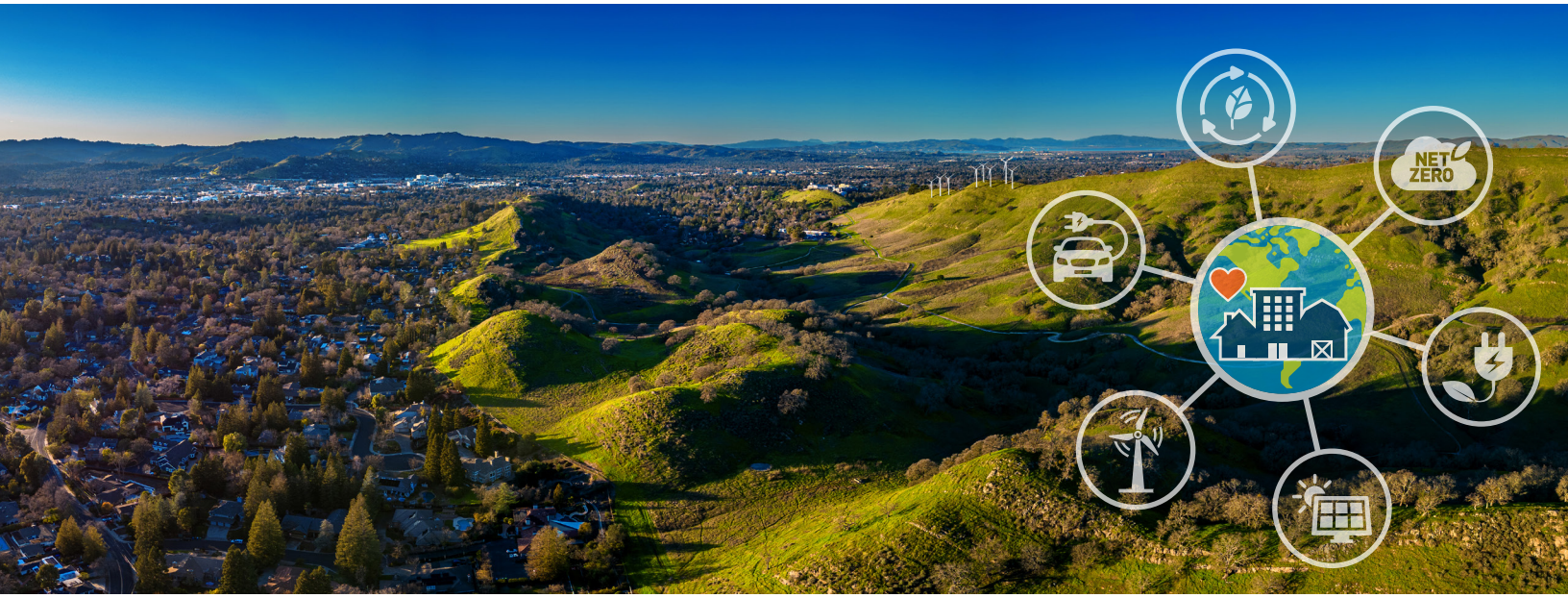

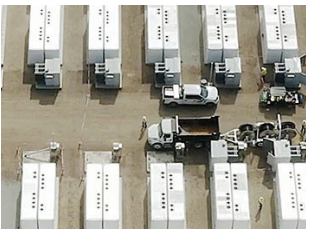



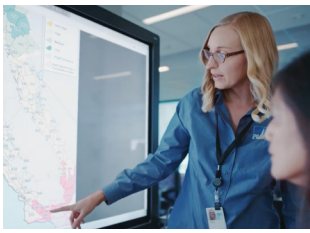

PG&E R&D Strategy Report

June 2023

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Written in collaboration with ADL Ventures

MESSAGE FROM THE CEO

Innovation has propelled California's energy progress for generations. The next wave of innovation is up to us.

At PG&E, we are building a climate-resilient energy system for California's future.

A system that starts with safety, even in the face of climate change. A system that harnesses the clean energy resources of today and tomorrow. A system that customers can rely on.

But we cannot build this system alone. We need solutions and ideas from a broad spectrum of sources.

That's why we are sharing our new, 2023 Research and Development Strategy, outlining our nearly 70 highest priority challenges in building the next generation of California's energy infrastructure.

We need **breakthrough thinking**, **radical collaboration**, and **swift execution** to act on these challenges. We openly share them because we want to partner with the best and the brightest as we work to serve people, the planet and the prosperity of our hometowns.

We encourage all thinkers, creators, dreamers and doers anywhere in the world to help us overcome these challenges. We want to hear from everyone—**private industry, academia, government agencies** or **startups** working on the next big thing in a garage.

Join us on our innovation journey. The future is ours to imagine and build, together.

Sincerely,

Patricia K. Poppe
Chief Executive Officer
PG&E Corporation

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

At PG&E, we see the potential of innovation to address emerging challenges across our operations, but more importantly, we recognize **the tremendous opportunity** that innovation offers to transform our energy system to deliver for **our people, the planet** and **the prosperity of California** for generations to come.

To capitalize on this opportunity and to align innovation efforts across the many facets of our operations, PG&E created the Grid Research, Innovation and Development (GRiD) team. A key part of our team's efforts over the past several months has been unpacking the areas where R&D is most needed across our system and distilling those needs into the nearly 70 problem statements that we share in this report.

By openly sharing our key problem statements, we aim to stimulate the external innovation ecosystem, to inspire bold ideas and ultimately, to identify the game-changing solutions that we will deploy to drive impact across our system.

In addition to this focused outward engagement, we are also looking inward to rewrite our internal playbooks on how to engage with innovators most effectively and implement novel solutions more rapidly. We will need to collaborate more closely than ever with stakeholders across our ecosystem—**from entrepreneurs to researchers to policy makers**—to meet the challenges ahead.

Our R&D Strategy will continue to evolve, as informed by the priorities set in our True North and Climate Strategies. As we make progress towards solving today's problem statements and as technology and system dynamics continue to evolve, so will our R&D needs. Our aim is to periodically refresh this document in order to keep the innovation community informed as to where collaboration would be most impactful.

We look forward to engaging with your big ideas as we bring our bold vision of the future to life together.

Quinn Nakayama
Senior Director
Grid Research, Innovation and Development

PG&E's Triple Bottom Line

PG&E's responsibilities as an energy provider go far beyond our core mission of providing safe, reliable, affordable, and clean energy to our 16 million customers. We also have a responsibility to build a better future for everyone whose lives we touch.

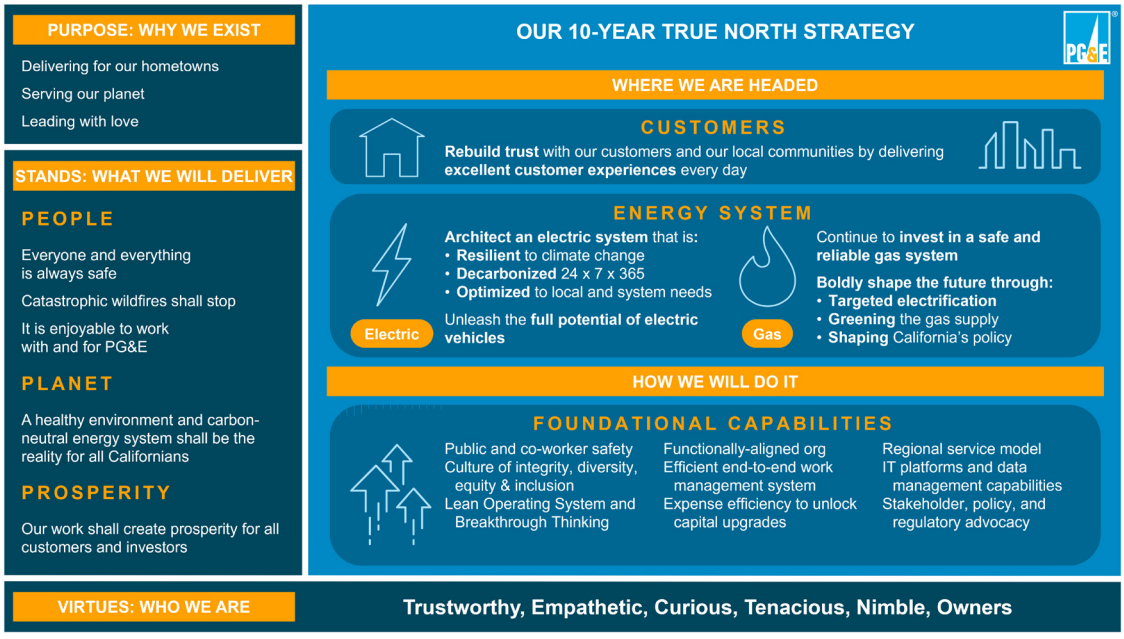
This means delivering for our hometowns, serving our planet, and leading with love. It means making it right and making it safe. It means helping drive clean energy technologies, while also ensuring that their benefits are accessible to all. And it means helping communities build resilience against climate change today—as well as tackling climate change—in ways that leave no one behind.

We approach this work through the "triple bottom line" framework of serving people, the planet, and California's prosperity—supported by strong operational performance.

Our True North Strategy

PG&E's True North Strategy represents our 10-year enterprise strategy that sets a clear strategic vision towards achieving our purpose and our climate commitments.

The strategy has three major components: focusing on **rebuilding trust** and delivering **excellent service** for our customers; architecting a **decarbonized, safe, and reliable energy system**; and enabling these outcomes by building strong foundational capabilities.

