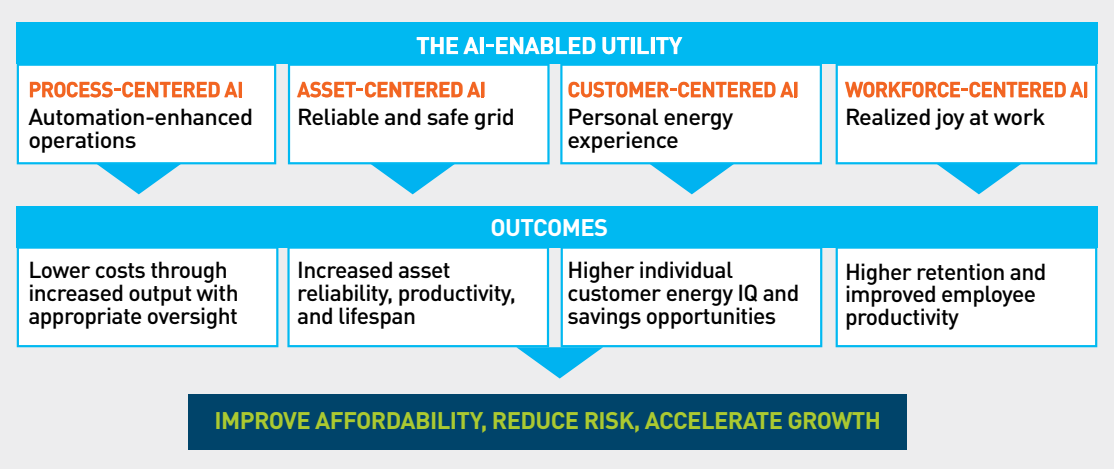
The AI-Enabled Utility

Our vision: The AI-enabled utility

Leveraging the power of AI to achieve our True North Strategy

Imagine an energy system where advanced automation facilitates our operations, predictive technologies preemptively avert faults, new insights are autonomously and organically generated from everyday grid operations, and every customer enjoys an increasingly personalized energy experience.

In pursuit of our True North Strategy goals, PG&E has embarked on a transformative journey to reimagine the way we deliver energy to all our customers. We believe that AI can play a crucial role in facilitating this journey and achieving our TNS. **While we have already applied machine learning to mitigate wildfire risks and enhance operations, this marks the first time we are holistically exploring the full potential of AI across our entire system.** Our goal is to make this AI-enabled utility a reality, enabling PG&E to reduce risks, accelerate growth, and deliver affordable energy by generating efficiencies. This ambitious vision involves leveraging AI responsibly to build the energy system of the future, one that is safe, clean, and affordable.



Our investments in building this future will be driven by our True North Strategy goals and will align to the four key pillars depicted above: **Process**, **Asset**, **Customer**, and **Workforce**. These pillars touch all facets of our operations, from customer interactions to internal processes and everything in between. While each pillar delivers unique benefits, they **all share a common goal: enhancing affordability**.

Process-centered AI: Intelligent orchestration and enhanced automation at scale

AI has the potential to enhance our operations and orchestrate energy resources across the grid, from energy generation and EVs to energy storage and smart home technology. The combination of multiple tools can accelerate the way we deliver work at scale. Intelligent orchestration and enhanced automation could enhance efficiency and reliability, reduce operational costs, and improve service delivery across the energy system, providing grid flexibility when the system needs it most and enabling our efforts to deliver clean and resilient energy for all.

Asset-centered AI: Predictive asset lifecycle management

PG&E strives to leverage **AI solutions to proactively manage asset lifecycles**. These capabilities could support our energy system with super-intelligent resilience enabled by technologies that are capable, with appropriate human oversight, of autonomously detecting and addressing faults or disruptions before they occur, executing optimized and targeted maintenance programs, and running simulations to analyze potential outcomes and prevent unwanted events based on real-life scenarios. This highly resilient and cost-effectively maintained energy system would support our efforts to rebuild trust with our customers and communities by delivering affordable energy and excellent customer experiences every day.

Customer-centered AI: AI at the service of the customer

PG&E seeks to offer a more personalized energy experience where **customer-centric AI solutions leverage data patterns**, such as energy consumption, to personalize interactions and optimize energy solutions to deliver greater value to all our customers. This will involve giving customers both more visibility into and more control over their energy usage (e.g., with home appliances).

Workforce-centered AI: Unleashing our coworkers' superpowers

Lastly, PG&E envisions boosting the **operational effectiveness of our workforce by leveraging human-centered AI**. Through the enhanced automation of repetitive processes, GenAI-powered knowledge creation, and aggregation of trustworthy data to support decision-making with appropriate safeguards, AI can increase efficiency and enable our coworkers to focus on areas requiring creative problem solving and specialized expertise, underscoring our commitment to ensure it is enjoyable to work with and for PG&E.

Taken together, these advanced capabilities will underscore and amplify PG&E's ongoing efforts to deliver on our TNS commitments. By integrating intelligent orchestration, end-to-end automation, predictive resilience, personalized customer experiences, and workforce-centric enhanced operational capabilities, PG&E is positioned to lead the way toward a cleaner, safer, and more customer-centric energy future.

Artificial intelligence (AI)[2] is an umbrella term for a variety of technologies[3] where "machine-based systems can, for a given set of human-defined objectives, make predictions, recommendations, or decisions influencing real or virtual environments."

The field of AI encompasses both well-established technologies such as **machine learning (ML)** and optimization, as well as promising but still relatively immature entrants like **Generative AI (GenAI)**.

AI's transformative power lies in its ability to operate under complexity and scale automation. By accounting for numerous factors in certain complex, high-dimensional spaces where human analytical skills are limited, AI algorithms can make more accurate predictions and find more optimal solutions. AI technologies can operate with minimal human intervention, thereby automating tasks that are repetitive and time consuming and promote speed, consistency, and lower operating costs across operations, while still maintaining human oversight to ensure reliability.

While traditional AI is a well-established field, **Generative AI** (GenAI) is a relatively new technology, and its transformative power is still evolving. Compared to traditional AI, GenAI is capable of creating new digital realities, such as written summaries of meeting minutes, professional portraits from casual pictures, new songs from existing music scores, and more. Because of its recency, GenAI still faces limitations and challenges, necessitating significant human oversight and monitoring to ensure trustworthy outcomes. As an operator of critical infrastructure, technology maturity is a key consideration for PG&E; therefore, we aim to approach GenAI with the appropriate governance and safeguards while remaining open to its full potential.

Throughout this report, **we use the term "AI" to encompass all technologies under its umbrella, including traditional ML and GenAI**. When discussing these subfields specifically, we will refer to them by their distinct terms—ML or GenAI. This distinction ensures clarity, as references to ML may include GenAI, (but not necessarily) whereas references to GenAI pertain solely to generative technologies.

[2]In this document the term AI is used as an umbrella term representing the variety of technologies generally unless specified otherwise.
[3]These technologies include automation, machine learning, deep learning, and generative AI (itself a subset of ML).

Why now: Capitalizing on the transformational power of AI

At PG&E, we believe that now is the time to build on our foundation of leveraging AI for select use cases to seize the opportunity to scale the transformational capabilities of AI more broadly across our operations.

Our shift to a more holistic embrace of AI's potential is driven both by the urgent need to deploy increasingly powerful tools to address the challenges posed by electrification, decarbonization, and climate change and by our conviction that our efforts to bolster our foundational capabilities in this space have equipped us to navigate the next chapter of broader transformation. As described in our 2023 R&D Strategy Report, we strongly believe that embracing novel technologies is essential to achieving our True North Strategy, and we view AI as a powerful and versatile accelerator of these efforts.

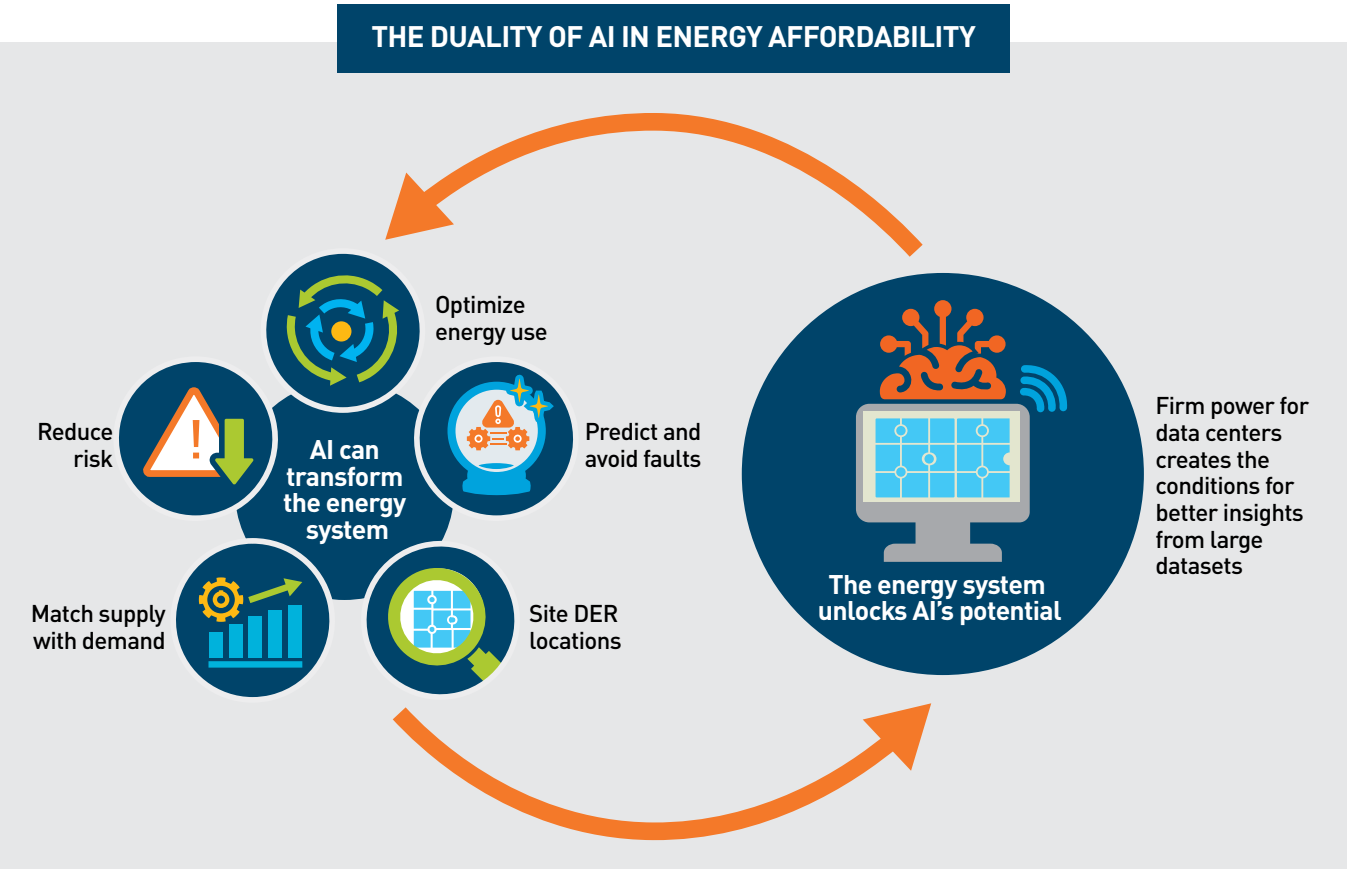
Duality of AI: Unlock AI-driven load growth to drive affordability

While AI has enormous potential to advance the capabilities of our energy system, **the electrical grid is the foundational enabler of this AI transformation** through its essential support of the burgeoning demand for data center operations and advanced computing technologies.

The recent surge in generative AI is already driving a significant increase in power demand. It is anticipated that U.S. power demand will double from 2022 levels to 35 GW by 2030[4], an amount comparable to one third of American homes.

For PG&E and other utilities to fully benefit from AI's potential to transform the grid for the benefit of our customers, communities and the planet, we must meet this growing demand with consistent power delivery. We are urgently deploying both conventional capacity upgrades and rapid, low-cost solutions to ensure we're able to unlock AI's transformative capabilities. This symbiotic relationship between the energy grid and AI technologies underscores the importance and urgency of acting now to create robust and adaptable energy infrastructure that supports continued technological innovation on the one hand and advances PG&E's ambitious True North Strategy goals on the other.

[4]McKinsey & Company, Investing in The Rising Data Center Economy, 2024, www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/investing-in-the-rising-data-center-economy



Building on strong foundations: Scaling PG&E's AI capabilities

PG&E has built the technical and governance foundations for a comprehensive AI strategy that reshapes our energy system operations. These efforts have included cross-cutting organizational investments in data-centric platforms, governance, and technological infrastructure, such as cloud computing, in addition to the development and refinement of AI-enabled solutions for targeted PG&E use cases.

As with any novel technology that PG&E plans to deploy broadly across our system, **we have been piloting a number of AI solutions over the last several years to deepen our understanding of the constituent benefits, risks, and capabilities of the technology as we begin to realize its value**. Many of these early efforts have focused on a concern that is of paramount importance to PG&E: ensuring the safety of our communities.

Computer vision for advanced inspections: PG&E's system inspections team developed a suite of tools ("Sherlock & Waldo") that allows desktop inspectors to efficiently view and mark potential equipment problems on high-resolution images captured through aerial inspections using drones and helicopters. These images are also used to train ML models to identify and classify electric system components. Together, these tools have improved the efficiency and effectiveness of the inspection process, saving 7,500 inspector hours annually, and have provided over 600,000 grid inventory data entries to support strategic maintenance and management of our electric assets.

Transformer predictive maintenance: PG&E developed ML models that assess the probability of whether a transformer will fail within the next 30 days and to flag high-risk transformers for desktop review enabling PG&E to investigate anomalies and identify potential failures before they occur. This predictive capability increases safety by avoiding failures that may cause ignitions, improves reliability, and enhances the efficiency of our maintenance efforts by better focusing our attention on our highest-risk assets.

Predictive wildfire risk assessment: PG&E built machine learning models that can process real-time weather data to proactively assess wildfire risk over a forward-looking 129-hour window, or approximately 5.5 days of enhanced visibility. This look-ahead guides how PG&E operates the grid in targeted locations based on the predicted timing and location of elevated fire danger, further advancing our ability to eliminate ignitions.

In addition to developing AI applications to enhance grid safety, we have also deployed targeted AI solutions across many other critical domains at PG&E. These use cases include both customer service and gas system applications. To reduce wait times and improve our customer service experience, PG&E is utilizing intelligent conversational assistants and AI-powered call-center software that can route calls more efficiently and personalize service with real time, relevant information specific to the customer. On our gas system, we are leveraging ML-based solutions to make it easier to detect underground gas pipes and provide insights on the duration of underground service tickets.

Developing and refining these pilot initiatives has taught us a tremendous amount about the nuances of launching and managing AI-enabled technologies across diverse use cases and has helped to inform our vision for deploying AI at scale. Equipped with this experience and with foundational digital transformation efforts well underway, **PG&E is now ready to move beyond pilot deployments to unleash the powers of AI more broadly in tackling the varied and complex challenges facing our energy system**.

Our approach to realizing our vision

PG&E's guiding principles for scaling AI

Achieving our TNS and its associated strategic outcomes guides our efforts in scaling AI and other novel technologies. The clear vision provided by TNS is crucial to navigating and prioritizing the wide range of potential AI applications across the many facets of PG&E's operations.

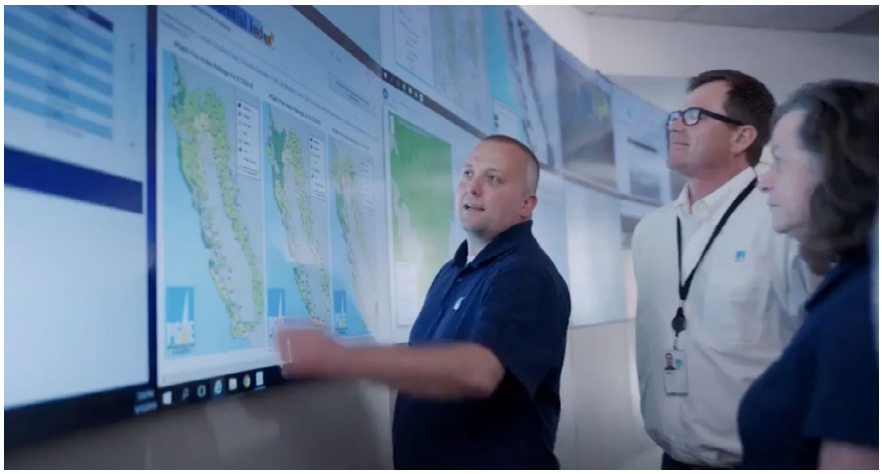
While our strategic roadmap seeks to thoughtfully prioritize investments in new capabilities in line with our TNS goals, we recognize that significant challenges await, and that progress rarely unfolds linearly. Additionally, we understand that many of the AI applications that we envision as central elements of this transformation are in their nascency and **much remains unknown about their ultimate role in the energy system**.

To manage this uncertainty while driving towards our vision for the future, PG&E has adopted an **approach to scaling AI that is rooted in a philosophy of resilience, adaptability, and responsible data-driven decision making**. We believe these guiding principles will steer PG&E throughout this journey and maximize the impact of our efforts to achieve a safe, resilient, and decarbonized grid for all.

Long-term strategic alignment: AI investments will service and advance our True North Strategy. As such, we aim to tightly align these investments with PG&E's broader strategic objectives. We will look beyond the AI opportunities' potential for financial return on investment to consider the long-term impacts of our decisions on achieving our TNS, specifically delivering excellent customer experiences, system resilience, and regulatory compliance. While TNS will serve as our North Star in these decisions, uncertainty is an inherent risk in our operations. We aim to plan for multiple future scenarios to ensure investments made today are flexible enough to adapt to regulatory shifts, new technologies, and changes in customer behavior in the future.

Robust consideration of risk: We are clear-eyed about the risks that AI poses to various aspects of our operations and the need for safeguards to ensure that use of AI is effective and reliable. In addition to evaluating the potential benefits that a particular application of AI may provide, we will also thoughtfully consider the degree of risk that it may introduce to the safety, security, and reliability of our operations and the extent to which we are confident in our current abilities to prevent and/or mitigate those impacts.

A holistic approach to transformation: The complex and interconnected nature of our energy system necessitates a holistic approach to building, maintaining, and ultimately transforming our operations. We recognize that scaling AI will be transformational to our business, and we are accordingly building the foundational capabilities, governance structures, and internal expertise required to support this level of change and to avoid or minimize any potential negative impacts. We will focus on initiatives with high benefits relative to costs, even when quantifying benefits, such as safety or other non-financial ones, can be challenging. This ensures we minimize potential negative impacts and prioritize high-impact projects that drive meaningful returns.



Long-term strategic alignment

PG&E's TNS serves as the strategic framework not only for our consideration of which AI applications to pursue but also for our R&D Strategy more broadly. As we assess a wide range of potential AI use cases, ensuring that any potential investment advances PG&E towards our TNS goals is the critical filter for prioritization.

Maintaining our focus on the brighter future that we are building instills discipline in our approach to scaling AI by focusing on applications where it is most consequential for our people and the planet. As we seek to evaluate the strategic alignment of AI use cases with TNS, we assess several different dimensions, which include rate stabilization potential, safety and reliability improvements, customer benefits, decarbonization impacts, and a variety of risks, among others.

The balance of this report details **67 high priority challenges that must be addressed to deliver on our TNS vision**. While there will be many considerations in building and prioritizing our AI roadmap for the years ahead, our R&D Strategy, firmly rooted in achieving TNS objectives, will be a central touchstone for ensuring that our AI investments target our most impactful challenges.

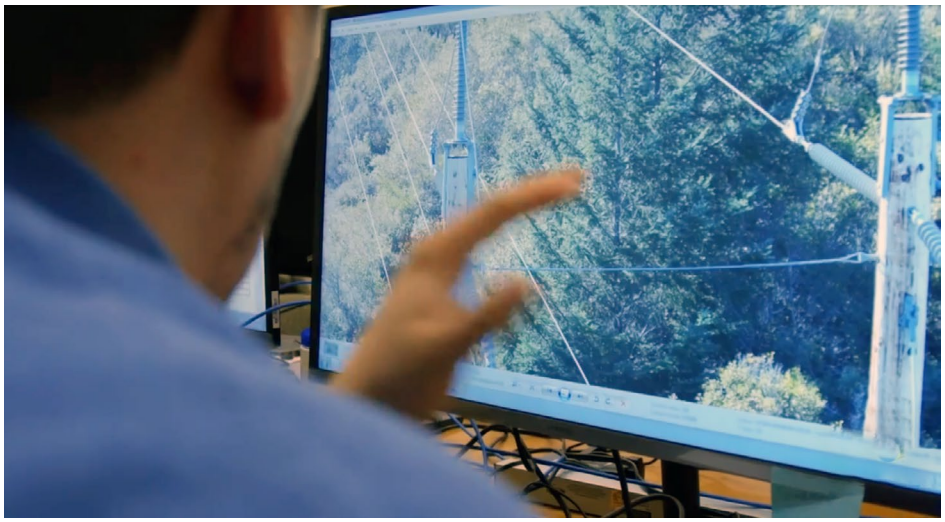
Risks unique to AI

As with many novel technologies, broad-based adoption of AI capabilities has the potential not only to unlock significant value across our operations but also to introduce new and material risks. As a provider of critical infrastructure, PG&E has the responsibility to ensure the safety, reliability, affordability, and equity of the energy system. **For this reason, we are and will continue to be conservative in our deployment of AI systems.**

In addition to evaluating alignment with our TNS goals, we also carefully consider the degree to which potential AI investments may incrementally increase various types of risk across our operations to more fully understand potential tradeoffs. While there are many dimensions to consider during this risk evaluation process, including assessing the risk of inaction, the primary sources of risk that are particularly relevant to applications of AI include:[5]

Hostile attacks: In addition to traditional cybersecurity risks, machine learning systems can also be vulnerable to intentional manipulation by hostile actors. These attacks often seek to exploit the data-driven nature of these systems to create negative outcomes. They may work through the careful manipulation of training or input data to either force the AI model to learn incorrect behavior or to produce desired model output. Other forms of hostile attacks may attempt to extract sensitive information about a model or its training data from AI tools or to compromise the tools and libraries used as inputs, a risk that can be particularly relevant to GenAI applications that are built on centralized models such as ChatGPT.

Model misuse: Outside of hostile attacks from external actors, AI models also pose risks from inadvertent misuse. This can occur when models are used to make predictions about situations or outcomes that lie outside of their training scope, resulting in errant or unpredicted behavior. A lack of necessary processes to enable human oversight to audit, interpret, or monitor ML results could exacerbate this risk by not providing sufficient opportunities for humans to intervene if models produce aberrant results.



[5] www.energy.gov/sites/default/files/2024-04/DOE%20CESER_EO14110-AI%20Report%20Summary_4-26-24.pdf

Model development failure: AI models can also introduce operational risks when training data is poorly designed or incomplete and/or when objectives are poorly defined. In the case of the former, a misalignment between a model's training data and its real-world application may bias the decision-making processes of a model by distorting its understanding of normal behavior. This may occur for example if a model is trained on a limited subset of data that provides a limited view of system dynamics. A model may also yield results that stray from the intended goals of its designers if objectives are poorly defined. For instance, an AI model could suggest a suboptimal outcome, such as prioritizing reliability over safety during an extreme weather event, if its objectives are not clearly defined, properly supervised, and sufficiently interpretable.

Whether through deliberate manipulation or unintentional misuse or failure, the unique risks of AI adoption enumerated above all have the potential to introduce real-world negative consequences across our energy system.
These potential impacts include:

Data privacy: Customer data or sensitive infrastructure details may be compromised or exposed

System safety and reliability: Unsafe operations or system downtime may result from misguided outcomes from AI models or AI system downtime

System performance: System may underperform based on AI model decision-making, decreasing efficiency and increasing cost

Bias and discrimination: Results produced by AI models may yield unfair and discriminatory outcomes, such as unequal access to energy programs and biased pricing models

Trust: Customers may not be familiar with or understand the AI technologies that we are putting into place, and this may negatively impact their trust in our processes

In addition, AI is understandably a primary target of new legislation and regulation and thus requires that we set up new compliance and legal processes. We are hard at work on this already and are committed to ensuring full compliance with all relevant laws and regulations, and to putting into place governance structures that will facilitate that compliance.

While PG&E understands that AI has the potential to introduce new and consequential risks to our operations, **we are also confident in our ability to establish the necessary guardrails, preventative frameworks, and security backstops necessary to minimize negative impacts to the safety, reliability, and security of our energy system**. Efforts are already underway across PG&E to lay the groundwork to support our AI transformation, and we will continue to build and refine these foundational competencies in the years ahead.

Holistic approach to AI transformation

Laying the groundwork for this transformational shift includes efforts to establish robust company-wide compliance and risk mitigation capabilities and to build out the prerequisite technical and organizational foundations to enable and manage broad deployment of AI. We believe that these goals—scaling AI deployment and effectively managing risk—are both critically important and inextricably linked. As such, we are in the process of investing in the expertise and training of our **people**, establishing and enhancing relevant **processes**, and building out the requisite technical **infrastructure** to enable us to responsibly and impactfully scale AI applications to benefit our **customers**, **communities**, and the state of **California**.

PEOPLE

Creating and adapting governance functions

- **Cybersecurity:** A cybersecurity organization with the relevant expertise and authority to provide necessary oversight and ensure compliance with established guardrails is a critical element of our risk mitigation strategy.
- **Data management:** A data management organization that deeply understands the nuances and complexities of the data requirements for AI applications will support our efforts to develop robust and predictable models.
- **Data science:** A data science organization that is empowered to establish best practices for model development and use will ensure strong centralized oversight and enhance consistency in approach across diverse AI use cases.

Training our coworkers for model development and use

Providing our coworkers with the necessary training, tools, and resources to navigate the unique risks associated with AI model development and use is a critical part of our organizational readiness efforts. Best practices will ensure that models enable humans to audit recommendations and understand underlying logic and will integrate appropriate levels of human supervision to ensure that models continue to perform as expected over time and that humans can review outputs and intervene when necessary.

PROCESSES

- **Data quality management:** Clear processes that define universal data standards across PG&E and govern the creation and ongoing maintenance of data quality are essential to scaling AI.
- **Data bias evaluation:** Processes that help model developers review and evaluate data bias, identify effective mitigants if available, and prudently escalate and deprioritize use cases where remedies to bias are infeasible will safeguard against unintentional bias in AI models.
- **Communication and collaboration:** Defined frameworks for communication and collaboration between model developers and users to establish the parameters of the model's use case(s), define clear objectives, and outline limitations will be a cornerstone of successful AI adoption by driving organizational alignment and reducing risk.
- **Ongoing review:** We will continue to review and refine all of our processes regarding the implementation of AI to ensure that we are adapting to new technological developments and new regulatory requirements and continuing to ensure a robust degree of oversight.

INFRASTRUCTURE

- **Centralized data platforms:** Building data architecture that provides high-quality, consistent data for centralized, seamless access by AI algorithms is paramount to successful implementation. In addition, the digitization and automation of data entry at scale will ensure the creation of quality data by design.
- **Cloud computing:** Investing in low latency, readily available cloud computing resources is essential to AI performance by allowing quick and efficient data processing for complex AI processes.
- **Data contextualization tools:** Designing intuitive, user-friendly tools and interfaces that provide coworkers with easy access to highly contextualized data analytics and visualization will enable PG&E to fully capitalize on the power of AI to enhance data-driven decision making throughout the organization.

PG&E's Data and IT teams, together with lines of businesses, have been working in partnership to advance many of the critical initiatives outlined above. These ongoing efforts include work to improve data accessibility, quality, and governance, to mature our analytical capabilities, and to establish foundational infrastructure to enable the scaled deployment of AI. While we have made meaningful progress in building coworker capabilities, governance frameworks, and technical infrastructure, we recognize that there is still work to be done to solidify the foundations necessary for successful scaling of AI.

An AI-enabled future

With a clear vision of our future articulated through our True North Strategy and with our digital transformation well underway, we are excited to embark on the next phase of scaling the transformative powers of AI across our operations. **Through AI solutions, such as deep automation, predictive analysis, and GenAI, we seek to accelerate the transformation of our energy system**, providing a highly personalized experience for our customers and empowering our coworkers with advanced capabilities to support joy at work. Realizing our transformative TNS vision through the scaled deployment of AI and other breakthrough solutions will not only help mitigate risks and stabilize bills by generating efficiencies but also will propel us toward a future of clean and resilient energy for all.

While we believe strongly in the fundamentally transformational power of AI, we at PG&E also believe that people are the cornerstone of innovation. We know that human ingenuity and collaborative partnerships with the innovation community will be the catalyzing forces that unlock AI's potential to transform our operations. It is with this conviction that we again **transparently share the most vexing challenges that we face on our journey to realizing our True North Strategy goals across the balance of this report**. For many of these challenges, we believe that AI is well positioned to drive meaningful progress, and we look forward to the opportunity to partner with the world's most innovative minds to develop these breakthrough solutions.

Advancing our R&D Strategy

What to look for in the months ahead

While we are excited to share our vision throughout this report for the enormous possibilities that AI holds to transform utility operations, we look forward to diving deeper and exploring many of these important topics in collaborative conversations with cross-industry leaders at our 2024 Innovation Summit. The Summit will be held on November 13 in San Jose, California.

Following the strong interest in and response to the 2023 Innovation Summit, we have reimagined this year's Innovation Summit to accommodate greater in-person participation, to facilitate deeper collaboration on a focused subset of high-potential challenges, and to showcase breakthrough innovation underway at PG&E and at other peer utilities. Throughout the day, we will explore the enormous potential that cutting-edge technologies, particularly those leveraging AI, have to transform utility operations to deliver better outcomes for our people, the planet, and the prosperity of all Californians.

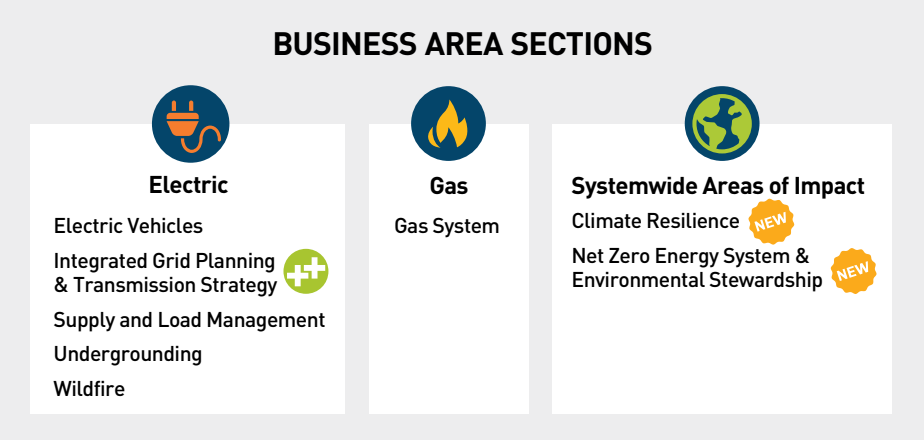
Following the Innovation Summit, and informed by what we learn through the Summit, we will be issuing targeted calls for partnership on some of our most impactful challenges. We look forward to sharing more on what these collaboration opportunities will look like in the months to come.

Navigating the 2024 R&D Strategy Report

The balance of this year's report dives into our **key innovation themes** for 2024 and **details 67 problem statements** that span the full breadth of our energy system operations and represent our highest priority innovation challenges.

Innovation themes

The themes we cover in the following sections align to eight distinct business areas, one of which has been expanded from last year's report and two of which are new additions.



As the majority of the core context driving the need for innovation across these areas remains unchanged from last year, we have collapsed much of the background to instead focus on key accomplishments over the last year and to **highlight applications of AI that we believe will be particularly promising**. For additional context on the driving forces behind the need for innovation across our electric and gas systems, please refer to our 2023 R&D Strategy Report.

Problem Statements

Of the 67 problem statements in this year's report, 50 appeared in the 2023 R&D Strategy Report, though a significant number have been updated and refined to reflect our evolving needs based on efforts over the last year. Additionally, we have **added 17 new problem statements that reflect emerging areas for R&D across our energy system**.

Lastly, we are excited to add a new section to this year's report for "graduated" problem statements for which we have identified and are pursuing a potential solution or range of solutions. While many of these technologies remain in the early stages of piloting at PG&E, we have sufficient confidence in their capabilities that we are removing the associated problem statements from active consideration as part of our 2024 R&D Strategy efforts. If continued piloting and demonstration reveal gaps that require further R&D to address, these problem statements may be resurfaced in future reports. We listed the 17 graduated problem statements in the final section of this year's report.

To help navigate our problem statement inventory and the additions and changes since last year, we have included a table on the following pages that provides a single snapshot of the entire catalog. The legend below explains icons used to denote new and updated problem statements, as well as to indicate the degree to which we anticipate applications of AI will be central to solving the challenges articulated. For the purposes of evaluating AI's potential to contribute to solution areas, we take a broad definition of AI which encompasses machine-based systems that are capable of facilitating decisions and/or making recommendations or predictions based on human-defined objectives, ranging from rule-based systems to deep learning algorithms.

PROBLEM STATEMENT STATUS	AI POTENTIAL AS A SOLUTION
NEW STATEMENT: This problem statement is a new addition to the 2024 report	**LOW AI POTENTIAL:** We do not believe that AI will play a significant role in the solution set
MINOR UPDATES: This problem statement appeared in the 2023 report but has been slightly modified	**MEDIUM AI POTENTIAL:** We see potential for AI to play a significant role in the solution set but are not confident this will be the case
MAJOR UPDATES: This problem statement appeared in the 2023 report but has undergone major updates	**HIGH AI POTENTIAL:** We believe that AI will play a significant role in the solution set

NEW STATEMENT:	MINOR UPDATES:	MAJOR UPDATES:	AI POTENTIAL: LOW	MEDIUM	HIGH

ELECTRIC VEHICLES

THEME 1: Ensure affordable and timely connection for every customer

1	Reducing cost and complexity of EV charging installation at multi-family buildings	MINOR	MEDIUM
2	Avoiding installation delays for public and fleet charging due to capacity constraints	MINOR	LOW
3	Simplifying EV charging installations for single-family homes	MAJOR	HIGH

THEME 2: Unlock potential of EVs as grid assets

4	Enabling widespread V2X interconnections	MINOR	MEDIUM
5	Increasing precision and efficacy of energy management programs	NEW	HIGH

INTEGRATED GRID PLANNING & TRANSMISSION STRATEGY

THEME 1: Reduce conventional capacity upgrades

6	Increasing utilization of existing T&D infrastructure	MINOR	HIGH
7	Maintaining operational flexibility as load factor increases	NEW	HIGH

THEME 2: Optimize prioritization and reduce costs for unavoidable capacity upgrades and new interconnections

8	Reducing cost of T&D asset replacement and upgrades		LOW
9	Accelerating new interconnection planning	NEW	HIGH
10	Streamlining design and estimation for routine projects	NEW	HIGH

THEME 3: Optimize system-level decision making

11	Aggregating holistic grid information for optimal system outcomes	NEW	MEDIUM
12	Increasing visibility into electrification pathways at the customer level	NEW	HIGH

SUPPLY AND LOAD MANAGEMENT

THEME 1: Expand load management capabilities across all levels of the system

13	Enhancing visibility into DER and EV Load Flexibility Potential	MAJOR	HIGH
14	Establishing interoperability at customer connection point	MAJOR	LOW
15	Enabling intelligent orchestration of DERs	NEW	HIGH

THEME 2: Deploy new clean supply and energy storage technologies

16	Deploying new clean supply and energy storage technologies	MAJOR	MEDIUM

UNDERGROUNDING

THEME 1: Improve the efficiency of underground construction across project lifecycle

17	Reducing cost and complexity of underground construction	++	
18	Optimizing soils and spoils management	NEW	

THEME 2: Deploy novel system components to reduce cost and complexity

19	Advancing underground cable and conduit technologies to extend pull lengths	++	
20	Reducing complexity and cost of splice technologies	NEW	

WILDFIRE

THEME 1: Improve monitoring, inspection, and analysis of asset health and integrity

21	Reducing ignition risk through improved asset diagnostics and predictive intervention	++	
22	Advancing overhead inspection capabilities		
23	Expanding capabilities and coverage of continuous fault monitoring	++	
24	Crowdsourcing third-party data		

THEME 2: Eliminate and rapidly suppress ignitions

25	Improving protection schemes and asset design to eliminate ignitions	++	
26	Expanding capabilities and scalability of fault current reduction technologies	++	
27	Advancing ignition notification and rapid suppression technologies	++	

THEME 3: Eliminate customer impacts from PSPS/EPSS

28	Mitigating customer impacts from PSPS/EPSS events	++	
29	Automating PSPS events to improve safety and decrease customer impacts	NEW	

THEME 4: Enhance understanding of tree health to optimize vegetation management

30	Enhancing diagnostic capabilities for hazard trees	++	
31	Addressing gaps in moisture monitoring and interpretation	++	
32	Understanding and predicting healthy tree failure	++	
33	Targeting removal of fire-damaged trees		

GAS

THEME 1: Maintain and increase the safety and reliability of the system while reducing operations and maintenance (O&M) costs

34	Streamlining above ground leak repairs	++	
35	Improving pipeline crack assessment technologies	++	
36	Verifying material properties for existing pipeline cost-effectively	++	
37	Reducing cost of well inspection and monitoring		
38	Reducing the cost of T&D leak detection	++	
39	Reducing false positives on leak detection surveys	++	
40	Enabling corrosion inspections for difficult to access spans	++	

GAS (continued)

41	Improving accuracy of well life estimations		
42	Increasing accuracy of geohazard risk assessment and monitoring	+	
43	Improving pipeline locating technologies	+	
44	Enabling remote meter set corrosion inspections	+	
45	Reducing cost of pipeline integrity inspection and monitoring	NEW	

THEME 2: Operating a clean fuels system

46	Understanding risks and impacts from trace RNG chemicals		
47	Increasing availability of operational data for hydrogen effects on gas system	++	
48	Mitigating hydrogen embrittlement at scale		
49	Understanding safety risks of hydrogen blend leaks	+	
50	Improving metering accuracy with hydrogen mixtures		
51	Ensuring compatibility of customer applications with mixed gas		
52	Reducing uncertainty of storage facility performance for hydrogen blends		
53	Eliminating gas appliance combustion emissions	+	
54	Facilitating cost-effective and safe deblending	+	
55	Enhancing gas quality analysis	NEW	

CLIMATE RESILIENCE

THEME 1: Improve and integrate climate and hazard data into utility planning for enhanced resilience

56	Addressing gaps in climate data	NEW	
57	Applying climate data in utility scenario-based planning and risk assessments	NEW	
58	Preparing for precipitation events with enhanced impact assessments and planning	NEW	

NET ZERO ENERGY SYSTEM & ENVIRONMENTAL STEWARDSHIP

THEME 1: Reducing gas supply chain emissions

59	Enhancing scalability of above ground leak detection and monitoring		
60	Improving emissions calculation methodologies		
61	Eliminating methane emissions from transmission pipeline blowdowns	+	
62	Reducing costs of interconnection skids	++	
63	Identifying cost-effective and scalable sources for RNG production	++	
64	Eliminating 100% of carbon emissions cost-effectively	NEW	

THEME 2: Holistically manage forest ecosystems

65	Optimizing deployment of forest management interventions	++	
66	Enhancing post-wildfire rehabilitation efforts to ensure future resilience	NEW	
67	Enabling wood management and conversion at scale		

Key R&D Themes across PG&E's Business

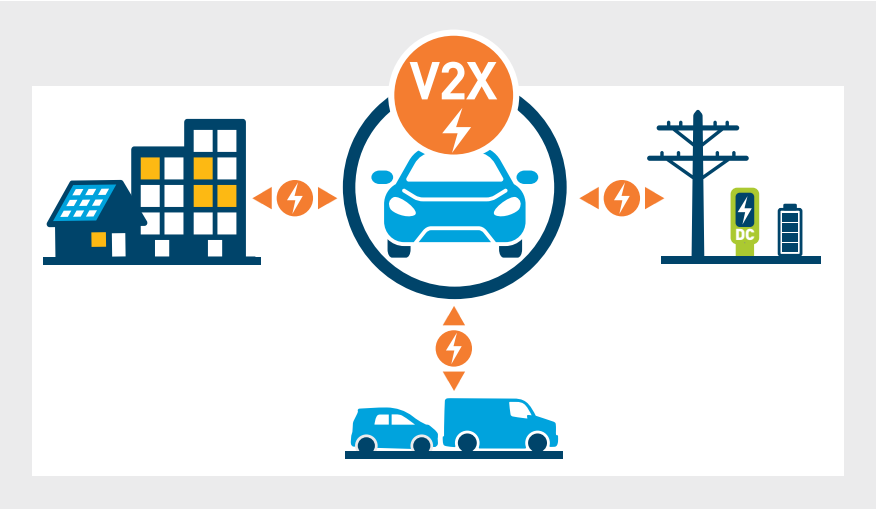
Electric Vehicles

Electric Vehicles

Transportation electrification represents one of the most meaningful opportunities available to decarbonize California, as the sector currently accounts for approximately 50% of the state's overall emissions. The transportation sector is also the dominant source of many air pollutants that are detrimental to human health, local air quality, and the well-being of California's ecosystems.

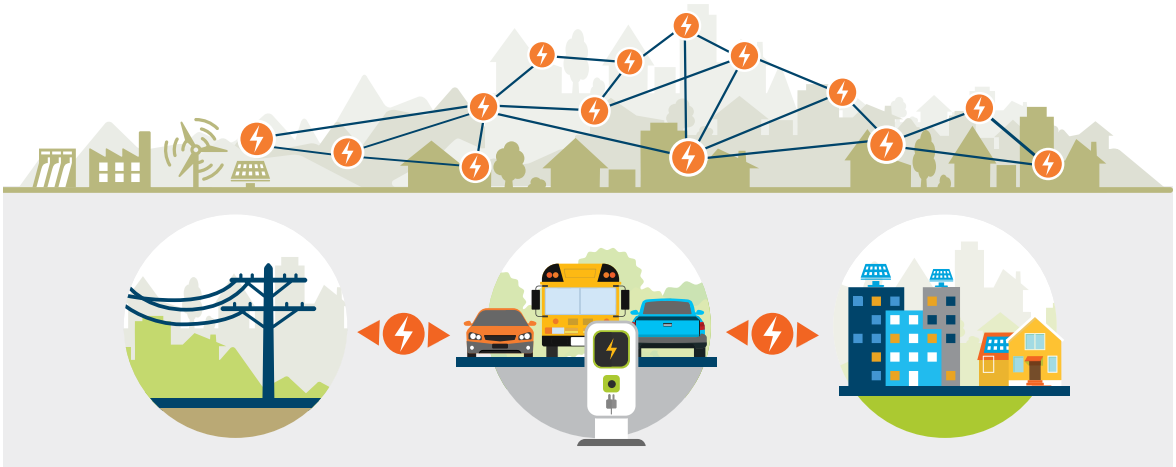
In recognition of the many benefits of reducing tailpipe emissions, the state of California adopted a pioneering regulation requiring all new **passenger cars and light-duty trucks sold within the state to be zero-emissions by 2035**.

PG&E is strongly committed to supporting California's ambitious EV transition. We plan to partner with our customers on their electrification journeys with **plans to power over 3 million electric vehicles (EVs) across our service area by 2030**. We are well on our way to achieving this goal. Today, over 600,000 EVs plug into PG&E's grid—representing one eighth of all electric vehicles driven in the US.



The rapid acceleration of EV adoption not only represents one of our largest opportunities to lower emissions in the communities we serve but is also projected to be the largest driver of load growth in PG&E's service area over the next 20 years.

Additionally, EVs also offer the potential to backstop renewables and balance the grid, to increase our resiliency in the face of emergencies, and to provide valuable grid services with bi-directional charging capabilities. Capitalizing on these opportunities will require a wide range of innovative technologies that can address grid capacity constraints, **decrease the total cost of ownership for customers, increase access to EV chargers**, ensure commercial customers can **connect their fleets in a timely manner,** and simplify deployment of bi-directional capabilities.



Accomplishments from the last year

In addition to reviewing dozens of submissions from the 2023 Pitch Fest, the EV team made significant progress toward addressing the Problem Statements listed in the 2023 report.

A few examples include:

Anticipating EV Adoption Patterns: PG&E is funding technologies that can help us more accurately map and anticipate EV adoption. Enhanced visibility into current and future EV ownership across our service area can enable PG&E to better support our customers' electrification goals.

Supporting Customers' EV Charging Needs: PG&E launched a pilot to identify charging solutions for parking constrained customers, including multi-family and customers without access to parking. The success of the pilot resulted in an RFP to identify partners to help scale these solutions more broadly across our service area.

Exploring and Deploying V2X Capabilities: In partnership with Zum and the Oakland Unified School District, PG&E deployed 74 bidirectional chargers and buses to create the first 100% electric school bus fleet in the nation that can also return energy to the grid at scale. More broadly, PG&E is continuing research into the potential for Vehicle-to-Everything (V2X) applications to increase customer and grid resiliency through testing different EV and EVSE systems.

PG&E is also pursuing several pilot projects through EPIC 4 that will support our customers' electrification journeys and evaluate the potential of managed charging to reduce or avoid grid constraints from increasing EV load.

BREAKTHROUGH THINKING IN ACTION:

Alleviating grid constraints through managed charging

Working with WeaveGrid, PG&E launched a program that utilizes software to manage residential customers' EV charging. This program optimizes charging schedules based on grid conditions. The program, funded by EPIC 4.04, will evaluate if managing EV load can alleviate distribution grid constraints and extend the life of distribution assets while providing financial benefits to the customer.

Intelligence and control at the grid edge

Over the last year, we also launched EPIC 4.02 where PG&E is investing in the next generation of advanced metering infrastructure (AMI) to support EV adoption through a partnership with Itron. This solution provides both intelligence and control at the grid edge, helping customers avoid costly panel upgrades and provide more options to prioritize devices on their network.

Both of these funding sources directly map to problem statements in the 2023 R&D Report that are rearticulated in this year's update.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Many EV manufacturers are already global leaders in applying ML and AI, producing smart vehicles that can drive autonomously and respond to real time traffic conditions. There is also significant potential for AI to transform these smart vehicles into grid assets, creating benefits for both EV owners and the broader energy ecosystem.

We see additional potential for new applications of AI to push these capabilities further and to support our customers as they embark on their transition from fossil-fuel powered vehicles to EVs.

Simplifying customer connections: The process to connect an EV charging station at a residential site faces many hurdles. Leveraging AI to streamline the connection process across the various workflows—for instance, residential capacity check before charger installation or utility and contractor schedule management—has the potential to dramatically expedite EV adoption and improve the customer experience. Making this process simpler, more transparent, and more affordable for our customers can mitigate obstacles to EV adoption, which is critical to achieving the climate goals of both PG&E and the state of California and essential to delivering downward rate pressure for all PG&E customers.

Disaggregating load for load management: The growing fleet of electric vehicles across PG&E's service area represents a largely untapped resource for supporting the grid. Artificial intelligence and supporting technologies will be instrumental in making sense of the enormous amount of data generated by EV driving and charging patterns. The ability to disaggregate usage data can enable the creation of customized charging profiles that in turn can be leveraged to design targeted load management programs. The use of AI can result in more effective load management programs to manage capacity constraints across the grid and avoid costly upgrades in some cases, as well as to create value for our customers through compensation for behavior shifts that support better system-wide outcomes.

Artificial intelligence will be just one piece of the puzzle needed to tackle the many thorny challenges related to the broad-based transition of the transportation sector. In the following pages, we describe the key innovation themes that we see as paramount to unleashing the full potential of EVs to support the grid, heal the planet, and enable our customers' electrification goals.

THEME 1

Ensure affordable and timely connection for every customer

To support EV charging equipment at both commercial and residential locations, many customers require upgrades to electrical systems, including panels at the customer level, and distribution infrastructure like transformers at the utility level.

These upgrades cost thousands of dollars, with project timelines often extending for months—factors that can deter or delay EV adoption. Additionally, complexities in coordinating, controlling, and covering the costs of charging infrastructure can further discourage customers from installing and operating EV chargers.

In addition to system barriers, customers also frequently lack visibility into the steps and resources needed for EV charger installations before purchasing an electric vehicle. This lack of clarity can leave them without accessible charging options, or worse, lead them to pursue unapproved solutions that overload local transformers and strain the grid.

To address these challenges, PG&E is focused on reducing the financial burden and speeding up timelines through cost-effective, scalable technologies. These solutions include those that either bypass the need for extensive electrical upgrades or enable the orchestration of energy loads to prevent transformer overloads. Enhancing customer education, visibility, and coordination in the charger installation process is also critical to facilitating a smoother transition toward widespread EV adoption. Additionally, we are committed to developing scalable charging solutions for customers in multi-family buildings, addressing key issues such as load management and billing, which are essential for meeting state and PG&E objectives.

THEME 2

Unlock potential of EVs as grid assets

Leveraging EVs as grid assets through vehicle-to-everything (V2X) technology and infrastructure presents a significant opportunity to reduce the cost of EV ownership and unlock new value streams.

These value streams can be harnessed to generate incremental revenue while enhancing service to both customers and the grid.

The current electric grid was not designed to accommodate the rapid and widespread electrification of vehicles, nor to dynamically manage volatile loads. While the increasing number of EVs adds complexity to grid operations, it also creates opportunities.

Given that an EV typically spends 95% of its time parked, with a range and capacity far beyond typical daily needs, these vehicles can serve as valuable grid assets.

Potential use cases include absorbing excess renewable energy, providing ancillary services like frequency regulation, exporting power during peak demand, and supporting microgrids in remote or high-fire-threat areas. By deploying V2X technology at scale, PG&E aims to improve grid resilience and boost EV adoption, exploring innovative ways to turn EVs into assets for customers and the grid, both at local and system-wide levels.

V2X technology also enables customers to use their EVs as backup power sources during grid stress, outages, or emergencies by exporting power from their vehicle—powering their homes, businesses, and communities. This not only enhances grid protection but also increases the overall value of EV ownership.

However, a key barrier to realizing these benefits lies in the additional costs and longer wait times associated with V2X infrastructure beyond standard charging setups. These challenges, like those identified in Theme 1, can reduce system value and hinder EV adoption. Furthermore, advanced technologies are needed to disaggregate customer energy data, enabling more customized charging programs that customers will increasingly rely on. Finally, customer behavior will play a critical role in this transition and future programs must take into account customer preferences.

PG&E is actively seeking solutions to reduce the costs of supporting V2X capabilities, improve data visibility, and create new avenues to maximize the potential of EVs as grid assets.

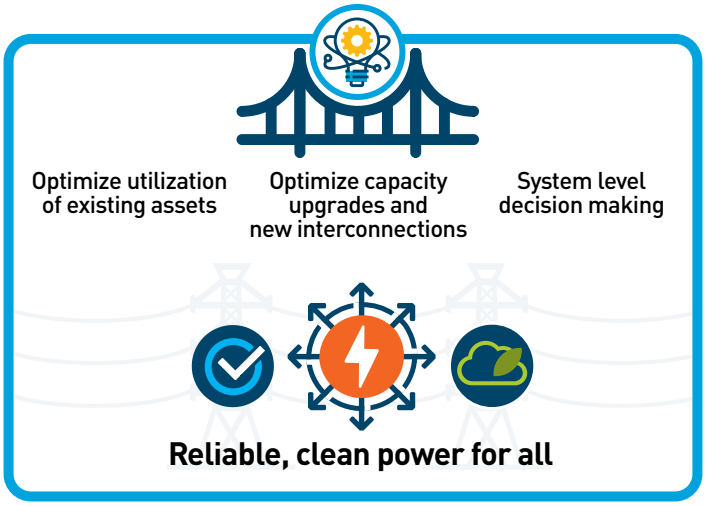
Integrated Grid Planning & Transmission Strategy

Integrated Grid Planning & Transmission Strategy

After years of minimal load growth across our system, PG&E is poised to see rapid growth in demand over the coming decades. Driven by the widespread adoption of EVs, the electrification of end uses across all sectors of society, and the recent surge in data-intensive applications, such as AI advancements, this growth in demand will touch every corner of our system and require a full-scale reimagining of the electric grid.

While we recognize the enormity of this challenge, we are also invigorated by the tremendous opportunity that this moment offers to invest in ground-breaking technologies and breakthrough ideas to refresh and reinvent the grid.

The tools and processes currently used to plan, prioritize, and execute grid upgrades were designed to safely connect individual loads to the system in a steady load growth paradigm. However, in a world where **PG&E is expecting load to double by 2040**, that paradigm no longer holds. In addition to the electrification of transportation, buildings, and industry, the recent advancement in generative AI is contributing to the increase in energy demand. **Data centers alone are projected to reach 35 GW by 2040 in the US–the equivalent to powering a third of American households.**



Along with an increasing share of intermittent renewable generation on the distribution system, this load growth has the potential to result in localized, temporary capacity constraints, as the pace and scale of upgrades may challenge our ability to eliminate the constraints as quickly as needed.

Accommodating the pace and scale of new loads connecting to the grid while maintaining reliable, affordable service for customers will require reimagining approaches to grid planning and T&D buildout. In order to deliver these benefits, **it is imperative that PG&E is able to make the right investments at the right time in the right place** and that our grid planning and transmission strategy processes are equipped with adequate tools to support this complex optimization exercise.

Accomplishments from the last year

Strategic and proactive planning of grid infrastructure upgrades and novel, comprehensive approaches to connecting new loads will enable efficient electrification, helping PG&E to deliver on the clean, reliable, and affordable grid of the future.

This is a substantial challenge, and our team has been steadily working on making progress towards our goal.

Automating distribution planning: Earlier this year, PG&E moved our distribution planning automation project, a co-development effort with Eaton's distribution power flow software, CYME, into production. Once the project is stabilized, PG&E's planning process will shift to a manage-by-exception process that enables engineers to focus on the circuits that most need their attention. Leveraging the AMI data from more than 11 million meters, this project lays the foundation for time-series capacity planning, further enhancing our grid planning capabilities, which is essential as DER penetration, including from EVs, continues to increase.

Streamlining interconnection studies: Our transmission teams have begun work with advanced software developers, such as GridAstra, to tackle the challenges presented by the lengthy interconnection studies required to accommodate forecasted new load growth. The tools being evaluated can streamline interconnection studies while simultaneously evaluating standard grid upgrade solutions, in addition to innovative solutions designed to optimize the existing grid via reconfiguration and deployment of grid-enhancing technologies.

Increasing reliability by extending asset life: As part of our efforts to extend the life of our assets across the T&D system, we are actively replacing bushings on transformers. To date, we have identified 44 projects with the specific goal of replacing known bad-actor bushings, known as COTA bushings. Bushings, which connect a transformer's internal windings to external electrical equipment, can degrade due to age, heat, and electrical stress. By replacing worn or damaged bushings, we can prevent failures and prolong the overall life of the transformer, thereby reducing operational costs and deferring investments. Our goal is to replace 20 bushing by the end of the year and to complete an additional 177 replacements by 2030.

In addition to the ongoing efforts described above, we are also working continually to improve and streamline our existing tools and processes, enabling more efficient and better informed decision-making across our vast and complex electrical system. In pursuit of this goal, we are collaborating with a range of partners to leverage best available solutions to transform our operations.

BREAKTHROUGH THINKING IN ACTION:

CYME Substation Modeling and Analysis

PG&E uses distribution planning tools to ensure that energy is delivered reliably and efficiently to customers. This process involves analyzing grid data, forecasting demand, and identifying potential bottlenecks or constraints in the distribution network.

Based on these analyses, we then make informed decisions about investments in new infrastructure, upgrades, or maintenance to optimize grid performance and meet the evolving needs of our customers.

The grid planning and transmission strategy teams have been working relentlessly on modeling substations within CYME, Eaton's power engineering software, to streamline the system analysis and modeling process. Currently, the process requires engineers to perform some of the substation-level analyses outside of CYME, either in separate protection analysis tools, spreadsheets, or on paper. By integrating additional components of substations into the distribution planning software, engineers can further study bank and feeder level upgrades, bank and feeder loss studies, substation elements of the distribution protection studies, and bank and feeder capability ratings.

This results in streamlined processes, increased grid efficiency, better informed decisions about substation expansion and maintenance, or targeted replacements based on detailed, data driven analysis.

These initiatives are a starting point and illustrate our commitment to achieving our goal of delivering affordable, clean, reliable, and accessible power to all our customers.

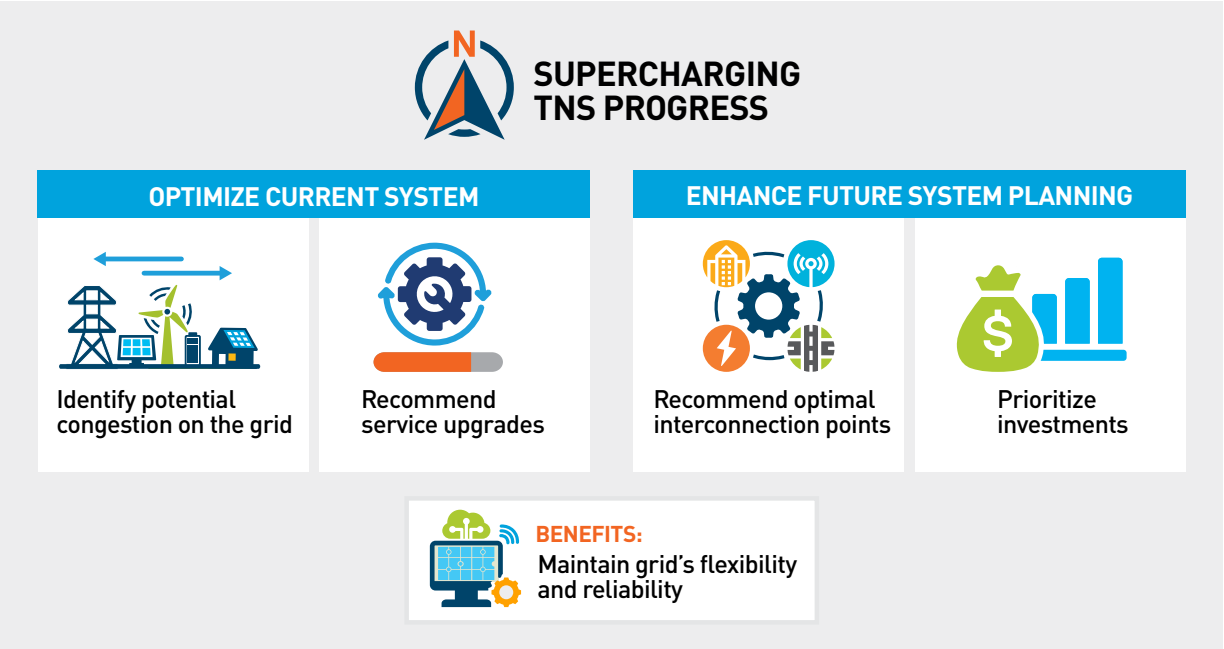
Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Our grid planning and transmission strategy goal is to deliver reliable, safe, and clean power to all customers while stabilizing bills and minimizing service upgrades costs.

PG&E can achieve this outcome by maximizing the utilization of current infrastructure to avoid or defer unnecessary investments and by fully taking advantage of the growing supply of renewables.

By increasing the capacity and flexibility of our existing infrastructure, optimizing investments, and making the most of DERs, grid planning can have a huge impact on stabilizing customer bills. Beyond our ongoing efforts to optimize the grid, we believe AI-powered tools can be utilized to further maximize the value of existing assets and recommend optimal interconnection points.

Optimizing the grid for real-time and future needs: By integrating data from smart meters, grid operations software, and weather conditions and forecasts, AI can optimize grid operations in real time, therefore maximizing existing assets' capacity. AI algorithms can also analyze historical data and, in combination with trends and future demand forecasts, can efficiently evaluate multiple future-state scenarios to help us identify potential congestion on the grid and recommend necessary upgrades to maintain the grid's flexibility and reliability.



Accelerating new interconnection recommendations: AI can be used to accelerate the complex grid modeling that underlies interconnection studies to significantly speed up the analysis process. Through optimization and simulation of numerous scenarios, AI can also recommend optimal interconnection points and capacity upgrades to maximize benefits to both PG&E and the communities we serve.

Streamlining project design and estimation: AI has the potential to greatly reduce the manual effort and time associated with the design and estimation processes for routine work across our energy system. Novel generative AI capabilities could create initial project designs and estimates for review and approval by engineers and estimators, reducing time spent on routine jobs and freeing up valuable resources for more complex projects.

Building on successful collaborations with ecosystem vendors, we continue to seek innovative technologies and cutting edge tools to increase the throughput of the existing T&D system, drive efficiency in the process of connecting new loads, increase the grid's ability to respond to fluctuating power demand and supply, and reduce the cost of infrastructure upgrades by making holistic decisions across the entire electric and gas transmission and distribution systems.

In conjunction with load management, these new methods promise to reduce costs and increase the reliability of the system, thereby lowering rates and improving the quality of the service for customers.

Our highest priority R&D challenges align to the three innovation themes detailed below.

THEME 1

Reduce conventional capacity upgrades

Accommodating the pace and scale of anticipated load growth will require more efficiently connecting new loads to the system while minimizing the need for T&D upgrades.

PG&E's planning process has been designed and operated for the last 40 years in a period of minimal load growth with power flowing mostly one way from generation to load.

This period was characterized by a consistent rate of new connections and individual service upgrade requests with T&D infrastructure typically only being replaced at the end of its useful life or due to failure. With customer-sited DER adoption increasing dramatically, not only is load growth expected to rise dramatically, but also the number of service upgrades and new service requests is expected to rise sharply.

While upgrading the system to accommodate new loads will be necessary, relying entirely on traditional system upgrades poses a series of challenges related to cost, labor, and land-use. Additionally, environmental concerns, long timelines associated with obtaining required permits, and the potential for customer and community objections to constructing new infrastructure can also complicate timely completion of traditional system upgrades.

It is therefore necessary for PG&E to increase the utilization of the existing T&D infrastructure to defer and mitigate the need for conventional capacity upgrades where possible. We seek novel technologies to safely increase the flexibility and/or thermal rating of grid assets, improve power quality on the T&D system, or otherwise increase the efficiency of T&D assets on the grid.

THEME 2

Optimize prioritization and reduce costs for unavoidable capacity upgrades and new interconnections

Where capacity upgrades are unavoidable, we are seeking novel tools to streamline the process for connecting new loads on the system, optimize capacity upgrade investments, minimize waste associated with completing upgrades, and optimize new interconnection planning processes.

While PG&E has identified and begun to utilize novel technologies such as advanced conductors, power flow devices, ambient adjusted ratings (AAR), and dynamic line ratings (DLR), there is still a need for innovation to accelerate the pace of progress.

While increasing utilization of the system through grid enhancing technologies and load management will be critical to managing load growth, PG&E will need to make significant investments in T&D capacity upgrades over the coming years. Business-as-usual equipment upgrades and replacement of aging T&D infrastructure will require continued investment. Ensuring these investments are optimized against the growing needs of the electric system and that T&D equipment is used as efficiently as possible are essential to minimizing rate increases and delays associated with these upgrades.

At the same time, we are seeking novel technologies that enable us to maximize the safe reuse of existing assets with remaining useful life. With limited load growth over the last 40 years, upgrading T&D infrastructure typically only happened when assets reached the end of their useful life or failed. However, the new era of rapid load growth will require more frequent upgrades and the potential for replacement of existing assets across the entire system. To this end, we seek novel solutions to safely refurbish and maximize reuse of this equipment on the system, as well as tools and systems to avoid early retirement of such assets.

For new interconnections, current forecasting and planning tools are not computationally optimized to evaluate and plan new interconnections, nor reflect the variety of capacity upgrades required to enable new interconnections, therefore slowing down the already uncertain study process. We are seeking solutions that are capable of running compute-intensive scenarios faster while increasing visibility into the type of capacity upgrade required to build new interconnections.

THEME 3

Optimize system-level decision making

Given the wealth of data available, such as new interconnection studies and future load forecasts, we are actively seeking innovative technologies that can integrate information across the electric and gas systems for transmission, distribution, and storage needs.

As electrification across transportation, buildings, and industry increases and aging grid infrastructure demands upgrades, strategic planning is crucial to ensure that investments optimize for load growth and flexibility and prioritize urgent needs while maximizing existing asset utilization and avoiding stranded assets.

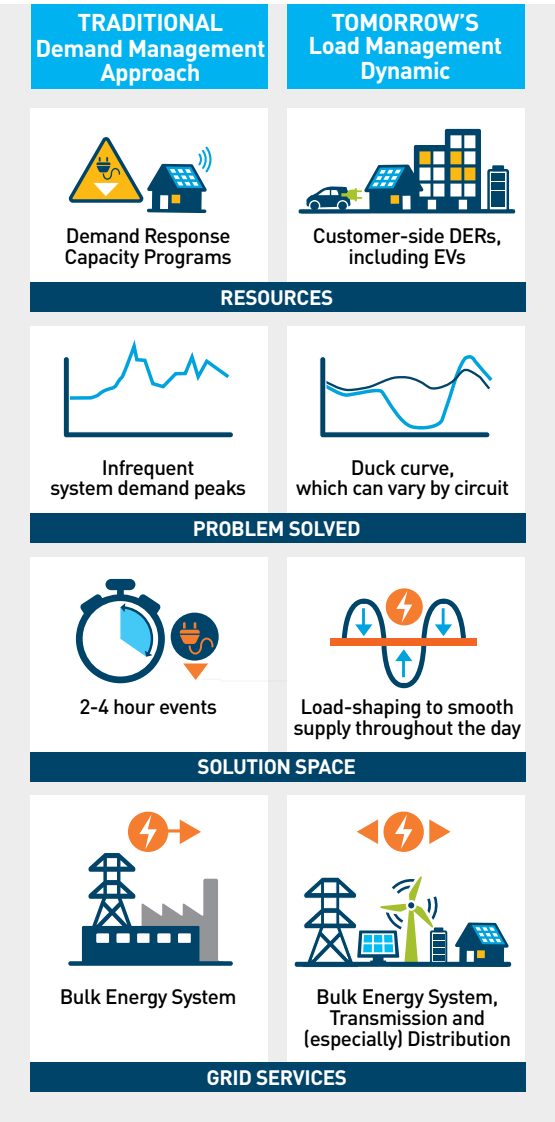
A consolidated view of current transmission constraints, future demand, and distribution and storage needs is indispensable for making informed decisions that lead to a reliable and affordable grid.

The process of planning upgrades and making investment decisions is complex and requires the integration of multiple sources of data across transmission, distribution, and storage. Currently, PG&E lacks the ability to consolidate all sources of data. Consequently, this limits our abilities in planning grid upgrades and new investment decisions effectively, leading to suboptimal outcomes for grid reliability and affordability. We are seeking novel technologies that can integrate information and support the planning and analyses of the transmission, distribution, and storage needs across the combined electric and gas systems.

Supply and Load Management

Supply and Load Management

As PG&E navigates an increasingly complex energy landscape, expanding load management capabilities and integrating new clean supply and energy storage technologies will be **critical to achieving our decarbonization goals while maintaining affordability and reliability**.



These efforts are foundational to ensuring the resilience, flexibility, and sustainability of the grid as **we transition toward a net zero energy system by 2040**. This challenge demands a strategic shift in how we manage both supply and load to meet California's evolving energy needs.

Traditionally, California has relied on expensive, carbon-intensive peaker plants and demand response (DR) events to manage infrequent demand spikes across the bulk energy system. More recently, California has added 11,200 MW of battery capacity which typically discharges over the peak and reduces our reliance on peaker plants, with more on the way. While these tools are effective in meeting high peak demand days, they do not provide distribution and transmission network benefits for routine operations. By leveraging customer resources more strategically, we can shift from merely reacting to high peak days with supply resources to continuously shaping load, enhancing overall grid efficiency, and minimizing cost.

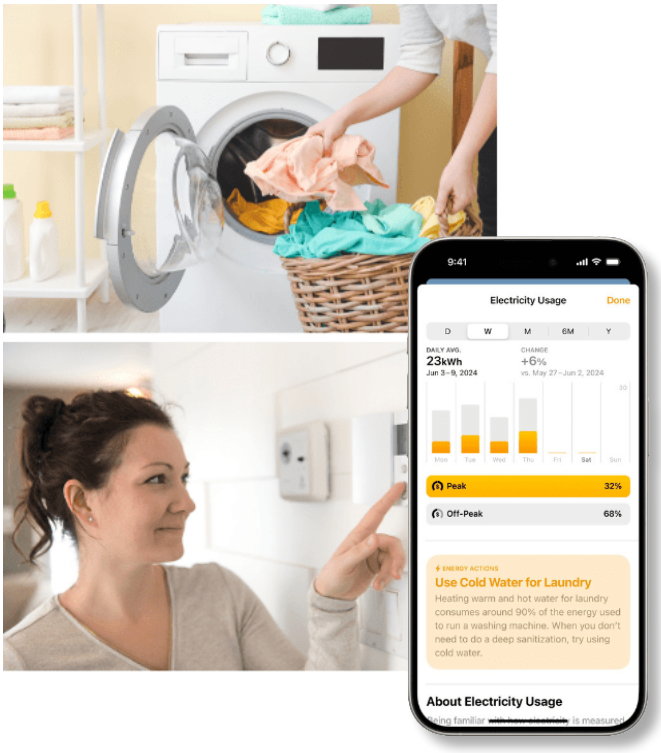
Load growth is placing new demands on the distribution grid, necessitating strategic investments to ensure reliable service. In some cases, investment in new or expanded distribution infrastructure is essential; in others, it may be more cost-effective to leverage the rapidly growing number of Distributed Energy Resources (DERs) that are increasingly connected to the system. These resources can not only manage peaks but also dynamically operate allowing response to current grid conditions, smoothing supply and load throughout the day.

Unmanaged demand creates large local network peaks, potentially triggering infrastructure investment. By moderating those peaks through managed exporting, scheduled load shifting, and demand reduction we can use the grid more efficiently, increasing available capacity. **Programs that cost less than traditional grid upgrades can limit infrastructure expansions to those that are essential. This helps maintain customer bill stability by lowering overall costs compared to the expense of those upgrades.**

Perhaps counterintuitively, the pathway to maximizing the impact of DERs at scale involves adopting a highly localized, time-oriented approach. By focusing on local grid conditions, we can enhance grid reliability, increase the grid's efficiency, and prioritize investments to the highest need areas.

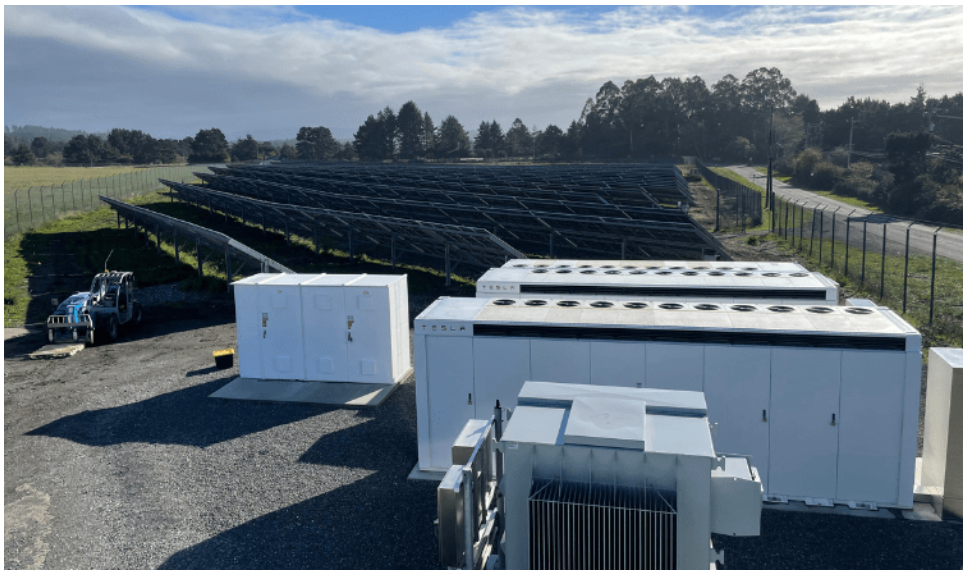
Expanding DER orchestration and load management is crucial, but integrating clean supply and energy storage technologies—including grid-edge generation and storage—is equally vital for PG&E's net zero goals. These technologies balance renewable energy's intermittency and meet peak demand. Seamless integration into grid infrastructure will enhance flexibility, reduce reliance on fossil fuels, and delay or defer costly upgrades required to move energy from centralized sources to population centers. A combined centralized and grid-edge generation/storage strategy will reduce required infrastructure and increase efficiencies.

By focusing on both expanding load management capabilities and integrating new clean technologies, PG&E is committed to leading California toward a sustainable energy future. These efforts are key to achieving PG&E's True North Strategy, ensuring the grid remains reliable, affordable, and adaptable as we continue to lead the energy transition.



Accomplishments from the last year

Modernizing our digital infrastructure: PG&E developed the NextGEN API to modernize our digital infrastructure, making it easier to connect with partner technologies and handle data at the speed and scale expected in the tech industry. As new load management technologies emerge within partner ecosystems, PG&E will help third parties connect to these grid-edge tools, allowing them to provide load management assets to PG&E. The first major step has been integrating with the Apple Home app.



Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Artificial Intelligence has the potential to revolutionize the way PG&E balances supply and load, driving significant progress in grid management and optimization.