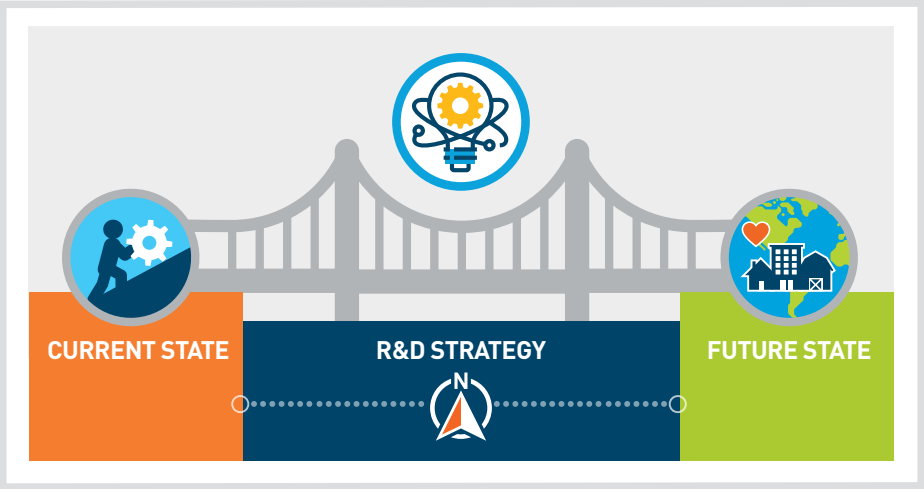


Our R&D Strategy

Building the future: Bringing True North to life

In 2022, PG&E articulated its **True North Strategy**, a bold, breakthrough vision that charts a course over the next 10 years towards achieving our purpose and our climate commitments.

Our True North Strategy reflects our deep conviction that **PG&E has a vital role to play in building a better future and in supporting California's transition to an emissions-neutral and more climate-resilient future**. As California's largest energy provider, PG&E's size and scale uniquely position us to be a positive force for change on behalf of the planet, our 16 million customers, and California's continued prosperity.



What does the future look like?

The future at PG&E is a cleaner, safer, and more reliable energy system that is more resilient to the effects of climate change, adaptable to system dynamics and local conditions, and more accessible to affordably support the needs of all customers in a timely manner.

CLEANER

We strive for a future that includes a **carbon-neutral energy system** capable of meeting the full range of our customers' needs with a portfolio of renewable and zero-carbon resources. The transition to this decarbonized system will dramatically reduce PG&E emissions and enable our customers to do the same, helping to heal the planet and to create a brighter world that supports healthier communities and ecosystems.

SAFER

We strive for a future that includes the **elimination of catastrophic wildfires** and the assurance that everything and everyone, from our customers to our co-workers, is always safe. Building this future will enable PG&E to restore and strengthen trust with our customers and our communities.

RESILIENT

We strive for a future that includes an **energy system purpose-built to withstand the evolving extremes of the physical world brought about by climate change**. The evolution of today's system to support this more resilient future will also bolster PG&E's ability to maintain service continuity and ensure safety amidst increasingly challenging environmental conditions.

MORE RELIABLE

We strive for a future that provides customers **freedom from the impacts of outages**, empowering customers with the **consistent energy service** needed to seamlessly operate their businesses and manage their everyday lives. Achieving this goal will enhance PG&E's ability to deliver excellent customer experiences every day.

ADAPTABLE

The future is a more dynamic energy system capable of **seamlessly optimizing operations based on system and local needs**. Architecting this future will rely on strong foundational capabilities of innovation and breakthrough thinking that will enable PG&E to see around corners and more nimbly adapt to evolving dynamics.

AFFORDABLE

The future is empowering our customers to **prosper by powering their lives and work without constraining their budgets**. Unlocking a more affordable energy system amidst system-wide transformational change will require prudent and high-impact investments, lean and efficient operations, and a continual focus on seizing **opportunities to deploy innovative solutions to maximize system value**.

ACCESSIBLE

The future is **providing timely access to clean, reliable energy** to support the evolving needs of our customers in their transition away from fossil-based fuels, whether plugging in a new EV or decarbonizing the hardest to tackle industrial processes. Building the capability to seamlessly connect customers will be a critical enabler to unlocking a cleaner, brighter future and **delivering on PG&E's triple bottom line of serving people, the planet, and the prosperity of California**.

Bringing our True North Strategy to life will require transformational change, **but the realization of this vision will create a future-proofed PG&E** capable of delivering on our responsibilities to our customers today, meeting their needs of tomorrow, and adapting to the continually evolving challenges beyond.

Where are we today?

The State of California has adopted some of the nation's most progressive clean energy policies, making it a national leader in the transition to a cleaner energy system. Our vision for the future is similarly ambitious; however, the challenges that we face to deliver on these goals are not insignificant. PG&E is resolute in our commitment to progress, and we are energized by our mission to deliver better outcomes for our customers and the planet every day.

As one of the nation's largest utilities, PG&E provides vital energy services to millions of customers across a large and heterogeneous service area, while **navigating the leading edge of emerging trends**, including accelerating EV adoption, increasing renewables penetration, and worsening climate impacts. The distinct characteristics of PG&E's customers, service area, and operating environment present a **unique set of challenges to identifying both system-wide and hyper-local solutions** that are scalable, universal, and outpace rapidly evolving system dynamics.

CHARACTERISTICS OF PG&E'S SYSTEM

SCALE:

The size of PG&E's operations provides both a unique opportunity for delivering positive impact at scale and a distinct challenge to executing on the change necessary to get there

PG&E operates and maintains:

>175,000 combined miles **electric & gas T&D ASSETS** = **7x**

Service area population:

16 million CALIFORNIANS (That's 1 in 20 Americans!)

Our unique challenge: Identifying technologies that are scalable in terms of cost, operability, and maintenance across PG&E's vast network of assets and dispersed communities of customers

HETEROGENEITY:

The heterogeneity of the geographies that comprise PG&E's service area is rivaled only by the diversity of our customers' needs

PG&E's service area encompasses wide ranging climate variability and spans urban centers and sparsely populated counties:

VS VS

PG&E serves a **wide spectrum** of customers

from aggressive early adopters of building and transportation electrification to some of the most difficult-to-electrify industrial end users.

Our unique challenge: Identifying universal solutions that can solve system-wide challenges while providing flexibility to address specialized needs

ON THE FRONT LINE:

Other utilities' challenges of tomorrow are PG&E's realities of today

PG&E territory is nation-leading in adoption of distributed energy resources (DERs):

1 out of 5

1 out of 7

Devastating effects of climate change:

Our unique challenge: Navigating the leading edge of today's technologies to identify the novel solutions capable of outpacing the impacts of evolving climate, customer, and regulatory dynamics

Navigating these unique challenges may not be straightforward, and there is still much to be done, but we have made meaningful strides over the last several years and continue to work diligently every day to make progress towards our goals.

CLEANER

96%

PG&E customers received **96% greenhouse gas-free electricity in 2022**, making PG&E's mix of electricity sources among the cleanest in the world.

1 billion

As of May 2023, PG&E has received **one billion cubic feet of RNG** onto its system since 2021.

SAFER

99%

The Enhanced Powerline Safety Settings (EPSS) program, a novel wildfire technology launched in 2021 that automatically shuts down electric lines if the systems sense a problem, led to a **99% reduction in acres impacted by wildfire** in High Fire Threat Districts (HFTDs) compared to a 2018–2020 3-year average.

>1,100

In 2021 alone, PG&E replaced nearly **1,200 miles of gas main**, while also making significant investments across our transmission assets and beating our target timeline for leak repairs.

>100%

PG&E exceeded its 2022 target of undergrounding 175 miles of electrical distribution lines in high wildfire risk areas. From 2023–2026, PG&E anticipates undergrounding an additional 2,100 miles of existing overhead distribution lines, further reducing wildfire risk in high wildfire risk areas.

MORE RELIABLE

88%

The adoption of a more targeted and focused approach to Public Safety Power Shutoffs (PSPS) events in 2021 resulted in an **88% decline in the number of customers impacted by these outages** compared to 2020 (from 653,000 to 80,400 customers).

We are proud of these achievements, but we are not complacent with these results. Building a decarbonized, resilient, and reliable energy system, equipped to safely and affordably power the lives and work of millions of Californians, will require sustained effort to build on our momentum and continually strive for progress. While PG&E is galvanized behind this mission, we recognize that **change on this scale is not possible without the support of a broader ecosystem of stakeholders and a wide range of bold, innovative ideas and technologies that have yet to be deployed at scale**.

In order to deliver on our True North Strategy, we are not only strengthening our foundational capabilities, but **we are also deepening our engagement with the innovation community and all it has to offer**. Adapting to the accelerating pace of change will require unprecedented collaboration with problem solvers across sectors, disciplines, and geographies to bring the world's most novel solutions to bear on our most vexing challenges.

Bridging the gap: How R&D helps us get there

Why is R&D important?

Bridging the gap between today's system and the ambitious future that we envision is **simply not possible without Research & Development (R&D)**.

The nation's electric grid and natural gas systems were designed for a world powered centrally by fossil fuels in which supply and demand dynamics evolved more predictably over time. Today, the operating environment for utilities globally is changing rapidly, placing increasing strain on systems that were designed for a fundamentally different world.

The accelerating forces of **electrification**, **decarbonization**, and **climate change** are driving the need for sweeping changes to transform our core operations. Given that California sits at the forefront of these trends, PG&E's need for breakthrough technologies may be more acute and more urgent than our peers' in many cases. In addition to this accelerated pace of change experienced by California's utilities, PG&E and other dual-commodity utilities also face a unique challenge in the scope and scale of change required as we must navigate evolving dynamics and dramatically transform operations concurrently across both our gas and electric systems.

Key trends driving the need for R&D

ELECTRIC

GAS

ELECTRIFICATION

The rapid pace of electrification, particularly the growing adoption of electric vehicles (EVs), is expected to result in an **unprecedented 70% growth in load over the next 20 years**.

Today's system must be transformed to accommodate such a significant increase in demand. Further, the **rapid, widely distributed, and unpredictable nature of load growth will challenge the limits of conventional technologies** to keep pace with the rate of change and to dynamically adapt to evolving needs.

Accelerating electrification similarly introduces challenges to PG&E's gas system, but in the opposite direction. Customers' **expected transition away from fossil-based natural gas** may result in meaningfully lower aggregate demand over the coming years.

Declining throughput and resulting downward pressure on revenues may create rate pressure, as PG&E necessarily would continue to incur substantial costs to maintain safe and reliable operations using current technologies.