AI has the potential to enhance real-time visibility, optimize resource orchestration, and improve grid reliability, making it possible to meet dynamic customer demands more efficiently.

Enhancing real-time visibility: AI-driven analytics have the potential to enable PG&E to process vast amounts of data from distributed energy resources, smart meters, and sensors. This advanced visibility allows for more accurate forecasts both of demand and grid flexibility potential. AI's ability to analyze complex data sets in real time ensures that the grid has the information to quickly adapt to fluctuations in supply and demand, reducing the need for costly infrastructure upgrades and minimizing operational risks.

Optimizing resource orchestration: AI has the potential to intelligently coordinate DERs by analyzing grid conditions and demand patterns, enabling dynamic adjustments that optimize supply and load balance. This capability is crucial for reducing reliance on carbon-intensive peaker plants and avoiding expensive distribution infrastructure expansions. By tapping into DERs that can provide services at the lowest cost to the system, AI ensures that energy resources are utilized to their fullest potential, delivering reliable service at a lower cost to PG&E customers.

As PG&E begins to integrate AI into our operations, the vision of a smarter, more resilient, and customer-centric grid becomes increasingly achievable. By harnessing AI's capabilities to enhance visibility and optimize orchestration, PG&E is positioned to lead California toward a sustainable energy future.

While AI will be a powerful tool in transforming our energy system, we are seeking a broad portfolio of novel technologies and breakthrough solutions to address the critical innovation themes detailed on the next page.

THEME 1

Expand load management capabilities across all levels of the system

As PG&E continues to evolve our grid management strategies, expanding load management capabilities across all levels of the system is crucial.

With the growing adoption and integration of Distributed Energy Resources, the focus has shifted from merely enhancing visibility to actively managing and optimizing these resources as an integrated tool for grid operations.

Equally important is offering a compelling value proposition to customers, encouraging them to leverage their DERs for load management. The benefits of participation must outweigh the opportunity costs to ensure widespread engagement.

PG&E has made early strides in improving visibility into DERs on our system. While we continue to enhance those capabilities, the next steps are to better identify and harness the load flexibility potential of those DERs. This involves not just monitoring these resources but intelligently orchestrating them in real time to balance supply and demand effectively. The deployment of the Distributed Energy Resource Management System (DERMS) has been a key development, but challenges remain in fully integrating and optimizing diverse DERs.

One of the significant barriers to effective load management is the lack of a standardized, interoperable interface across devices that PG&E can use to orchestrate the DERs on our system. This fragmentation hinders communication with and between smart devices, batteries, electric vehicles, and the grid, limiting the full potential of load flexibility. To unlock this potential, there is a pressing need for a common framework that allows for seamless integration and communication across different technologies.

PG&E recognizes that achieving standardized interoperability cannot be done in isolation. It requires collaboration across the industry, including vendors, regulators, and other utilities. By working together, we can establish a unified customer interface for DERs, enabling greater load flexibility and paving the way for a more resilient and adaptable grid.

This theme underscores PG&E's commitment to expanding load management capabilities by improving the visibility of DERs and focusing on their intelligent orchestration and seamless integration. Through strategic collaboration and innovation, PG&E aims to build a grid that is not only more efficient and reliable but also fully capable of meeting the demands of a rapidly changing energy landscape.

THEME 2

Deploy new clean supply and energy storage technologies

As PG&E works toward a net zero grid by 2040, the integration of new clean supply and energy storage technologies into the existing energy system is critical.

While these technologies are essential for balancing the intermittency of renewable energy and meeting peak demand, the primary challenge for PG&E lies in effectively incorporating them into PG&E's operations to ensure reliability, affordability, and scalability.

PG&E is looking for better ways to integrate new zero-carbon supply and storage solutions, including but not limited to long-duration storage, enhanced geothermal, and grid-edge technologies, into our portfolio. This involves understanding the operational characteristics of these technologies and how they reduce greenhouse gas emissions in hard-to-decarbonize hours (e.g., peak, overnight, and seasonal). By developing a diverse portfolio of carbon-free resources, PG&E can enhance grid flexibility, reduce reliance on traditional fossil-based generation, and avoid the need for costly infrastructure upgrades.

To maximize the impact of these technologies, PG&E will prioritize the deployment of new generation and DERs in high-value locations where they can provide the greatest benefit to grid flexibility. This strategic approach will ensure that the new technologies support the grid during peak demand and provide ancillary services, such as voltage regulation and frequency support.

PG&E's Utility-Owned Generation group (UOG) is an important piece of our overall energy supply team, and we anticipate expanding the number of UOG projects that bid into our portfolio as PG&E ramps its energy supply to meet California's growing demands. PG&E's commercial procurement team is focused on determining where new resources are needed, and at what time of day their energy must be produced. This detailed approach will allow us to create more thoughtful requests for offers and ensure that the bids we receive from all parties, including UOG, provide maximum benefit for our customers and our system.

Undergrounding

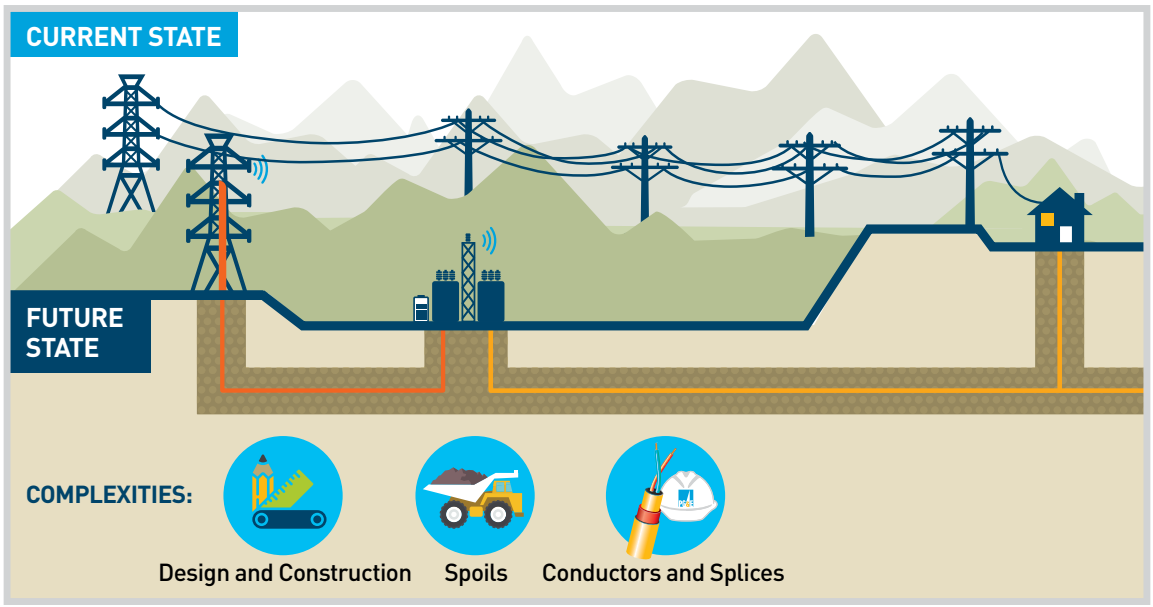
Undergrounding

Wildfires have long been a threat to the vibrant communities and beautiful landscapes of California. However, hotter temperatures and lower rainfall amounts driven by global climate change are intensifying the scale and impact of wildfires across the state.

Eight of the ten largest wildfires in California's modern history have occurred within the last five years, making it ever more imperative to take bold action that ensures the safety and prosperity of all Californians.

PG&E's Wildfire Mitigation Plan outlines our comprehensive strategy to stop catastrophic wildfires. As part of this strategy, **PG&E has a goal to underground 10,000 miles of distribution lines where fire risk is the highest**, with an additional goal of minimizing disruptions to customers from Public Safety Power Shutoffs (PSPS) and Enhanced Powerline Safety Settings (EPSS). This program is the largest of its kind in the U.S., and while ambitious, it is also the most effective long-term solution for keeping customers and communities safe.

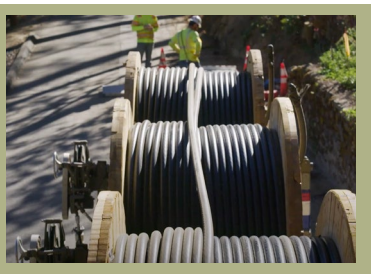
Beyond improving that safety of our communities, undergrounding can also offer long-term cost savings benefits in certain circumstances by reducing the ongoing cost associated with routine maintenance, repairs, and vegetation management relative to overhead infrastructure. As a result, strategic undergrounding can help create an energy system that is safer, more resilient, and more affordable for our customers.



UNDERGROUNDING DISTRIBUTION LINES

COMPLETED MILES:			PROJECTED COMPLETED MILES:	
2021	2022	2023	2024	THROUGH YEAR END 2026
73	180	365	250	1,000

As part of our wildfire mitigation efforts, we have launched the largest undergrounding effort ever undertaken by any US utility with a goal to bury 10,000 miles of electric distribution lines.



Accomplishments from the last year

Since announcing the 10k Undergrounding program in 2021, we have been working urgently to make meaningful progress towards our goal. Through year-end 2026, we plan to move over 1,000 additional miles of distribution lines underground, a distance twice that from San Diego to San Francisco.

Reducing ignition risk: Wildfire ignition risk has nearly been eliminated at the locations where we have placed overhead power line underground.

Avoiding outages for our customers: Our most recent undergrounding work in 2023 resulted in avoided PSPS and storm-related outages for 15,000 customers.

Improving resilience against climate impacts: Undergrounded wires are less susceptible to stress and damage associated with extreme weather, increasing the resiliency of the energy system in the face of climate impacts.

While we are proud of the progress we have made, we are also relentlessly pursuing opportunities to improve the efficiency and cost effectiveness of our work. These efforts have taken many forms, including reviewing our internal standards and work methods, engaging with potential cost sharing partners (e.g., telecommunications utilities), and advancing cost-savings innovations with both external parties and our own internal experts.

As a result of this work, we have made our communities safer, our service more reliable, and our system more resilient.

BREAKTHROUGH THINKING IN ACTION:

Native Slurry Backfill

PG&E's 10,000-mile undergrounding program produces a high volume of spoils each year, as many of the program's projects are completed in some of the most challenging and remote terrain in our service area. As a result of this high volume of spoils, the current process has high programmatic costs for the transportation and disposal of spoils, as well as additional costs to transport backfill materials to various undergrounding projects. Responding to these challenges, the PG&E team devised a strategy to implement the use of Native Slurry Backfill.

Native Slurry Backfill is a material comprised of the native soils produced at each undergrounding project. The native soil from each project is used as the base for a controlled low-strength slurry that can be implemented as a backfill material and meets PG&E and agency standards. **The use of Native Slurry Backfill eliminates up to 95% of the spoils generated on undergrounding projects**, which the program is typically required to transport and dispose. Native Slurry Backfill also eliminates the need to transport additional backfill material to undergrounding projects.

The use of this process significantly reduces costs related to trucking, materials, and spoils disposal. Moreover, implementing Native Slurry Backfill results in fewer trucks hauling materials in and out of our project sites which lessens our impacts to roads and traffic, reduces our CO_2 emissions, and makes our work safer by significantly reducing the frequency of large trucks driving on narrow rural roads.

PG&E has started piloting the use of Native Slurry Backfill on two separate undergrounding projects (Antler and Electra). While still in the early stages of piloting, Native Slurry Backfill shows strong potential to significantly reduce the cost of transportation and disposal of spoils, helping our program achieve our cost and mileage targets.

BREAKTHROUGH THINKING IN ACTION:

Novel Boring Technology

By early 2025, PG&E will begin an EPIC-funded pilot demonstration in partnership with Blue Grit Robotics of their novel earthworm-inspired boring technology. In contrast to traditional boring technologies, the technology operates without the use of drilling fluid. This is a significant advancement that has the **potential to dramatically reduce the cost and complexity of trucking large volumes of excess spoils generated during conventional boring** to processing and disposal sites which are often long distances from remote job sites. Beyond cost savings, the decreased need for off-hauling drilling mud and in-hauling clean dirt to backfill trenches would also greatly reduce overall trucking miles, resulting in lower GHG emissions and increased safety for our coworkers.

The initial demonstration will enable PG&E to assess the basic functionality of the prototype, including better understanding of personnel requirements for operation, bore rate, and compatibility with various soil types. Over the course of the next year, we plan to work in partnership with Blue Grit Robotics to collaboratively advance the capabilities of the technology with the ultimate goal of deploying the technology more broadly to support our upcoming efforts to underground services and secondaries.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Over the long run, undergrounding has the potential to lower the operational costs of our distribution system by reducing tree trimming and maintenance expenses and reducing costs associated with rebuilding infrastructure after storms and fires.

While PG&E's **investment in undergrounding provides the most effective available safeguard against the devastating effects of catastrophic fires**, we recognize that it is critical to complete this work in the most cost-efficient way possible to stabilize bills in the near-term. As a result of the diligent efforts and breakthrough thinking of our coworkers, we are continuing to drive costs down, achieving a realized cost per mile in 2023 that was nearly 10% lower than our original forecasts for the year.

We know that there is still progress to be made. **New applications of artificial intelligence and machine learning have the potential to amplify our existing efforts to drive efficiencies across the program.** In particular, these technologies can augment current processes to identify, optimize, and efficiently execute the planning, design, and construction of undergrounding projects.

Project selection: Today, PG&E utilizes a combination of predictive models that assess wildfire and reliability risk at the circuit level to inform a manual review process to select candidate circuit segments for undergrounding. Advanced AI capabilities could streamline and enhance efforts to optimize the project portfolio. By providing the ability to seamlessly evaluate network effects across multiple combinations of adjacent circuit segments, we can better identify project portfolios that not only reduce wildfire risk but also maximize our ability to mitigate the impact of outage programs, such as EPSS and PSPS, by assessing the reliability impacts of undergrounding upstream or adjacent circuit segments.

Supply chain planning: As with any construction project, having the right materials and equipment available at the right place at the right time has the potential to drive huge savings across our undergrounding portfolio. New capabilities that can simultaneously understand the evolving needs of current and upcoming projects, our existing inventories, and dynamic supplier lead times in real-time and proactively suggest materials orders to avoid inventory shortfalls could transform the way that PG&E currently manages procurement and ensure that our crews in the field always have what they need when they need it.

Beyond the examples enumerated here, we will continue to seek out opportunities to collaborate with our vendor partners and the broader innovation community to identify cutting-edge solutions that can rapidly reduce risk in the most cost-efficient ways possible across our undergrounding portfolio.

As we move towards identifying solutions to eliminate wildfire risk through undergrounding, we have defined several key challenges across two key themes as outlined below.

THEME 1

Improve the efficiency of underground construction across project lifecycle

Our crews deploy a range of construction methods and technologies across PG&E's undergrounding program to address the broad spectrum of conditions that exist across our service area.

From traversing steep grade to blasting through hard rock to trenching along narrow roadways, each project presents unique challenges that require a diverse toolkit to tackle effectively.

While PG&E has identified novel technologies and approaches that show early promise in addressing a number of these challenges, there is still a need for innovative solutions that could further reduce the cost and complexity of undergrounding.

Civil construction drives the majority of undergrounding costs, but these can be highly variable. Based on the location of PG&E's highest fire threat areas, many of our undergrounding projects are located in remote geographies where on-site conditions are often space-constrained, rocky, or steep. Traditional construction technologies are not well-suited to these conditions, which can add cost to the construction process. In addition to these challenging use cases, PG&E is also seeking novel approaches to burying smaller and mid-sized runs of electrical conduit that are less costly and less disruptive than traditional trenching methods designed for larger jobs. These solutions could be scaled broadly across PG&E's undergrounding program and prove especially useful for connecting customers to newly buried distribution lines.

Innovative construction technologies are also needed to reduce spoils generation and associated handling and processing costs, which drive a significant portion of the overall civil construction costs. The need to track, process, and transport spoils in compliance with strict regulations, especially hazardous material and drilling mud, can also dramatically increase project costs. Existing technologies utilized throughout the surveying, construction, and installation processes typically result in the displacement of spoils, which we believe could be avoided altogether or significantly reduced with novel solutions. Beyond reducing the volume of spoils created, novel methods for the processing and removal of spoils at scale (including trenching, boring, at-surface solutions, etc.) will also be necessary.

THEME 2

Deploy novel system components to reduce cost and complexity

Underground cables, conduit, and splices rely on time-tested technologies that have been utilized across the industry for decades.

Innovations to these foundational components of undergrounding projects could help address critical pain points and cost drivers, thereby unlocking value across the entire undergrounding portfolio.

When moving distribution lines underground, PG&E first installs conduit which serves to protect the underground cables and to streamline maintenance and repair efforts that may be necessary over the life of the infrastructure. Underground cables are then pulled through these runs of installed conduit and spliced together to create miles of continuous underground distribution lines. Novel technologies that could extend the length of individual cable pulls would decrease the number of splices and primary boxes per mile and could meaningfully reduce costs across the program.

Innovations to current splicing methods and enclosures could also drive cost and time savings for PG&E's undergrounding efforts. Current splicing techniques rely heavily on time-intensive manual labor and involve complex, multi-step processes, which can result in defective splices and increased maintenance needs. We are seeking solutions to address these challenges, including splicing technologies that reduce on-site manual installation work and splice enclosures that could be installed at grade or reduce construction efforts relative to current primary box technology.

Wildfire

Wildfire

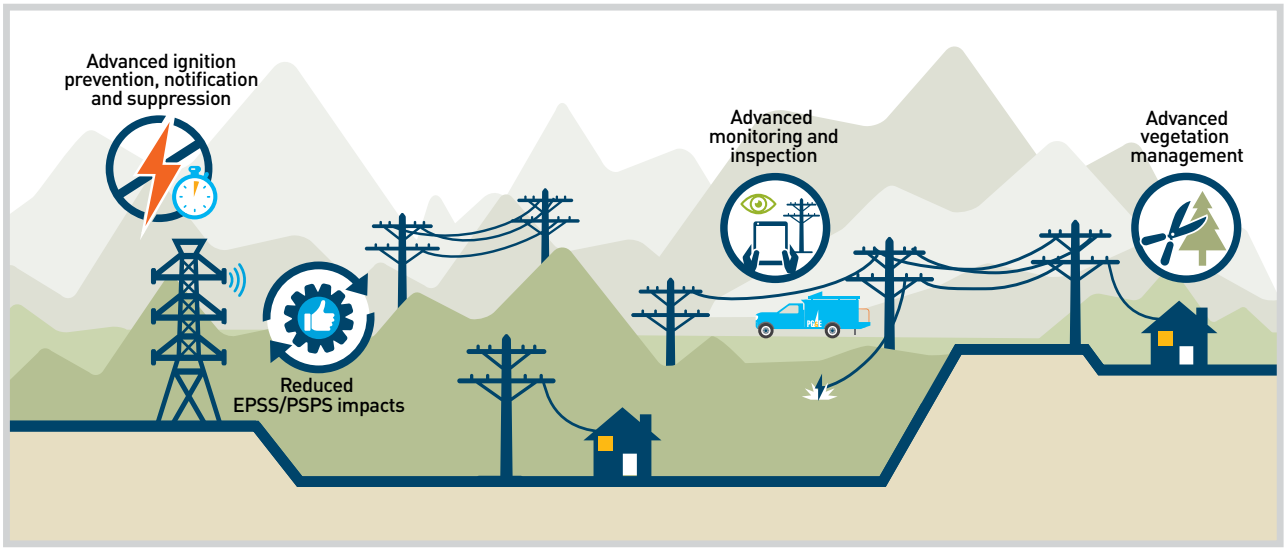
Wildfires have long been a part of California's history, dating back thousands of years. However, recent fire seasons have been marked by increasing intensity and expanding duration, as warming temperatures and lower precipitation rates create conditions ripe for ignition and spread.

Increasingly destructive fires can dramatically and irreparably affect residents through displacement, negative health impacts and injuries, and severe property damage, **making PG&E's efforts to eliminate the risk of catastrophic wildfires more important and more urgent than ever**. While these emerging dynamics are playing out across the western United States, they are in many ways uniquely impactful for PG&E, given that **more than half of our service area and approximately one-third of our assets are located within High Fire-Threat Districts (HFTDs)**.

In recognition of this growing threat and the urgent need to end the devastating effects of wildfire on our communities and ecosystems, **PG&E has undertaken a comprehensive and multi-faceted portfolio of efforts to eliminate the risk of catastrophic fire**. Our investments in wildfire mitigation span several key initiatives that seek to eliminate controllable sources of ignition through **asset monitoring and vegetation management**, **protect against heightened risk from external conditions through proactive de-energization schemes**, and **rapidly identify and suppress any ignitions that do occur in proximity to our assets**.

CATASTROPHIC WILDFIRE GOAL: Zero

AREAS TO ADDRESS:



Accomplishments from the last year

PG&E coworkers work diligently every day across our vast service area performing inspections, mitigating encroaching or unhealthy vegetation, completing maintenance and repairs, and responding to potential threats across our system.

These efforts, enhanced by a range of innovative technologies and strong partnerships across the state, have yielded meaningful strides in improving the safety and reliability of our system over the last several years. Our efforts in 2023 continued to build on this progress.

Reducing ignitions: The number of CPUC-reportable ignitions in HFTDs decreased by 48% in 2023 relative to 2020–2022 three-year average, an outcome driven in large part by our improved vegetation management practices, extensive asset monitoring and maintenance, and advanced protection programs, such as EPSS and PSPS.

- Our coworkers completed more than 287,000 inspections on distribution, transmission, and substation assets and addressed more than 68,000 distribution and transmission maintenance tags over 2023.
- In addition to ongoing inspections, PG&E also made significant strides in our undergrounding and system hardening efforts in 2023, providing more permanent solutions to ignition risk reduction. Last year we undergrounded 365 miles of distribution lines, bringing the program total to over 600 miles, and hardened an additional 133 overhead circuit miles.

Improving reliability for our customers: We've continually implemented updates that enabled us to narrow the geographic focus of PSPS events and limit the duration of EPSS outages to limit average customer outages to 193-minutes in 2023, less than our 210-minute target. To further mitigate customer reliability impacts in 2023, we provided more than 4,000 batteries to customers at risk of outages associated with PSPS events and EPSS.

In addition to the progress noted above, **PG&E has also pursued opportunities to partner with a range of technology providers**, **universities**, and other **public institutions** to deploy leading-edge solutions that can augment our efforts to eliminate wildfire risk throughout our service area.

BREAKTHROUGH THINKING IN ACTION:

AI-enabled cameras for early ignition detection

As part of our partnership with ALERTWest, PG&E has deployed over 600 AI-enabled high-definition cameras over the past several years in HFTDs throughout our service area. The cameras are instrumental in enhancing situational awareness across some of our most vulnerable geographies and enabling fire suppression agencies to respond quickly. PG&E has installed 24 additional AI cameras since mid-summer and plans to continue strategically building out the network through the balance of 2024 and into 2025.

The AI wildfire detection capabilities embedded across this HD camera network provide alerts to Hazard Awareness and Warning Center (HAWC) analysts when potential evidence of a fire is detected. The AI technology enables more accurate identification of ignitions by filtering out false positives from sources like dust, fog, or haze and can reduce the time elapsed between ignition and response by fire agencies. The ability for fire agencies to view the AI detections in real-time reduces the response time, which can result in a significant reduction in the impact of the incident.

Since deployment in June 2023, we continue to work with our partners to monitor and evaluate the AI system's performance for areas of refinement that can further enhance our ability to stop catastrophic wildfires at the source.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Despite our extensive wildfire mitigation initiatives, we have not yet managed to completely eliminate the risk of catastrophic wildfires and are continually seeking cutting-edge technologies to eliminate risk, while mitigating outage impacts to our customers.

Additionally, we are constantly evaluating opportunities to improve the efficiency of our efforts to maximize the risk-reduction benefit per dollar of investment.

With Waldo and other novel AI solutions developed by PG&E, we have already witnessed the enormous power of artificial intelligence to augment the efforts and capabilities of our dedicated coworkers. We know that these early deployments of AI-enabled solutions are only the beginning of the ways in which these technologies can fundamentally reshape our work to protect the safety and prosperity of our communities.

Improving asset health assessments: PG&E manages a vast network of assets of varying types, which are periodically inspected to identify signs of degradation to be addressed through our ongoing maintenance efforts. While these inspections are frequent and thorough, there is significant potential to improve the precision and cost-effectiveness of these efforts through the application of artificial intelligence. Applying these technologies to supplement existing processes to understand degradation patterns and timelines based on asset type, weather and grid conditions, visual signs of damage, and various failure modes could yield huge gains in our ability to optimize our asset management efforts based on intelligent risk predictions.

Enhancing diagnostics of vegetation health: Similar to asset management inspections, PG&E carries out vegetation management patrols across thousands of line miles every year seeking to identify unhealthy trees that may pose an ignition risk. Our service area is home to a vast array of plant life species, all of which respond differently to local environmental conditions and demonstrate unique growth and aging patterns, even at the individual tree level. Novel applications of artificial intelligence could be hugely beneficial to our ability to understand various indicators of tree health by species and predict the likelihood of failure at the individual tree level, especially in the context of evolving weather patterns.

Beyond these promising use cases, we are continually evaluating solutions to make our ignition prevention and wildfire mitigation efforts more efficient, effective, and invisible to our customers. Later in the report, we describe several problem statements where we seek breakthrough thinking from the innovation community to advance the cutting-edge technologies that we presently have deployed across our system in pursuit of putting an end to catastrophic wildfires. These problem statements align to the four innovation themes described on the next page.

THEME 1

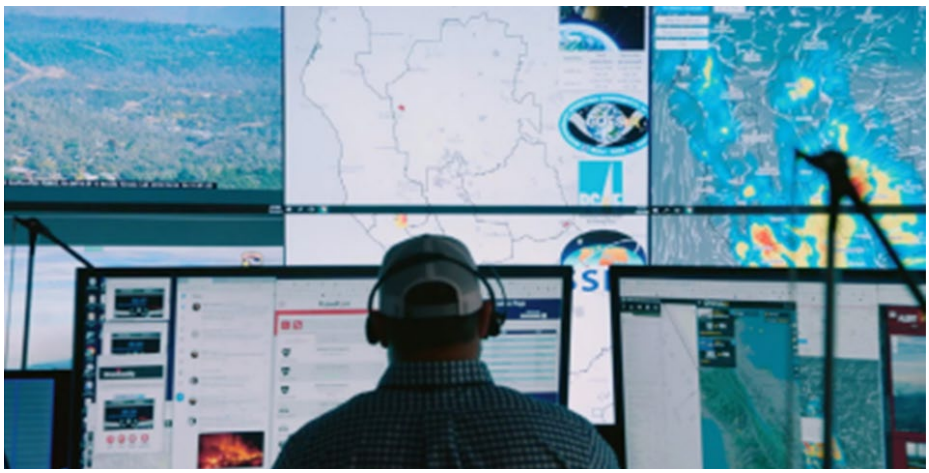
Improve monitoring, inspection, and analysis of asset health and integrity

Currently, PG&E uses various sensors and means of periodic point-in-time data collection to monitor transmission and distribution assets in HFTDs, including LiDAR, infrared, and drone technologies, in addition to visual inspections.

These methods of inspection and monitoring are best-in-class industry practice; however, room for improvement still exists, as they are costly, often rely on subjective human judgment, and lack the ability to assess the interior conditions of our assets.

Periodic inspections will also not immediately identify incipient issues that begin to manifest between cycles. These available monitoring and inspection methods therefore make it difficult to fully understand the state of an asset's health and optimize interventions across the system.

PG&E is seeking innovative technologies that can achieve scale across the system to more frequently, precisely, and thoroughly assess the condition of assets and systematically predict asset degradation and failures based on asset type and a range of external factors. These novel solutions should be cost effective as well as more accurate, less subjective, and more comprehensive than current methods.



THEME 2

Eliminate and rapidly suppress ignitions

PG&E achieved a 72% decrease in ignitions on EPSS-enabled power lines in 2023 versus the 2018–2020 annual average; however, advancements in ignition prevention, notification, and suppression technologies could further amplify our efforts to put an end to catastrophic wildfires.

While we have made meaningful progress in reducing ignitions over the last several years, closing the gap to completely eliminate ignitions caused by high-impedance faults on equipment energized at primary voltage levels and faults on equipment energized at secondary voltage levels remains an opportunity for further progress.

While enhancements to and extension of EPSS capabilities is one area where we seek innovative solutions, re-thinking the fundamental designs of core system components such that if equipment fails, it does so in a reliably safe manner is also an area of interest.

In addition to eliminating ignition risk from our assets, it is also imperative that we have comprehensive and real-time alert and notification capabilities in place to enable rapid response to developing threats. PG&E's Hazard Awareness & Warning Center (HAWC) supports 24/7 monitoring of evolving risks across our systems, but these efforts could be further enhanced through the availability of real-time ignition data across the entire system.

PG&E seeks to identify and deploy novel technologies that could reduce remaining ignitions across the system, including augmented EPSS capabilities and a scalable method of eliminating fault energy. We are also interested in innovative electrical asset design improvements that prioritize asset failure safety, as well as advanced solutions providing real-time notification of events, with coverage across the entire system, which could help manage remaining reportable ignitions prior to spread. Finally, PG&E is seeking to better understand the potential for game-changing wildfire suppression technologies to be another risk reduction tactic as part of public-private partnerships. This innovation area is the focus of the global **XPRIZE Wildfire** innovation challenge co-sponsored by PG&E.

THEME 3

Eliminate customer impacts from PSPS/EPSS

PG&E has been working intently to reduce the size and impact of PSPS and EPSS events, as the effects on customers can be significant and costly.

We have seen success in our efforts thus far: PSPS events have continued to decrease in scope and duration, driven by meteorology model enhancements and installation of sectionalizing devices.

In addition, PG&E has undertaken a range of measures, including targeted vegetation management and adjustments to EPSS device settings to improve coordination, to continue to minimize impacts to customers with a specific focus on those areas that have experienced multiple outages.

In spite of these gains and their effectiveness in preventing wildfire ignition, PSPS and EPSS events may negatively affect certain customers due to the potential for disruptive, lengthy, and costly outages. PG&E has deployed backup generation solutions at customer sites to avoid outages in specific cases; however, available backup technologies are primarily fossil-fuel based, resulting in increased emissions, and difficult to scale. To address these challenges, we are pursuing novel, clean backup energy solutions that can eliminate the impacts of grid outages for our customers.

Technologies that can assess and analyze evolving risk conditions on a hyperlocal basis and enable an automated, localized response by grid assets would provide greater ability to rapidly de-energize and re-energize sections of the grid. These capabilities could both reduce risk by shortening response times to fast-changing environmental conditions and decrease customer outage times by enabling the rapid restoration of power as risk subsides.

THEME 4

Enhance understanding of tree health to optimize vegetation management

Vegetation management is crucial for ensuring asset health, energy reliability, and reduced wildfire risk in PG&E's service area.

PG&E is required to keep all vegetation at least 18" and 48" from primary distribution lines in Local Responsibility Areas and High Fire Threat Districts/State Responsibility Areas, respectively, and to prevent it from adding strain or abrasion to secondary lines. Additional clearances are mandated for transmission lines.

Along with ensuring sufficient clearances for transmission and distribution lines, identifying and mitigating hazard trees is another critical function of our vegetation management efforts. Every line mile is patrolled at least once annually to assess vegetation clearance accordingly and to abate trees that could present an encroachment, failure, or ignition risk. PG&E's vegetation management practices are intensive; however, there were still 26 CPUC reportable ignitions in HFTDs in 2023 due to vegetation contact.

Current models and analytical tools are insufficient in their ability to precisely target vegetation management patrols at a hyperlocal level and to comprehensively assess the condition of individual trees during inspections. Determining how frequently patrols should occur in individual geographic areas is a complex problem and addressing this would make PG&E's vegetation management patrols more targeted, effective, and rigorous.

Limitations in data, diagnostic tools, and predictive models around vegetation growth are especially important to address when considering how to maximize the efficacy of vegetation management inspections. Improved assessment capabilities would enable PG&E to better ascertain risks at the tree level and to take a more targeted approach to abatement that balances ignition risk prevention with the preservation of California's beautiful natural landscapes. PG&E strives to avoid removing trees unnecessarily, including avoiding aggressive removal of fire-damaged trees as many tree species in California are fire-adapted and can recover from high-intensity, low-duration fires. Additional innovation is also required to accurately determine how a range of environmental factors, including moisture, affect tree health and risk, as well as to determine why outwardly healthy trees fail.

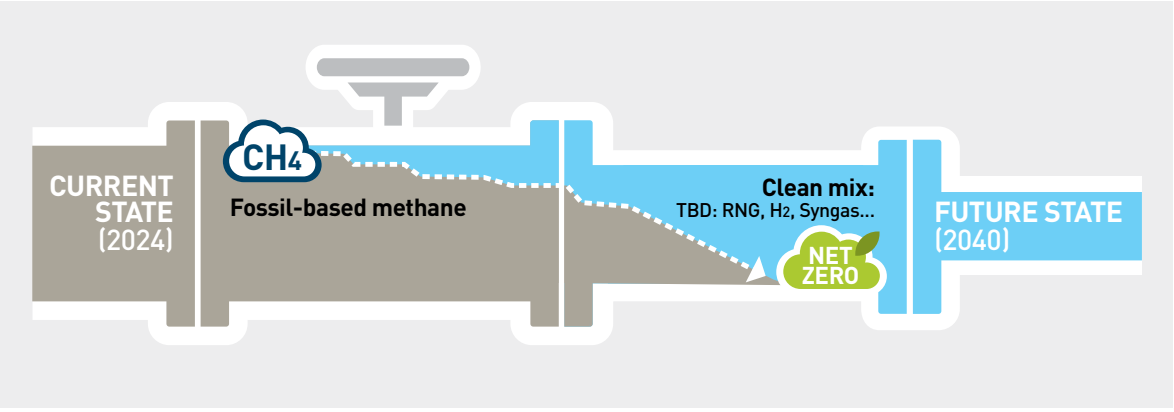
PG&E is pursuing solutions to advance our vegetation management practices to continue preventing ignitions and resulting damage while maintaining our commitment to environmental stewardship. We are looking for novel technologies to more accurately determine when trees must be removed or trimmed based on potential damage to assets and resulting fire risk, as well as solutions to direct more targeted patrols and maximize risk reduction furthered by vegetation management efforts.

Gas

Gas

PG&E owns and operates one of the nation's largest natural gas systems comprising nearly 50,000 miles of combined transmission and distribution pipeline that serve approximately 4.5 million customer accounts. Today, methane represents nearly 100% of the approximately 880,000 million cubic feet of annual throughput delivered by our system.

PG&E's Climate Strategy charts an ambitious course to a net zero energy system by 2040, five years ahead of California's stipulated timeline. To deliver on this goal, we will need to evolve the natural gas system to integrate cleaner fuels and improve the safety and integrity of gas operations. Doing so will enable us to deliver on our **mission to help heal the planet and to support the prosperity of California as its economy makes the transition away from fossil fuels**. Though essential, this undertaking will require tremendous effort as we balance our two critical priorities of meeting our customers' needs today with safe, reliable, and affordable service and successfully navigating an orderly transition to net zero.



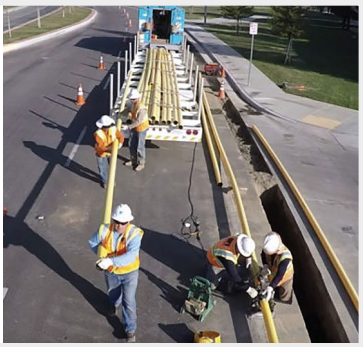
CONSIDERATIONS:
Reduce emissions and throughput, maintain infrastructure cost effectively

Beyond considerations of cost and scale of renewable alternatives to fossil-based methane, including **renewable natural gas (RNG)**, **hydrogen**, and **syngas**, there are also many unknowns surrounding how well-suited existing infrastructure and operations are to the introduction of certain methane alternatives (e.g., hydrogen) and to what degree today's end uses are compatible with various blends.

The net zero transition will also impact the demand dynamics of our natural gas system. Increasing electrification across residential, commercial, and industrial end uses will decrease our system's overall throughput and the number of remaining connections. This transition will challenge the economics of the system as the ongoing costs to maintain safety and reliability will be spread over fewer customers over time. **Identifying novel solutions and technologies that can maximize the efficiency of these ongoing maintenance and repair activities and amplify the impact of emissions reduction investments will be critical to providing affordable service in the years ahead.**

In addition to our net zero commitments, we have also set targets for methane emissions reductions from ongoing operations. As outlined in our Climate Strategy, we have **committed to reducing Scope 1 emissions from natural gas operations by 45% by 2030**, compared to a 2015 baseline. While much work remains to be done, we have already made measurable progress against this goal.

We have committed to reducing emissions from natural gas operations by **45% by 2030**.



As with progress across all of our strategic initiatives, we are proud of what we have accomplished to date but continue to seek novel ways to keep pushing forward to deliver on the balance of our commitment.

Accomplishments from the last year

Investing in R&D to future-proof the gas system for the migration to low-carbon and clean fuels, coupled with efforts to reduce emissions and increase efficiency of maintenance activities, will ensure that PG&E is able to deliver on our goals of providing reliable, affordable energy to customers, offering lower carbon and clean alternatives to natural gas, lowering emissions across the system, executing strategic electrification projects, and ensuring the safety of our customers and coworkers.

As a result of work on the gas system's safety and maintenance, we have made our gas system cleaner, safer, and more reliable for our customers, and we will continue to make meaningful progress towards our goals.

Increasing reliability through inspections: In 2023, PG&E completed all required strength-testing requirements for our pipelines, and increased pipeline piggability—the ability to use devices known as "pigs" for inspection, cleaning, and maintenance—from 49% to roughly 51% of our 6,400 mile gas transmission system. By deploying novel technologies that enable more scalable approaches to system-wide inspection and maintenance, PG&E will be able to increase system reliability by amplifying the impact of current efforts to rapidly identify and address conditions that may result in service disruptions.

While we have made significant progress in improving the safety and reducing emissions of our gas operations and supply, we are continuing to develop methods and opportunities to improve the safety, cost-effectiveness and environmental impacts of our gas system. This is exemplified in our R&D investments for ongoing and planned projects.

BREAKTHROUGH THINKING IN ACTION:

Distributed fiber optic sensor monitoring of pipeline strain and integrity for cost-effective and safe operation under geohazard conditions

This pilot, funded by the DOT/PHMSA (U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration) University grant and SBIR (Small Business Innovation Research) funds, is focused on enabling the direct monitoring of full-profile strain on affected pipelines from seismic activities without requiring pipeline excavation and in a more cost-effective manner than traditional in-line inspections.

It is the first direct pipeline full-length strain profile monitoring in the North American oil and gas industry. The pilot consists of a field installation of next-generation technology—distributed fiber optic sensing (DFOS)—on a backbone transmission pipeline at a Calaveras fault-crossing and landslide mitigation project. On-demand monitoring at the site began in August 2023. The success of the project will provide a new, reliable, accurate, and economically viable solution for pipelines under seismic conditions and will also confirm and calibrate the related pipeline strain modeling that the industry currently relies upon. This project is representative of PG&E's goals to reduce costs while improving safety and is a top priority of the Transmission Integrity Management Program (TIMP) Fault Crossing Program.

BREAKTHROUGH THINKING IN ACTION:

Decarbonizing large commercial and industrial equipment with hydrogen

This project, in collaboration with UCLA, Graniterock, and the State of California Energy Commission, will investigate the impacts of hydrogen-natural gas blends on existing and new equipment and assess the maximum concentration of hydrogen that can be handled by these appliances with and without modification.

Collecting this data is crucial for both policymakers and the private sector to advance the industry's understanding of the additional research and infrastructure investments needed to enable the large-scale deployment of hydrogen. Through this study, the team will enhance the understanding of the technical and economic feasibility of introducing hydrogen and hydrogen-natural gas blends for decarbonization of industrial and large commercial building applications.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

PG&E is firmly committed to supporting our customers through the net zero transition in the most cost effective, least disruptive manner possible.

To do so, we are pursuing a diversity of near-term win-win options to support the decarbonization of the gas system while also seeking automated, efficient solutions to achieve meaningful emissions reductions and safety and reliability improvements over the longer term. To drive down the costs of our gas system while maintaining safety and reliability, much progress must be made. Artificial intelligence and machine learning applications hold tremendous potential to enhance our efforts in monitoring, planning, field operations, compliance, and gas emissions reductions. These applications can help reduce the costs of both maintaining our current gas system and making necessary infrastructure upgrades to transition to a cleaner fuels supply.

Enhancing safety through proactive maintenance: Applications of AI/ML can enable predictive maintenance in gas operations by analyzing sensor data, inspection and maintenance records, and other inputs to detect early signs of equipment failure or anomalies in operational data such as gas composition. By enabling early intervention, these capabilities could reduce the risk of leaks, equipment failures, and safety hazards, contributing to both operational efficiency and emissions reductions.

Optimizing system planning: AI-driven tools can help optimize project planning for pipeline construction or maintenance by simultaneously considering numerous factors such as weather patterns, traffic, and resource availability.

Enhancing personnel training and field work: In the field, AI-driven tools could optimize task assignments and safety protocols, while augmented reality technology could offer real-time guidance on pipeline schematics and hazard alerts, enhancing both efficiency and safety for technicians working in high-risk environments.

To accelerate the decarbonization of our gas system, we will also continue to deepen our engagement with peer utilities, industry consortia, and others in our ecosystem that are grappling with the same evolving system dynamics to socialize our collective learnings. Additionally, we seek novel solutions and technologies from the innovation ecosystem that will enable PG&E to deliver on our ambitious emissions reduction goals while providing safe, reliable service more cost effectively than ever before.

We are seeking breakthrough thinking and technologies to advance our efforts across the two key themes outlined below.

THEME 1

Maintain and increase the safety and reliability of the system while reducing operations and maintenance (O&M) costs

Both the scope and scale of our O&M programs, which entail ongoing work across the full extent of our 50,000-mile pipeline network, require substantial investments of time and resources every year.

These efforts take a variety of forms, from routine periodic leak inspections to emergency actions following natural disasters, and employ a wide array of technologies, ranging from drone and aerial surveys to in-line and nondestructive inspection technologies.

While we continually seek and deploy state of the art solutions to enhance the efficacy and efficiency of these programs, the changing dynamics of our natural gas system in the face of accelerating electrification and decarbonization make this pursuit more imperative than ever.

Given the broad scope of our inspection, maintenance, and repair efforts, there are numerous avenues through which novel technologies and solutions could make a meaningful impact on our operations. Generally, we are seeking solutions that could help automate, optimize, and better target existing processes based on a more comprehensive and real-time understanding of conditions across the system. These types of capabilities could enable a more targeted approach to maintenance efforts that enhances our ability to proactively address developing issues and efficiently direct resources based on risk level or other factors without the need for as frequent system-wide inspections. While we will continue to make all necessary investments to ensure the safe and reliable delivery of energy across our system, innovative approaches can help to ensure that those investments do not place an undue burden on our customers.

THEME 2

Operating a clean fuels system

Greening the gas system is core to PG&E's True North Strategy and the achievement of broader decarbonization goals at the state level; however, much remains unknown about what this transition will look like at a large scale and how it will impact today's gas infrastructure.

While it is widely expected that hydrogen, RNG, and other clean fuels will be important energy sources in the future, there is little certainty across the broader utility industry about exactly how these emerging fuels will be utilized in the future and how existing infrastructure and customer end uses will need to adapt in order to accommodate the switch from 100% fossil natural gas.

Foundational R&D and earlier stage research is needed, as a better understanding of cleaner alternative fuels, their interaction with and impact on current system components and infrastructure, and other operational considerations will help to inform the path towards greening the gas supply.

In order to determine the optimal path to a net zero future, PG&E is seeking the help of the scientific community to deepen the industry's understanding of the economics, properties, and interaction effects of cleaner fuels in today's system architecture. Additionally, we seek avenues to extend this research beyond controlled laboratory settings to better inform our understanding of how RNG and hydrogen might affect our existing gas infrastructure and operations under a wide range of real-world conditions. Developing this base of knowledge is critical to our ability to smoothly transition our system to green alternatives.

Beyond foundational research, we are also pursuing novel approaches and technologies that will help address known barriers to the introduction of cleaner fuels to our system. These include studying the safety risks of hydrogen blend leaks and scalable solutions to reduce or avoid pipeline embrittlement resulting from the introduction of hydrogen. As the path forward becomes clearer over the coming years, we anticipate that our R&D needs related to decarbonizing the gas system will shift away from foundational research and towards deployable technology necessary to implement the transition.

Climate Resilience

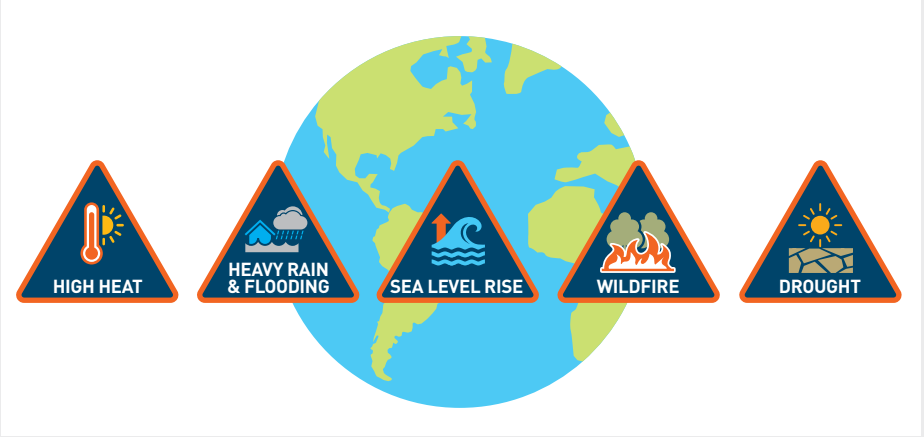
Climate Resilience

The increasing severity of climate change impacts, including extreme temperatures and storms, heavy flooding, rising sea levels, and intensifying wildfires, are significantly impacting PG&E's energy system and challenging our ability to provide safe and reliable service for our customers.

As we seek to transition to a climate- and nature-positive energy system, increased and improved adaptation and resilience measures will be critical to maintaining our infrastructure and delivering exceptional customer service in the face of increasing climate risks.

As defined in our Climate Strategy Report, **climate resilience is the ability to anticipate, absorb, recover, and learn from climate-driven hazard events that disrupt the normal functioning of a system or community**. For PG&E, becoming climate resilient means that we systematically account for the physical risks of climate change in how we plan, invest in, and operate the energy system on behalf of the communities we serve.

HAZARDS TO CLIMATE RESILIENCE



Developing the capabilities to comprehensively assess and interpret these risks and to adapt the core processes that underpin our daily operations to mitigate against these risks will be no small feat. However, doing so is not only integral to achieving our True North Strategy goals but also central to the long-term viability of our energy system.

Enhancing our ability to adequately account for a range of potential climate scenarios will make our energy system safer, more reliable, and more adaptable. PG&E has invested heavily in bolstering our resilience to increased wildfire risk and is constantly seeking new avenues to further enhance these capabilities.

In addition to mitigating ignition risk, other resilience measures, such as **strengthening our infrastructure**, **employing climate-informed maintenance practices**, and **expanding the use of advanced outage detection and prediction technologies** to cover broader a range of climate events, can also enhance safety across the system, while simultaneously improving reliability for our customers. Climate resilience enables PG&E to become more adaptable to the impacts of climate change, which will become even more necessary in the coming decades as the impacts of climate hazards are projected to increase. By improving adaptability, PG&E can better anticipate and effectively respond to climate-related challenges.

In addition to enhancing our ability to safely and reliably operate our energy system, **incorporating climate resilience into our planning processes can also make our system more affordable over the long-term**. Hardening our assets to withstand the physical strain associated with increasingly extreme weather events will unavoidably require significant investments.

However, **with advanced climate resilience capabilities, we can optimize our investments based on the projected evolution of climate risk impacts over the life of our assets**. In practice, these capabilities could enable PG&E to avoid siting new infrastructure in locations that may be increasingly susceptible to flooding or wildfire risk and to better tailor and more proactively deploy hardening efforts based on the projected severity of future climate hazards. By making better-informed investments, we can reduce the likelihood of costly disruptions, avoid emergency repairs, and lower maintenance expenses for years to come.

Climate change risks impact stakeholders within PG&E's service area and far beyond. As such, **climate resilience is a shared goal that should be integrated at the landscape level, across multiple systems and utility service areas**. Taking this broad view of climate resilience will require the development of common frameworks for utilities to inform climate vulnerability assessments and resiliency design criteria to support better investment decisions across regions and the electric industry as a whole. Furthermore, existing regulatory structures for utility planning and investment may need to be adjusted to incorporate the growth of climate risk over the coming decades, allowing utilities to make decisions today that support grid resilience in the future.

Enhancing strategies and technologies for climate resilience, including advancements in physical climate and hazard data and more precise evaluations of the impacts of extreme weather events on **infrastructure**, **communities**, and **ecosystems**, will help us move towards our goal of creating a safer, affordable, more resilient, and more reliable energy system.

Accomplishments from the last year

PG&E has made significant progress in our pursuit of building and planning for climate resilience throughout our system in recent years. Our Climate Strategy Report emphasizes our dedication to creating an energy system that can withstand the physical effects of climate change while delivering for our customers.

This commitment involves making informed decisions based on the best-available forward-looking climate models, progressing on our commitment to bury 10,000 miles of power lines in areas with the most extreme wildfire fire risk, and implementing Enhanced Powerline Safety Settings in these high-risk areas. PG&E's system planning team is also working to incorporate forward-looking climate projections into internal load forecasts.

Industry partnerships to advance common capabilities: To contribute to and learn from the industry's progress in climate resilience, PG&E participates in technical advisory committees to advance shared understanding of adaptation to physical climate risks, and is working with both the Institute of Electrical and Electronics Engineers (IEEE) and with Electric Power Research Institute's (EPRI) ongoing Climate Resilience and Adaptation Initiative (READi) to help develop climate resilience metrics for utilities. PG&E also contributes to developing tools, such as the Cal-Adapt Analytics Engine and climate risk data and analytics, to enhance the industry's ability to predict the evolving impacts of climate hazards.

Laying data foundations: PG&E's Climate Resilience team is working on an effort to integrate asset data in Foundry with climate data in AWS, which is a complex, long-term process due to the vast differences between proprietary asset data and the complexity of climate data. This is an important step for applying climate-informed infrastructure planning.

Planning for the road ahead: PG&E's 2024 Climate Adaptation and Vulnerability Assessment (CAVA), filed earlier this year in accordance with CPUC requirements, thoroughly examines how climate-related hazards currently, and will increasingly, impact PG&E's operations, assets, and services in the decades to come. The extensive report combines the best available climate projections, focused on expected conditions in 2050, to examine the vulnerability of assets and critical operations to assign relative risk ratings. Additionally, the plan incorporates the implementation of a Community Engagement Plan to recommend potential adaptation and resilience measures for PG&E. PG&E is prioritizing the incorporation of the identified adaptation options from the CAVA report in our risk-based planning processes with consideration for overall cost implications for our customers.

In addition to our efforts to advance the industry's and our own ability to understand and plan for climate impacts, we have also engaged in novel partnerships to put these learnings to work in practice.

RADICAL COLLABORATION IN ACTION:

Partnering with local stakeholders to advance resilience

PG&E, together with the City of Menlo Park, the San Francisquito Creek Joint Powers Authority, and Meta, submitted a grant application to the Federal Emergency Management Agency's Building Resilient Infrastructure and Communities program for the Menlo Park SAFER Bay project. This initiative aims to protect local communities in East Palo Alto and Menlo Park and PG&E's Ravenswood substation from flooding due to sea-level rise.

Through the construction of a levee that includes both traditional and horizontal (ecotone) designs, the project will enhance flood protection and support tidal marsh wetland restoration. This combination of engineered and nature-based solutions demonstrates a forward-thinking approach to climate resilience, blending infrastructure with ecological restoration to address sea-level rise in a sustainable way.

As a result of these recent resilience studies, industry engagements, and stakeholder collaborations, PG&E has helped to make our communities more resilient to the physical impacts of climate change. However, there is much progress that remains to be made.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

Research and development, including advancing applications of artificial intelligence and machine learning, are needed to accelerate our climate adaptation capabilities.

While these advances will depend on enhanced availability and aggregation of climate data, as well as improved foundational understanding of how climate impacts may evolve over time, we believe that novel applications of AI can also significantly improve our ability to predict and respond to a wide range of potential climate scenarios with greater accuracy and efficiency.

Optimizing infrastructure planning for climate impacts: AI/ML-driven models can analyze vast amounts of climate and utility operational data to better predict potential risks to assets. With increased foresight into future risks across the system, PG&E can take preemptive measures to protect vulnerable infrastructure and communities, thereby improving safety and reliability and avoiding costly damages.

Optimizing field team operations: AI can help anticipate the timing, location, and severity of extreme climate-driven hazards across PG&E's service area with greater precision. Equipped with more accurate, predictive information, we can more optimally prepare and deploy our resources for emergency response, both protecting the safety of our coworkers and enabling more rapid response in our communities.

Potential advancements provided by AI/ML and other novel technologies can not only bolster our immediate response capabilities but also inform long-term planning and policymaking, empowering us to build more resilient systems that can withstand future climate challenges. PG&E seeks to partner with the innovation community to enhance access to granular climate data, more effectively integrate climate projections into scenario planning and risk modeling, and better understand and respond to high heat and precipitation events. Our innovation goals include partnering with relevant stakeholders across PG&E's region and beyond to proactively develop interconnected solutions, reducing costs for stakeholders while charting the path towards a more sustainable and resilient future that ensures the safety and well-being of our communities and ecosystems alike.

THEME 1

Improve and integrate climate and hazard data into utility planning for enhanced resilience

Current utility infrastructure and operations were not designed to withstand the climate hazards that are projected over the next few decades and beyond.

There is a critical need to better understand how varying climate conditions and scenarios will impact our operations and surrounding infrastructure so that PG&E's assets can be designed and maintained to withstand the challenges posed by a changing climate.

PG&E currently utilizes advanced climate data projections, yet there are still gaps in historical and observational data, particularly on the local scale. Improving localized climate data (including downscaled climate model projections) for informed planning around near-term and longer-term climate conditions can improve their subsequent integration in risk and scenario-based assessments.

Enhanced data and modeling of climate hazard impacts on dependent, non-PG&E infrastructure and communities can cost-effectively optimize infrastructure maintenance and investments, improve planning for field work, and minimize outages for customers. This is essential for enhancing tactical operational responses to climate-driven events, including the preparation and deployment of emergency response resources and field teams to ensure the safety of employees and customers. PG&E seeks solutions from the scientific and innovation communities to enhance granular climate data, accurately link historical weather conditions to asset failures, and analyze the impacts of compounding and cascading events.

Alongside wildfire risks, California will increasingly need to plan for high heat and precipitation events that can cause severe outages and costly impacts on field team operations. Severe precipitation events and future sea level rise threaten the integrity of PG&E's assets and adjacent infrastructure. PG&E is seeking to improve our techniques for modeling the impacts of both extreme floods and low-probability flood events on infrastructure on a granular scale and to develop cost-effective and durable adaptation strategies that are integrated at the landscape level.

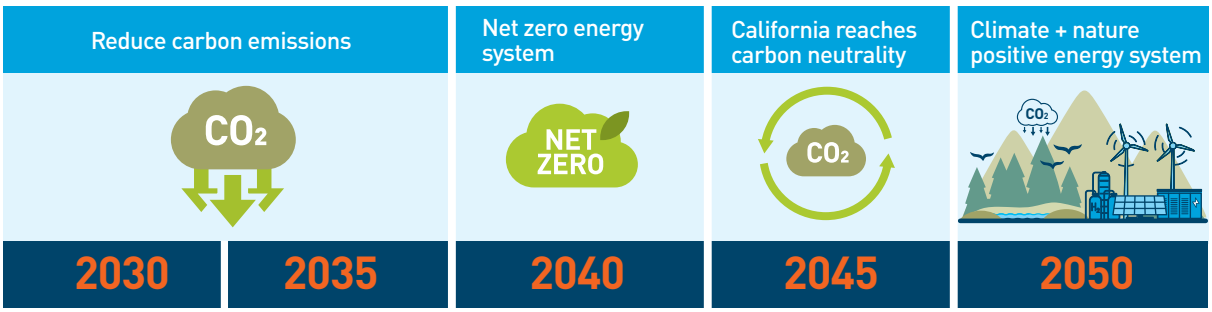
As PG&E advances our climate resilience planning and modeling efforts, we expect our R&D focus to increasingly pivot towards adopting new technologies that enhance infrastructure resilience and support service area adaptation.

Net Zero Energy System & Environmental Stewardship

Net Zero Energy System & Environmental Stewardship

Across the state of California, we have seen firsthand the real and potentially devastating effects of climate change on the landscapes that we cherish and the communities in which we live and work. Responding to the call to stem its effects is a generational challenge that will push the boundaries of ingenuity and innovation.

California has taken a bold leadership position in the fight against climate change, setting a **target of achieving statewide carbon neutrality by 2045**. As the state's largest energy provider, **PG&E recognizes our vital role in advancing these transformational efforts**. We are actively working to decarbonize our energy system and operations and support our customers in their own efforts to reduce their carbon footprints.



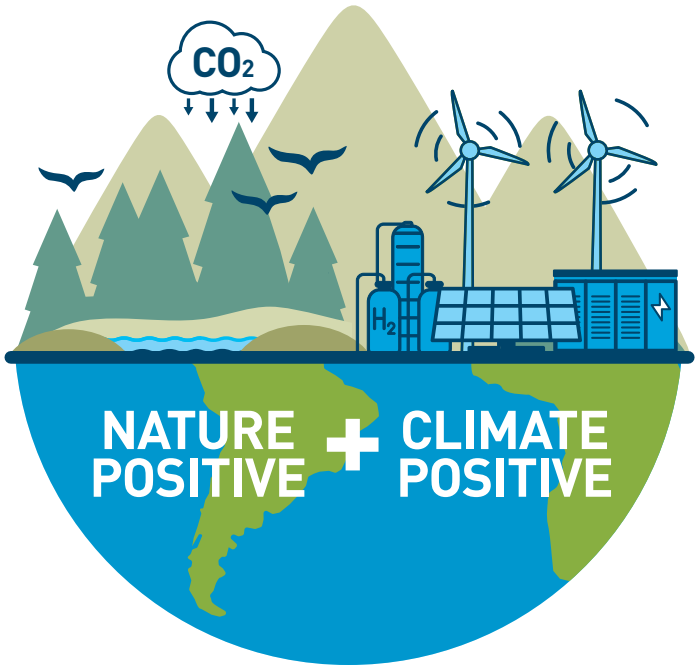
PG&E is committed to reaching net zero by 2040, five years prior to California's carbon neutrality goal, and to **achieving a climate-positive energy system**—one that removes more greenhouse gases than it emits—**and a nature-positive energy system**—focused on restoring and enhancing biodiversity and ecosystems—**by 2050**.

In accomplishing our goals, our aim is to create an energy system that provides reliable access to clean and affordable energy and protects our planet by promoting biodiversity and healthy ecosystems throughout our service area.

We recognize that **this is a critical time for climate change action** to make collective progress towards stabilizing the climate and protecting the natural environment. PG&E's plans for the future are integrated into the company's True North Strategy, our enterprise strategy that sets a clear strategic vision toward achieving our purpose and our climate and environmental commitments.

Net Zero Energy System

As the operator of a dual-commodity energy system, PG&E is uniquely positioned to lead this transition and shape the future—with a continued focus on helping our customers and hometowns prosper. On our way to a net zero energy system, we are making meaningful strides towards reducing our greenhouse gas emissions in line with our True North and Climate Strategy targets.



Climate-Positive

PG&E's climate-positive commitment goes beyond net zero emissions to removing more greenhouse gases than we emit and working with our customers to reduce their carbon footprints as well.

KEY INITIATIVES:

- **Delivering cleaner energy:** PG&E is making progress towards delivering decarbonized energy 24 x 7 x 365. Efforts on this front include shifting our energy mix towards clean generation sources, while also managing energy demand as a reliable, cost-effective alternative to traditional generation solutions.
- **Enabling transportation and building electrification:** Electrification will drive unprecedented growth across our electric system, and we are working diligently to ensure we are capable of supporting our customers along their electrification journeys. In addition to proactive capacity upgrades, we are also pursuing novel applications that enable EVs to support grid operations and a portfolio of building decarbonization and energy efficiency solutions.
- **Greening the gas supply:** PG&E is actively working to transition the gas system to transport and deliver cleaner fuels to help decarbonize PG&E's operations and the energy used by our customers. These efforts include adding increasing volumes of renewable natural gas (RNG) across our system, exploring opportunities with hydrogen and other GHG-free alternatives, and proactively working with our hard-to-electrify customers to identify pathways to reduce emissions.

Nature-Positive

Our long-term objective is to become a nature-positive company, going further than avoiding impacts on the natural environment. In partnership with stakeholders across the state, we aim to invest in environmental initiatives and research to restore biodiversity across ecosystems and habitats. Our collaborative and cost-responsible approach focuses on efforts that encompass land, air, water, and habitat.

KEY INITIATIVES:

- **Land and habitat conservation and restoration:** We have a long history of programs and partnerships to protect and restore species and their habitats, including protecting federally- and state-designated endangered and threatened species that call our service area home. As we provide energy service to our customers, we also strive to be responsible stewards of the lands we own and where we operate, conserving thousands of acres of land and proactively planning for future restoration efforts.
- **Water conservation:** Water is essential to operating our infrastructure, including our vast network of hydroelectric generating stations, just as it is essential to our customers in their daily lives. PG&E is promoting sustainable water use across our own operations and helping our customers do the same by strategically managing power generation facilities, reducing consumption at our offices and service centers, and providing outreach and guidance on conservation measures to customers.
- **Air, waste, and remediation:** We are committed to reducing air emissions and waste from our facilities and operations, while also addressing impacts to the environment from historic operations in accordance with today's regulatory standards.

PG&E is also exploring new, emerging technologies, including **nature-based solutions (NBS) in our forest management strategy** and **various forms of carbon capture, storage, and utilization for our operations**.

The future energy landscape will incorporate a network of **carbon sinks** and **renewable energy and storage assets**, which will support the stability of the grid but also help PG&E meet our net zero targets and mitigate environmental impacts for a cleaner, resilient, and affordable future. While we are in the early stages with these efforts, they are areas of increasing interest as we seek to address emissions from aspects of our operations that are difficult to decarbonize.

Accomplishments from the last year

PG&E is already making progress in reducing our emissions on the path to net zero and in promoting environmental stewardship in our operations.

Reducing Emissions: In 2023, PG&E reduced Scope 1 and 2 emissions by 27% and Scope 3 emissions by 19% relative to a 2015 baseline—exceeding our annual reduction goals.

- Electric System: PG&E supplied 100% greenhouse gas-free electricity to residential and business customers to whom we directly sell power, marking an exciting milestone in our efforts to decarbonize delivered energy. We relied on a combination of wind and solar renewable resources, nuclear power, and hydropower to meet customer demand. We also connected new battery storage capacity to the state's electric grid, now totaling more than 2,100 MW.
- Gas System: In 2023, we achieved a 38% methane emissions reduction across our natural gas pipeline system compared to a 2015 baseline. To align with our goals of greening the gas supply, PG&E began accepting RNG from 36 dairies across our service area between 2021 and 2023. By the end of 2024, we expect that figure to grow to 48 dairies.

  We also exceeded our internal target of less than 150 days for the average duration of Grade 2 open leaks, with average days open of 113 days in 2023 enabling us to reduce our backlog and minimize methane emissions from leaks.

Protecting California's lands & habitats: PG&E completed our unprecedented Land Conservation Commitment (LCC), which will permanently protect approximately 140,000 acres of PG&E-owned watershed lands for the benefit, education, and enjoyment of the public. This landmark effort, underway for about 20 years, was achieved through the development of unique conservation agreements and partnerships with private conservation groups, Native American tribal organizations, and the California Department of Forestry and Fire Protection (CAL FIRE).

PG&E has also begun piloting new community partnerships to build more resilient forests and communities. Through these pilots, PG&E is co-creating a diverse array of locally-led projects to reduce wildfire risk by better managing fuels and supporting community risk reduction—with many benefits to customers, the state, and forest ecosystems.

While we are proud of the progress we have made, we continue to explore innovative solutions to accelerate these efforts, including exploring various technologies that can augment our methane detection capabilities and reduce costs relative to current methods.

BREAKTHROUGH THINKING IN ACTION:

Near field fixed monitoring for wellheads at underground storage facilities

PG&E is testing the technical specifications and leak detection capabilities of various methane sensors for continuous monitoring of wellheads at underground storage facilities.

Continuous monitoring improves both customer and coworker safety and can reduce operating risks though early detection of high-risk methane leaks, potentially preventing loss of containment. This type of monitoring can reduce O&M costs when compared to daily wellhead leak surveys.

Supercharging progress: How AI can accelerate our efforts to stabilize customer bills and achieve TNS outcomes

PG&E's climate goals guide our work in helping to transition California to a decarbonized and more climate-resilient economy.

Reducing emissions in line with PG&E's net zero goal includes developing solutions that not only serve customers and ecosystems within PG&E's service area but also Californians more widely. We're focused on continuing to make significant progress in renewables and energy storage, integrating cleaner fuels into the natural gas system, and investing in energy efficiency and electrification. As we decarbonize the energy system, we're also focused on delivering stable rates for customers and ensuring the benefits of a cleaner energy system are accessible to all.

To deliver on these collective goals, PG&E is pursuing opportunities to implement innovative, cost-effective solutions that are aligned with our net zero plan. Novel applications of artificial intelligence and machine learning may be particularly impactful across many of our key initiatives, helping to optimize our emissions reduction and sustainability efforts to maximize efficacy and cost-effectiveness. Armed with better intelligence and optimization capabilities, PG&E can also prioritize interventions that yield the highest impact per dollar invested.

Predicting and detecting methane leaks: Advanced machine learning algorithms can help detect methane leaks in real-time across vast utility infrastructure networks and predict where future leaks may occur based on observed historical patterns. This enhanced situational awareness can help reduce greenhouse gas emissions by accelerating repair timelines.

Quantifying forest management value streams: Advanced AI models can integrate environmental, economic, and wildfire risk data to assess and optimize land use treatments, such as controlled burns or selective logging, to build more resilient forests and communities. AI can help prioritize utility investments by quantifying the wildfire risk reduction, ecological benefits, and economic returns of various interventions. The ability to accurately assess the value of these efforts across a wide range of outcomes can also help drive alignment and financial support from a broader pool of stakeholders, potentially reducing costs for PG&E.

Enhancing carbon capture efficiency: AI/ML-driven optimization algorithms can enhance the efficiency of carbon capture systems by continuously adjusting operational parameters based on real-time data, such as flue gas composition, temperature, and pressure, to maximize the capture rate of CO_2 while minimizing energy consumption.

In addition to pursuing cutting-edge AI solutions, we are also seeking to collaborate with the innovation community to help advance our efforts in solving the challenges detailed in this report. These are all areas where meaningful advances to available state-of-the-art technologies could drive outsized impact toward a net zero energy system and environmental stewardship at PG&E and across the industry.

THEME 1

Reducing gas supply chain emissions

Meeting our net zero targets will require investment in equipment to more effectively abate methane emissions across our operations, as well as novel technologies to cost-effectively produce and integrate increasing volumes of GHG-free alternatives into our natural gas system. Innovative means to remove residual carbon emissions at scale will also be an essential part of achieving a climate-positive energy system.

PG&E's goal is to reduce methane emissions from the gas system by 45% from 2015 to 2030 through more effective monitoring of emissions from leaks at wellheads and reducing blowdown emissions.

Meeting this target will require innovation on multiple fronts:

- Innovative means to remove residual carbon emissions at scale will also be an essential part of achieving a climate-positive energy system.
- Refining existing methane emissions calculations to enable PG&E to create more accurate baselines to take a more targeted approach to prioritizing investments and to precisely accounting for changes over time.
- Innovative methane detection technologies at storage facility wellheads to enable PG&E to more cost-effectively abate methane emissions across the system.
- Novel methods to eliminate emissions from routine pipeline blowdowns that occur during regular maintenance and inspections.

Greening PG&E's gas supply will come in a variety of forms, including blending of RNG, hydrogen, and other GHG-free alternatives into our natural gas system. It will also entail more economic interconnection skids to efficiently integrate clean fuels into the system. By 2030, PG&E's goal is to deliver 15% RNG in its core gas throughput, necessitating new solutions to reduce the costs of producing RNG from traditional sources and for alternative RNG production sources, such as woody biomass and power-to-methane to fill this gap cost-effectively.

At the same time, we aim to reduce emissions from our owned natural gas generation resources, which we expect to continue to operate to deliver energy for our customers.

We also seek innovative technologies to cost-effectively remove residual carbon emissions that may be costly to abate through other measures. One of these solutions may be CCUS, which also requires infrastructure to transport, utilize, and/or store the captured carbon.

Delivering on these goals requires innovative research and technologies to cost-effectively and proactively reduce and balance out emissions from our gas supply and owned gas generation facilities, so that we may meet our long-term climate commitments.

THEME 2

Holistically manage forest ecosystems

Optimized forest management can enable PG&E to target root causes of wildfires by promoting and supporting healthier forests through standard setting for third parties and identification/quantification of value streams associated with healthier forests that can bring more stakeholders into the process.

PG&E's current investments in forest management are typically targeted efforts that focus on avoiding damage to PG&E assets, including preventing contact that could result in ignition, removing debris following a weather or fire event, and clearing areas surrounding PG&E rights-of-way.

However, as part of PG&E's commitment to environmental stewardship, we are continually evaluating more holistic approaches that focus on ecological restoration and address the root causes of many wildfires by promoting healthier forests.

These interventions may include proactive post-wildfire restoration, leveraging easements to create expanded rights of way to provide expanded fuel breaks to slow fire spread, or controlled burns, among others.

There is a significant opportunity for new technologies and breakthrough thinking to re-envision forest management practices across PG&E and a wider collection of stakeholders. Improvements to advanced analytics and modeling capabilities could unlock the potential for forest management practices that are more targeted to local conditions and better optimized across a range of desired outcomes, including preventing ignitions, reducing greenhouse gas (GHG) emissions, and improving overall ecosystem health. Additionally, by enhancing our understanding of the range of benefits created through alternative interventions, PG&E can better assess tradeoffs with conventional wildfire mitigation measures and continue to strengthen our layers of protection.

Beyond expanding the tools available to promote healthy ecosystems, broadening the circle of participants willing to support and contribute to these efforts is also critical. Identifying novel ways to engage with and incentivize stakeholders with a vested interest in improving the health of California's ecosystem can further amplify the impacts of PG&E's ongoing forest and land management efforts.

To support all of these outcomes, PG&E seeks more granular models capable of optimizing PG&E and partner efforts based on multiple factors, including wildfire ignition risk, fire spread velocity, and woody debris volume. We are also seeking technologies that will improve the safety, efficiency, and cost-effectiveness of managing and disposing of wood debris generated through our forest management efforts. These advances will allow us to progress towards a healthier and safer environment and ecosystems for our customers and communities.

2024 R&D Problem Statements

Of the 67 problem statements in this year's report, 50 appeared in the 2023 R&D Strategy Report, though a significant number have been updated and refined to reflect our evolving needs based on efforts over the last year.

Additionally, we have added 17 new problem statements that reflect emerging areas for R&D across our energy system. Lastly, we are excited to add a new section to this year's report for "graduated" problem statements for which we have identified and are pursuing a potential solution or range of solutions.

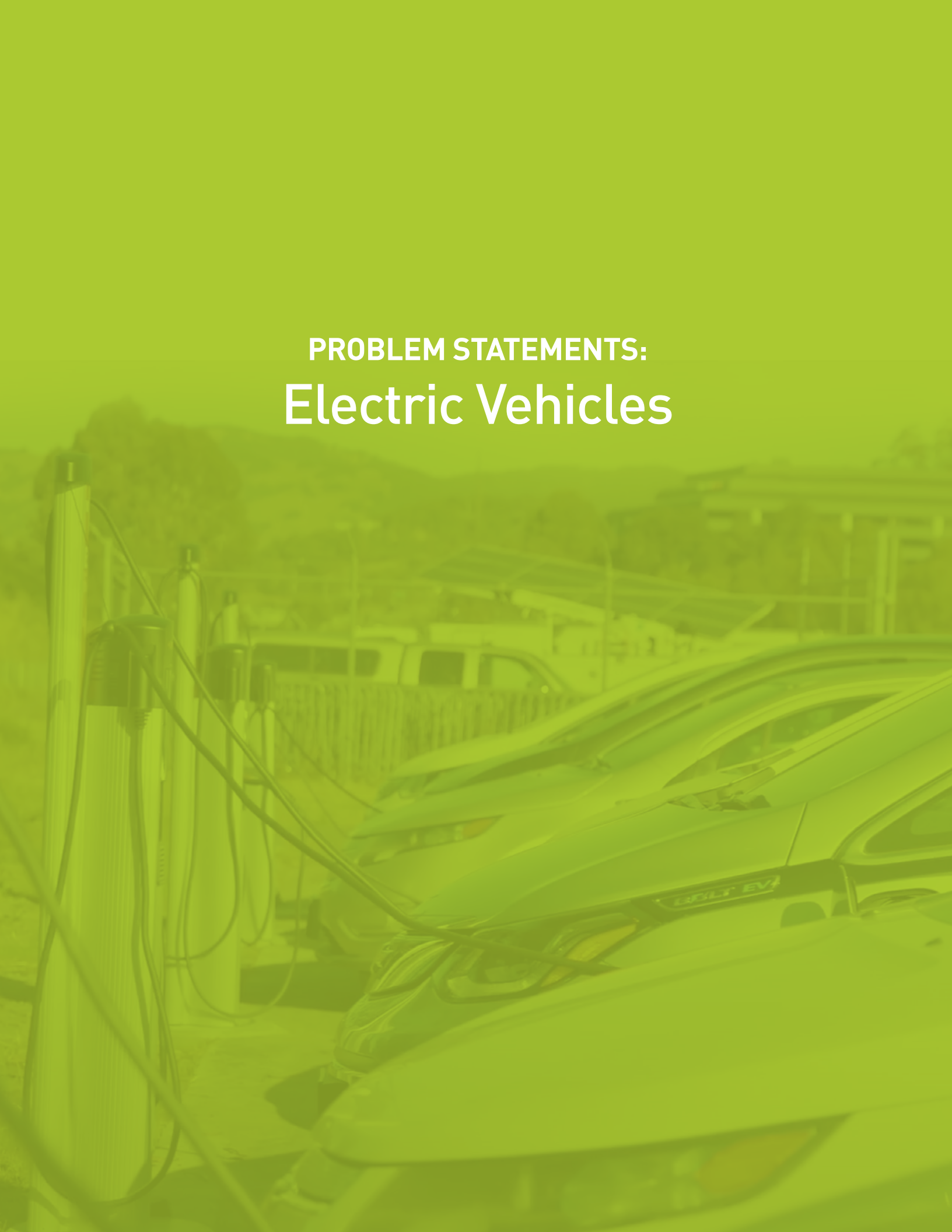
While many of these technologies remain in the early stages of piloting at PG&E, we have sufficient confidence in their capabilities that we are removing the associated problem statements from active consideration as part of our 2024 R&D Strategy efforts. The 17 graduated problem statements can be found at the end of this section.