DECARBONIZATION

For its many benefits, the shift to renewable energy sources will **also introduce material challenges**. These challenges include a steepening duck curve, seasonal variability in energy production (e.g., lower winter output), reduction in available dispatchable resources, and an **increasing need for both more diversity in types of generation and expanded transmission capacity** to integrate renewable generation into the broader system.

The interconnection of growing numbers of DERs will not only require PG&E to accurately anticipate evolving net load dynamics across the system, **but also to anticipate, mitigate, and optimize the impacts and opportunities of DERs on the hyper-local system as well**.

There are considerable gaps in the industry's knowledge regarding **existing alternatives' long-term cost, availability, compatibility with existing infrastructure**, and capacity to address the full spectrum of customer applications.

This incomplete understanding of the tradeoffs associated with each alternative introduces risk to the large foundational investments needed to meet our net zero goals.

CLIMATE CHANGE

California is at the forefront of experiencing the impacts of climate change. Highly variable weather conditions from extreme drought to torrential rates of precipitation have created a myriad of challenges and heightened risk to both our electrical system and our communities more broadly.

Some of the most notable impacts include the **increased severity and duration of wildfire season**, the heightened risk of damage to key infrastructure with **severe storms and rising sea levels**, and the added unpredictability of renewable output under highly variable weather patterns.

Climate change is increasing the incidence of severe weather that poses a risk to the integrity of our assets. Though most of our natural gas network is buried underground, it is susceptible to risks from landslides and erosion that may materialize more frequently with worsening climate impacts.

Further, the nature of our weather patterns leads to times of extreme heat and extreme cold which could result in **needing additional capacity investments in the system**. PG&E is currently undertaking a multi-year effort to assess climate-related vulnerabilities across our gas and electric assets, operations, and services to comprehensively document the anticipated impacts of climate change on our systems.

The historical modes of operating were not designed to meet these challenges, which is why we are aggressively pursuing novel technologies, solutions, and business models to deliver on our vision for the future. **R&D is critical to bringing these technologies and solutions from conception to reality at the scale necessary to effect system-wide change.** We are investing significantly in building the strong foundational capabilities needed to deliver on our True North Strategy and invite innovators to help achieve these ambitious goals. Innovation from a broad range of stakeholders will be needed to bridge the gap between the system of today and that of the future.

The role of the entrepreneurial community

We seek **bold, breakthrough thinking from the entrepreneurial community** to push the boundaries of what is currently possible with the technologies of today. The rapid pace of change affecting our energy system necessitates that we adapt more quickly than ever before, embracing broad-based and stepwise transformation across our operations.

We are confident that the world's innovators not only can help us to solve our most vexing challenges with new and novel technologies, but also can help us see around corners and move quickly as circumstances continue to evolve.

While PG&E has a clear vision of the future that we seek to build via our True North Strategy, **the tools necessary to realize or even accelerate this vision may not exist today**. Entrepreneurs will be critical to paving the way forward by delivering novel solutions that will fill the gaps between today's technologies and the capabilities needed to serve the planet and the people and prosperity of California in the decades ahead.

For our part, PG&E seeks to accelerate the pace of development and commercialization of these novel solutions by piloting and deploying them across our system and providing commercial support as an early adopter. We believe that PG&E and the entrepreneurial community can work in close collaboration to leverage our respective strengths and expertise to bring game-changing technologies to market sooner. As partners dedicated to building a cleaner and brighter world, **we will deliver the change necessary to achieve our climate commitments and bring our True North Strategy to life**.

Innovation beyond the entrepreneurial community

While critical to delivering on our goals, novel technologies alone will not be sufficient to bring about the far-reaching changes needed to realize our vision of the future.

Solving the challenges presented by climate change and decarbonization will require concerted and sustained efforts across every corner of society.

It will require bold action and breakthrough thinking by regulators and policymakers, by academics and researchers, and by private industry and capital.



Beyond partnering with the entrepreneurial community, PG&E will continue to engage with **government bodies, universities, national labs,** and **industry consortia** to help inform our collective understanding of the evolving dynamics impacting the nation's utilities and possible solution spaces. We will leverage our position at the leading edge of many of these impacts to help direct the foundational research critical to shaping and refining the strategies and tools needed across the industry. We will leverage our position at the leading edge of many of these impacts to help direct the foundational research critical to shaping and refining the strategies and tools needed across the industry.
We will collaborate in close partnership with the policy makers and thought leaders, continuing to build on the foundational, forward-looking work of the California Energy Commission.

Goal of this report

The balance of this report outlines **nearly 70 high priority problem statements** we are seeking to address through innovative technologies and breakthrough foundational research. These problem statements span the gas and electric sides of our business and align to several key themes described in subsequent sections.

Our ultimate goal is to identify, test, refine, and deploy novel solutions and technologies that help us address these problem statements and deliver on our strategic vision for the future. While foundational research is needed to better understand evolving dynamics and potential paths forward in some areas, when it comes to PG&E's direct involvement, we are generally looking for technologies that have successfully progressed out of the foundational research phase, are ready to pilot or deploy near-term, and have a clear path to commercialization at scale.

This document may be technical in places, indicative of our desire to engage with solution providers positioned to address these technical challenges. We are looking to you, the entrepreneurial and research communities, for the innovative thinking and bold action that will make these novel solutions a reality that can drive meaningful impact.

We are seeking transformative improvements that can holistically address the problem statements outlined in this report, rather than point solutions that solve niche problems.

THEMES AND PROBLEM STATEMENTS:
The remainder of this report articulates the themes and problem statements that currently represent the biggest technology gaps towards delivering on our True North Strategy.

These problem statements are aligned with six key business areas that are core to PG&E's operations and encompass challenges that are most urgent and critical to achieving our goals. These needs will undoubtedly evolve over time as dynamics shift; as such, this will be a living document that we intend to update periodically to communicate evolving priorities. We also recognize that this report likely does not capture the full range of problem statements that we will need to address to achieve our True North outcomes. We welcome your feedback on topics that may be missing or require re-framing, as we seek to continually refine our strategy over time.

The next section will outline the means and mechanisms through which we plan to engage and collaborate with the external innovation community.

How we'll do it

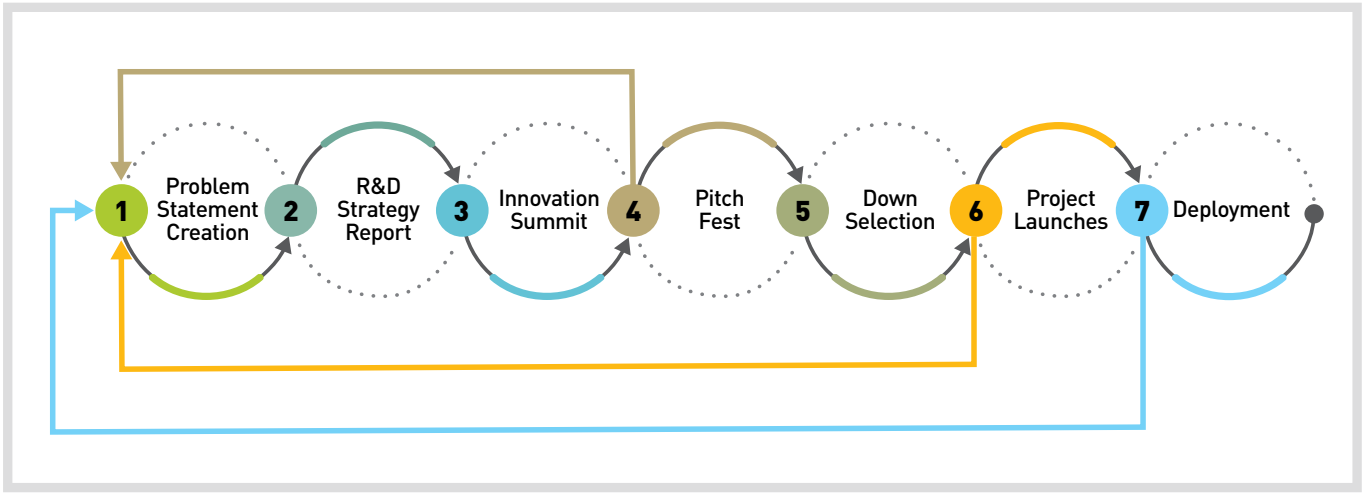
This report will serve as the basis for PG&E's first-ever Innovation Summit and subsequent Innovation Pitch Fest series.

2023 Innovation Summit

The PG&E Innovation Summit 2023 is a hybrid in-person and online event on July 25 in San Ramon, California. See pge.com/innovation for agenda and registration details.

The event's primary purpose is to engage with the external innovation community using this report to broadly socialize PG&E's R&D strategy and dive deeper into each of the report's themes through a series of subject-matter expert-led breakout sessions.

Following PG&E Innovation Summit 2023, all interested researchers, innovators, and entrepreneurs of any description will have the opportunity, through an online portal to be announced on July 25, to apply to pitch the ideas, research, technologies, or solutions they are developing that they believe can materially address one or more of the problem statements in the report.



Pitch Fests

All applications will be reviewed by subject-matter experts; selected applicants will be invited to the in-person Innovation Pitch Fest series to be held in September.

At the Innovation Pitch Fests, selected applicants will present their solutions directly to panels of key PG&E subject matter experts (SMEs) and decision makers.

The Innovation Pitch Fests have the potential to lead to direct opportunities between PG&E and the participating applicants through various other PG&E programs and funding mechanisms for both its gas and electric businesses, inform partnership opportunities on state and federal government grant applications and lead to PG&E providing letters of support and commitment to entrepreneurs in their government grant applications. They will also help to forge closer relationships amongst government agencies, industry consortia, academia, venture capitalists, and accelerators and incubators for the benefit of helping PG&E accelerate its progress on its key challenges.

EPIC PROGRAM

Electric-related technology solutions pitched to PG&E will also influence the scoping of the next wave of projects through PG&E's Electric Program Investment Charge (EPIC) program.

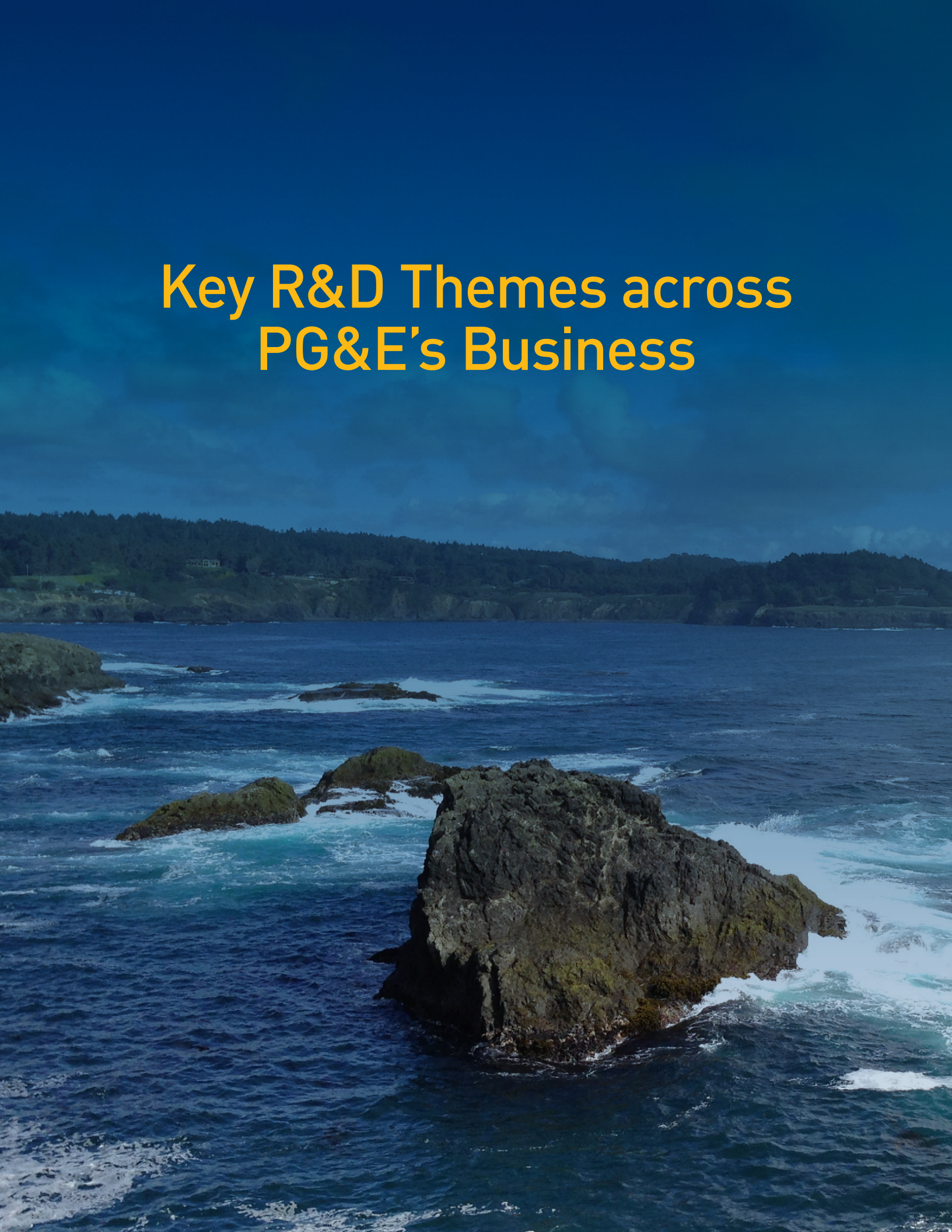
Learn more about EPIC:

UPCOMING EPIC BUDGET:
$83 million

EPIC is PG&E's primary vehicle for Research, Development and Demonstration on the electric side of its business, and the budget to fund projects through PG&E's upcoming EPIC 4 cycle is $83M. In the second half of 2023, PG&E intends to scope and select EPIC 4 projects and, pending final CPUC program authorization, launch projects at the start of 2024. Each of PG&E's EPIC 4 projects will require external innovation partners, and the input PG&E receives through the Innovation Pitch Fests will directly influence the scope of the Requests for Proposals (RFPs) issued for these projects.

The PG&E Innovation Summit 2023 and Innovation Pitch Fests are only the beginning of PG&E's focused engagement with the external innovation community. These efforts and multi-party collaboration will also shape the evolution of PG&E's R&D Strategy over the years to come. As PG&E continues to solve its innovation needs at scale, our needs will evolve, and our R&D Strategy will also continue to evolve to reflect the changing needs of our system.

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

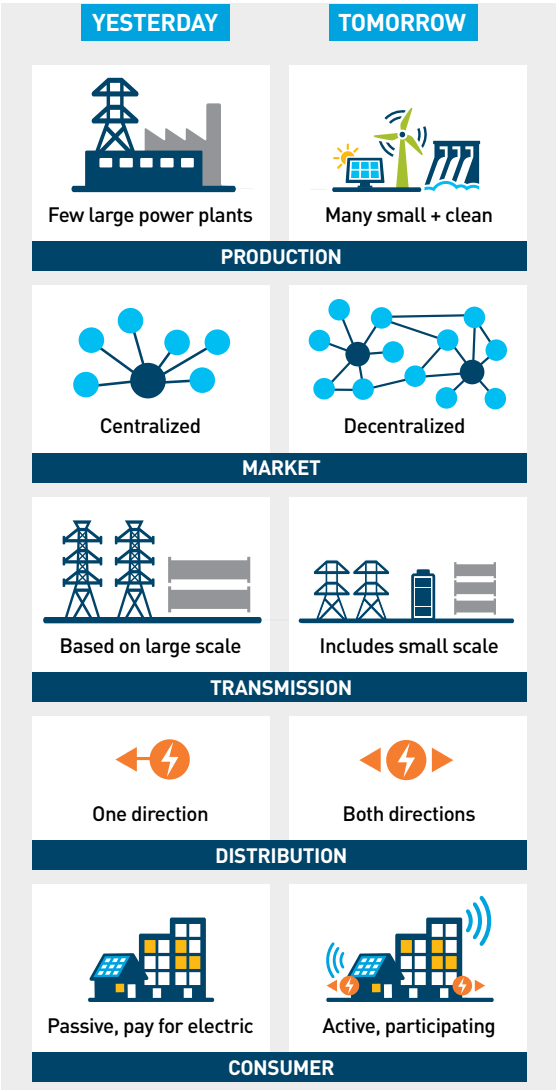


Supply and Load Management

Supply and Load Management

What is driving the need for innovation?

PG&E's electric grid is in the midst of a once in a generation transformation. The existing grid was designed to serve a fundamentally different set of needs than those represented across our customers and communities today. The urgent need to mitigate climate change is a key motivator of this transformation, as **we seek to transition our system to 100% clean generation by 2040** while supporting our customers as they also transition away from fossil-based fuels.



Electricity represents about 14% of the state's carbon emissions, making decarbonization of the electric supply one of PG&E's most meaningful opportunities to contribute to statewide emissions reduction. While we already deliver some of the nation's cleanest electricity to customers, the concurrent and unprecedented load growth from electrification will require the deployment of new clean generation far in excess of what would be needed to meet today's needs. **Expanded deployment of existing technologies will play a critical role in the transition to a net zero energy system;** however, novel clean energy supply and storage technologies will also be an important part of the solution as PG&E and California seek to deliver on our ambitious climate commitments.

In addition to increasing the need for novel supply technologies, the high penetration of un-orchestrated DERs could also pose risks for grid operations and planning and leave the potential of these resources to support grid operations un-tapped. However, strategically managing these assets represents tremendous potential to backstop intermittent renewables and balance increasingly volatile load.

FOR EXAMPLE:

By 2035 there is expected to be sufficient storage capacity in California's EV batteries—around 70–80 kWh each—**to power every home in the state for three days.**

Harnessing EVs and other newly electrified loads as flexible grid resources is essential for maintaining functional and reliable operations for the grid of tomorrow and is one of our greatest available opportunities to ensure affordability for years to come.

While we are investing significantly in our grid to enable electrification, we must also be able to coordinate new load growth within the limits of the grid. **This strategic coordination will enable PG&E to avoid capacity constraints while providing the opportunity to lower rates by optimizing investments needed to support new load.**

On the supply side, increasing penetration of intermittent wind and solar, retiring natural gas-fired generation plants, declining hydroelectric power productivity, and extreme weather conditions are contributing to an increasingly volatile net load and capacity shortages across the state. The increasing share of variable renewable resources in the electric supply exacerbates the problem of mismatched midday peak supply and evening peak demand, with the evening ramp rate roughly doubling between 2015 and 2021. This is leading to increased curtailment of renewable supply and challenging the current capabilities for matching supply and demand on a real-time, daily, and seasonal basis. At the same time, the interconnection queue is growing, and transmission infrastructure is constrained across the system.

In light of these evolving dynamics, we view **comprehensive load management and novel clean energy supply and storage technologies as key enablers of the electricity grid of the future**. Both are essential to delivering on PG&E's promise of a decarbonized, resilient, and affordable electricity system. Building out these capabilities will require deep collaboration with the innovation community. From comprehensive load management to next generation clean supply, the need for rapid innovation and deployment is tremendous.

Building the future: How does R&D help us deliver on our True North Strategy?

Equipping PG&E with tools and processes to integrate new storage and generation technologies and automate load management at all levels of the grid will unlock and optimize the full value of DERs for both customers and the grid, ensuring a reliable, affordable, nimble, and resilient grid of the future.

MORE RELIABLE

Effective load management and new storage technologies are essential to balancing and backstopping the increasingly variable and distributed load on the grid. DERs including EVs, heat pumps, and electric water heaters are projected to reach a total capacity greater than all generation on the system combined by 2030 with **tremendous potential to balance variable generation on the grid** as well as potential to cause significant reliability issues if unmanaged.