To help navigate our problem statement inventory and the additions and changes since last year, we have added icons to denote updates and changes, as well as to indicate the degree to which we anticipate applications of AI will be central to solving the challenges articulated. For the purposes of evaluating AI's potential to contribute to solution areas, we take a broad definition of AI which encompasses machine-based systems that are capable of making decisions, recommendations, or predictions based on human-defined objectives, ranging from rule-based systems to deep learning algorithms.

PROBLEM STATEMENT STATUS	AI POTENTIAL AS A SOLUTION
NEW STATEMENT: This problem statement is a new addition to the 2024 report	**LOW AI POTENTIAL:** We do not believe that AI will play a significant role in the solution set
MINOR UPDATES: This problem statement appeared in the 2023 report but has been slightly modified	**MEDIUM AI POTENTIAL:** We see potential for AI to play a significant role in the solution set but are not confident this will be the case
MAJOR UPDATES: This problem statement appeared in the 2023 report but has undergone major updates	**HIGH AI POTENTIAL:** We believe that AI will play a significant role in the solution set

PROBLEM STATEMENTS:

Electric Vehicles



THEME 1

Ensure affordable and timely connection for every customer

PROBLEM STATEMENT 1

Reducing cost and complexity of EV charging installation at multi-family buildings

Connecting an EV charger at a multi-family home can be an involved and costly process, complicated by both physical constraints (e.g., parking garage layouts), third party (i.e., property owner/manager) decision making, and access to public charging.

Why is this important?	Nearly half of California's population lives in multi-family homes, yet many do not have access to EV charging stations at home or near their home, which makes it more challenging for these customers to adopt an EV. Installing chargers in these buildings often requires expensive and time-consuming upgrades to the electrical system and utility service. A key challenge is that these upgrades frequently need to take place in shared areas, like garages or parking lots, adding layers of coordination between residents and property owners and their agents (e.g., property managers). In addition to technical hurdles, there are economic and logistical challenges unique to shared infrastructure. Property managers or building owners may be reluctant to invest in these costly and complex installations, especially in older buildings requiring significant upgrades. Meanwhile, solutions in this market need to also account for the uncertainty around charger usage, managing tenant access to charging stations, and handling billing for charger use. Despite these obstacles, expanding access to EV chargers in multi-family homes, particularly in disadvantaged communities, is critical to achieving California's ambitious EV adoption targets.
What is the current state and its primary limitations?	At present, property owners or managers collaborate with electricians and PG&E to evaluate the building's existing electrical infrastructure and the capacity of the local utility service. This assessment helps determine the scope of upgrades required to install EV charging equipment. If the local utility service lacks sufficient capacity, PG&E must first complete grid upgrades before the charging equipment can be installed. In addition, property managers must decide on the number of charging ports needed, manage access to the charging equipment, handle ongoing maintenance, and oversee customer billing for charger usage. **Primary limitations include:** • High costs and extended wait times associated with lower utilization multi-family charging infrastructure installation and necessary electrical upgrades • Lack of education to simplify the process and marketing to communicate the benefits to each stakeholder involved in the process • Ambiguity and coordination challenges around who is responsible to bear expense to install and maintain the charging infrastructure • Inadequate systems to manage billing at the individual tenant level • Complexity in fairly managing and sharing electric infrastructure in common spaces
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Eliminate the need for costly electrical work and upgrades, potentially through a new charger design to simplify installation • Reduce costs and timelines to bridge the installation gap for multi-family charging infrastructure • Facilitate seamless billing at the customer level, removing coordination burden on property managers

PROBLEM STATEMENT 2

Avoiding installation delays for public and fleet charging due to capacity constraints

PG&E is deploying systems that are able to dynamically limit power flow to public and fleet charging based on system constraints; however, not all existing charging equipment has the ability respond to PG&E's signals by modulating load within these dynamic constraints or by utilizing alternate sources (e.g., storage) to meet load.

Why is this important?	PG&E is actively supporting fleet electrification, but capacity constraints in the electrical system can result in delays while necessary upgrades are completed. To address this, PG&E is deploying systems that allow dynamic load management within the limits of the current infrastructure. These systems require charging equipment to respond to signals that adjust power usage as capacity fluctuates. As we scale public and fleet EV charging, we will need circuits that are capable of handling the load of large-scale charging infrastructure. We may also need to more dynamically manage these circuits which will require public and fleet charging customers who can operate within dynamic constraints. Both elements are critical to help California achieve its goal of transitioning 100% of medium- and heavy-duty vehicles to zero-emission vehicles (ZEVs) by 2045.
What is the current state and its primary limitations?	PG&E is in the process of deploying dynamic systems to manage capacity on constrained circuits, allowing for the connection of new EV charging infrastructure (both DCFC and L2) while larger-scale upgrades are being implemented. To fully benefit from this approach and connect to constrained circuits sooner, all charging equipment must be capable of flexibly adjusting power draw as system conditions change. Additionally, in situations where grid power is restricted or unavailable, alternative energy sources such as storage may be needed to meet demand during vehicle charging. **Primary limitations include:** • Lack of ability to ingest and respond to real-time signals to modulate load at scale to match capacity on a near real-time basis • Limited integrated demand-offsetting solutions to reduce dependency on grid during times of constrained capacity
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable customers to adjust consumption based on a real-time or near real-time signals from PG&E • Enable customers to more seamlessly integrate DERs as a demand offsetting solution when grid capacity is limited, such that power needs can be met by a dynamic mix of energy resources as conditions on the grid change

PROBLEM STATEMENT 3

Simplifying EV charging installations for single-family homes

Customers connecting an EV charger to a single-family home may encounter unanticipated costs and significant wait times. Greater visibility into whether customers require on-site electrical work and/or upgrades would ease pain for all stakeholders involved. Further, identifying solutions to mitigate a panel upgrade can reduce costs and timeliness of connections.

Why is this important?	Many PG&E customers are unaware if their existing electrical systems and utility service can support EV charging before purchasing an EV. This includes limitations on service panels, utility wires, and upstream distribution infrastructure (e.g., transformers). Without clear visibility into their systems' capacity and the potential impact of increased load, customers can be caught off guard by lengthy wait times or unexpectedly high costs due to required upgrades. To avoid these expenses and delays, some customers may opt for unpermitted electrical work, which limits PG&E's ability to effectively manage the distribution system. As EV adoption grows, unmanaged charging load can lead to issues like transformer failures, resulting in outages and costly repairs for PG&E. Improving the current connection process and enhancing the ability to manage new EV loads can eliminate key barriers to EV adoption. This would also allow PG&E to offer a more seamless, transparent, and efficient experience for customers transitioning to EVs. Moreover, these issues are not limited to EVs; other residential electrification, as well as distributed energy resource projects, face similar challenges, highlighting the broader need to address these problems across various customer solutions.
What is the current state and its primary limitations?	Currently, the installation of home EV chargers can be time-consuming and costly, often reaching thousands of dollars depending on the extent of the required upgrades. To avoid these high costs and long delays, some customers may choose to bypass utility notification and local permitting processes and install EV charging equipment without proper approvals. This forces PG&E into a reactive approach and can lead to a more expensive solution to address the issue, increasing overall risks and costs for both the utility and the customer. Required work to install an EV charger may include one or a combination of the following, totaling upwards of $7,000 in a worst-case scenario. • Charger purchase + installation: $800–$2,000 • New service panel: $2,000–$5,000 **Primary limitations include:** • Potential inability for customers to install traditional at home charging due to transformer and/or constraints on the distribution system • Lack of customer visibility into their home electrical system and utility service constraints to understand EV installation costs prior to purchase • High costs and long timelines for customers that require electrical upgrades to support at-home charging • Lack of visibility into increasing charging loads and evolving constraints at the service transformer level
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Increase customer visibility into the whole home load constraints that exist on their current system to help customers identify the best approach to install an EV charging station as well as additional electrification efforts (e.g., heat pump water heaters) before the purchase of an EV • Reduce the costs to the customer for electrical upgrades or avoid them altogether • Enhance visibility for PG&E into changing conditions at the service transformer level to better anticipate and avoid failures • Coordinate single sites and service groups through managed charging to avoid transformer failures and costly repairs for PG&E

THEME 2

Unlock potential of EVs as grid assets

PROBLEM STATEMENT 4

Enabling widespread V2X interconnections

Technologies required to enable V2X are costly, time-consuming, and complicated to install and manage for both the utility and customer. With deployment underway, simplifying the technology that's required for V2X and the process to interconnect the systems, especially if other DERs are present, is a focus area.

Why is this important?	As EV ownership rises nationwide, the increased demand places additional stress on the electrical grid, creating new challenges and costs for both customers and PG&E. The number of EVs equipped with V2X capabilities, which includes vehicle-to-home (V2H) and vehicle-to-grid (V2G), is growing, allowing them to supply power back to the grid. V2X can help alleviate grid stress by utilizing the high-capacity batteries of parked EVs to provide power back to the grid during peak demand events, reduce demand on the grid during peak events by powering homes with EVs, or serve as a backup power source during outages. With future EVs expected to have 60–80 kWh of battery capacity, PG&E's goal of supporting 3 million EVs by 2030 could translate into 180–240 GWh of battery capacity available to bolster the grid. In addition to reducing grid stress, V2X offers a new value stream for customers by enabling them to receive payments from utilities for the power their EVs provide to the grid. This can lower the total cost of EV ownership and drive broader EV adoption. However, overcoming existing barriers to V2X enablement is crucial to unlocking its full potential for customers, utilities, and the wider ratepayer community.
What is the current state and its primary limitations?	The implementation of V2X requires additional investments from both customers and utilities, beyond the initial costs associated with standard one-way charging. These additional expenses include a higher purchase price for V2X capable EVs and EV chargers as well as the additional equipment needed to enable V2X such as inverters and dark start batteries. Costs may also include the purchase and installation of new electrical panels, costly on-site work to upgrade wiring and components, and relocating loads to accommodate two-way power flow. Enabling V2X at a customer's home or business also requires a customer to go through the interconnection process to ensure the system is safe to connect to the grid. This is a complex and often lengthy process to navigate through and comes with additional costs. **Primary limitations include:** • High total cost of installation, ranging from $10–$20k, with panel upgrades and electrical work to install bi-directional chargers as the largest driver • Commercially available bi-directional chargers are currently limited and costly • Installing V2X infrastructure is time consuming due to the often-necessary electrical upgrades and the required interconnection process
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce the cost or the need for electrical and panel upgrades when installing a bi-directional charger • Enable more rapid installation of V2X equipment through a streamlined interconnection process • Decrease the cost of V2X charging equipment to lower the total upfront expense of enabling V2X

NEW

PROBLEM STATEMENT 5

Increasing precision and efficacy of energy management programs

Current residential EV energy management lacks precision due to limited disaggregation capabilities. Utilities do not have the ability to accurately identify where EVs "reside" on the system, analyze end-use consumption patterns, and enable targeted load management strategies that address both bulk system and distribution constraints effectively.

Why is this important?	Increasing and effectively managing residential EV adoption are two essential pathways to helping California meet its climate goals. Additionally, EV load growth contributes directly to rate stabilization by enabling more efficient use of grid assets. Further, with the increasing awareness of variable rates and availability of residential DER systems to respond to price signals, there is a greater interest among customers to understand how their EVs can participate in value sharing programs. Without access to the data, PG&E is limited in our ability to predict and manage bulk system and distribution constraints, resulting in a broad set of outcomes: • PG&E value-sharing programs are less targeted and effective, impacting customer affordability and system burden • Customers are less willing and able to participate in managed charging • More grid resources are needed to accomplish the same goals, less efficiently • Assets like service transformers can require emergency repair or have a shortened lifespan
What is the current state and its primary limitations?	Customers do not always notify PG&E when they adopt an EV and install charging equipment, and therefore, PG&E cannot identify which residential customers own EVs and are likely to charge at home. PG&E also does not have the data required to disaggregate load based on EV and non-EV usage at the individual residential customer level. With limited exceptions, such as participants enrolled in managed charging programs, individual customer charging patterns and preferences are also largely unknown to PG&E. This lack of visibility limits the effectiveness and impact of essential programs to support the broader system goals. With growing demand for EVs across the portfolio, the opportunity to drive load management strategy increases both in scale and complexity. **Primary limitations include:** • Lack of data on which residential customers own EVs • Lack of access to the data and a corresponding control platform to support targeted load management for residential customers • The vast majority of customers also do not have this disaggregated data, blinding them to the potential for load management options available
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Disaggregate load at the customer level at an affordable cost to deploy system-wide to all customers, independent of or interoperable with all EV software systems • Assist in identifying customer behavior and preferences based on past usage and stated outcomes • Enable load shedding recommendations based on market dynamics, particularly in combination with bulk system and distribution constraints in mind

PROBLEM STATEMENTS:

Integrated Grid Planning & Transmission Strategy

THEME 1

Reduce conventional capacity upgrades

PROBLEM STATEMENT 6

Increasing utilization of existing T&D infrastructure

PG&E is not equipped with the tools necessary to maximize utilization of our current T&D system. This limits our ability to accommodate rapid increases in load growth in a time and cost-efficient manner.

Why is this important?	Electrification is expected to double load across PG&E's service area by 2040, straining the limits of the existing T&D system and necessitating significant investment in upgrades to accommodate the new load. Utilizing conventional methods for capacity upgrades to manage this growth will require tens of billions of dollars in investment. At the same time, the electrification of buildings, transportation, and industry represents a significant opportunity to increase the amount of electricity flowing through the existing system, thereby making the system more efficient and stabilizing customer bills.
What is the current state and its primary limitations?	PG&E has been exploring various cutting-edge technologies, including dynamic line rating, smart metering data, and new conductor materials, that decrease energy losses and increase transmission capacity to uprate existing assets. Conventional techniques for upgrading the T&D system are time and resource intensive, requiring multi-year planning and investment cycles and costly new capacity projects. Most often, these projects specify the replacement of existing assets and infrastructure in favor of newer, larger systems. Beyond the capital cost and construction effort required to build these new systems, this approach may also result in right-of-way issues if the new footprint extends beyond that of existing assets, further increasing project costs and timelines. **Primary limitations include:** • Limited ability to maximize the capacity delivery potential of the current infrastructure (structures, right-of-way) due to insufficient conductor capacity • Inability to fully leverage the dynamic capacity of existing conductors • Multi-year, resource intensive planning and investment timelines • High-cost capacity upgrade projects • Increased emissions and land use impact and potential right-of-way issues from expanding T&D footprint
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML to:** • Defer or eliminate the need for new conventional capacity projects • Cost-effectively increase the thermal rating of grid assets, improve the power quality, and/or improve the efficiency of existing T&D assets in a manner that doesn't compromise system safety or reliability

NEW

PROBLEM STATEMENT 7

Maintaining operational flexibility as load factor increases

It is difficult to increase the load factor of existing T&D infrastructure without impacting flexibility. As an asset's load factor increases, it becomes increasingly difficult to orchestrate loads with high operational flexibility.

Why is this important?	The flexibility of the energy system describes its ability to adapt to changing conditions, such as fluctuating power supply and demand. The grid was initially designed for a constant flow of power, generated by fossil fuel power stations and consumed in foreseeable patterns. As consumers, energy suppliers, and developers rapidly adopt renewable energy, the grid must adapt to new types of loads, for example, millions of electric vehicles charging at night or data centers running at maximum capacity to train large language models. These loads are more intermittent by nature than what the grid is designed to accommodate. The existing grid thus lacks the necessary degree of flexibility, which can lead to decreased reliability and safety, increased operational costs, and capacity costs. Ultimately, this can lead to suboptimal outcomes for grid affordability and reliability and can slow the transition to a clean energy system.
What is the current state and its primary limitations?	Currently, while most renewable power is connected to the grid, it lacks the ability to respond to large fluctuations in demand and supply dynamically and rapidly. This is mostly due to inadequate infrastructure, tools, and technology. **Primary limitations include:** • Lack of energy storage assets • Hardware and material limitations (e.g., limited dynamic rating) • Limited operational awareness into balancing clean vs. conventional power • Lack of adequate demand-response programs
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Upgrade infrastructure with solutions that provide real-time insights and control of the grid's assets, such as smart grid technologies and enhanced automation with appropriate oversight • Enable the deployment of effective demand-response programs • Dispatch power from various generation sources in the most effective way • Increase flexibility of existing system, such as through leveraging storage solutions

THEME 2

Optimize prioritization and reduce costs for unavoidable capacity upgrades and new interconnections

PROBLEM STATEMENT 8

Reducing cost of T&D asset replacement and upgrades

Upgrades to the T&D system typically require up-rating existing infrastructure which may require obtaining new rights of way and trigger costly foundational investments in assets that otherwise may still have useful life or could be partially upgraded at lower cost than a full redesign.

Why is this important?	With unprecedented load growth expected in the coming years, PG&E will need to make significant investments in upgrading and expanding our existing infrastructure. In many cases, upgrade projects aimed at increasing system capacity also trigger more extensive investments in foundational infrastructure, such as replacing existing wood poles if a line segment requires reconductoring. These upgrades may also necessitate obtaining new rights of way to accommodate new infrastructure, which can significantly increase the cost and timeline required to complete the buildout.
What is the current state and its primary limitations?	With limited load growth over the past 40 years, T&D infrastructure has typically been replaced due to failure or reaching the end of its useful life. Load growth over the coming decade, however, is expected to increase dramatically. This will require upgrading T&D infrastructure more frequently, much of which will have useful life remaining. In many cases, traditional capacity upgrades would also require PG&E to identify and obtain new rights of way for siting new infrastructure, which could result in the underutilization of our existing asset footprint. This existing footprint also includes gas pipelines and other existing underground infrastructure that are decommissioned or soon to be, which could be repurposed to support capacity upgrades for the electric system. However, PG&E lacks the minimally invasive technologies that would be necessary to pull underground cable through existing buried infrastructure, thereby capitalizing on the cost savings opportunity. **Primary limitations include:** • Lack of sufficient tools to accurately determine remaining useful life of existing assets • Limited T&D components that may be re-used on other parts of the system (i.e., insulators that may be re-used on upgraded poles) • Lack of technologies to enable co-location of new infrastructure in existing rights of way • Inability to pull and splice underground cable of varying sizes in existing buried conduit with minimal trenching or surface disruption
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Maximize the safe reuse and/or extend the useful life of existing assets • Test and qualify existing T&D equipment for reuse • Maximize the utilization of existing rights of way to support necessary capacity upgrades • Install underground cables in existing buried conduit cost efficiently and with minimal surface-level disturbance (i.e., avoid the need for open trenching)

NEW

PROBLEM STATEMENT 9

Accelerating new interconnection planning

Current forecasting and planning tools are not computationally optimized to evaluate and plan new interconnections, nor reflect the variety of capacity upgrades required to enable the new interconnection, therefore slowing down the already uncertain study process.

Why is this important?	Renewables are set to contribute 80% of new power generation capacity deployed through 2030. New interconnections are critical to the transition to a clean energy system as they enable the integration of renewable power into the grid, thereby reducing the share of fossil fuels in the energy mix. To study new interconnection requests, PG&E needs to process multiple and complex scenarios to gain a comprehensive view of the feasibility and impacts of new interconnections and make informed decisions about whether to proceed with the project. These calculations and simulations require significant computing power to ensure timely results.
What is the current state and its primary limitations?	Connecting a new power generation source to the grid involves building new infrastructure and may require upgrades on existing equipment to prevent voltage issues, overloading of equipment, or protection challenges. The process of studying a new interconnection request requires modeling thousands of scenarios, and processing large amounts of data, such as customer data, grid information, environmental impacts, economics, geographic information system (GIS) data, and more. PG&E has invested in co-developing solutions with vendors, but vendors currently lack either computational power to process a large amount of data or experience in power flow modeling. In addition, the customer study process to approve a new interconnection is uncertain: the capacity upgrades required to accommodate the new interconnection can include a variety of upgrades, from small projects (e.g., adding a transformer) to larger efforts (e.g., line work or substation work), which involve more regulatory processes, thereby lengthening the interconnection approval process. **Primary limitations include:** • Lack of visibility into the impact of a new interconnection on existing infrastructure • Lack of computationally optimized tools • Inability to transfer large data repositories to vendors who can provide robust computation capabilities
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable automation with appropriate safeguards to transfer data repositories to vendors • Computationally optimized tools to process new interconnection scenarios • Increased visibility into the type of capacity upgrades required to accommodate new interconnection

NEW

PROBLEM STATEMENT 10

Streamlining design and estimation for routine projects

The design and estimation process for routine or straightforward projects is time-consuming and manual, reducing the capacity for coworkers to focus on higher value-add projects that require more creativity and expertise.

Why is this important?	Across our combined operations, PG&E completes thousands of construction projects a year, which include capacity upgrades, undergrounding projects, and routine repairs and replacements. From prioritization to design and estimation to construction, PG&E invests substantial time and resources on an annual basis completing these projects. While many of these efforts require deep expertise and creativity to solve for the specific constraints of the project, a substantial portion of this work is represented by straightforward use cases in which the design and estimation process is highly standardized from one job to the next. Novel technologies that could streamline or automate the design and estimation process for standard use cases could expand the available capacity of our estimators. This increased bandwidth could in turn be redirected to designing and estimating for complex projects, which benefit more from the expertise and creativity of our teams.
What is the current state and its primary limitations?	Despite a high degree of standardization across many projects, the design and estimation process relies heavily on manual effort to draft designs, specify materials, and produce estimates. This multi-step process lacks automation and requires handoffs between multiple teams, adding further complexity. **Primary limitations include:** • Lack of automated tooling or capabilities to support design and estimation of straightforward construction projects • Increased opportunity for variability and human error due to manual nature of process
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce the manual effort and time to completion for designing and estimating routine projects • Increase standardization, where possible, across similar projects to reduce overall system complexity

THEME 3

Optimize system-level decision making

NEW

PROBLEM STATEMENT 11

Aggregating holistic grid information for optimal system outcomes

The absence of a tool that consolidates all comprehensive, publicly accessible datasets hinders our ability to gain a holistic view across transmission, distribution, and storage needs, limiting effective planning and investment decisions and potentially leading to suboptimal outcomes for grid reliability and affordability.

Why is this important?	As electrification across transportation, buildings, and industry increases and aging grid infrastructure requires upgrades, strategic planning is crucial to ensuring that investments optimize for load growth and flexibility and prioritize urgent needs while maximizing existing asset utilization and avoiding stranded assets. A consolidated view of current transmission constraints, future demand, and distribution and storage needs is indispensable for making informed decisions that lead to a reliable and affordable grid.
What is the current state and its primary limitations?	Information that documents existing system constraints, load growth, and new interconnection studies is accessible internally and shared with regulators. For example, the DDOR is a strategic planning document submitted by utilities, including PG&E, to regulatory bodies that identifies grid needs, proposes DER solutions to defer traditional grid investments, and evaluates the cost-effectiveness of these solutions. While the information is available, it is highly fragmented, therefore limiting our ability to make decisions informed by comprehensive consideration of all existing data. **Primary limitations include:** • Lack of tools capable of consolidating transmission and distribution constraints, new interconnection studies, and demand forecasts
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Consolidate new interconnection studies, transmission and distribution constraints, and load growth data, as well as climate and weather data, wildfire risks, inputs from stakeholders, and environmental impact data • Comprehensively analyze aggregated data sources enumerated above to optimize system planning investments across both the electric and gas systems

NEW

PROBLEM STATEMENT 12

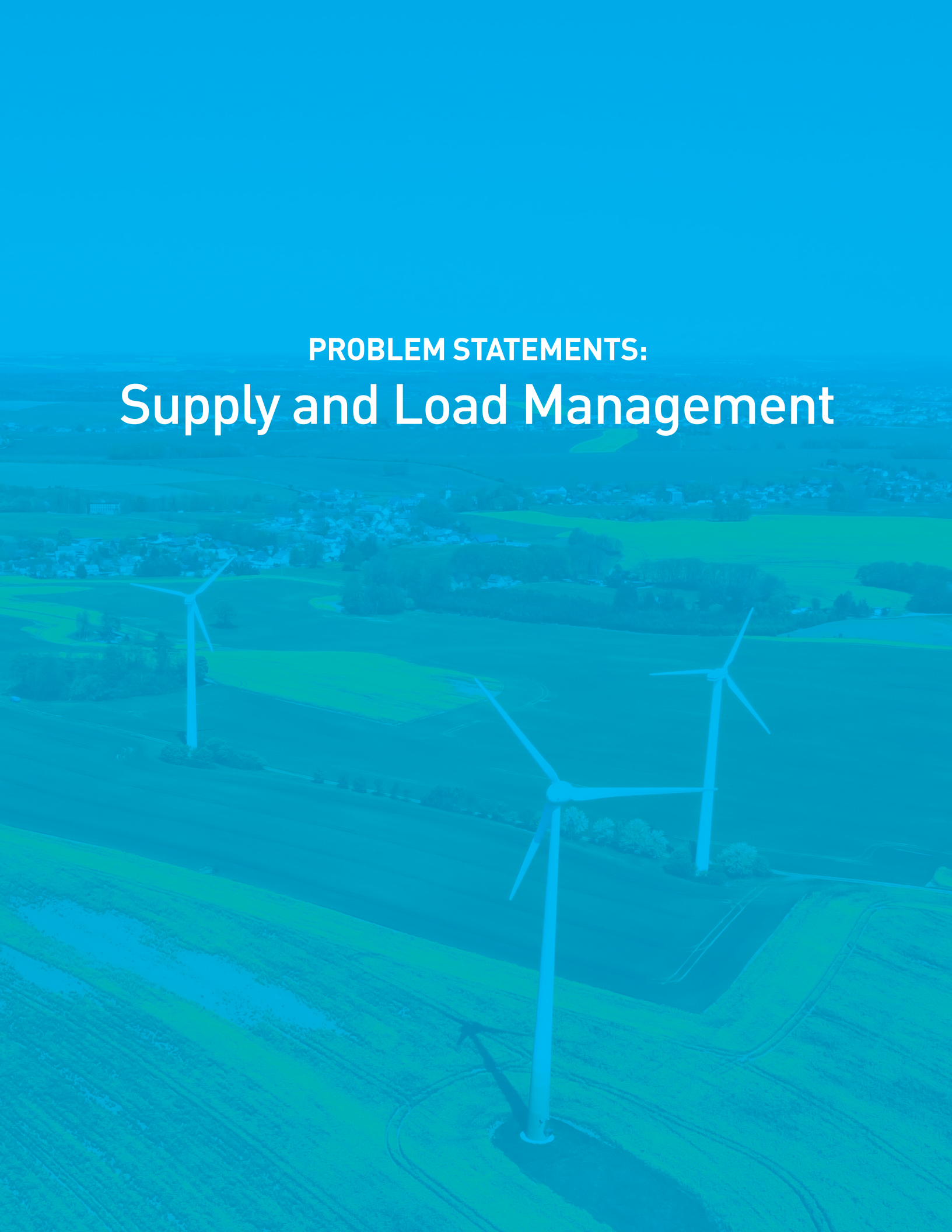
Increasing visibility into electrification pathways at the customer level

PG&E has very little granular information about individual customer load behind-the-meter and how this may evolve in the future, thereby limiting our ability to intelligently plan for demand shifts over time and complicating cost-benefit analyses for capacity upgrades and gas distribution pipeline retirement projects.

Why is this important?	PG&E needs analytical methods to better and more granularly forecast the incremental electric demand increase associated with customer building electrification and EV adoption. The peak electric design demand increase in both summer and winter is particularly important for understanding electric system upgrade costs and informing distribution pipeline section retirement. Across customer meter sets, this has implications for system-level electrification, pipeline retirement, and footprint reduction opportunities. Limited understanding of the impact of the adoption of EVs and increased building electrification on summer and winter peak demands compounds this challenge.
What is the current state and its primary limitations?	PG&E does not have much information about customers' behind-the-meter load and how that will continue to evolve over time, including impacts to summer and winter peaks. As a result, we have not identified whether summer or winter peak demand will be the driver of electric capacity upgrades. The combination of building electrification and customer EV adoption driving electric demand is difficult to forecast, complicating how to most efficiently upgrade electric system capacity by minimizing the need to perform multiple capacity upgrades. **Primary limitations include:** • Insufficient data on customers' behind-the-meter load • Inability to analyze whether summer or winter peak demand should be used to make decisions about electric capacity upgrades on a given distribution circuit • Lack of understanding of how and when customer EV adoption will drive electric demand for charging and on peak electric demand, as well as implications for peak and off-peak hours and impacts of vehicle-to-grid charging on peak electric load
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Gain a granular understanding of customers' behind-the-meter load and anticipated evolution over the short- and medium-term • Predict how summer and winter peak demand will be impacted by shifts in customer electrification • Predict customers' proclivity to electrify and associated capacity needs at the circuit, transformer and/or meter level • Evaluate the costs and likelihood of full electrification at the meter and/or transformer level

PROBLEM STATEMENTS:

Supply and Load Management



THEME 1

Expand load management capabilities across all levels of the system

PROBLEM STATEMENT 13

Enhancing visibility into DER and EV Load Flexibility Potential

PG&E lacks consistent visibility into the device type, location, program participation, and energy usage data of existing and new DER customers. Further, PG&E lacks data on the potential of these DERs as sources of grid flexibility and accurate forecasts of performance when those resources are called upon. This poses a major challenge for distribution and transmission planning and operations and is a barrier to designing and implementing targeted load management programs at the system level and the distribution level.

Why is this important?	Visibility into Distributed Energy Resources (DER) and Electric Vehicle (EV) load data is crucial for PG&E for several key reasons. First, the inability to predict the demand expected from DERs when relying primarily on aggregated meter data creates challenges in accurately forecasting energy needs and ensuring reliable grid operations. Second, without detailed information, PG&E cannot assess the flexibility potential of DERs, including EVs, which limits its ability to leverage these assets for grid stability and efficiency. Lastly, the lack of visibility into how much of this flexibility potential can be captured under the right incentive structures challenges PG&E when seeking to design and implement highly effective load management programs. Addressing these gaps is essential for enhancing grid reliability, optimizing resource use, and supporting the sustainable and efficient integration of renewable energy.
What is the current state and its primary limitations?	While most DERs are connected to the internet and store location and usage data, these data are not consistently available to PG&E. Beyond site-level meter data at the hourly or 15-minute interval level, PG&E lacks a comprehensive system to collect essential information about non-market participating resources, which influences accurate forecasting. Questions we must be able to answer with better data and better forecasts include: what programs are DERs participating in, who is operating them, what are the performance duration and fatigue limitations, and what forms of automation are they capable of using? **Primary limitations include:** • A lack of visibility into the location and asset type for both existing and new DERs connected to the system • A lack of a standardized method to securely capture electricity usage data at the device level
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Capture real-time DER-specific location and usage data comprehensively across all DERs in the network and securely store this information in a centralized repository • Forecast the ability of DERs to respond to direct scheduling, automation, price, or other firm and non-firm control signals at times when the grid needs it most—either to peak shave or absorb excess supply, both at the system level and the distribution level • Evaluate data to maximize predictability with statistical confidence of various types or combinations of DER technologies and load management responses

PROBLEM STATEMENT 14

Establishing interoperability at customer connection point

The industry lacks a common framework for interoperability so that flexibility services can be seamlessly integrated into grid operations. PG&E lacks a consistent interface at customer sites capable of coordinating flexible loads with local conditions on the distribution system. This gap limits the potential for comprehensive load management on the distribution system.

Why is this important?	A lack of interoperable devices hinders the seamless integration of smart home and vehicle-to-everything technologies. Incompatible systems across automotive, energy, and home sectors impede effective communication, utility signal responsiveness, and operational simplification, limiting the potential benefits of integrated energy management solutions. While the capacity in which PG&E is involved in load management on the distribution system is yet to be determined, establishing a consistent interface at the customer site level is an essential building block of distribution-level load management. This interface can enable coordination between customer sites and the distribution grid in real-time and minimize the need for expensive service upgrades by managing customer loads within service constraints. This point of interface with the customer could provide additional value by avoiding the need for costly panel or service upgrades and by capturing insights that could be leveraged for bill savings. Without a unified interface, the potential benefits of advanced energy management, such as cost savings and the avoidance of expensive service upgrades, remain largely untapped.
What is the current state and its primary limitations?	This lack of interoperability prevents the development of flexible, plug-and-play solutions that can adapt to real-time conditions on the distribution grid. Specifically, PG&E faces challenges in coordinating flexible loads at customer sites because the interfaces in place are not consistent or capable of aligning with local distribution system needs. Prevalence of bespoke technologies hinders effective communication, responsiveness to price and DR signals, and operational efficiency. Current electrical equipment at the customer connection point lacks the capabilities to detect real-time conditions both behind the customer meter and on the local distribution feeder. This limits the potential to optimize load at a customer site within service level constraints and to coordinate with the distribution grid to maximize the value of customer-sited flexible loads. While standards are still maturing, vendor-specific APIs offer a limited and unsustainable long-term solution. **Primary limitations include:** • Inability to assess real-time conditions on local distribution feeders and behind customer meters based on limitations of customer connection point interface capabilities • Lack of universally consistent protocols that enable communication across customer-sited DERs and coordination with grid conditions
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Enable seamless interoperability between customer connection interfaces, ensuring that different devices and systems across energy, automotive, and home sectors can communicate and function together effectively

Note: In this category, PG&E is particularly interested in collaboration across utilities to establish clear expectations that can inform the next generations of standards and technologies that meet those standards.

NEW

PROBLEM STATEMENT 15

Enabling intelligent orchestration of DERs

PG&E faces challenges in effectively orchestrating DERs due to limitations in coordinating devices behind the meter, across different types, and in multi-use scenarios. These limitations hinder the ability to use DERs effectively to manage local network constraints, leading to reliance on costly infrastructure investments and fossil-based generation.