AFFORDABLE

PG&E is projecting 70% load growth over the next 20 years, largely driven by the electrification of transportation, building heating & cooling, domestic water heating, and cooking. With current tools and processes, grid upgrades required to accommodate these planned load increases may cost upwards of tens of billions of dollars. Load management capabilities across all levels of the transmission and distribution grid and strategic integration of storage assets may enable PG&E to **minimize costs associated with customer site and service upgrades, transformer and circuit upgrades, substation and transmission build-outs, and wholesale capacity procurement,** which will effectively minimize rate increases for customers.

CLEANER

PG&E's goal of achieving 70% renewable electricity on the grid by 2030 will require load management on a daily and seasonal basis to **ensure PG&E maximizes the use of clean generation on the system by shifting demand to periods of higher renewable generation**. Efficiently integrating new sources of renewable energy supply and storage will complement load management in achieving this goal.

RESILIENT

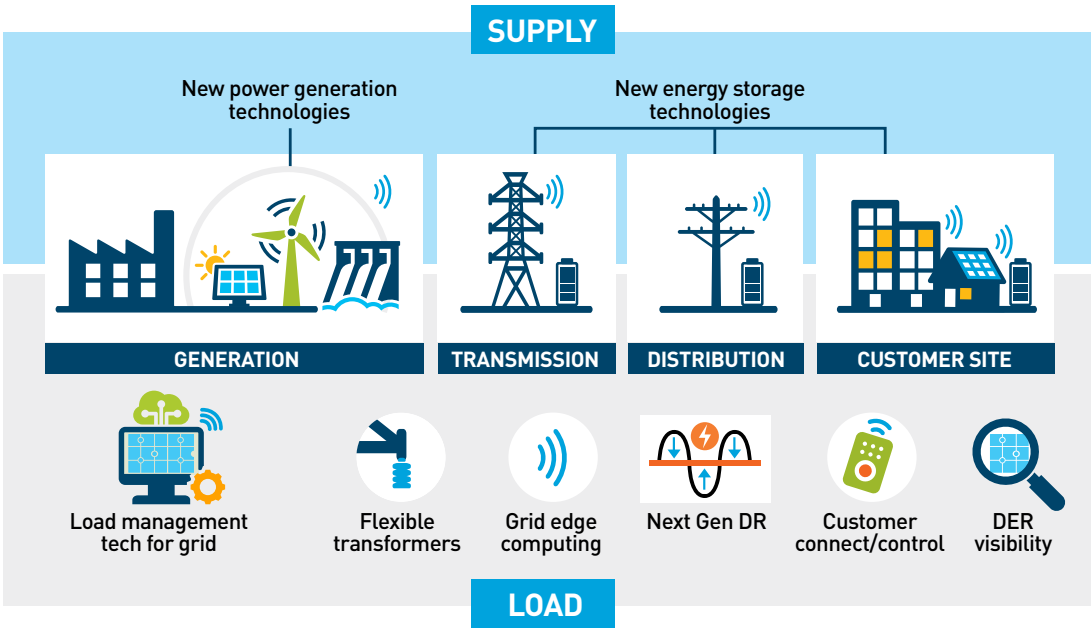
Automated grid edge computing capabilities will make the grid more resilient by automatically monitoring and managing rapidly changing conditions on the transmission and distribution systems and balancing the system without human intervention. These capabilities are also **critical to improving reliability and safety** by automatically detecting faults and enabling a more rapid and targeted response to minimize ignition risk.

ADAPTABLE

Successfully capturing the vast majority of new controllable loads in managed programs will dramatically **enhance PG&E's ability to optimize operations based on customer and local grid needs**, in addition to transmission level conditions.

Defining success

We aspire to play an important role in expanding load management capabilities across all levels of our grid and seek to partner with the innovation community to make comprehensive load management a core capability. On the supply side, we seek to integrate promising new forms of generation and storage technologies at the lowest capital cost and highest-value locations to deliver the clean, affordable, and resilient grid of the future.



THEME 1

Expand load management capabilities across all levels of the system

Developing load management capabilities at the transmission, distribution, and customer levels is necessary to accommodate and balance the massive influx of distributed energy resources (DERs) on the system and manage the increasingly intermittent, non-dispatchable supply mix.

DERs are key to achieving PG&E's goal of a net zero grid by 2040. To deliver on this promise, these assets must be managed effectively against real-time grid conditions at all levels of the system including the ability to mitigate issues when distribution and broader system needs are in conflict.

On the distribution side, load management can limit localized constraints, optimize power flows, and reduce the need for service upgrades, reducing the cost for customers to adopt DERs. At the transmission level, aggregating load management resources can provide resource adequacy, emergency response, and ancillary services to maintain balance between supply and demand.

Comprehensively managing load across the entire system will require a robust set of capabilities including visibility into the location and energy usage of all DERs connected to the grid, grid edge computing that automatically coordinates between customer sites and the distribution grid to balance supply and load in real-time, and a consistent control interface at the customer site level to coordinate customer loads against real-time conditions on the distribution and transmission grids.

THEME 2

Deploy new clean supply and energy storage technologies

Effectively evaluating and deploying next-generation energy supply and storage technologies is essential to achieving PG&E's goal of a net zero energy system by 2040.

To support anticipated load growth, our system needs to deliver clean energy and storage far in excess of what would be required to meet the needs of today.

By demonstrating new supply and storage technologies, we intend to understand the use cases, interconnection processes, and operational characteristics in order to develop roadmaps for deploying these technologies more widely on the system.

Of particular interest are storage technologies capable of 8+ hour discharge, technologies that provide firm renewable generation, flatten the "duck curve" and/or provide ancillary services, as well as solutions that can provide other benefits to customers, such as resiliency during Public Safety Power Shutoff or Enhanced Powerline Safety Settings events. The ability to flexibly site and seamlessly interconnect are also desirable characteristics, along with the minimization of land needs through optimizing energy density and technical design, enhanced operational safety characteristics, and ease of maintenance and operations.

Integrated Grid Planning

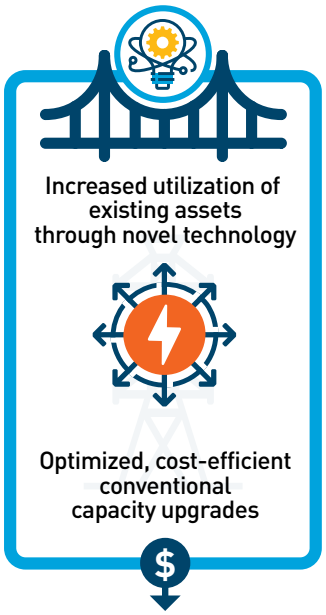
Integrated Grid Planning (IGP)

What is driving the need for innovation?

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 and the electrification of end uses across all sectors of society, this growth in demand will touch every corner of our system and require a full-scale re-imagining 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 a 70% increase in load over the next 20 years** that paradigm is no longer relevant. 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 re-imagining approaches to grid planning and T&D buildout. Specifically, we seek to increase the throughput of the existing T&D system, drive efficiency in the process of connecting new loads, and reduce the cost of infrastructure upgrades. In conjunction with load management, these new methods promise to reduce costs and increase reliability of the system as a whole, thereby lowering rates and improving the quality of the service for customers.

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 IGP processes are equipped to support this complex optimization exercise.

While the need for new approaches to IGP is becoming more acute with the buildout of EV charging infrastructure and increasing service upgrade requests due to electrification, the potential value of new IGP tools, processes, and technologies is also increasing.

FOR EXAMPLE:

The more loads connecting to the system, the greater the opportunity to optimize the size and location of new infrastructure to accommodate new load; and the more upgrades required for existing infrastructure, **the greater the potential to refurbish and reuse components, thereby reducing waste on the system**.

The value of revamping IGP tools and processes will both relieve constraints in the near term and facilitate load growth on the system over the next 20 years.

Building the future: How does R&D help us deliver on our True North Strategy?

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

CLEANER

Electrification of transportation, buildings, and industry is essential, lowering the emissions of customers and communities served (Scope 4 emissions). Increasing the pace and reducing the cost of connecting new loads to the system will **enable PG&E to achieve its climate goals, in addition to delivering an equitable energy future**.

AFFORDABLE

Increasing the efficiency of the existing grid and reducing the cost of new infrastructure buildout are **critical to keeping costs down for customers**, both in terms of rates and service upgrade costs. Allowing customers to efficiently adopt EVs and other DERs will further reduce costs and provide additional revenue-earning opportunities.

MORE RELIABLE

Ensuring the grid is equipped to reliably support the projected 70% increase in load growth alongside an increasingly distributed, intermittent supply mix is **essential to providing reliable energy to PG&E customers**. Enabling customers to efficiently adopt DERs is the foundation for system-wide load management, which is necessary for balancing increasingly volatile supply and demand.

ACCESSIBLE

Enhancing our ability to rapidly and strategically scale the capacity of our grid through optimized and cost-efficient investments informed by a comprehensive understanding of evolving needs will ensure our ability to provide our customers with **timely access to the energy needed to power their lives and work**.

Defining success

We seek to identify novel tools and technologies that improve the IGP process, increase utilization of the existing system, and reduce waste for necessary grid upgrades. Our goals are to reduce lead times for service upgrades and new service connections, defer or eliminate the need for further T&D buildout, and increase reuse of T&D asset components.

We have identified problem statements in two categories as outlined 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 IGP 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. It is therefore necessary for PG&E to increase the utilization of the existing T&D infrastructure to delay 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

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, and minimize waste associated with completing upgrades.

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.

In addition, business-as-usual equipment upgrades and replacement of aging T&D infrastructure will require continued investment. Ensuring these investments are optimized against new loads connecting to the system, and that T&D equipment is used as efficiently as possible, is essential to minimizing rate increases and delays associated with these upgrades.

Current processes for connecting new loads to the system and upgrading T&D capacity are not sufficient to handle the pace and scale of load growth over the coming years. These processes are designed to consider individual load connection requests in a largely manual, iterative process that does not always consider the most current information. With the volume of new flexible loads connecting to the system, we are seeking tools to ensure that every customer is able to cost-effectively connect new loads to the system with minimal delay. In addition, we are looking for capabilities to help customers make more informed decisions on where to locate and how to size new loads, streamline the application and review process, and optimize T&D upgrades based on the forecasted load profiles and flexibility of connecting loads.

At the same time, for upgrades that are approved, 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.

Electric Vehicles

Electric Vehicles

What is driving the need for innovation?

Transportation is by far the single largest source of greenhouse gas emissions across the state, contributing to over 40% of the state's overall emissions. California has set one of the nation's most ambitious EV mandates to spur rapid decarbonization across the state, requiring all vehicles sold by 2035 to be zero-emissions.

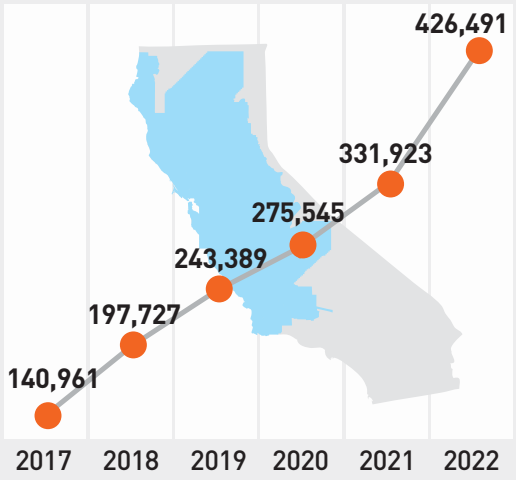
1.2 million
needed by 2030
to meet the 2035 goals

To meet the growing charging demands of future EVs, **California aims to have 250,000 charging stations installed by 2025**, including 10,000 fast chargers and 200 hydrogen fueling stations; however, the California Energy Commission (CEC) has projected that the state will need 1.2 million charging stations by 2030 to meet the 2035 goals, which is roughly a 93% increase from the current state.

PG&E has ambitious goals of its own. We plan to support our customers in their path to decarbonization by encouraging the adoption of 3 million EVs across our system, leading to a cumulative reduction of 58+ MMT of carbon emissions.[1] These goals are ambitious, but we believe they are achievable, as we have already made significant progress: **roughly one in seven of all EVs in the US can be found in PG&E's service area today**—that's over 425,000 EVs charging on PG&E's grid.

Building on this momentum, PG&E will continue to work in tandem with the state to provide our customers with the necessary tools, resources, and incentives to seamlessly transition and to create a more prosperous future where we can all breathe freely.

Plug-in electric vehicles in PG&E's Service Area



Source: EPRI

[1]Covers the period from 2022 to 2030; "MMT" refers to million metric tons.

This rapid acceleration of EV adoption is projected to be the largest driver of load growth in PG&E's service area over the next 20 years, presenting both challenges in infrastructure buildout and major opportunities in optimizing energy use and lowering emissions in the communities we serve.

In order to capitalize on these opportunities, several challenges must be addressed including **decreasing the total cost of ownership for customers, increasing access to EV chargers**, increasing educational opportunities focused on the electrification process, ensuring commercial customers can connect their fleets **in a timely manner**, and addressing grid capacity constraints.

We are collaborating with various stakeholders to address these challenges and to facilitate a smooth and orderly path to increased EV adoption. These efforts include building the large-scale electric infrastructure needed to incorporate EV charging systems into the energy grid and launching several **customer programs and pilots to increase charging infrastructure at multi-family dwellings, workplaces, and schools, throughout urban corridors and in disadvantaged communities.**

While our customer incentives and pilot programs have thus far seen success, we will need innovative solutions to make our vision of widespread EV adoption a reality for all. EVs not only present opportunities to decarbonize our communities, but also offer opportunities to backstop renewables and balance the grid, as well as increase our resiliency in the face of emergencies. **Further, EV models are increasingly equipped with bi-directional charging capabilities, opening up new possibilities to provide valuable grid services and reduce total cost of ownership.** In order to maximize the full potential of EVs, we plan to engage innovators to solve some of the biggest bottlenecks to EV proliferation and open up new value streams to support PG&E's customers and the grid.

Building the future: How does R&D help us deliver on our True North Strategy?

Enabling the widespread adoption of EVs and unleashing their potential as grid assets will allow PG&E to maximize the value of existing infrastructure, boost resiliency for both customers and the grid, and reduce emissions in the communities we serve.

AFFORDABLE

Identifying novel technologies and solutions to cost-effectively build out EV infrastructure represents an opportunity to potentially **reduce electric rates to customers** as load growth from EVs will be one of PG&E's most significant new revenue opportunities over the coming years.

MORE RELIABLE

EVs present a unique opportunity to alleviate grid capacity constraints through load shifting/throttling or through V2X infrastructure which can **strengthen system reliability** during outages or emergency events.

SAFER

The potential of EVs to support the grid during periods of emergency or grid strain can help to **limit outage-related safety impacts faced by our customers and communities**.

ACCESSIBLE

Facilitating a high density of low-cost charger installations across residences, workplaces, major corridors, and disadvantaged communities will give customers **increased accessibility to chargers** and greater day-to-day convenience in fueling and operating EVs.

CLEANER

Encouraging and streamlining increased EV adoption will enable our customers and communities to reduce their carbon footprints and **increase access to cleaner air**.

Defining success

We are positioned to play a central role in supporting the EV transition by deploying novel technologies and solutions that will enable the rapid and cost-effective adoption of EVs across our state.

While PG&E's EV programs and incentives have encouraged increased adoption, advanced solutions that forge pathways to maximize the value of EVs to both the customers and the grid and **technologies to ease the EV charging installation process have the potential to reduce or eliminate the barriers in the way of reaching zero gas powered vehicles sold by 2035**.

AREAS TO ADDRESS

Decrease installation costs

Increase charger access: home, work, apartment, recreation, schools, fleets

Connect more seamlessly and more quickly

To reach both the state's and our own goals, we have outlined several of the biggest challenge areas where we are seeking step-change technological improvement over the current state.

THEME 1

Ensure affordable and timely connection for every customer

Costs associated with foundational upgrades to customers sites, broader system capacity upgrades, lengthy timelines, and a lack of customer visibility into the process required to complete this work are considerable barriers to accelerating EV adoption.

The customer electrification process can be costly and time consuming, as significant foundational upgrades such as electrical, panel, and transformer upgrades are required to support EV charging equipment at many customer locations.

Such upgrades can cost thousands of dollars, and the wait time to complete the work can take months, potentially discouraging or slowing the pace of EV adoption. Similar upgrades may be required for both multi-family unit residents and customers intending to electrify their fleets. On top of upgrades, additional challenges associated with coordination, control, and cost of charging infrastructure may prevent these customers from installing and operating chargers.

In addition to system barriers, customers often lack visibility into the resources required to complete the EV charger installation process prior to purchasing an EV. These barriers and inconveniences may leave vehicle owners either without a convenient charging option or may encourage customers to seek unpermitted solutions that place stress and often overload local transformers.

PG&E aims to ease the financial burden and timelines associated with required charging installation upgrades through low-cost technologies that can be implemented at scale or solutions that avoid electrical upgrades altogether by allowing for the orchestration of loads in a manner that ensures overloads do not occur. Increasing education, visibility, and coordination of the charger installation process will help facilitate a smooth transition to increased EV adoption. Additionally, we seek scalable charging solutions specifically designed to be used by our customers in multi-family buildings that can effectively manage billing and load concerns as increasing multi-family charger accessibility is paramount to meeting both state- and PG&E-level goals.

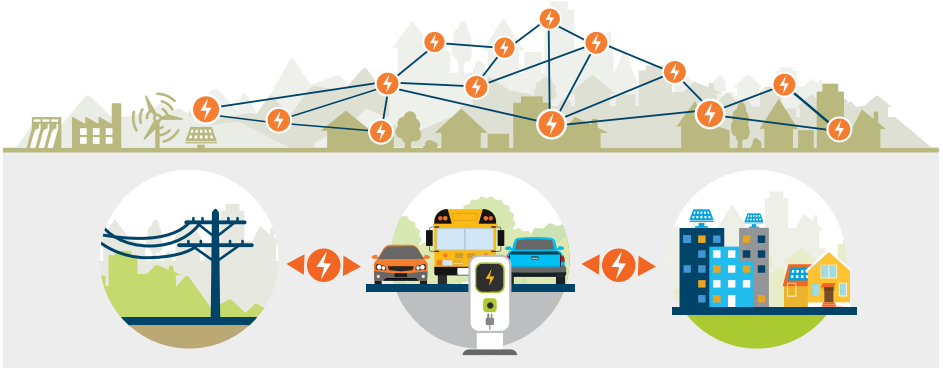
THEME 2

Unlock potential of EVs as grid assets

Enabling vehicle-to-everything (V2X) infrastructure and making full use of EVs as grid assets can create opportunities to reduce the cost of ownership and unlock novel value streams that could be leveraged to generate incremental revenue and better serve customers and the grid.

Today's electric grid was not designed to support such rapid and widespread vehicle electrification nor dynamically manage volatile loads. While EV proliferation adds complexity to grid operations, there are also many ways in which EVs can serve as grid assets as 95% of an average EV's time is spent parked with available range and capacity that far exceeds the needs of tomorrow.

Example opportunities include absorbing otherwise excess renewable energy generation, providing ancillary grid services such as frequency regulation, exporting power during periods of peak grid demand, and enabling microgrids to provide service in hard-to-reach or high-fire-threat areas. PG&E is seeking to improve grid resiliency and increase overall EV adoption by deploying vehicle-to-everything infrastructure at scale and by investigating other creative ways in which EVs can become an asset for both the customer and the grid at both a hyper-local and a macro need.



V2X infrastructure provides opportunities for customers to back up their homes, businesses, and communities during periods of grid stress or during outages or emergency situations by injecting power back to the grid. This not only protects the grid, but it also increases the value of EVs to customers and has the potential to decrease total cost of ownership. A key barrier to realizing these benefits, however, lies in the additional costs and wait times beyond standard charging infrastructure. These upgrades can exacerbate the problems identified under Theme 1, reduce overall system value, and potentially deter adoption.

PG&E is seeking solutions that optimize and enhance the value of EVs by reducing costs associated with supporting V2X capabilities and providing new avenues to maximize the potential of EVs as grid assets.