Why is this important?	Intelligent orchestration of DERs is essential to managing the significant costs of new distribution and transmission system investments, which directly impact customer bills. Without the ability to use DERs to guarantee that our system capacity is sufficient, particularly at the distribution level, PG&Es options are limited to making new infrastructure investments to meet anticipated customer needs. This approach imposes a greater financial burden on customers—both individually and collectively—and perpetuates reliance on centralized generation, fossil resources, and carbon-intensive peaker plants to meet increasing net load. The duck curve illustrates the challenge of excess supply during midday and sharp peaks in the evening, when solar production declines just as residential consumption rises. During these peak periods, we often must rely on costly, fossil-based generation. At the same time, excess daytime generation is frequently exported over long distances because we lack adequate resources to absorb solar production locally. PG&E needs flexible demand technologies to balance supply when it becomes inflexible.
What is the current state and its primary limitations?	Despite the initial rollout of PG&E's DERMS platform, we still encounter limitations related to integrating and optimizing DERs. **These limitations fall into three categories:** • Coordination of DERs behind the meter • Coordination across multiple DER types and programs • Coordination with DERs providing multiple values (e.g., multi-use DERs, DERs participating in multiple programs, and DERs addressing multiple grid needs across distribution, transmission and supply/generation.)
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Coordinate DERs behind-the-meter, giving PG&E operational confidence in the performance of all devices behind a customer meter • Optimize front-of-the-meter and behind-the-meter participation of multiple DER types and programs to provide the highest avoided cost of upgrades at the lowest opportunity cost to the customer, VPP, or project developer

THEME 2

Deploy new clean supply and energy storage technologies

PROBLEM STATEMENT 16

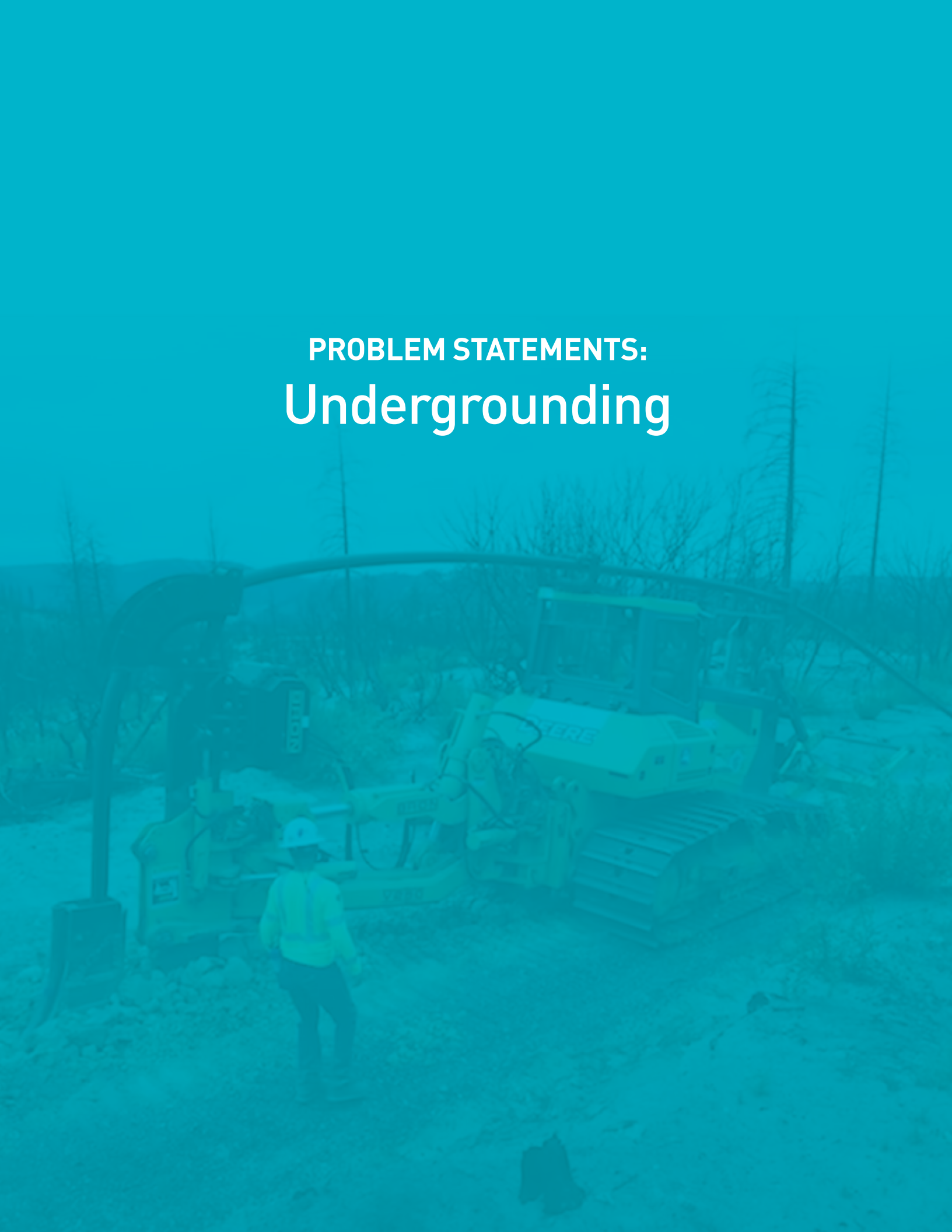
Deploying new clean supply and energy storage technologies

PG&E has not yet integrated clean energy resources and storage technologies in a way that optimizes existing infrastructure to provide the most sustainable and affordable integration for our customers.

Why is this important?	New forms of zero-carbon supply and storage will be necessary to maintain reliability and affordability during the transition to a net zero grid by 2040. New generation technologies often lack the operational characteristics of thermal generation, such as inertia, which presents additional challenges. Beyond the long-duration storage PG&E and other California Load Serving Entities are procuring, an additional 2,000 MW of long-duration storage (half 12-hour and half multi-day) will be integrated into the system by the mid-2030s. PG&E must determine where resources should be procured to ensure local reliability, while also focusing on how and when our customers use electricity to make sure that generation can meet that need. Load growth will require a balanced approach to hedge against any one resource failing to perform as anticipated and to solve multiple operational challenges. Therefore, PG&E and other developers will need to manage a diverse set of resources, including centralized batteries and generation, along with grid edge DERs and EV load flexibility. Intelligently using data to site these new resources, minimize interconnection, and maximize their benefits will be a key enabler. For hydroelectric resources, discovering new methods of repowering existing hydro is crucial. Many components are nearing the end of their useful lives, and modular hydro generation technologies, combined with optimization and sensor technologies, could maximize the efficiency and longevity of these existing assets.
What is the current state and its primary limitations?	While over a third of California's electricity comes from renewable sources and battery storage capacity has increased by nearly 20 times since 2019, achieving net zero objectives while maintaining reliability and affordability will require a broader range of clean supply and storage technologies.
What are the desired outcomes from R&D?	**Desired solution capabilities include:** • Technologies that can support the seamless integration of new clean supply and energy storage technologies into the system while maximizing output from existing infrastructure • Applications of AI data analytics or other tools to optimize the type and location of resources necessary to minimize system impacts and maximize benefits to both the distribution and transmission systems • Optimized and repowered hydroelectric generation using modular technologies and advanced optimization/sensor systems

PROBLEM STATEMENTS:

Undergrounding



THEME 1

Improve the efficiency of underground construction across project lifecycle

PROBLEM STATEMENT 17

Reducing cost and complexity of underground construction

Converting overhead lines to underground has a high unit cost per line mile due to challenging environmental conditions and terrain (e.g., hard rock, loose soils, canyons, creeks), lack of space and presence of existing underground facilities in existing rights of way, and the complex, multi-step nature of available construction methods.

Why is this important?	Civil construction comprises the largest part of the total cost of undergrounding, and therefore represents the most significant opportunity for cost savings through the deployment of novel technologies. Costs may vary widely depending on several factors, including the project's setting (urban vs. rural), terrain type, and topographical features. PG&E's current undergrounding portfolio faces unique challenges along many of these dimensions, which make the work especially costly. Specifically, a large portion of the scheduled work is located in remote and difficult to access areas, crosses through extremely hard rock (i.e., granite), may traverse steep grades and rocky terrain or require water crossings. Addressing these challenging use cases is essential to the cost-effective completion of our 10,000-mile undergrounding program.
What is the current state and its primary limitations?	A variety of methods are utilized during underground construction, ranging from open cut trenching to horizontal directional drilling depending on the terrain. While specialized solutions are needed to reduce costs and improve efficiency of projects in some of our most challenging terrains, there is also a need for innovative solutions that can more efficiently complete work across broad portions of the portfolio. Specifically, there is a gap in the market for technology that enables a seamless approach to trenching, installing, and backfilling small to mid-sized conduit, as well as for boring technologies that avoid the creation of wet spoils that require processing prior to disposal. There is currently no one-size-fits-all approach or comprehensive portfolio of cost-effective point solutions that can be easily deployed across the full range of conditions encountered across the undergrounding portfolio. **Primary limitations include:** • Inability to cost effectively underground through hard rock, over steep terrain, and across canyons and water crossings • Inability to easily maneuver in locations that are difficult to access and where space is constrained by difficult topography or existing underground facilities • Lack of end-to-end solutions to enable the seamless burial of mid-sized conduit
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable cost effective undergrounding in remote, rocky, and steep terrain • Enable efficient water crossings, compliant with all applicable regulations • Cost-effectively construct mid-sized trenches (4-8" width; 42" depth), filling the gap between micro-trenching and other methods suited to larger conduits • Underground runs of small electrical conduit (less than 4") with minimal surface disruption and high navigability

NEW STATEMENT: NEW | MINOR UPDATES: | MAJOR UPDATES: | AI POTENTIAL: LOW MEDIUM HIGH

NEW

PROBLEM STATEMENT 18

Optimizing soils and spoils management

Managing the soils and spoils generated by existing underground construction methods is a complex, costly, and time-consuming process that often requires the relocation of large volumes of spoils from remote construction sites for offsite processing and disposal.

Why is this important?	Underground construction unavoidably disturbs soil at the site, generating large volumes of excess spoils that must be properly processed and disposed of. Specific requirements dictate the handling of different types of spoils and result in the need for variable processing approaches depending on the moisture content, trace constituents, and size of included debris. In many cases, large volumes of spoils must be transported from remote construction sites to processing or giveaway facilities. Not only is it costly to transport spoils, but it also produces emissions from over the road trucking. The ability to cost-effectively process and dispose of spoils or reduce the overall volume generated during excavation could meaningfully reduce costs per mile across the entire undergrounding portfolio.
What is the current state and its primary limitations?	PG&E has invested considerably in developing a toolkit of approaches to address the most common types of spoils generated across the undergrounding portfolio. In many cases, these efforts have focused on optimizing processes, cultivating additional partnerships for giveaway programs, and enhancing data capabilities for trackability. While these efforts have yielded cost and efficiency improvements across our spoils management efforts, there is still ample opportunity for innovative technologies to improve on-site processing capabilities or reduce the volume of spoils generated altogether. **Primary limitations include:** • Inability to avoid generation of large volumes of spoils when trenching and creation of wet spoils when boring • Lack of on-site processing technologies that are well-suited for deployment to remote construction sites and for cost-effectively handling smaller volumes of spoils
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Minimize the volume of spoils created during the excavation process or generation of giveaway-ready spoils • Avoid the creation of wet spoils during the boring process • Enable the cost-effective separation of sediment from wet spoils in smaller volumes than currently possible with existing technology

THEME 2

Deploy novel system components to reduce cost and complexity

PROBLEM STATEMENT 19

Advancing underground cable and conduit technologies to extend pull lengths

Current underground cable and conduit designs limit cable pull lengths, in part due to excessive friction created during the pulling process which can damage the cable. Shorter pull lengths result in more frequent installation of primary boxes and splices and generate additional spoils.

Why is this important?	Existing underground cable and conduit technologies impose limitations on the undergrounding construction process that render it more costly and time consuming. Notably, excess friction created when pulling cable through today's conduit and resulting concerns around the integrity of underground cable casings limit pull lengths. Shorter pull lengths create the need to install additional primary boxes and splices to join adjacent runs of cable, both of which add time, cost, and complexity to undergrounding projects. The ability to extend current pull lengths could therefore result in significant cost and time savings across the entire underground portfolio by reducing the number of connections needed.
What is the current state and its primary limitations?	PG&E currently utilizes Ethylene Propylene Rubber (EPR) for medium voltage conductors across all underground installations. These are installed in American National Standards Institute (ANSI) Schedule 40 PVC or High-Density Polyethylene (HDPE) conduit with maximum pull lengths ranging from 800 feet for less than 300 degrees in factory bends to 1,200 feet for zero degrees of factory bends to avoid excess strain on the casing of the conductor. **Primary limitations include:** • Inability to extend pull lengths without straining or damaging cable casings • Shorter pull lengths result in an increased need for splices and splice enclosures
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable longer pull lengths and reduce the number of connections, while maintaining a similar load profile • Better lubricate conductors during pulling or other novel approached to reducing the friction coefficient

NEW

PROBLEM STATEMENT 20

Reducing complexity and cost of splice technologies

Splices are a common failure point for underground networks due to their complexity and reliance on manual workmanship performed in underground primary boxes, which are large, costly, and difficult to transport to remote construction sites.

Why is this important?	Current splice technologies present a cost and time challenge to the undergrounding program, as splices require manual workmanship that must be completed in the field. The complex nature of installation under non-pristine field conditions creates the potential for workmanship errors that may lead to cable degradation over time. Additionally, primary boxes, which are installed to house splices, are costly and difficult to transport to remote job sites. Once on site, additional construction efforts are required to install these large enclosures underground, a process which also generates excess spoils that must be properly disposed of. Novel alternatives to traditional splices and enclosures could reduce the cost and complexity of underground construction in the near term, while also addressing a potential failure point for underground cables in the future.
What is the current state and its primary limitations?	Today, splices used to join adjacent runs of underground cable are installed manually in the field. The complex process involves multiple steps to remove the outer casings of the cable, joining the exposed conductors, and installing a protective seal to insulate the splice from moisture and debris. Even when completed by skilled technicians, the intricacy of the process creates opportunity for workmanship errors, which can result in premature cable degradation over time. Current splice enclosures are bulky concrete structures that weigh thousands of pounds, making them difficult to transport to remote job sites. Additionally, these enclosures must be buried which requires incremental construction efforts and generates excess spoils. Splicing in underground boxes also adds complexity to the already intricate workmanship due to tight space constraints. **Primary limitations include:** • Complicated, manual splicing methods are time consuming, error prone, and result in a common driver of maintenance and repairs • Necessity to bury primary boxes adds cost to construction efforts and complexity to the splicing process
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce the complexity of traditional splicing methods or reduce the overall time and cost associated with connections • Automate splicing, manufacture splices, or otherwise meaningfully reduce the manual effort associated with current splicing and splice monitoring methods • House splices at-grade and avoid the need to bury splice enclosures

PROBLEM STATEMENTS:

Wildfire

THEME 1

Improve monitoring, inspection, and analysis of asset condition

PROBLEM STATEMENT 21

Reducing ignition risk through improved asset diagnostics and predictive intervention

Current technologies lack the ability to accurately infer how environmental factors (e.g., extreme weather) contribute to asset degradation and to predict which degradations render distribution and transmission assets more or less susceptible to failure over time, limiting the ability to adopt a more tailored approach to inspections and interventions and the ability to avoid costs associated with the premature replacement of assets.

Why is this important?	Even with best-in-class technologies, PG&E is unable to predict, with a high degree of certainty, the expected safe lifetime of distribution and transmission assets once degradation has been documented or estimate how repairs will impact the remaining useful life. The increasing frequency of extreme weather events across PG&E's service area adds further complexity to understanding the rate and severity of asset degradation over time. PG&E takes a proactive approach to managing potential asset failures in order to reduce associated ignition risk and minimize disruptions to customers. Improvements in available diagnostic technologies and/or predictive solutions could help PG&E achieve our goal of zero reportable ignitions moving forward. Innovations that could equip PG&E with better, more granular intelligence on the rate of asset degradation and the probability and time horizon of failure would also enable PG&E to avoid costly premature asset replacements and to adopt a more tailored approach to asset inspections and interventions. In addition to improving customer reliability, these capabilities could also drive meaningful cost savings, while ensuring the safety of the system.
What is the current state and its primary limitations?	PG&E's assets degrade over the course of decades as a result of both environmental and non-environmental factors. PG&E inspects our transmission assets on a regular annual cycle via visual inspections, augmented by remote sensing technology in certain instances. For some assets, such as overhead transformers, PG&E has also built analytical models that help assess their condition and determine when repairs and replacements might be needed. The data that is collected via existing inspections methods provides some indication of asset health based on visible, external conditions, but does not equip PG&E's inspection crews to accurately predict how degradation may evolve over time, what external indicators of degradation render an asset more of less susceptible to failure, or how repairs or other remedial measures might impact this evolution. **Primary limitations include:** • Incomplete understanding of how various degrees of degradation visible during annual inspection cycles will evolve and impact remaining useful life of various assets • Inability to systematically incorporate the impact of external factors (e.g., weather) into asset lifetime assessments, especially in the context of the increasing frequency of extreme heat and weather events
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Improve accuracy of PG&E's asset degradation assessments to better identify and understand a wide range of indicators of wear and tear across the distribution and transmission systems • Enable more accurate understanding or prediction of assets' remaining safe and useful lifetime based on asset type, current age, identified signs of degradation, repair history, and a wide range of environmental conditions • Enable root cause analysis of asset failures to facilitate the refinement of asset lifetime predictions and to continually improve the asset inspection process

NEW STATEMENT: NEW | MINOR UPDATES: + | MAJOR UPDATES: + | AI POTENTIAL: LOW MEDIUM HIGH

PROBLEM STATEMENT 22

Advancing overhead inspection capabilities

Best in class technologies for performing inspections of overhead assets are resource intensive and provide limited visibility into internal degradation, resulting in an incomplete understanding of asset health.

Why is this important?	PG&E invests heavily in the inspection and monitoring of its electrical assets and continually seeks and deploys process and technology improvements that will enhance the efficacy of these efforts. PG&E currently conducts periodic inspections of its overhead assets utilizing a range of methods from drones to in-person visual surveys. From data collection to review, analysis, and diagnosis, overhead inspections require extensive labor-hours. While performed by skilled employees, the technologies available to the industry to conduct these inspections are unable to assess the internal condition of conductors and other critical assets or to systematically and definitively analyze and diagnose external asset conditions. PG&E is therefore seeking novel solutions that can improve on current state-of-the-art methods by providing enhanced visibility into internal asset conditions and superior diagnostic testing capabilities.
What is the current state and its primary limitations?	PG&E inspects nearly 100,000 miles of power lines every year, and we ensure that the entire overhead system is either inspected or patrolled annually. A range of technologies, including LiDAR, drone photography, and others, are used to collect data across our transmission assets. There is not currently an established comparable suite of technologies for distribution assets; however, PG&E is piloting drone inspections on the distribution side that could enable the acquisition of large amounts of information cost-effectively. However, there is not yet an automated or efficient solution for analyzing the large volumes of high-definition images that are collected during these surveys. Additionally, data collection methods are largely limited to the external conditions of assets, though infrared technology has been piloted on a limited scale. **Primary limitations include:** • Highly resource intensive nature of current visual inspection processes • Limited ability to assess the interior condition of assets, especially on the distribution system • Largely manual process for reviewing the data collected by inspections • Varied asset material types across the system, including wood and steel, creating challenges for assessment of interior conditions
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Replace or augment inspection technologies for overhead assets with more accurate, frequent, and cost-effective solutions that cover the entire system and reduce crew-hours in the field • Capture actionable data on internal asset condition • Enable efficient and systematic review of data collected by routine inspections

PROBLEM STATEMENT 23

Expanding capabilities and coverage of continuous fault monitoring

While capable of identifying and geolocating faults, current continuous monitoring technologies are unable to determine when an identified fault will result in failure or to extrapolate observed patterns to predict when and where a fault is likely to occur in the future. Additionally, there is currently no cost-effective solution for extending existing capabilities to the secondary and service level, limiting visibility into asset conditions and PG&E's ability to effectively triage evolving threats across the entire system.

Why is this important?	PG&E utilizes a combination of continuous monitoring technologies and comprehensive routine inspections to identify evolving risks across our overhead system. While these methods are effective at identifying and locating faults, current technologies lack the ability to accurately assess when an identified fault may result in failure or to predict when and where future faults may occur. As a result, our ability to triage interventions based on risk level is limited, as is our ability to address evolving conditions to avoid a fault before it occurs. Enhanced predictive and diagnostic capabilities that could provide comprehensive coverage of the overhead system would help PG&E to further reduce wildfire risk across our service area.
What is the current state and its primary limitations?	The ongoing rollout of next generation smart meter technology will provide PG&E with greater insight into evolving conditions across our electric system. With this technology and vendor partners, we have seen early successes in accurately detecting, categorizing, and precisely locating anomalies on the grid that were previously invisible to grid operators unless a failure occurred. In addition to new smart meter technology, we have also rolled out other continuous monitoring devices, including onsite sensors to detect overheating in transformers and pole sensors that collect and monitor a wide range of data related to condition of distribution poles and the assets attached to them. The deployment of this suite of technologies provides PG&E with more data than ever on conditions across much of our system. While this visibility is intensely helpful in understanding the current state of many of our assets, today's technologies cannot leverage this visibility into either specific, actionable insights or extrapolative, predictive intelligence. Additionally, while monitoring capabilities now extend across much of our system, gaps remain in our ability to continuously monitor services and secondaries. **Primary limitations include:** • Insufficient communications capabilities to provide real-time systemwide connectivity, including the most remote areas of the grid • Lack of a single, comprehensive device/solution that could be deployed across the system to detect and locate a wide range of issues (as opposed to a patchwork of technologies targeted at various use cases) • Inability to derive actionable insight from anomaly data to inform tailored interventions • Gaps in cost-effective monitoring capabilities for services and secondaries • Lack of analytical frameworks to extrapolate data collected on observed conditions and outcomes pertaining to individual assets to predictive system-wide capabilities
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce costs of deploying and maintaining monitoring systems at scale • Provide real-time communications connectivity for sensors in the field capable of relaying ongoing information back to central operators • Assist in analyzing and interpreting data collected across the system over time to develop better diagnostic and predictive capabilities with regards to grid conditions

PROBLEM STATEMENT 24

Crowdsourcing third-party data

Third parties, such as the public and companies unaffiliated with PG&E, collect a tremendous amount of data that could be relevant to the efficient monitoring of PG&E assets and vegetation nearby, but there is no comprehensive method of collecting and utilizing all of this data.

Why is this important?	PG&E lacks robust crowdsourcing capabilities to collect and analyze third-party data that could be relevant to monitoring asset health and system risk. There is an opportunity for collaboration with both the general public and private companies to collect a wide range of valuable data types in PG&E's service area, such as LiDAR data collected by fleets of self-driving cars, to give just one example. Expanding our ability to source and interpret data from third parties on a broader scale could further enhance our ability to evaluate asset health outside of routine inspection cycles.
What is the current state and its primary limitations?	PG&E has pursued crowdsourcing of data through the mobile app Report It, which enables the public to send in photos or videos of non-emergency safety concerns related to PG&E assets. This data is manually reviewed to determine what action needs to be taken. The methods for analyzing the crowdsourced data are therefore inefficient, and PG&E has not yet extended crowdsourcing technologies to include partnerships with private companies that collect data in PG&E's service area. Third-party data could enhance asset monitoring efforts, but current crowdsourcing methods do not allow for the efficient capture and analysis of all of this data. **Primary limitations include:** • Inefficiency of manually reviewing the currently available crowdsourced data • Limited scope of current crowdsourcing efforts, in terms of types and sources of datasets • PG&E does not have crowdsourcing capabilities that could support identification and reporting of emergency situations, as *Report It* is limited to non-emergency situations
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable the broader crowdsourcing of data across PG&E's service area to expand monitoring capabilities and system reliability • Introduce machine learning and automation into the review and analysis of crowdsourced data • Expand types and scale of data collected beyond photos and videos submitted through external app

THEME 2

Eliminate and rapidly suppress ignitions

PROBLEM STATEMENT 25

Improving protection schemes and asset design to eliminate ignitions

While EPSS is enabled on all circuits in HFTDs, there are still reportable ignitions occurring on EPSS-enabled circuits due to unsafe failure modes of electrical equipment and gaps in the abilities of ignition prevention technologies.

Why is this important?	PG&E's Enhanced Powerline Safety Settings have been effective in significantly reducing ignitions on power lines, but they are not yet able to prevent all ignitions on EPSS-enabled circuits. While EPSS has resulted in a 72% reduction in CPUC-reportable ignitions on EPSS-enabled power lines in high fire threat districts compared to the 2018–2020 yearly average, PG&E is targeting zero total ignitions. There is opportunity to address the challenge of ignition prevention across multiple fronts, both by designing electrical equipment to fail safely and by augmenting the capabilities of ignition protection schemes. Today's mainstream electrical equipment is not designed to fail safely and thus poses an ignition and wildfire risk that must be proactively managed through ongoing monitoring and frequent inspections. Improving equipment designs to eliminate unsafe failure modes could not only reduce the risk of ignitions, but also could reduce costs associated with the mitigation of asset failure risk. Beyond equipment design, improvements to ignition prevention schemes could also further reduce risk, while improving reliability for our customers. Enhancing the abilities of existing ignition prevention systems, such as EPSS, would enable PG&E to more proactively address developing risks and to eliminate ignitions across the system.
What is the current state and its primary limitations?	EPSS effectively prevents many ignitions, as these advanced safety settings involve adjusting the sensitivity of safety equipment to de-energize within one-tenth of a second of an object (particularly vegetation) striking a line. Despite a drastic reduction, there are still reportable ignitions on EPSS-enabled circuits, indicating that gaps in EPSS capability still remain. The Down Conductor Detection (DCD) program may be helpful in addressing some of these gaps in EPSS, but its sensitivity may limit its applicability. While EPSS has been very successful in reducing ignitions across the system, unsafe failure modes of today's electrical equipment (e.g., sparking, flaming, etc.) remain an unaddressed root cause of many ignitions. Given that many of PG&E's assets exist in locations that are prone to wildfire based on environmental conditions, asset failures that expel sparks, flames, or excessive heat introduce a significant amount of risk to the system. Altering the basic designs of these system components to reduce this risk at the source could be hugely impactful in terms of risk reduction and reallocation of resources. **Primary limitations include:** • Inability of existing EPSS technology to comprehensively eliminate all ignitions on enabled circuits • Gaps in technologies that are used alongside EPSS (e.g., Down Conductor Detection) • Legacy design principles that do not prioritize 'fail-safe' behavior as a critical element of equipment functionality
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reimagine failure behavior of electrical equipment to limit outcomes that could lead to ignitions • Prioritize asset monitoring by targeting the source of the risk

PROBLEM STATEMENT 26

Expanding capabilities and scalability of fault current reduction technologies

Current technologies to reduce fault current, a leading cause of ignition risk, are only capable of addressing a subset of fault types, cannot de-energize rapidly enough in all cases, and are costly and complex to deploy with PG&E's existing asset configurations.

Why is this important?	Line-to-ground faults and fault current are some of the leading causes of ignition and wildfire risk. Some current technologies are effective but not scalable, and alternative technologies to Rapid Earth Fault Current Limiters (REFCL) have not been able to scale and to match REFCL's effectiveness. Eliminating fault current could not only drastically reduce this ignition risk and prevent wildfires but also reduce costs incurred to repair damaged assets.
What is the current state and its primary limitations?	PG&E's primary methods of reducing the risk of fault current causing ignitions involve rapid de-energization in response to fault detection. This includes EPSS which PG&E has now deployed broadly, and REFCL, which PG&E is currently demonstrating on a limited number of circuits. Preliminary results suggest that REFCL may be an effective technology for rapidly reducing current in faults on 12kV distribution circuits, but its scalability is limited due to the complexity and high capital costs associated with its deployment. As a result, other system-wide solutions should continue to be explored to comprehensively eliminate fault current. PG&E needs effective technologies that can cost effectively scale across the entire system, enhancing current capabilities by improving accuracy, addressing historically challenging high-impedance faults and lower-voltage faults in the secondary system, and increasing the speed of de-energization. **Primary limitations include:** • Costliness and scalability of current technologies. Retrofitting extensive sections of PG&E's existing system with REFCL technology would be extremely complex and likely cost-prohibitive. Without a scalable technology to address fault current, there are not viable options for its widespread elimination and mitigation • Adverse impacts on reliability due to de-energization • Inadequate response time of conventional distribution protection schemes to effectively prevent ignitions in an energized wire down scenario • Gaps in abilities of current technologies to pinpoint the specific location of a fault along the circuit • Continued occurrences of false positives and negatives in current de-energization technologies
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Eliminate ignition risk associated with fault current • De-energize a line or significantly reduce conductor fault currents before or just after the conductor hits the ground • Cost-effectively and easily scale across PG&E's system

PROBLEM STATEMENT 27

Advancing ignition notification and rapid suppression technologies

Today's technologies are limited in their ability to accurately identify, precisely locate, and rapidly suppress ignitions across PG&E's entire system on a near real-time basis to prevent any ignition from spreading into a larger wildfire.

Why is this important?	While PG&E utilizes several different methods and technologies as a part of our ignition monitoring and notification system, today's technologies have significant gaps. PG&E is therefore limited in our ability to quickly and systematically identify and precisely locate every ignition across the system, increasing the risk of wildfires. Once an ignition has been identified, current suppression methods are unable to immediately contain the threat of wildfire, as response times are limited by the proximity of available first responders to the site of ignition and their ability to rapidly access the location, which is often in remote and difficult terrain. Advances in both ignition notification and suppression systems would help to ensure that PG&E and other key stakeholders have timely awareness of ignitions and to reduce response times, thereby increasing the likelihood of stopping fires before they spread.
What is the current state and its primary limitations?	PG&E's Hazard Awareness & Warning Center utilizes AI-monitored terrestrial cameras, satellites, fire and safety agency connections, and social media monitoring to assess ignition risks and respond to ignitions. Despite this, there are still notable capability gaps in the current monitoring systems and room for improvement in response times. First responders across the state bravely place themselves in harm's way to safeguard the communities and ecosystems of California from the threat of wildfire. While the efforts of these individuals are irreplaceable, the response time to any given ignition is constrained by the physical proximity of available first responders to the ignition site and their ability to access the location through often challenging terrain. **Primary limitations include:** • Gaps in the scope of coverage across all in-scope assets • Latency in notification times • Limitations in locational accuracy of alerts critical to dispatching resources to precise locations for response • Difficulty in rapidly accessing ignition sites to contain the threat of wildfire spread
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Expand real-time notification capabilities across all applicable assets on PG&E's network • Reduce latency, improve precision of alerts, and identify ignitions below current size thresholds • Enable PG&E to more efficiently direct response resources to ignition location to more effectively eliminate the risk of ignition events and the spread of fires • Improve timeliness of ignition response and suppression by avoiding need to physically relocate resources from central dispatch point to ignition location • Reduce risk to first responders • Provide enhanced awareness into a wider range of system conditions beyond ignition notification

THEME 3

Eliminate customer impacts from PSPS/EPSS

PROBLEM STATEMENT 28

Mitigating customer impacts from PSPS/EPSS events

Existing technologies for mitigating the impacts of PSPS/EPSS events are difficult to scale across all affected customers areas, often rely on non-renewable fuel sources, and are not optimized to provide additional services to the grid beyond local reliability benefits.

Why is this important?	Wildfire risk is a reality of the environment in which PG&E operates that will likely be exacerbated over the coming years due to climate impacts. In order to mitigate this risk and the associated threat to our customers and communities, PG&E has employed a broad range of measures, including Public Safety Power Shutoffs and Enhanced Powerline Safety Settings. While these programs have proven effective at reducing the risk of ignition across the system, they also result in lengthy and often unpredictable outages for customers, sometimes impacting the same groups of customers multiple times throughout a wildfire season. Eliminating these impacts is essential to delivering superior service and reliable power to our customers, as well as reducing GHG emissions from diesel generators that are selectively deployed to provide backup power during outages.
What is the current state and its primary limitations?	PSPS and EPSS programs result in the temporary de-energization of portions of PG&E's system at select times to reduce imminent ignition risks. Though effective at decreasing the incidence of ignition, these programs are also highly impactful to customers as they result in outages that can be unpredictable and lengthy. Existing back-up generation technologies are difficult and often uneconomic to scale broadly and rapidly relocate based on the PSPS/EPSS event location. Additionally, these technologies are generally powered by non-renewable fuel sources, increasing system emissions, and are not optimized to provide additional benefits beyond reliability to the grid. While PG&E has also undertaken an initiative to provide behind-the-meter batteries to a limited number of individual customers most susceptible to repeat PSPS and EPSS outages, there may be other renewable resiliency solutions that are more economically feasible at larger scale than this approach. **Primary limitations include:** • Inability to sufficiently mitigate the frequency and duration of customer impacts associated with PSPS and EPSS programs • Reliance on non-renewable backup generation • Limited ability to systematically provide clean distributed energy resources to support individual customer resiliency during events
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Eliminate customer impacts resulting from PSPS and EPSS events • Provide a broader range of grid services, in addition to enhancing reliability

NEW

PROBLEM STATEMENT 29

Automating PSPS events to improve safety and decrease customer impacts

The current process for de-energizing and re-energizing portions of the grid for Public Safety Power Shutoff events is highly manual in nature, limiting the ability to respond in real and granularly target events based on time to evolving conditions on the grid.

Why is this important?	Public Safety Power Shutoffs are critical to PG&E's ongoing efforts to eliminate ignitions across the system. By proactively deenergizing our equipment in these areas, we can effectively reduce the likelihood that weather-related damage to those assets will result in an ignition, thereby keeping our customers and communities safe. While PSPS has been an effective tool for reducing ignitions, improving our ability to more granularly target events and respond more rapidly to the evolution of local conditions would not only enhance our ability to eliminate ignitions but also could enable PG&E to better target outages to minimize impacts to surrounding homes and businesses.
What is the current state and its primary limitations?	Today, PG&E risk models utilize a broad range of inputs, including local environmental conditions, forecasted wind and weather patterns, and vegetation load surrounding PG&E assets, to assess localized wildfire risk. Based on the output of these models, PG&E plans PSPS events in locations with increased probability of heightened wildfire risk and notifies customers of upcoming outages. Grid operators manually intervene to de-energize affected portions of the grid and subsequently restore power when updated risk models indicate that the threat of ignition has subsided. Given that today's process for calling and executing PSPS events involves multiple manual steps, PG&E is unable to incorporate the most current data available due to the required time to process and react to changing conditions. Innovations to provide greater situational awareness at the grid edge, to communicate evolving conditions back to grid operators, and to enable automated responses to identified risks could result in more targeted PSPS events that dynamically respond to dynamic environmental conditions. **Primary limitations include:** • Multi-step, manual nature of the current process to call and execute PSPS events • Inability to seamlessly gather, process, and react to granular, real-time awareness collected at the grid edge
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable greater orchestration and enhanced automation of PSPS event execution with appropriate oversight

THEME 4

Enhance understanding of tree health to optimize vegetation management

PROBLEM STATEMENT 30

Enhancing diagnostic capabilities for hazard trees

Existing research, modeling, and analytics solutions are not capable of comprehensively diagnosing the health of individual trees, limiting the ability to precisely and consistently identify hazard trees and optimize interventions, despite frequent vegetation management patrols.

Why is this important?	Vegetation contact with electrical assets is a primary cause of ignitions across PG&E's service area, resulting in 26 reportable ignitions in HFTDs in 2023. PG&E therefore invests extensive time and resources in managing vegetation to minimize this risk. Vegetation management patrols are conducted system-wide on an annual basis and occur with even greater frequency in high fire threat districts. Despite the frequency of patrols, current inspections methods and technologies are limited in their ability to accurately and comprehensively diagnose the health of individual trees in all cases. Improved analytics, modeling, or other solutions to provide a more granular understanding of evolving risks of individual trees in terms of both severity and timing would enable a more targeted approach to vegetation management that maximizes the efficiency of resources based on risk reduction potential.
What is the current state and its primary limitations?	In addition to annual patrols of the overhead system, PG&E also performs annual vegetation management patrols to ensure all vegetation along overhead electric lines is compliant with applicable regulations. For HFTDs, the frequency of these patrols is increased to semi-annually. While comprehensive in scope, these patrols rely largely on visual inspection and the presence of outward signs of damage to identify potential hazard trees due to the lack of technologies to enable a more comprehensive understanding of tree health. Even in cases where outward signs of damage or disease are visible, dynamic environmental conditions and variability in individual trees' adaptability and resiliency to these conditions further complicates the ability to develop a precise understanding of the severity and immediacy of the risk. **Primary limitations include:** • Lack of comprehensive species-level datasets on failure modes and associated indicators for trees found within PG&E's service area • Insufficient capabilities for predictively modeling the probability and timing of failure resulting from various hazards with the accuracy and precision necessary to support more targeted interventions • Lack of scalable technologies to augment visual inspections for a more comprehensive assessment of tree health during routine inspection cycles
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enhance ability to identify hazard trees during annual and second patrol inspections • Collect and analyze data to better understand the timing and likelihood of failure of hazard trees based on species, local conditions, and other key factors • Optimize the timing and method of intervention for individual trees based on risk

PROBLEM STATEMENT 31

Addressing gaps in moisture monitoring and interpretation

The industry's current understanding of how various moisture readings impact the health of different tree species is limited, and the continued evolution of local climates is making these interpretations even more complex. As a result, it is more difficult to identify areas with high probability of individual tree health issues and vulnerability to wildfire if failure were to occur based on evolving moisture conditions.