Wildfires

Wildfires

What is driving the need for innovation?

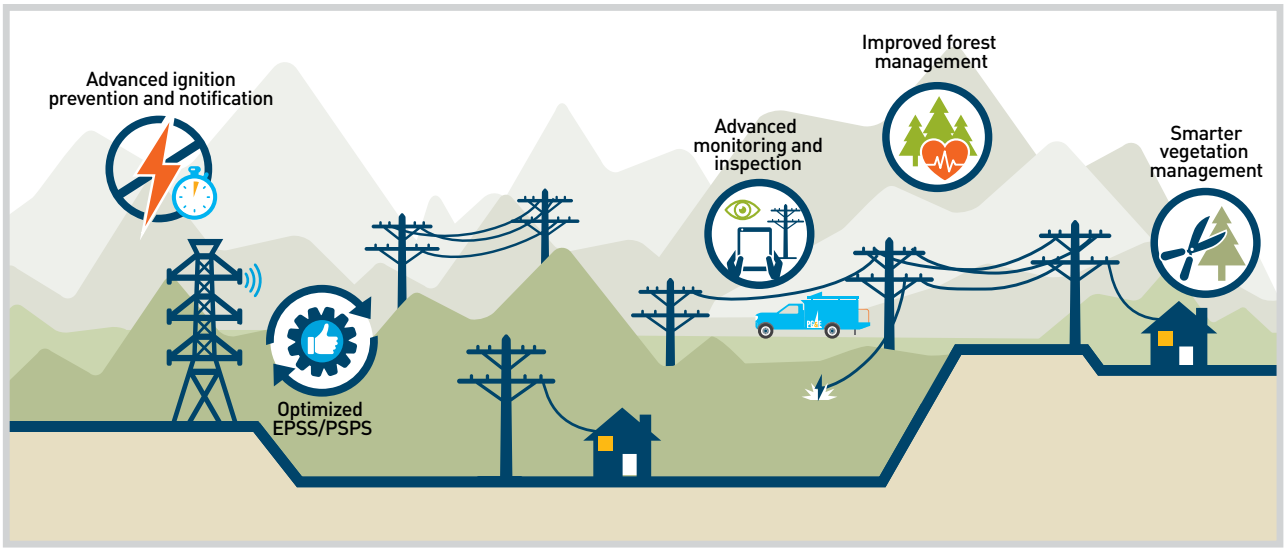
The effects of climate change are increasing the severity and duration of wildfire season in California. Reduced snowpack, prolonged droughts, and more rapid evaporation of surface water observed in recent years have exacerbated the risk of wildfire ignition and spread.

18 of the 20
most destructive wildfires in California's history have occurred since 2000
with seven of these burning across 2020 and 2021

These 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). **Wildfire risk is therefore PG&E's top safety concern**, as we have a responsibility to our customers and our co-workers to improve the safety of our system. In pursuit of this goal, we have enhanced our wildfire mitigation capabilities with a wide range of novel solutions to adapt and harden our system and to proactively detect and eliminate imminent ignition risks. Our deep and continued investments in ongoing system monitoring and maintenance and extensive vegetation management programs also remain critical to our risk mitigation efforts.

AREAS TO ADDRESS:



In recent years, PG&E has implemented numerous breakthrough technologies and processes and undertaken significant efforts and costs to prevent the occurrence and spread of wildfires. These include our **Public Safety Power Shutoff (PSPS) program, Enhanced Powerline Safety Settings (EPSS), our 10,000-mile undergrounding program, and our extensive vegetation management program** that abates approximately one million trees annually. The complete portfolio of efforts that PG&E is currently pursuing for wildfire mitigation can be found in our 2023 Wildfire Mitigation Plan. PG&E is also sponsoring the XPRIZE Wildfire and other industry and academic initiatives, on which our R&D Strategy seeks to build.

Despite our extensive wildfire mitigation initiatives, we have not yet managed to completely eliminate the risk of catastrophic wildfires. We are therefore continually **looking for the most cutting-edge technologies and aggressive methods** to eliminate wildfire risk while minimizing customer impacts. Improved monitoring, management, and operation of assets can lead us to the ultimate cessation of catastrophic wildfires while enhancing PG&E's ability to deliver affordable and reliable electricity.

Building the future: How does R&D help us deliver on our True North Strategy?

Improving strategies and technologies for wildfire prevention and mitigation, including advancements in asset inspection and monitoring, more targeted and shorter outage events, and optimized forest and vegetation management, will help us move towards our goal of architecting a safer, affordable, more resilient, more reliable energy system.

SAFER

By preventing ignitions and putting an end to catastrophic wildfires, we are able to better serve our communities by **ensuring that everyone and everything is always safe**. Delivering on this goal also promotes cleaner air, preserves our ecosystems, and bolsters the wellbeing and prosperity of communities across our service area.

MORE RESILIENT

Advancing our asset monitoring and vegetation management programs and enhancing our existing EPSS and PSPS activities will help us avoid the effects of degradation and third-party contact with assets and further **create a resilient energy system by minimizing damage caused by ignitions**.

MORE RELIABLE

Continuing to drive down the frequency and scale of programs that mitigate wildfire risk through power line de-energization (such as EPSS and PSPS), as well as reducing the risk of unexpected, unsafe asset failure through advanced monitoring and inspections will allow us to **provide consistent, reliable service to customers**.

AFFORDABLE

More efficient and targeted wildfire mitigation practices will both improve the cost-effectiveness of our current methods and prevent expenses associated with ignition and wildfire cleanup; the resulting overall cost-efficiency in wildfire prevention and mitigation programs will **translate to lower rates for customers**.

Defining success

PG&E is dedicated to customer-focused wildfire mitigation and continuously driving down ignitions that involve our assets. Novel solutions and emerging technologies can enhance and supplement our current programs and ensure that wildfire mitigation programs do not hinder our ability to deliver reliable energy and positive customer experiences.

We intend to engage with innovators to find cutting-edge solutions for our most pervasive problems and roadblocks to our goal of ending catastrophic wildfires. Our goal is to identify novel technologies that can help us efficiently and cost-effectively manage the health of our assets at scale, continue to reduce the occurrence and severity of wildfires across our service area, and minimize associated customer impacts.

To guide our pursuit of these solutions, we have identified five key themes defined below.

THEME 1

Deploy advanced monitoring, inspection, and analytics for asset health and integrity

More accurate, comprehensive, and cost-efficient monitoring and inspection of PG&E's assets can provide a better picture of asset health, including asset degradation and failure, on a continuous and real-time basis rather than relying solely on point in time inspections.

Currently, PG&E uses various sensors and means of collection to monitor transmission and distribution assets in HFTDs, including LiDAR, infrared, and drone technologies, but periodic, point-in-time inspections remain the standard for the majority of assets.[2]

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 a portfolio of innovative technologies that can achieve scale across the system to better monitor assets on an ongoing basis and systematically predict, identify, and communicate asset degradation and failures. These novel methods of inspecting and monitoring asset health should be cost effective as well as more accurate, less subjective, and more comprehensive than current methods.

[2]PG&E's current inspection programs follow California's General Order 165, which establishes inspection requirements for electrical distribution and transmission facilities to ensure safe and high-quality electrical service.

THEME 2

Eliminate ignitions with improved protection schemes

Advancements in EPSS and electrical asset design can help PG&E eliminate ignitions by addressing gaps in current ignition prevention methods and pursuing safety in asset failure.

Meaningful strides have been made in reducing the number of wildfire ignitions across PG&E's system, but there were still 31 reportable ignitions on EPSS-enabled circuits in 2022. PG&E achieved a 68% decrease in ignitions on EPSS-enabled power lines in 2022 versus the 2018–2020 annual average. Preventing 100% of ignitions that are caused by high-impedance faults on equipment energized at primary voltage levels and faults that occur on equipment energized at secondary voltage levels remain opportunities for further progress.

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.

THEME 3

Eliminate customer impacts from PSPS/EPSS

PSPS and EPSS events, despite their effectiveness in reducing ignition frequency and severity, can negatively impact customers through disruptive outages and could be improved through reduced frequency, shorter outage events through advanced patrols, and accurate communication with customers on the length and likelihood of outages.

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 size and scope, driven by meteorology model enhancements, installation of sectionalizing devices and favorable weather in 2022. In addition, PG&E responded to 89% of outages on EPSS-enabled lines within 60 minutes (42 minutes on average) and reduced outage duration times by 56% in 2022, compared to the previous year.

PSPS and EPSS are extremely effective tools for wildfire ignition prevention but may negatively affect customers due to the potential for disruptive, lengthy, and costly outages. These events may be especially disruptive if the advance notifications of impending outages are inaccurate due to gaps between forecasting models and actual events and if the same customers are repeatedly impacted by multiple closely timed events. In limited cases, PG&E has deployed backup generation solutions at customer sites to avoid outages; however, available backup technologies are primarily fossil-fuel based and result in increased emissions.

Technologies that are able to more precisely identify the location of a potential issue would further enhance our ability to re-energize more quickly. Currently, manual patrols are conducted to determine whether repairs are needed, largely based on visual assessment of the condition of the line. In cases where the impact was temporary (e.g., a falling tree branch that did not damage the line), the lack of precise locational information for the issue may result in lengthier patrols as there is also no visual indication of where the problem occurred. By identifying technologies that can pinpoint problems on the system, both during an energized and a de-energized state, patrols can much more targeted and more effective in identifying root causes that did or did not damage our equipment.

PG&E seeks novel solutions to limit the impacts of outages by more precisely targeting events with increased asset sectionalization, improving customer communications regarding the likelihood and length of outages, and enhancing our abilities to re-energize the grid quickly and safely. Additionally, we are pursuing novel, clean backup energy solutions that can eliminate the impacts of grid outages for our customers.

THEME 4

Enable better-informed and targeted vegetation management

The continued occurrence of ignitions caused by vegetation, as well as the customer dissatisfaction vegetation management can cause, can be addressed through more targeted patrols and enhanced abilities to accurately determine when trees should be removed or abated.

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 inches away from primary distribution lines and prevent it from adding strain or abrasion on secondary lines, while additional clearances are mandated during fire season.