Why is this important?	Moisture is a parameter utilized to assess wildfire ignition and propagation risks; however, the understanding of the precise linkage between moisture and risk and under what conditions different types of moisture (i.e., soil, atmospheric, tree) may be most impactful remains incomplete. The ongoing evolution of weather conditions driven by climate change further complicates the interpretation of how various moisture readings may impact tree health, as little is known about the adaptability of different species to shifting moisture ranges. Additionally, available methods for assessing live fuel moisture require off-site analysis and can be highly sensitive to timing of sample collection, even on an intra-day basis (i.e., whether collected during the morning or evening). Given these limitations it is difficult to systematically incorporate moisture readings into tree assessments in a meaningful way to reduce risk.
What is the current state and its primary limitations?	Despite industry consensus that various moisture readings are important to understanding tree health and associated ignition risk, there is a lack of technical capabilities and foundational research to enable a complete understanding of the relationship between moisture and ignition risk. Looking forward, the anticipated divergence of future climate conditions from historical norms will add further complexity to understanding moisture's impact as the adaptability to various species to evolving conditions remains to be seen. **Primary limitations include:** • Insufficient understanding of how various moisture sources and observed levels impact individual tree health and associated wildfire risk • A lack of data and research into how the impacts of climate change may affect this relationship over time and which species may pose greater risk based on evolving conditions • Inability to perform live fuel moisture calculations without the need for off-site analysis
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Improve ability to model tree health based on a variety of moisture conditions and climate scenarios • Enhanced predictive capability to extrapolate analysis of individual tree health to understand ignition and wildfire risk in a given locality • Enable live fuel moisture sampling on-site

PROBLEM STATEMENT 32

Understanding and predicting healthy tree failure

Healthy trees can fail despite having no visible defects, thus creating an ignition risk that PG&E cannot currently identify and abate through vegetation management.

Why is this important?	PG&E conducts vegetation management patrols throughout the year to limit encroachment and contact with electrical assets and to remediate vegetation with perceptible visual defects to reduce the risk of wildfire ignition and propagation. While these efforts are comprehensive across PG&E's entire system, they are unable to fully eliminate risks from vegetation, especially from hidden defects in trees that outwardly appear to be healthy. Improved insight into the causes of healthy tree failure would better enable PG&E to assess and mitigate the risk that these trees fail in contact with PG&E's assets, possibly resulting in an ignition event.
What is the current state and its primary limitations?	Vegetation management patrols involve the identification of dead and dying trees that could fail and come into contact with assets, creating an ignition risk. However, current vegetation management procedures rely heavily on the outward appearance of trees to provide visual indication of a defect. These methods cannot accurately determine when healthy-looking trees may fail, and as a result, healthy trees can still pose a wildfire risk that PG&E currently cannot abate. **Primary limitations include:** • Inadequate research into why healthy trees fail, limiting PG&E's ability to reduce this risk • Lack of technologies capable of scalably and cost-effectively assessing the internal conditions of trees near electrical assets and modeling the risk of failure
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Improve ability to identify hazard trees with a healthy outward appearance and determine if and when they should be abated or removed • Reduce the number of ignitions from trees falling unexpectedly

PROBLEM STATEMENT 33

Targeting removal of fire-damaged trees

Current technologies are not able to systematically determine whether a fire-damaged tree will subsequently recover, leading PG&E to take a conservative approach to abatement in order to limit wildfire ignition and propagation risk as much as possible.

Why is this important?	As part of our vegetation management practices, PG&E removes trees that have been damaged by fires, as they are presumed to be injured or weakened and likely to present a further risk to assets and potentially cause an ignition. However, many tree species in California are fire-adapted, meaning that they are able to sustain fire damage and to continue to recover, grow, and thrive without introducing incremental risk to the system. The ability to better understand the condition of fire-damaged or injured trees would enable PG&E to better target tree removal efforts, helping to preserve more of the current ecosystem and to reduce negative customer experiences that result from tree removal.
What is the current state and its primary limitations?	PG&E currently takes a conservative approach in our removal of fire-damaged or injured trees in order to ensure asset health and prevent additional ignition risk. This may result in the removal of trees that may not actually be a threat to assets, given that current technologies are not able to discern when a fire-damaged tree is or is not likely to pose an increased threat to the system. **Primary limitations include:** • Limited knowledge of which fire-damaged trees are potentially an ignition risk and the level of risk posed • Inability to perform extent of fire damaged/injury assessments at scale in the field
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Perform tree and fire-type analysis to more accurately determine when trees have to be removed and when they are not likely to pose a risk to assets • Balance ensured asset health and safety with smarter, more cost-effective tree removal and improved customer satisfaction • Reduce VM costs and preserve the environment without compromising safety

PROBLEM STATEMENTS:

Gas

THEME 1

Maintain and increase the safety and reliability of the system while reducing operations and maintenance (O&M) costs

PROBLEM STATEMENT 34

Streamlining above ground leak repairs

Current technologies to repair meter set leaks (typically smaller "fuzz" leaks) are time consuming and require a full breakdown of the meter set, at times resulting in a backlog of repairs and contributing to system emissions and operational costs.

Why is this important?	Meter set leaks contribute approximately 11% of total baseline emissions from PG&E's gas system. Many meter sets are added to the repair queue during the course of the year, potentially resulting in a backlog awaiting service at any given time. Existing time-consuming repair technologies impede progress against the backlog and delay addressing associated emissions.
What is the current state and its primary limitations?	The current state leak repair technologies require shutting off service to the meter and fully breaking down the meter set in order to complete repair. The process can be extremely time consuming to complete and may pose a safety risk to coworkers completing repairs in the field, as well as disrupt customer service. **Primary limitations include:** • The lengthy process to repair meter set leaks requiring temporary service shutoff and full meter set disassembly and reassembly takes an average of 45 minutes • Increased potential for necessary return service trips due to the invasive nature of existing repair method
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Shorten leak repair time for meter set leaks on the high and low side • Reduce likelihood of need for follow-up service visit • Ensure high quality seal that can maintain pressure at 60 psi • Allow for subsequent parts replacements and repairs • Promote coworker safety while assessing meter set and completing repairs

PROBLEM STATEMENT 35

Improving pipeline crack assessment technologies

Existing technologies used to locate and size cracks across PG&E's network of natural gas pipelines are costly, time intensive, and not well suited to all use cases across PG&E's system, especially for smaller diameter pipes (6" or less), making compliance with regulations to complete crack assessments very costly.

Why is this important?	PG&E utilizes crack detection technologies across vast sections of our natural gas transmission network. These periodic safety assessments and maintenance routines, as required by the Pipeline and Hazardous Materials Safety Administration's (PHMSA) Mega Rule, are intended to identify and assess the size of any cracks in the walls of existing pipes. Completing these surveys with a high degree of accuracy and fidelity is critical to PG&E's ability to proactively address developing issues and maintain overall system safety; however, no economical solution to perform these assessment processes on small-diameter pipes (6" or less) currently exists. Additionally, given the size and scope of PG&E's transmission network, identifying methods for completing these inspections in a timely and cost-efficient manner could result in significant O&M savings across the system.
What is the current state and its primary limitations?	PG&E currently utilizes a range of technologies to perform periodic crack assessment surveys across our 6,500-mile transmission network. PG&E's system includes 1,271 miles of pipelines with diameters of 6 inches and smaller in our integrity assessment plan. Of these, currently 39 miles have crack threats and are located in medium or high consequence areas. While existing crack assessment methods exist for larger-diameter pipelines, no known time- and cost-effective methods exist for smaller-diameter pipelines. Improving the accuracy, efficiency, and cost profile of these processes for pipelines of all diameters could greatly increase overall system safety while reducing maintenance costs. **Primary limitations include:** • Costly and resource-intensive nature of existing processes for smaller diameter pipes • Inability to cost-effectively perform crack assessments on smaller diameter pipes • Segments of smaller-diameter pipelines must be taken out of service for crack assessments, sometimes for extended periods
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Locate and size cracks in steel pipes 6" or smaller in diameter • Reduce the cost and time associated with performing crack assessments on pipelines of all diameters in compliance with regulation • Improve the accuracy of crack detection and sizing • Eliminate customer impacts or significantly reduce impact's scope and duration • Identify which anomalies should be assessed through "learning" from Electromagnetic Acoustic Transducer (EMAT) runs

PROBLEM STATEMENT 36

Verifying material properties for existing pipeline cost-effectively

New regulations require that PG&E verify grade and establish populations of pipelines across our existing network of installed underground assets; however, existing field in situ and laboratory-based technologies are costly, disruptive, and can result in excessive GHG emissions.

Why is this important?	Requirements for the Pipeline and Hazardous Materials Safety Administration's 2019 Mega Rule require that PG&E expand the scope of many existing inspection and monitoring processes across our transmission pipeline system and deploy entirely new processes across many of our assets. As part of these new regulations, PG&E must measure or verify and record several different material properties across our pipeline network, including grade, and establish populations of pipelines with similar material properties. While compliance is relatively straightforward for new pipes installed going forward, PG&E has thousands of miles of existing pipeline in place for which these properties must be verified. Completing this effort across the entire system utilizing existing technology would be cost prohibitive and extremely disruptive. This data is critical to PG&E's management of our assets in a cost-effective manner since it directly feeds into repair decisions and integrity management programs. Further, compliance with this mandate for the installed base of assets requires either (1) the verification of actual laboratory strength and composition measurement, (2) utilizing in-situ nondestructive strength and chemical composition measurements performed opportunistically during an excavation, or (3) updating existing models used to drive maintenance and repair decisions with extremely conservative strength and material toughness values, decreasing estimates of remaining useful life and increasing the likelihood of a repair or pipe replacement.
What is the current state and its primary limitations?	Currently, in-ditch non-destructive testing methods have started deployment, but the associated field operation efficiency and cost leaves room for further innovation. If required, destructive testing methods are still the only option available to verify material toughness for installed transmission pipelines, which requires excavating and cutting out the existing pipes, and sending them to the lab for testing. Performing this process requires shutting down the impacted section, releases GHG emissions into the atmosphere, and disrupts customers. One alternative option for strength and toughness verification requires the use of conservative values in Fitness for Service calculations in models used to predict the failure behavior of pipes where cracks have been detected. The use of conservative toughness values will drive unnecessary repairs and/or pipe replacements. **Primary limitations include:** • Lack of nondestructive testing methods capable of verifying toughness • Costly and resource intensive nature of existing process • Lack of accurate, repeatable and highly efficient in-line testing methods • Environmental and customer impacts inherent to destructive testing methods
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Verify strength/grade and establish different populations of pipeline material types using in-line methods • Verify populations of pipe within PG&E's existing pipeline network using in-line methods • Evaluate material toughness for existing pipes via nondestructive methods that are accurate, repeatable, and reliable • Significantly reduce costs and timelines associated with verification process • Avoid negative environmental and customer impacts

Note: Datasets that include toughness measures for steel of similar formulation to that used in natural gas pipeline networks are also of interest.

PROBLEM STATEMENT 37

Reducing cost of well inspection and monitoring

Current technologies for required periodic inspections and continuous monitoring of storage wells are very costly (up to $3M per well for in-line methods), creating a large cost burden to maintain compliance with current regulations.

Why is this important?	Well intervention activities to perform conventional casing inspections introduce risk to our operations, often imposing damage to the wells being inspected and reducing reliability with the need to temporarily take wells out of service. These methods are also costly, ranging up to $3M per well. Current regulations require performing well interventions frequently if an alternative frequency is not approved. Continuous monitoring solutions that could help reduce the risk of these more intensive inspections are not presently cost-effective and/or technically mature enough to deploy. Identifying more cost-effective and technically mature options for meeting these requirements could yield considerable savings across the system.
What is the current state and its primary limitations?	PG&E currently utilizes various technologies to inspect the condition of the steel casings that serve as a protective barrier for the well. Given that these steel casings may extend more than a mile below ground, gathering comprehensive data for the full expanse of the system is operationally impactful and costly. High resolution in-line technologies are incredibly costly. The current process requires that operations be shut down and tubing be pulled out to complete inspections. Medium-resolution in-line thru-tubing inspection can avoid the extremely costly tubing pull-out, though sacrifices some degree of accuracy and still requires operations be shut down. PG&E is exploring continuous monitoring solutions, such as distributed fiber optic sensors, to gather and transmit data on an ongoing basis to provide a better real-time understanding of well conditions. While this technology has the potential to reduce the necessary frequency of more intensive in-line inspections, installation and real-time monitoring costs of current monitoring solutions are cost-prohibitive to utilization at scale at the current stage. **Primary limitations include:** • High costs of high-resolution in-line inspection technologies • Accuracy and performance gaps associated with less costly medium-resolution thru-tubing inspection technologies, relative to existing high-resolution options • Installation and real-time monitoring costs for fiber optic sensor technologies • Need to shut down well operations and/or pull-out tubing to complete in-line inspections
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Cost-effectively meet regulatory requirements for periodic in-line inspections that are at least as accurate as existing methods • Reduce the installation and real-time monitoring costs of continuous monitoring solutions, while ensuring high-quality, continuous data transmission

PROBLEM STATEMENT 38

Reducing the cost of T&D leak detection

Current leak detection methods rely heavily on manual effort to complete surveys (on foot or by vehicle/air) and to identify issues and anomalies, resulting in high costs and frequent truck rolls. Any technologies that can detect T&D leaks remotely, cost-effectively, and accurately would reduce both monitoring cost and system risk.

Why is this important?	PG&E completes leak detection surveys of transmission assets semi-annually and of distribution assets every three years. PG&E uses a variety of methods to complete these surveys, ultimately relying on foot patrols in many areas. Given the size of PG&E's transmission (nearly 7,000 miles) and distribution systems (42,000 miles), completing these leak surveys requires a massive mobilization of resources and adds significant cost to operating the system.
What is the current state and its primary limitations?	PG&E currently performs leak surveys on transmission assets via helicopter and foot patrol and distribution assets via a combination of foot patrols and on-road vehicles. While helicopters and vehicles quicken the process, completing these surveys over thousands of miles of pipeline requires a tremendous number of resources. Further, additional foot patrol resources must be deployed to any areas where leak indications were identified during initial surveys. **Primary limitations include:** • Costliness and labor-intensiveness of current initial survey methods • Inability to determine the exact location of below ground leaks with current instruments, which causes time consuming leak investigations to grade and later repair
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Survey leaks with advanced tools that reduce costs and foot patrols necessary to maintain compliance with leak detection survey regulatory requirements, whether the technology is handheld, aerial, or Advanced Mobile Leak Detection (AMLD) • Increase the accuracy and reliability of leak detection technologies to direct deeper inspection efforts more precisely

PROBLEM STATEMENT 39

Reducing false positives on leak detection surveys

False positives are common when conducting leak surveys on both transmission and distribution assets due to difficulty in distinguishing between methane leaks from the gas system and naturally occurring methane, resulting in the unnecessary deployment of resources.

Why is this important?	Leak detection surveys of PG&E's expansive network of transmission and distribution pipelines are resource-intensive processes that must be completed regularly to maintain the safety of the system. Any issues detected during these initial surveys must be investigated more deeply following initial inspection, requiring the deployment of additional resources (e.g., truck rolls) across the system. Given the scale of these efforts, it is critical that the information gathered during inspection surveys is as accurate as possible in order to most effectively direct PG&E's resources for addressing actual safety concerns.
What is the current state and its primary limitations?	Current leak detection technologies utilized during foot patrol surveys are not capable of adequately distinguishing between naturally occurring methane and methane emitted from gas pipelines. As a result, these technologies may falsely identify a pipeline leak if methane from other naturally occurring sources (e.g., cows, wastewater treatment, etc.) is detected in the vicinity of the survey. **Primary limitations include:** • Inability to distinguish between methane released from the gas system as result of a leak and methane from other naturally occurring sources • Unnecessary deployment of additional resources to complete deeper field inspections and surveys resulting from inaccurate readings
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable personnel completing initial foot patrol surveys to accurately distinguish between methane leaks and naturally occurring methane (e.g., based on the presence of other trace gasses only present in pipelines) • Otherwise reduce false positives that result in the needless deployment of additional survey and inspection resources

PROBLEM STATEMENT 40

Enabling corrosion inspections for difficult to access spans

Intentionally exposed pipeline spans occur in remote locations where the pipeline needs to exit the ground. These can be both difficult and time consuming to access and potentially dangerous to inspect. The spans can go out of compliance due to the difficulty in both inspection and remediation.

Why is this important?	PG&E's gas transmission system includes approximately 1,000 exposed spans that must be inspected for signs of corrosion every three years. Given that many of these exposed spans are located in remote and difficult-to-access areas (often at water crossings and wash-outs), completing these inspections can be time-consuming, costly, and potentially dangerous for inspectors operating in hazardous conditions on-site.
What is the current state and its primary limitations?	Currently, PG&E coworkers travel to exposed spans, often in remote locations, to visually inspect and assess corrosion and coating conditions. These visits are completed every three years on each span, resulting in approximately 300 inspections per year. **Primary limitations include:** • Difficulties and safety concerns traveling to and accessing exposed spans in remote locations and in difficult or even hazardous terrain • Necessity for PG&E coworkers to contend with hazardous conditions in order to reach and visually inspect exposed spans • High-cost burden associated with maintaining compliance for inspection requirements
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce costs associated with corrosion inspections on exposed spans • Limit the need for coworkers to physically travel to remote sites to perform inspections, thereby reducing safety concerns • Shorten timelines associated with completing corrosion inspections, particularly in challenging terrain

PROBLEM STATEMENT 41

Improving accuracy of well life estimations

Current technologies and methodologies to estimate the safe and useful remaining life of existing wells are unable to produce highly accurate and reliable estimates, which can result in the early retirement of useful wells and the incurrence of substantial avoidable cost to construct new wells.

Why is this important?	PG&E and other utilities across the industry periodically receive requests from regulators to provide information on the remaining safe and useful life of their existing storage wells. The current understanding of the key determinants of a well's lifetime are not well understood, especially in the absence of any identifiable defects, limiting the ability of utilities to accurately forecast remaining useful life of existing wells. Developing the ability to understand and more accurately predict the remaining life of existing wells would enable utilities to provide better information to regulators, avoid early retirement of existing wells, and more optimally manage their portfolio of storage assets given better visibility into the remaining lifespans of individual wells.
What is the current state and its primary limitations?	There is limited understanding across the industry of how to accurately estimate the remaining useful life of a storage well, especially if there are no observable defects that can serve as the basis for forward-looking predictions of degradation. **Primary limitations include:** • Lack of baseline understanding of the most critical factors in determining the useful remaining life of a well • Difficulty modeling how various factors or conditions may evolve over time and/or interact with each other to produce different outcomes for existing wells • Heterogeneity of well depths, locations, geological formations, etc. make the development of a generalizable model difficult
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Identify the critical determinants of well longevity • Model how those critical determinants will evolve over time, taking into consideration well-specific characteristics, use profile, etc., and how those changes and interaction effects will impact the longevity of the well • Provide better substantiated estimates of remaining useful life for existing wells

PROBLEM STATEMENT 42

Increasing accuracy of geohazard risk assessment and monitoring

There is a lack of available technologies to enable the accurate assessment and cost-effective monitoring of pipeline assets subject to geohazards.

Why is this important?	Significant portions of PG&E's gas pipelines are subject to enhanced geohazard risk due to unique geological and topographical features that naturally occur across our service area. While these assets are subject to annual inspection cycles, as well as emergency inspections in cases of detectable increases in risk, the industry's ability to accurately understand, predict, and model changing risk levels is insufficient to enable the consistent and proactive identification of emerging issues. As a result, PG&E invests significant resources in completing annual inspections and emergency inspections but is unable to effectively mitigate geohazard risks off-cycle, as evolving geological conditions can be difficult to monitor and their impacts difficult to predict.
What is the current state and its primary limitations?	There are many water-crossings across PG&E's gas system that are subject to annual geohazard risk surveys, which are completed via visual inspection during on-site visits. Additionally, in the event of a detectable geohazard event (e.g., large landslide, earthquake, etc.), PG&E personnel make emergency, off-cycle site visits to assess the condition of the asset and its surrounding environment. In some cases, frequent return visits are made in the aftermath of an event to continue to monitor evolving risks. Each of these geohazard projects can cost well into the millions of dollars. Emerging threats resulting from subtler or more gradual changes to the local topography can be more difficult to proactively identify before a problem develops. PG&E has tested multiple methods of remote monitoring, including satellite imagery and strain attachments, but more research and testing is needed to improve the accuracy, reliability, and costs of these methods. **Primary limitations include:** • Lack of comprehensive visibility into the integrity of assets subject to enhanced geohazard risk between periodic inspection cycles • Resource intensive nature of existing geohazard inspection processes • Inability to more effectively target geohazard risk resources given limited understanding of how assets tolerate different geohazards
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Remotely identify, track, and monitor geohazards affecting pipeline assets • Provide better ongoing visibility into the integrity of assets subject to enhanced geohazard risk • Enhance understanding of how developing geohazards may impact PG&E assets, including the ability to more accurately model these impacts • Increase ability to optimize the deployment of geohazard monitoring resources

PROBLEM STATEMENT 43

Improving pipeline locating technologies

Best-in-class technologies are unable to cost effectively locate pipelines and other third-party utilities under the full spectrum of conditions relevant to PG&E's system. Even advanced options, such as ground penetrating radar, are limited in their usefulness based on the burial depth of pipes and surrounding soil conditions, sometimes necessitating the disassembly of nearby meter sets to use costly in-line technologies.

Why is this important?	PG&E is required to locate and mark existing pipelines whenever subsurface work (i.e., digging) is conducted near our assets. The process must be completed frequently across the system and can be time-consuming and costly depending on the burial depth, soil conditions, and congestion of the underground area being mapped. While superior technologies to complete this process can provide significant efficiency gains, the accuracy of these locating and marking processes are critical to avoid utility strikes, which can pose considerable safety risks.
What is the current state and its primary limitations?	PG&E utilizes a range of technologies to complete subsurface surveys today, including electromagnetic scanning and ground penetrating radar (GPR). In cases where these best-in-class methods are unable to provide sufficiently accurate readings, meter sets may be disassembled to insert in-line locating devices into the pipeline. **Primary limitations include:** • High cost-and resource-intensive approach in order to provide most accurate readings • Difficulty obtaining accurate information across the full range of conditions locators encounter across PG&E's system, notably at depths greater than 9–10 feet, in soil with high moisture content, and non-metallic pipelines (e.g., MDPE) • Inability to accurately assess the location of assets on the vertical plane (i.e., pipeline depth) • Inability to distinguish between multiple facilities (e.g., which pipelines are owned by PG&E and which assets are still in service)
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Quickly, accurately, and/or cost-effectively provide intelligence on subterranean assets, including MDPE and other non-metallic materials • Enable fast and accurate readings across a wider range of circumstances with little need for advanced interpretive capabilities to understand output from the locating device

PROBLEM STATEMENT 44

Enabling remote meter set corrosion inspections

Current methods for completing mandatory meter set inspections for corrosion are performed via in-person visual inspection every three years, requiring a large investment of manual effort.

Why is this important?	PG&E currently conducts visual inspections for atmospheric corrosion of meter sets every three years; however, this visual inspection is time consuming, costly, and requires significant labor to complete. Alternative techniques for carrying out meter set corrosion inspections have the potential to both reduce costs and enhance safety and reliability by more effectively and proactively addressing atmospheric corrosion.
What is the current state and its primary limitations?	PG&E's inspection of atmospheric corrosion of meter sets involves a PG&E technician traveling to all customer sites and visually inspecting meter sets every three years. **Primary limitations include:** • Costly and inefficient current meter set corrosion inspection techniques • Challenges accessing customer premises
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce the necessity of in-person, visual inspections of meter sets • Monitor meter sets remotely or proactively detect and alert on corrosion • Introduce situational awareness at the meter set to alert when elevated corrosion risk is detected or automatically shut off if failure is imminent

NEW

PROBLEM STATEMENT 45

Reducing cost of pipeline integrity inspection and monitoring

The current inspection practice is mainly based on intrusive, costly in-line and/or direct assessment technologies, which are not techno-economically suited for periodic inspection and monitoring in the long run, especially with the high percentage of unpiggable or difficult-to-inspect pipelines at PG&E.

Why is this important?	Current regulations require that in-line inspections or direct assessments or pressure tests be completed as frequently as every 7 years. Maintaining compliance with these requirements is costly and even disruptive if the operations must be shut down in order to complete the process. In addition, lack of cost-effective monitoring that can be frequently implemented is still a safety concern. Identifying more cost-effective and field-proven options for meeting these requirements could yield considerable savings while enhancing safety across the system.
What is the current state and its primary limitations?	Currently, intrusive or disruptive methods are the only options available to conduct high-resolution integrity assessment of installed pipelines. This approach requires excavation, line upgrades, and/or out-of-service for intensive inspection and also is not a viable monitoring solution, especially for unpiggable or difficult-to-inspect pipelines. Non-intrusive or less-intrusive inspection and/or monitoring solutions that could complement and help reduce the frequency of these intrusive inspections, or eliminate pressure tests, and/or further improve safety are not presently fully ready or field validated to deploy. Additionally, electrical interference (primarily in the Bay Area) due to overhead utility lines, BART, and other transit systems create signals that interfere with traditional Indirect Inspection tools (IIT). Some research is being performed to improve the quality of IIT surveys within the Bay Area and other vicinities affected by DC and other electric interferences. **Primary limitations include:** • The need to upgrade pipelines, shut down impacted sections, releasing GHG emissions into the atmosphere and/or disrupting customers. • Electromagnetic interference makes it challenging to obtain accurate measurements in ECDA/SCCDA assessments
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Non-destructively inspect and/or monitor existing pipelines via non-intrusive or less-intrusive methods that are repeatable, reliable, and of sufficient usable accuracy to at least complement the current practice • Significantly reduce costs and timelines associated with inspection, monitoring, and integrity assessment processes • Reduce the deployment costs of continuous or on-demand monitoring solutions, while ensuring high quality and ongoing data transmission • Avoid negative environmental and customer impacts • Eliminate and/or minimize the impact of electrical interference caused by BART and other electromagnetic sources for "Indirect Inspection" surveys in ECDA/SCCDA assessments

THEME 2

Operating a clean fuels system

PROBLEM STATEMENT 46

Understanding risks and impacts from trace RNG chemicals

There is an incomplete understanding of (1) the exact chemical composition of RNG, especially trace chemicals, and (2) the impacts of these various trace chemicals on health and safety, gas system components, and end use applications. This lack of certainty limits the ability to adequately adapt the system to minimize the effects of these impacts.

Why is this important?	Currently, the chemical properties of RNG are not universally well understood as different feedstocks result in variations in composition. The incomplete understanding of the chemical composition of RNG creates multiple potential risks for increased adoption, including potential negative effects to human health and the environment, compromised pipeline integrity, and negative impacts to gas system components creating operational issues and customer end use impacts. In order for PG&E to expand our procurement of RNG to decarbonize the gas system, these risks must be better understood so that they can be effectively managed or avoided altogether.
What is the current state and its primary limitations?	The industry's current understanding of the varying trace constituents present in RNG based on different feedstocks is incomplete. Further, the potential impacts of these constituents and how those impacts differ based on variable concentrations is limited. Potential areas of impact may include gas system operations and longevity, environmental considerations, and human health and safety.
What are the desired outcomes from R&D?	• Identification and deeper understanding of all chemical components of RNG and how they vary by feedstock • Determination of long-term impacts and effects of trace constituents across a wide range of dimensions, including environment, human health, system components, etc.

PROBLEM STATEMENT 47

Increasing availability of operational data for hydrogen effects on gas system

Although studies of the chemical and physical properties of hydrogen-methane blends in controlled lab settings are informative, understanding how these mixtures behave in the pipeline system is critical to enabling decarbonization. PG&E lacks operational data on how factors such as temperature, humidity, pressure and volume fluctuations due to changing supply and demand dynamics, and true gas quality representations affect how hydrogen blends perform in an actual pipeline setting.

Why is this important?	Laboratory studies of the effects of hydrogen on natural gas system components are critical to building a foundational understanding of how our system may tolerate the introduction of increasing partial pressures of hydrogen. However, data collected in small-scale and controlled environments are unable to capture how the full range of environmental and system conditions present in a true operational setting may alter the range of expected outcomes. Several field demonstrations are presently underway, but the focus is largely on the low-pressure gas distribution networks and the scale of these types of field demonstrations must be greatly expanded in order to provide a dataset of sufficient size to begin to inform our operational understanding of the impacts of hydrogen blending on the gas system. To address this gap, PG&E announced our plans to build a gas transmission hydrogen blending testing facility, known as **Hydrogen to Infinity**, with an estimated cost of $94M. The goal of the facility is to provide the information necessary to support a future hydrogen injection standard for blending into our transmission and distribution networks and share this information with national and international gas utilities, industry, and research associations.
What is the current state and its primary limitations?	Currently, PG&E has analytical data from computational and laboratory studies, providing a theoretical basis for understanding the science and impacts of hydrogen's properties and phenomena. **Primary limitations include:** • Lack of field studies and demonstrations in a high-pressure gas transmission system and at higher hydrogen partial pressures that capture the effects of fluctuations in a broad range of critical variables that may impact real, operational systems over time • Lack of real-world data to analyze gas properties, dynamics, composition, and quality under different blends and supply and demand conditions
What are the desired outcomes from R&D?	• Engagement with stakeholders and partners in industry and government to gain financial support and offset the cost of design, construction, and testing of real-world hydrogen blending effects • Gas transmission field demonstrations to provide operational data from real-life environments to inform a future hydrogen injection standard for California

PROBLEM STATEMENT 48

Mitigating hydrogen embrittlement at scale

Introducing hydrogen to the gas supply may cause pipelines, especially steel, to become embrittled, decreasing their structural integrity and increasing susceptibility to cracks, ultimately leading to higher O&M costs and posing major safety risks. Various materials and methods exist for mitigating embrittlement, but these can be costly at scale.

Why is this important?	PG&E is exploring the introduction of hydrogen into its existing gas infrastructure and assets in an effort to decarbonize the gas system. Hydrogen's chemical behavior, however, varies greatly from that of methane and must be understood to avoid the safety risks and increased O&M costs. Hydrogen can easily migrate into the crystal structure of most metals; therefore, steel pipes, particularly steel welds, used for transmission can suffer from embrittlement after continuous exposure to hydrogen. To ensure that pipelines retain their structural integrity, any pipe transporting hydrogen (or any metal exposed to hydrogen) must be resistant to cracking. The embrittlement of pipelines and other issues relating to structural integrity pose major safety risks and associated O&M costs, thus must be addressed at scale for existing pipes before hydrogen can be introduced to the gas system.
What is the current state and its primary limitations?	While the phenomenon of hydrogen embrittlement is well understood in theory, gaps in knowledge remain around the impacts on pipeline integrity from variables including hydrogen blend rate, pressure and pressure cycling, temperature, and other conditions. Current solutions to avoid pipeline embrittlement with the addition of hydrogen exist; however, they are expensive, time consuming, and difficult to implement at scale. While there are new pipeline technologies on the market that are not susceptible to embrittlement, such as fiber reinforced polymer (FRP) pipelines, these solutions do not allow PG&E to reuse existing infrastructure and avoid stranded assets. Additionally, recent technological advancements include pipeline crawling mechanisms that can be used to apply coatings to the inside of existing pipelines but have yet to be commercialized specifically for anti-embrittlement purposes. **Primary limitations include:** • Limited understanding of how different levels of hydrogen blending may affect levels of observed embrittlement over time • High capital costs for deployment of existing solutions to hydrogen embrittlement for existing pipes
What are the desired outcomes from R&D?	• Cost effective and scalable solution to protect existing pipelines from embrittlement • Research to determine the relationship between hydrogen partial pressure and structural effects of embrittlement • Research to investigate how other gas additives could prevent hydrogen from migrating into crystal structure of metals and avoid embrittlement • A cost effective and scalable pipeline that is embrittlement-resistant for deployment in new projects

PROBLEM STATEMENT 49

Understanding safety risks of hydrogen blend leaks

Different blends of hydrogen-methane will have different safety-related properties (e.g., explosivity, flammability, dispersion, etc.) that may require adjustments to existing leak detection methods and safety protocols in order to ensure personnel and customer safety; however, the particular nuances of these qualities are not well understood.

Why is this important?	As PG&E prepares to introduce blending of hydrogen into natural gas pipelines to decarbonize the gas system, safety risks associated with different blend rates must be investigated and understood. Based on the partial pressure of the hydrogen in the blend, various mixtures of hydrogen and natural gas will have different safety-related properties, such as explosivity, dispersion behavior, ignition, and flammability. Effectiveness of odorants is also of concern for detecting and repairing leaks and failures, particularly those in residential or commercial end-use buildings. These risks must be defined and understood in order to maximize system readiness for hydrogen blending and to determine whether safety protocols and equipment need to be modified for various gaseous mixtures.
What is the current state and its primary limitations?	The explosive characteristics of hydrogen mixing in natural gas are fairly well understood for a range of blend percentages up to 50%; however, further modeling may be beneficial for evaluating safety zone classifications for the full range of hydrogen blending and for defining the blending parameters. The industry's understanding of other safety related properties, including the effectiveness of odorants in different blends needs to be more fully developed before introducing blending at scale across the system. **Primary limitations include:** • Incomplete understanding of how varying partial pressures of hydrogen affect explosivity • Additional risk associated with the largely invisible nature of hydrogen flames to the human eye • Lack of sufficient data across a range of other safety parameters, including odorant effectiveness, dispersion behavior, etc., to inform updates to safety protocols
What are the desired outcomes from R&D?	• Deeper understanding of safe hydrogen blend rates to mitigate safety risks and any associated impacts to customers or coworkers • Determination whether the safety zones for natural gas need to be modified for a mixture of hydrogen, RNG, and natural gas • Investigation of effectiveness and safety of odorants for detecting and repairing leaks of various gaseous mixtures

PROBLEM STATEMENT 50

Improving metering accuracy with hydrogen mixtures

Hydrogen blending changes the physical properties of gas, such as pressure, flow rates, and calorific value, which may require changes to existing metering equipment to maintain proper operation, accounting, and billing across the gas system; however, the precise impacts of these changes are unknown.

Why is this important?	Increased hydrogen blending in the natural gas system will alter the physical properties of the gaseous mixture, potentially necessitating updates in current metering systems and technology to ensure accurate measurements of gas composition and flow rates. Measuring the calorific value of natural gas serves several purposes, including determining the transaction value of natural gas, quality control based on heating value standards for the injection of hydrogen, controlling plant combustion equipment for stable operation, and controlling air-fuel ratios for gas turbine generators that require precise combustion control. Technology that accurately measures hydrogen flow will be key to governing and predicting gas behavior and properties in the pipeline system.
What is the current state and its primary limitations?	While technology to accurately meter hydrogen exists, further research, development, and validation is required to provide more rigorous and systematic understanding of the impacts of hydrogen blending at various levels on a wide range of equipment and metering components. Initial lab research has provided some initial insight; however, current state understanding of how actual operational conditions may affect these findings is also limited. **Primary limitations include:** • The effectiveness of analyzers measuring the calorific value of blended gas above 10% hydrogen by volume • Effects of hydrogen blending across different meter types, at different hydrogen blend levels, and under conditions better reflecting actual operations • Impacts to durability of various system components, including adhesives, lubricants, and fasteners • How impacts vary across different industrial end uses and equipment components
What are the desired outcomes from R&D?	• Better understanding of the properties associated with different blends of hydrogen and natural gas • Additional research to test, model, and assess blending and injection methods for optimal homogeneity, O&M, and cost • Accurate metering equipment compatible with various hydrogen and natural gas mixtures • Standardized method to test metering equipment for accuracy when measuring hydrogen and hydrogen blended gas flow rates

PROBLEM STATEMENT 51

Ensuring compatibility of customer applications with mixed gas

Existing customer end uses are designed for conventional natural gas, and the effects of introducing gas blends on the safety, efficiency, and reliability of their operation is unknown, introducing a significant barrier to meaningful decarbonization of the gas system.

Why is this important?	In order to introduce hydrogen and other renewable gasses into the gas system, it is crucial to understand the impacts on existing equipment, appliances, and industrial processes that use natural gas as fuel or feedstock. Numerous appliances, such as cookers, ovens, stovetops, boilers, and furnaces, were designed to run on conventional natural gas, and their functionality may be limited if they are fueled by mixed gas. Additionally, many industrial processes rely on very specialized equipment that may be impacted with the introduction of gas blends. The lack of mixed gas compatibility for gas-powered industrial, residential, and commercial equipment presents a significant bottleneck for the decarbonization of the gas system, and research must be done to best prepare existing and future equipment for the transition.
What is the current state and its primary limitations?	Currently, PG&E is focused on developing customer appliances and industrial processes that are compatible with low blends of hydrogen (up to 30%) eventually moving to 100%. These projects include the development of appliances and gas-fired heat pumps that can operate with varying levels of natural gas and hydrogen while eliminating common problems such as flash-back. PG&E is also investigating the use of hydrogen in industrial burners and developing burners that are fuel flexible; however, these technologies may be decades away from being commercialized in residential settings. **Primary limitations include:** • Incomplete understanding of how hydrogen blending at different levels affects the full range of impacted customer ends uses • Lack of commercially available customer end uses designed for hydrogen blend compatibility • Lack of commercially available options to retrofit the range of existing end uses and appliances for hydrogen blend compatibility
What are the desired outcomes from R&D?	• Better understanding of the effects of mixed gas on existing appliances • Research on the adaptation of residential and commercial appliances for use with hydrogen-methane blends, particularly for hard to electrify customer equipment • Investigate how industrial equipment and processes can safely and effectively be adapted to run on gaseous mixtures

PROBLEM STATEMENT 52

Reducing uncertainty of storage facility performance for hydrogen blends

Hydrogen blends will need to be stored in existing underground gas facilities; however, much is unknown about how these facilities will perform with the introduction of hydrogen, including sealability, microbial response, and overall well integrity.

Why is this important?	Hydrogen must be stored across seasons in order to balance the load of the electric and gas systems and maintain seasonal price stability. Given the high costs of new underground storage facilities, the ability to store hydrogen in existing underground storage wells (e.g., depleted gas reservoirs) will be critical to cost-effectively decarbonizing the gas system. The performance of existing storage facilities in terms of integrity, sealability, and losses through various system components is largely unknown. Understanding these performance impacts, and the ability to mitigate any negative consequences identified, will be critical to enabling the decarbonization of the gas system.
What is the current state and its primary limitations?	There is a limited body of existing literature on the impacts of hydrogen on underground storage facilities; however, the limited nature of these studies does not provide a sufficiently comprehensive understanding of possible outcomes. PG&E is engaging in a small number of studies to help broaden this knowledge base. **Primary limitations include:** • Lack of comprehensive understanding of how the introduction of hydrogen into existing underground storage facilities impacts sealability, well integrity, and microbial response • Inability to accurately anticipate losses over time through cap rock or storage formations or threaded connections in the well bore
What are the desired outcomes from R&D?	• Identification of components, interaction effects, and operational risks that pose the largest challenges to seasonal storage of hydrogen • Field demonstrations to provide operational data from real-life environments on the impacts of hydrogen on underground storage facilities (e.g., depleted gas reservoirs)

PROBLEM STATEMENT 53

Eliminating gas appliance combustion emissions

Emerging regulations will require the elimination of oxides of nitrogen (NOx) emissions from gas appliances by 2030 across parts of California. Solutions that will enable compliance for existing end uses powered by natural gas or future gaseous mixtures are not widely commercially available.

Why is this important?	Methane and NOx emissions from gas appliances, particularly cookers, stovetops, and ovens can lead to negative climate and human health impacts and pose a potential risk to customer trust in the gas system. Eliminating NOx emissions from gas-based end uses is critical to ensuring compliance with recently approved regulation issued by the Bay Area Air Quality Management District that will take effect by 2030.
What is the current state and its primary limitations?	Existing appliances emit NOx when burning natural gas, RNG, and/or hydrogen. Based on new regulations that will take effect in the latter part of this decade, these emissions must be eliminated across a range of customer appliances. **Primary limitations include:** • Inability for existing end uses and appliances covered by new regulations to meet zero-NOx standard • Limited existing research into gaseous mixture end uses that would comply with zero-NOx standard
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Retrofit of existing appliances to enable compliance with zero-NOx standard • Comprehensive research into the sources and impacts of natural gas appliance emissions • Research into zero-NOx emissions designs for clean fuels compatible appliances

PROBLEM STATEMENT 54

Facilitating cost-effective and safe deblending

Various end use applications may require pure natural gas or hydrogen to operate, requiring the deblending of methane-hydrogen mixtures at the point of demand. Technologies to facilitate this process are not commercially available.

Why is this important?	The future pipeline blend of gases may not be suitable for all existing end use applications, as some may instead require pure hydrogen or methane to operate. For example, hydrogen ignites at a wider range of temperatures than methane, which may impact the safety and reliability of some gas-based equipment operated by customers. Before hydrogen blending can be introduced to the gas supply, separation technologies must be deployed at these sites where deblending is necessary to provide pure hydrogen or methane to ensure compatibility with end uses applications.
What is the current state and its primary limitations?	PG&E does not currently have solutions to support deblending at customer sites that meets desired technical and economic requirements. **Primary limitations include:** • Lack of cost-effective deblending technologies scalable across PG&E's gas system
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Cost-effectively separate hydrogen-methane blends into component streams at the point of demand with a small physical footprint • Deblending even at very low concentrations of hydrogen

NEW

PROBLEM STATEMENT 55

Enhancing gas quality analysis

Gas quality analysis is a key parameter for all gas operators. However, the analytical solutions provided by suppliers are not always consistent with the needs of the gas industry, particularly for RNG analysis, which has additional constituents not typically found in traditional natural gas.

Why is this important?	Gas quality analysis is crucial for ensuring that gas meets the specific quality standard needed for health, safety, integrity, and environmental compliance. It is also crucial for pipeline integrity, pipeline operations, and effective performance of end user equipment.
What is the current state and its primary limitations?	Gas analyzers continuously monitor and measure concentrations of natural gas constituents and the BTU value throughout the system. Renewable Natural Gas (RNG) contains several additional constituents. The constituents of concern (COC) are included in the RNG tariff (GR 29) Table 1. Additional on-line analyzers, as well as typical gas chromatograph (gas analyzers), are located on the RNG interconnection facility. These analyzers continuously measure H_2S, H_2O, O_2, CO_2, BTU, and are programmed to shut-in the flow of RNG into PG&E's pipeline system should an exceedance event occur. PG&E's existing natural gas analyzers are installed at various locations on the system. The data collected by the analyzers is monitored by gas control to ensure that the quality of natural gas meets the tariffs (e.g., Gas Rule 21) requirements. **Primary limitations include:** • Number of gas parameters assessed in a single unit, portability, and total cost of ownership • Ability to detect trace constituents (e.g., siloxanes, hydrogen, mercaptans etc.), particularly found in RNG
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Understand and define the requirements and needs for online and portable gas quality analysis (used for monitoring) • Accurately detect trace impurities in RNG • Cost-effectively analyze gas composition at various RNG interconnection points in the gas system

PROBLEM STATEMENTS:

Climate Resilience

THEME 1

Improve and integrate climate and hazard data into utility planning for enhanced resilience

NEW

PROBLEM STATEMENT 56

Addressing gaps in climate data

PG&E utilizes the latest climate data in our vulnerability, adaptation, and risk assessments. However, the accuracy of historical, observational, and projected climate data remains inherently uncertain due to unpredictability of future human activities, natural variability, and the complexities of climate systems, posing challenges for modeling forward-looking climate events. The lack of sufficient localized climate data, limited availability of historical data, and uncertainties in observational data contribute to these challenges, impacting our ability to make informed decisions and perform accurate modeling.

Why is this important?	Climate data is a crucial element of accurate forward-looking projections and modeling. The outputs of these modeling efforts in turn are critical for planning the future siting, construction, and upgrades of utility assets to better ensure long-term resilience to climate events. Informing these processes with up-to-date and precise data is crucial to maintaining the integrity of our assets, ensuring grid reliability, and providing maintenance crews with advanced notice when localized climate conditions may impact their operations.
What is the current state and its primary limitations?	In our climate vulnerability analyses, PG&E relies primarily on data from the Cal-Adapt Analytics Engine. Modern climate data is generated from integrating long-term records, satellite observations, and paleoclimate data to determine long-term trends. While climate data has advanced significantly, there are many regions with scarce data and temporal gaps, which impact the accuracy of forecasts and projections. Limitations in data resolution and data collection inconsistencies result in unreliable projections and modeling outputs. **Primary limitations include:** • Spatial and temporal gaps, data resolution limitations, and data collection inconsistencies of local observational climate data • Gaps in local-level historical climate data • Downscaling large-scale climate model data outputs to more localized, granular projections is not always precise or reliable, particularly when a locality lacks accurate observational climate data • Limited data about *dependent infrastructure*—non-utility owned infrastructure that supports energy system resilience—and how their climate hazard vulnerabilities can impact the performance and reliability of PG&E's infrastructure and energy system (e.g., condition of the levees around a substation)
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Enhance the availability and precision of observational climate data on a local level • Address data gaps in localized historical climate data • Improve the reliability of modeled downscaled climate projections • Enhance predictions of atmospheric phenomena, from large-scale synoptic events (e.g., cyclones) to localized mesoscale phenomena (e.g., lightning and rainstorms) • Improve monitoring and collection of data, including climate hazard data, related to *dependent infrastructure*, such as non-utility owned infrastructure that supports energy system resilience

NEW

PROBLEM STATEMENT 57

Applying climate data in utility scenario-based planning and risk assessments

The inherent complexity of climate model projections and modeling their impacts on infrastructure make it difficult to fully and accurately incorporate these considerations into subsequent utility scenario-based planning, risk modeling, and tactical operational response to climate-driven events, limiting our ability to adequately prepare for these anticipated outcomes.

Why is this important?	Improvements in the utilization and application of climate analysis and visualization tools that PG&E relies on could enable us to conduct more accurate scenario-based planning and impact assessments, which would inform optimized siting of new infrastructure, asset hardening efforts, and operational responses to increasingly extreme weather and climate events. By improving our understanding of climate risks and their potential impacts on infrastructure, PG&E can more effectively allocate resources, develop contingency plans, and respond swiftly to emerging threats. Additionally, advancements in scenario-based planning that incorporate both PG&E assets and non-PG&E infrastructure can further enhance planning and investment decisions, alleviating the need for extra costs arising from unplanned asset replacements due to unexpected climate events.
What is the current state and its primary limitations?	PG&E relies on science-based, downscaled projections from Global Climate Models (GCMs) and interpretations of climate hazard data to conduct scenario-based planning and vulnerability and risk assessments. PG&E strives to be able to identify, at a highly granular level, specific locations within our service area likely to experience energy-related disruptions from the tactical to long-term prediction horizons, thereby enabling more effective planning and operational response, and to quantify risk across hazards. PG&E's modeling of the impacts of climate hazard conditions on infrastructure can also be enhanced through applications of scenario-based power-flow models, which can model how the direct impacts of climate change on infrastructure could subsequently impact customers. **Primary limitations include:** • PG&E's asset failure models, based primarily on observed historical data, face uncertainty in predicting asset performance under increasing climate-driven hazards due to insufficient documentation of failure causes and challenges in linking specific weather and climate events, like high heat, to asset failures • Decision-making gaps between climate model outputs and exposure/sensitivity of assets and communities, including which precise locations are likely to experience outages from weather or climate events in scenario-based power flow analysis • Lack of uniformity in how high heat events are defined, in terms of threshold and duration • Limited methodology for analysis of the impact of climate hazard events on dependent, non-utility owned infrastructure that supports energy system resilience • Limitations on modeling the impacts of compounding and cascading events within PG&E's service area and surrounding communities, as these interactions can be highly non-linear and difficult to predict accurately
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Apply best-in-class standard techniques that can probabilistically indicate which utility assets are most likely to fail due to climate-driven hazards and which customers are most likely to be impacted as a result, including addressing gaps in historical asset failures and weather/climate data • Enhance the integration of climate model data with PG&E system operations, assets, and planning scenarios, particularly for identifying precise locations of impacts (including through integration of power flow analysis with climate exposure and sensitivity analysis) • Standardize and better predict high heat events through data harmonization across sources and more accurate simulation of different scenarios (i.e., different thresholds and durations) • Improve tactical operational response for field teams, including assessing the impact of climate-driven hazards on employee safety and supporting the continued safe operation of field workers in extreme conditions, including high heat, to reduce health impacts and costs associated with work interruptions • Integrate relevant data about dependent, non-utility owned infrastructure to analyze vulnerability to climate hazard events, and their subsequent impacts on utility assets and service area to reduce costs of infrastructure upgrades • Effectively incorporate compounding and cascading events in future scenario-based power-flow analyses and modeled impacts on infrastructure and communities

NEW

PROBLEM STATEMENT 58

Preparing for precipitation events with enhanced impact assessments and planning

Accurately studying and incorporating precipitation events into planning is crucial for PG&E's utility operations, as increasingly unpredictable precipitation, along with sea level rise, impact PG&E's service area and infrastructure management. Limitations in precipitation data and their integration into impact assessments can constrain effective infrastructure planning and resilience strategies for extreme precipitation events in the short- and long-term.

Why is this important?	Due to climate change, the severity and magnitude of precipitation events are increasing, leading to more frequent flooding, landslides, and atmospheric river events, along with rising sea levels. These events may impact existing electric and gas assets, including non-dam hydropower assets, electric substations, and gas measurement and control stations. Understanding how the magnitude, intensity, and duration of these events impact, or may impact, existing infrastructure and customers in our service area is critical to developing long-term effective climate resilience and adaptation measures and improving service reliability and emergency response. In addition, enabling climate-informed siting and design for new energy system infrastructure is vital; examples include using forward-looking precipitation data and hydrologic studies in planning to avoid siting structures in vulnerable locations, such as floodplains.
What is the current state and its primary limitations?	PG&E implements watershed management and flood adaptation infrastructure, such as perimeter flood walls, for flood management. PG&E has recently provided funding for constructing a levee to support the Ravenswood Substation, which will also provide flood protection for communities and roads. PG&E leverages the best available precipitation and precipitation-adjacent data, but there are limitations in their granularity and availability. The 2024 CAVA integrates floodplain data from the Federal Emergency Management Agency (FEMA) with precipitation projections to determine inland flood hazard and risk. This data is historical and may not accurately determine future at-risk areas, yet there is currently no better method than integrating this information with precipitation projections. Low-probability flood events and their impact on Delta levee infrastructure are not well represented in overtopping and failure risk assessments, as Delta systems are complex and low-probability events are typically under-assessed. **Primary limitations include:** • Granular projections of climate-driven precipitation and riverine flooding are limited by spatial and temporal resolution and the complexity of integrating these models with detailed hydrological simulations • Limited understanding of the impact of low-probability flood events on Delta levee systems, and follow-on impacts to PG&E infrastructure • Uncertainty of performance of aging levee infrastructure and complex hydrodynamic models for Delta levee systems and extreme flood events
What are the desired outcomes from R&D?	**Novel solutions, including AI/ML, to:** • Improve assessment of how precipitation events like storms and flooding impact asset deterioration and failure rates, including effectively locating future at-risk areas • Better understand and incorporate low-probably flood events in overtopping and failure risk assessments of Delta levee infrastructure, for an infrastructure-informed version of flood risk, to reduce costs from flood impacts

PROBLEM STATEMENTS:

Net Zero Energy System & Environmental Stewardship

THEME 1

Reducing gas supply chain emissions

PROBLEM STATEMENT 59

Enhancing scalability of above ground leak detection and monitoring

The current practice of conducting daily leak surveys to monitor for emissions at wellheads is neither cost efficient nor scalable.

Why is this important?	PG&E owns and operates 116 wells at 3 natural gas storage fields located in California and is a partner in a fourth storage field. California's Underground Gas Storage regulations require gas utilities to conduct daily or continuous leak screening at each injection/withdrawal wellhead assembly and attached pipelines. PG&E currently conducts daily foot leak surveys at wellhead assemblies in order to maintain compliance with this requirement; however, this labor-intensive approach is costly and inefficient when scaled across PG&E's underground storage facilities on a daily basis.
What is the current state and its primary limitations?	PG&E currently performs daily foot patrols at injection and withdrawal wellhead assemblies and attached pipelines to screen for methane leaks. This process must be completed across PG&E's underground storage facilities, necessitating a significant ongoing commitment of personnel resources to maintain compliance with daily requirements. Alternative technologies that would enable compliance through continuous monitoring have high initial deployment costs. **Primary limitations include:** • Time and resource intensive nature of daily foot patrols • High deployment costs of continuous monitoring solutions at scale
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce the costs and manual effort required to maintain compliance with methane detection regulations at storage facility wellheads

NEW STATEMENT: NEW | MINOR UPDATES: + | MAJOR UPDATES: ++ | AI POTENTIAL: LOW MEDIUM HIGH

PROBLEM STATEMENT 60

Improving emissions calculation methodologies

Current methods for estimating emissions at transmission metering and regulation (M&R) stations, compressor stations, and underground storage facilities rely on either population-based emissions factors or single point-in-time measurements to estimate annual emissions. The resulting baseline estimates are typically inaccurate at the individual component level, inhibiting PG&E's ability to demonstrate abatement through emissions reduction efforts.

Why is this important?	PG&E has set ambitious goals to reduce emissions from our natural gas operations by 45% by 2030. In order to do so, it is imperative to accurately understand baseline emissions across various system components in order to optimize investments to maximize reductions and to accurately account for the impact of those efforts.
What is the current state and its primary limitations?	The current industry-standard emissions calculation methodology for several critical components of the transmission system, including M&R stations, compressor stations, and underground storage facilities relies on simplifying approaches to extrapolate annual emissions based on single point-in-time measurements or standard population-based factors. While these approaches yield results efficiently, the output is often unreliable at the individual component level. As such, it is difficult to identify parts of the system that would benefit most from investment in emissions reduction upgrades and to accurately account for those reductions once investments are made. **Primary limitations include:** • Inability to create accurate emissions baselines based on actual emissions data at the individual site level • Lack of onsite technologies capable of capturing and recording actual emissions at frequent intervals in order to build more accurate baselines
What are the desired outcomes from R&D?	• Revision of emissions calculations methodologies for various system components to provide more specific estimates based on component-level data • Ability to detect and record on-site emissions levels at frequent intervals at the component level

PROBLEM STATEMENT 61

Eliminating methane emissions from transmission pipeline blowdowns

Pipeline blowdowns are routine operations on natural gas transmission and distribution systems to allow operators to safely perform maintenance, inspections, construction, and emergency response. This practice results in blowing down gas to the atmosphere which results in GHG emissions. PG&E has decreased blowdown emissions over the past decade but needs to further abate these emissions in order to meet desired climate goals.

Why is this important?	To deliver on our 2030 goal of reducing overall gas system emissions by 45%, PG&E is targeting a reduction in operational emissions by 85%. These emissions result from everyday operations and maintenance routines, including blowdowns which are often used to purge gas from a section of pipeline during maintenance, testing, or emergencies.
What is the current state and its primary limitations?	While effective technologies to abate blowdown emissions exist, current options are very costly, resource intensive to implement, and require heavy equipment. Current methane abatement strategies used when venting pipelines include cross-compression, flaring, and thermal oxidation. These methods are effective at reducing emissions released into the atmosphere during the venting process but are costly and time-consuming and require heavy equipment. **Primary limitations include:** • Cost and resource intensity of current methane abatement technologies utilizing heavy equipment • Inability to scale cross-compression technologies
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Reduce cost and size of required equipment relative to current state of the art cross-compression technologies • Capture, neutralize, or otherwise prevent emissions from entering the atmosphere

PROBLEM STATEMENT 62

Reducing costs of interconnection skids

Interconnection skids for biomethane projects are costly and can materially impact overall project economics.

Why is this important?	Interconnection skids connect RNG from distributed production plants to the natural gas system. These mechanisms contain complex equipment for metering, gas quality analysis, and odorization to enable the safe introduction of biomethane into PG&E's gas system. PG&E currently utilizes an in-house standard design gas interconnection skid, as the commercially available options did not meet PG&E's specifications. PG&E's current design covers the material fabrication, inspection, testing, and documentation requirements for the pre-fabricated skid. Novel solutions to reduce cost could therefore materially reduce the overall project cost of providing clean and reliable energy service to gas customers.
What is the current state and its primary limitations?	Interconnection skids contain a range of complex equipment, including meters and analyzers to measure the volume and the quality of the gas, odorization, and other technologies to ensure biomethane is compliant with a range of standards specific to PG&E's gas system. PG&E currently utilizes skids based on in-house designs that are calibrated to our system's unique specifications. **Primary limitations include:** • Current in-house design biomethane interconnection skid costs over $800,000 • High cost of skid components that are approved for utility use
What are the desired outcomes from R&D?	**Novel technologies to:** • Significantly reduce costs relative to current levels ($800k today) • Increase available options in metering and analyzers approved for utility use

PROBLEM STATEMENT 63

Identifying cost-effective and scalable sources for RNG production

Traditional RNG production feedstocks do not exist in sufficient volume to replace the entire throughput of PG&E's gas system at a reasonable cost, making it critical to identify new cost-effective and scalable methods of gaseous fuel production in order to achieve climate commitments.

Why is this important?	PG&E aims to source 15% of gas throughput for core customers from RNG by 2030 as part of our efforts to achieve a net zero energy system by 2040. However, RNG production has not been scaled to levels sufficient to meaningfully impact PG&E's nearly one trillion cubic feet of natural gas provided per year. Current sources of RNG alone, which include landfills, wastewater treatment plants, and byproducts from the agricultural sector, will not be nearly enough to supply the needed production capacity to meet this goal at a reasonable cost. Due to the limited number of landfills and farms that can cost-effectively produce RNG directly from biogas, alternative cost-effective sources are needed to fill this gap and meet decarbonization goals while minimizing costs to ratepayers for gas supply procurement.
What is the current state and its primary limitations?	According to NREL, methane potential from biomass sources in the entire US is roughly 420 billion cubic feet per year, which is less than half of our annual natural gas throughput. Given the inherent limits of biomass' potential to supplant natural gas in the gas supply, it is critical to identify alternative sources of RNG that would be able to account for the balance of our needs. Further, today's sources of RNG are significantly more expensive to procure than equivalent volumes of fossil gas. **Primary limitations include:** • High cost of RNG based on current production methods • Low throughput and scale of RNG at production plants • Limited availability of feedstock located near pipeline infrastructure to support current methods of RNG production • Utility procurement competitiveness with other markets
What are the desired outcomes from R&D?	• Research and quantify the potential of alternative RNG production sources in California, such as woody (or other) biomass, wastewater treatment plants, and Power-to-Methane • Accelerate development of the Power-to-Methane solution utilizing already captured CO_2 at RNG production plants to create green methane • Novel technologies to reduce the costs of producing RNG from traditional sources • Novel technologies to produce RNG from nontraditional feedstocks such as woody biomass to greatly accelerate progress towards PG&E's goals of achieving 15% of core gas throughput from RNG by 2030

NEW

PROBLEM STATEMENT 64

Eliminating 100% of carbon emissions cost-effectively

PG&E must cost-effectively and efficiently minimize and remove the residual carbon emissions that are costliest to abate, while continuing to operate thermal units. One possible solution is carbon capture, utilization and storage (CCUS), which allows a carbon emitting source to be carbon neutral or even carbon negative. However, CCUS is costly, and little to no known infrastructure exists today to transport, utilize, and/or store captured carbon safely, reliably, cost-effectively, and at scale.

Why is this important?	PG&E's tail-end carbon emissions from our thermal generation, particularly the last 10–20% of emissions, are the most difficult and costly to abate, requiring technological solutions that can be implemented cost-effectively at scale. Our internal pathways study confirms that CCUS will be needed to help PG&E capture the tail end of our emissions profile needed to meet our climate commitments. The resulting captured carbon (whether from PG&E or third-party production facilities) can then be sequestered underground or used to make high value end products (e.g., green methane, additive in tires, etc.).
What is the current state and its primary limitations?	PG&E is working to minimize emissions from our gas units through improving operational efficiency and the blending of hydrogen and RNG, but there is a limit to the effectiveness of these methods. While CCUS is a potential solution, there are challenges with deploying it cost-effectively and at scale. Moreover, transport and disposal infrastructure, as well as end-use markets, do not yet exist to support CCUS at the scale required for safe, efficient, and widespread use. **Primary limitations include:** • Complexity of removing emissions from point sources, and high capital and operational costs of CCUS • Repurposing existing natural gas pipelines for safe and reliable transportation of CO_2 requires different operations and maintenance practices and procedures, which are not yet well understood at PG&E • Limited end use markets exist to create value-added products using captured carbon • Additional research and development, along with vendor networks for support, is needed to build up this industry to scale
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Efficiently and cost-effectively capture and store tail-end emissions from thermal units • Perform carbon capture on miniaturized or small-format applications such as gas generation equipment • Identify potential capture and storage locations within the state to determine if PG&E has existing infrastructure that could be used to transport that carbon • Retrofit strategic portions of our existing natural gas system to transport carbon from source of capture (whether PG&E or third party) to sequestration sites (PG&E or third party) • Leverage captured carbon to create valuable products, especially in a distributed and/or modular format

THEME 2

Holistically manage forest ecosystems

PROBLEM STATEMENT 65

Optimizing deployment of forest management interventions

The lack of relevant advanced analytics and valuation methodologies to accurately assess the wildfire risk reduction potential, environmental benefits, and economic value of various land use treatment investments limits PG&E's ability to optimally deploy a broader portfolio of potential interventions and to quantify the benefits of these investments across multiple stakeholders.

Why is this important?	Healthy forest ecosystems can reduce wildfire risk by increasing forest resilience and reducing wildfire spread and consequences risk. The industry currently lacks the ability to analyze the impact of various land treatment investments, such as controlled burns or selective logging, on wildfire risk reduction and other desired outcomes and to quantify the size of various value streams created through those investments. The ability to adopt a more targeted, data driven approach to and to comprehensively quantify the value of various forest management interventions could not only broaden the portfolio of tools at PG&E's disposal but also could expand the potential pool of stakeholders willing to support or co-fund these efforts. This more holistic approach to forest management could in turn lead to better outcomes across a range of PG&E objectives, including mitigating ignition and consequence risk, increasing reliability, minimizing emissions, and supporting the overall health of our communities and the planet.
What is the current state and its primary limitations?	Today's solutions for analyzing, optimizing, and valuing forest land treatments across a wide range of desired outcomes, including improving public safety, asset protection, reliability, and hydro system value, are insufficient. There is no robust and scalable optimization and valuation methodology to accurately assess the myriad benefits that healthy forests can provide for an electric utility or to evaluate how forest restoration investments might compare against other wildfire mitigation alternatives along key outcomes of interest. Beyond consideration of outcomes relevant to electric utilities, modeling capabilities that would enable PG&E to quantify the full range of value streams created for all impacted stakeholders also are not currently available. **Primary limitations include:** • Lack of generally agreed upon methodology for optimizing and valuing a broad range of forest management interventions • Lack of tools capable of assessing the relative value of different interventions for the utility use case, as well as for other potential stakeholders
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Quantify the return on investment of potential utility forest health restorations along a range of different outcomes (e.g., reliability, ignition risk, consequence risk) to enable comparison of alternative approaches • Enable the assessment and valuation of various benefits with respect to different geographic scales (e.g., landscape-scale vs. areas adjacent to PG&E infrastructure) • Optimize land management prioritization and maximize value of potential PG&E efforts supporting, collaborating, and/or advising on work on third-party lands near assets

NEW

PROBLEM STATEMENT 66

Enhancing post-wildfire rehabilitation efforts to ensure future resilience

The industry lacks tools and analytical frameworks to evaluate alternative approaches to post-wildfire rehabilitation that could promote landscapes that are more fire resilient in the future.

Why is this important?	In the aftermath of a wildfire, PG&E undertakes extensive efforts to restore and rehabilitate damaged electrical system components and landscapes. These efforts are largely focused on restoring power to affected communities as rapidly as possible and removing remnants of fire-damaged trees and other vegetation from the surrounding area. While these outcomes are of paramount importance to ensuring the health and safety of our customers in these areas, there is also an opportunity to take an expanded view of the goals of post-wildfire rehabilitation to include fostering more fire-resilient ecosystems. Taking a new approach to post-fire rehabilitation that includes a broader range of alternative interventions could result in a future where California's landscapes are less susceptible to wildfires that burn with the intensity characteristic of more recent fires, thereby protecting our communities and increasing the value of rehabilitation efforts.
What is the current state and its primary limitations?	Today's approach to post-wildfire rehabilitation focuses primarily on the removal of fire-damaged vegetation and assets and restoration of the system and landscape to its former condition. Alternative approaches to rehabilitation that look beyond reestablishing the pre-fire condition could provide a broader range of potential benefits, including improving the landscape's resilience to fire in the future. However, the industry lacks tools to analyze and evaluate the tradeoffs between various approaches to maximize the benefits of rehabilitation efforts across the entire ecosystem. **Primary limitations include:** • Lack of analytical frameworks to assess the benefits and tradeoffs of various approaches to post-wildfire restoration • Lack of tool(s) capable of facilitating like-to-like evaluation of alternative interventions based on the specifics of the geography
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Enable the quantification and evaluation of the costs and benefits of various approaches to post-wildfire rehabilitation based on the location • Optimize rehabilitation efforts to improve fire resilience of fire-impacted landscapes

PROBLEM STATEMENT 67

Enabling wood management and conversion at scale

PG&E generates and manages large amounts of wood debris resulting from vegetation management programs, which is labor intensive, potentially creating safety risks to coworkers, and requires wide-scale use of GHG emitting equipment.

Why is this important?	PG&E manages large amounts of wood debris across our service area, including clearing debris after wildfires and storms, trimming vegetation encroaching on electrical assets, and removing unhealthy trees that pose a risk to the system. Wood is bulky and heavy, and methods for its removal and management are difficult, costly, and resource-intensive. Additionally, these processes are often conducted in remote locations, creating additional costs for transportation and concerns around safety due to the risk of motor vehicle incidents. More efficient means to manage woody debris, including limiting the need for transportation, can increase safety, reduce costs and GHG emissions associated with the process, and enable more productive use of resulting woody biomass.
What is the current state and its primary limitations?	PG&E's vegetation management work covers 1 to 2 million trees annually, generating large amounts of wood debris. Using machinery typically powered by fossil fuels, crews cut and spread, chip, or remove wood debris that is smaller than 4 inches in diameter. Larger debris is either left on-site or managed through other PG&E programs. PG&E has also begun to explore creating biochar through burning wood and carbonizing wood waste, which could have significant environmental benefits although current methods are not yet scalable across PG&E's system. **Primary limitations include:** • Lack of technologies that could be deployed in remote field locations to reduce the mass or volume of woody biomass for removal • GHGs and pollutants emitted by onsite equipment • Costliness and difficulty of wood management
What are the desired outcomes from R&D?	**Novel technologies, including AI/ML, to:** • Cost effectively densify woody biomass close to the wood source • Improve the safety of existing wood management methods, including reducing the number of road miles traveled to support these efforts • Eliminate GHG emissions associated with wood management • Find productive end uses for woody biomass created during vegetation management (e.g., biochar, RNG, etc.)

Graduated Problem Statements

This section of the report includes 17 “graduated” problem statements that appeared in our 2023 R&D Strategy Report but are no longer included as part of the 67 problem statements for which we are actively seeking solutions. The following pages detail the rationale for graduating each of these problem statements.

Electric Vehicles

Novel grid applications

Today's grid was not built for a world in which electric vehicles are a dominant form of transportation, not only challenging our capacity to rapidly absorb the rate of EV adoption, but also limiting our ability to capitalize on the full potential of EVs as grid assets.

Graduation Category: Original statement too generalized or too narrow

Graduation Rationale: This high level problem statement does not capture the specific problems that the EV team is currently tackling. Load disaggregation, customer connections, and V2X challenges are more focused problem statements that speak more directly to PG&E's R&D needs.

Integrated Grid Planning & Transmission Strategy

Service upgrade planning and connecting new loads

PG&E's current tools and processes for planning service upgrades and connecting new loads to the system are not designed to accommodate the expected pace and scale of load growth over the coming years, requiring new tools to more efficiently integrate high volumes of new load requests and more effectively plan for service upgrades.

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: The IGP team has recently made a decision on new tools to support the planning process and is no longer actively exploring additional solutions to this challenge.

Supply and Load Management

Grid edge computing

PG&E's current centralized monitoring and control system is not equipped to efficiently manage an increasingly complex distribution grid characterized by higher volumes of customer sited DERs and increasingly bidirectional power flows in the least cost way. Decentralized computing solutions capable of coordinating customer sited DERs with real time grid conditions are needed to limit service disruptions and automate power flow optimization on the distribution system.

Graduation Category: Original statement too generalized or too narrow

Graduation Rationale: The original statement focused solely on the grid edge and computing does not fully address PG&E's needs, which also include managing customers on multiple programs and coordination of different types of DERs.

Optimizing the deployment and market integration of long-duration storage assets

Long duration assets will likely be an integral part of the net zero transition; however, much remains unknown across the industry regarding the implications of deploying and integrating these assets into the existing portfolio of supply resources at scale.

Graduation Category: Original statement too generalized or too narrow

Graduation Rationale: PG&E will require a broader range of technologies to support the net zero transition, including multi-day storage, generation, DERs, hydro power, and more.

Undergrounding

Site survey of terrain conditions and other obstructions

Existing site survey and mapping tools lack speed and accuracy and are inadequate in identifying soil types and third-party utilities, resulting in suboptimal route planning and construction and less efficient spoils mitigation and management.

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: PG&E has explored numerous solutions in this space and continues to evaluate a handful of these technologies for suitability for our undergrounding use cases.

Service drops

Conventional methods for undergrounding the service drops for an individual customer are both costly and burdensome to customers, often requiring enhanced coordination to schedule work and disruption of customer property.

Graduation Category: Original statement covered sufficiently in another problem statement/ business area

Graduation Rationale: Current problem statement addressing construction methods was expanded to focus more specifically on smaller runs of conduit, making this statement redundant.

Wildfire

Fail-safe electrical equipment design

Mainstream electrical equipment is not primarily designed to fail safely, thus increasing the risk of catastrophic wildfires, as well as adding costs for monitoring and fault mitigation to compensate for the lack of fail-safe design as a primary design principle.

Graduation Category: Original statement covered sufficiently in another problem statement/ business area

Graduation Rationale: Specific context regarding fail-safe behavior of electrical assets is covered as a subset of the issues addressed by problem statement 25 in the 2024 report.

Fault location and response

State of the art technologies are limited in their ability to precisely locate faults and incipient faults, limiting PG&E's ability to respond immediately to restore power or address a developing risk as valuable time must be spent identifying the precise location in the field.

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: New monitoring technologies are capable of geolocating faults, making this problem statement no longer relevant.

Lengthy PSPS/EPSS patrols

Outage patrols that are needed to conclude EPSS and PSPS events can be personnel-intensive, often limited to daylight hours, and therefore take an extended amount of time to complete, exacerbating inconvenience for customers as timelines for power restoration can be lengthy and difficult to predict.

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: The capabilities of new monitoring technologies to geolocate faults has reduced the duration of PSPS/EPSS patrols due to enhanced locational precision.

Broad EPSS impacts

Relay response rates for EPSS are not currently fast enough for PG&E to perform micro-targeted EPSS activations when there are multiple protective devices on the feeder, leading to more customers being affected by outages than necessary.

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: PG&E has made significant progress improving algorithms and fine tuning EPSS settings to narrow impacts.

Gas

Toughness assessments for existing pipe

New regulations require that PG&E obtain the material toughness of pipeline across its existing network of installed underground assets; however, existing technologies are extremely costly and disruptive.

Graduation Category: Original statement covered sufficiently in another problem statement/ business area

Graduation Rationale: Context combined with problem statement 36 in the 2024 report, as a subset of the material properties to be verified.

Crack assessment technologies

Existing technologies used to locate and size cracks across PG&E's network of natural gas pipelines are costly, time intensive, and not well suited to all use cases across PG&E's system.

Graduation Category: Original statement covered sufficiently in another problem statement/ business area

Graduation Rationale: Context combined with problem statement 35 in the 2024 report to consolidate challenges related to crack assessments.

Manual customer shutoffs

Currently, field service agents must perform physical site visits to shut off meters at vacant properties, as current technology is not enabled for remote control. This results in long queues for meters awaiting service and also limits the ability to quickly react at scale to shutoff meters in the event of an emergency (e.g., flooding).

Graduation Category: Improvements in technology/capabilities under evaluation

Graduation Rationale: PG&E has a project under development that is making progress on remote shutoffs.

Distribution saddle leak repairs

The gas system includes a significant amount of Aldyl-a pipe that becomes brittle and leaks over time, especially at saddles. Current repair methods rely on cutting out and fully replacing the saddle, which can be costly and wasteful.

Graduation Category: No longer a significant concern at this time

Graduation Rationale: Saddle leak issues are not a more frequent occurrence than other types of leaks and are not a high R&D priority at this time.

Plastic insert detection

Current technologies utilized to detect plastic inserts within steel pipelines, including bolt-on-tee and radiographic testing, are either intrusive or costly and time-consuming, delaying other work on steel pipelines until testing is completed. In some situations, neither technology can be used.

Graduation Category: No longer a significant concern at this time

Graduation Rationale: This is no longer a concern for PG&E at this time and there is no viable better solution than the current practice.

Optimal decarbonization pathway

While there are numerous possible pathways for decarbonizing the gas system, the lack of a holistic understanding of the full cost-benefit tradeoff of pursuing any given pathway in light of PG&E's unique system characteristics limits PG&E's ability to assess the options and optimize investment decisions accordingly.

Graduation Category: Not applicable for R&D

Graduation Rationale: While still an area of interest, this challenge is not a strong fit for PG&E's R&D process.

Woody biomass as an energy source

The large amount of woody biomass in California forests that must be managed as part of wildfire risk mitigation measures could serve as a rich source of RNG feedstock; however, the existing technology does not support the conversion of woody biomass into RNG cost-effectively at scale.

Graduation Category: Original statement covered sufficiently in another problem statement/ business area

Graduation Rationale: This challenge is addressed by a combination of problem statements 60 and 64.