Every line mile is patrolled at least once annually to assess vegetation clearance accordingly and to abate trees that could present an encroachment and ignition risk. PG&E's vegetation management practices are among the most intensive in the world, but there were still 38 reportable ignitions in HFTDs in 2022 due to vegetation contact.

Current models and methods are insufficient in their ability to precisely target vegetation management patrols at a hyperlocal level and to assess the optimal course of action on a smaller scale. 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 research and data around vegetation growth are especially important to address when considering unhealthy or fire-damaged trees. Additional research is required to accurately determine how to best measure moisture to assess tree health and risk, as well as to determine why apparently green healthy trees fail. Improved understanding 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.

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.

THEME 5

Develop a holistic approach to forest management across stakeholders

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, there is an opportunity to apply a more holistic approach that focuses on ecological restoration and addresses the root causes of many wildfires by supporting healthier forests.

Based on our current estimates, PG&E's forest management efforts could generate up to one million tons of wood debris in 2023 alone. Our vegetation management crews must remove or mitigate this enormous volume of biomass across PG&E's vast service area, an effort that results in tens of millions of dollars in direct costs, greenhouse gas emissions from equipment and controlled burns, and a potential missed opportunity for more productive reuse of this source of woody biomass.

Beyond novel solutions to better address the byproduct of our vegetation and forest management efforts, there is a significant opportunity for novel technologies and breakthrough thinking to enable a broader re-envisioning of forest management practices across PG&E and a wider collection of stakeholders. Improvements to advanced analytics and modeling capabilities could unlock the potential for more nuanced forest management practices that are more targeted to local conditions and better optimized across a range of desired outcomes, including ignition risk prevention, Green House Gas (GHG) emission reductions, and improved overall ecosystem health.

Identifying novel ways to engage with and incentivize a broader group of stakeholders that have a vested interest in improving the health of California's ecosystem could also further amplify the impacts of PG&E's ongoing forest and land management efforts.

To support our efforts, PG&E seeks more granular models capable of optimizing PG&E crew and vendor efforts based on multiple factors, including ignition risk, 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 continuously work towards a healthier and safer environment in California.

Undergrounding

Undergrounding

What is driving the need for innovation?

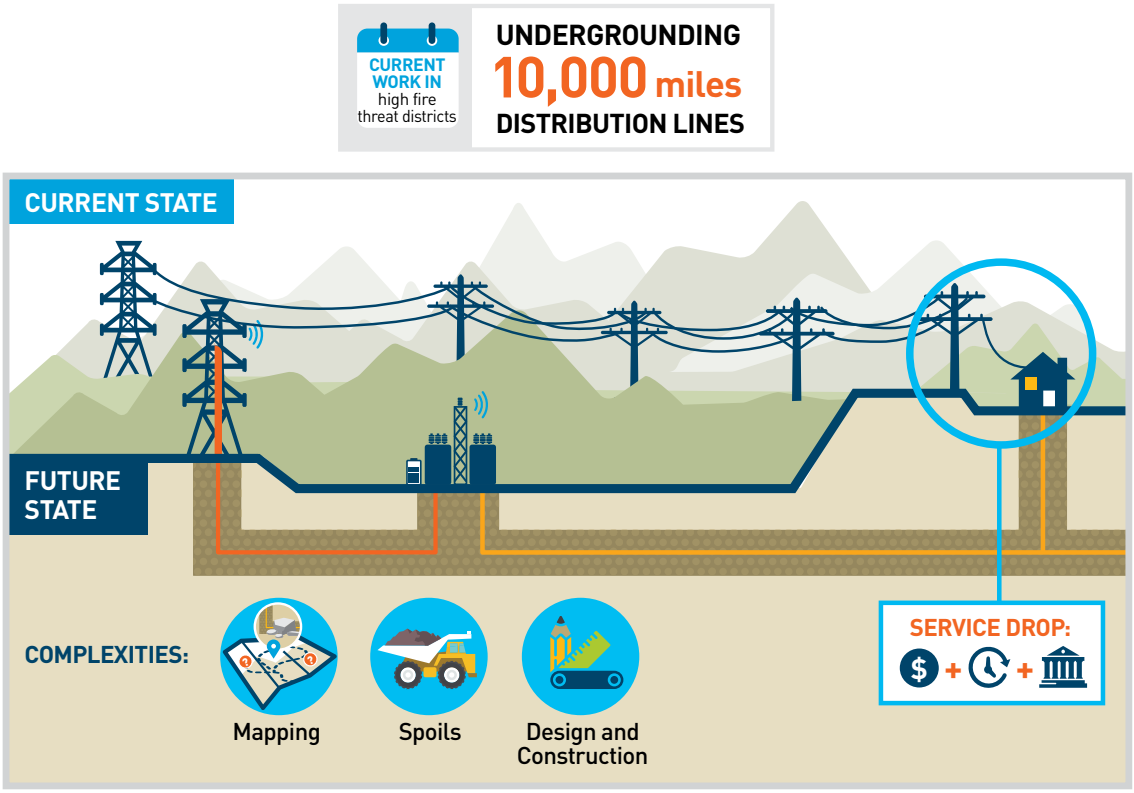
Wildfires pose a significant threat to California's natural resources, public safety, and economic well-being. While the impacts of climate change are exacerbating this threat, PG&E is working urgently to stop catastrophic wildfires.

To demonstrate our unwavering commitment to the environment and the communities we serve, we have launched an **integrated strategy**, detailed in the 2023–2025 Wildfire Mitigation Plan, to **manage and reduce both ignition and propagation risk**, including the Enhanced Powerline Safety Settings (EPSS) program and our 10,000-mile distribution line undergrounding program.[3] Through EPSS measures alone, we reduced the number of acres impacted by ignitions by 99% in 2022 compared to the 2018–2020 three-year average. Such progress notwithstanding, we recognize that novel and cutting-edge technical solutions are still required to fully eliminate wildfire ignition risk.

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

We are specifically targeting our efforts in the highest risk areas where undergrounding will have the greatest impact by reducing ignition risk by nearly 99% at installation locations. Beyond virtually eliminating the risk of utility-caused ignitions, undergrounding offers many additional benefits to our customers and stakeholders, including **reducing power outages** and **improving overall system reliability**, **reducing the cost and scale of vegetation management**, and driving long-term **affordability** for our customers.

[3]Additional information on all of these programs may be found in our 2023–2025 Wildfire Mitigation Plan.



In 2021–2022, we undergrounded over 250 miles of distribution lines and are well on track to reach our goal of 350 additional miles by the end of 2023. While initial progress has been strong, the myriad of engineering, cost, and project/construction management hurdles associated with undergrounding vast sections of distribution lines in remote and difficult terrains represent material challenges to our organization.

Innovation is needed to support PG&E's efforts to complete this ambitious portfolio of work on an accelerated timeline and at a lower cost per mile relative to today's state of the art. Though many of PG&E's pain points are shared by other utilities, our remote, steep, and rocky terrain presents a set of unique challenges for which we are seeking novel approaches.

Building the future: How does R&D help us deliver on our True North Strategy?

Identifying novel solutions to reduce the challenges and costs associated with undergrounding across all components of the distribution systems in high-risk areas will help us reach our True North goals to eliminate the risk of catastrophic wildfires and provide more reliable, safe, and affordable energy to customers.

SAFER

By undergrounding 10,000 miles of distribution lines in HFTDs, we will eliminate meaningful risk of wildfire ignitions across our system, thus helping to **eliminate catastrophic wildfires across our service area**.

RESILIENT

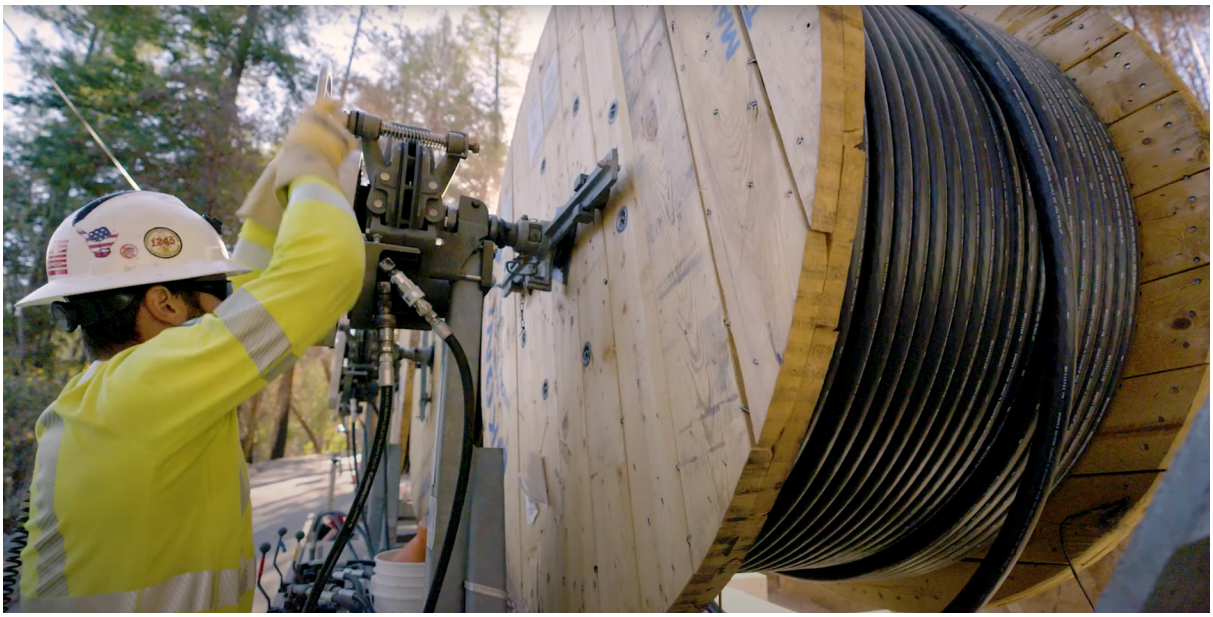
Underground wires will be less susceptible to stress and damage associated with extreme weather, **increasing the resiliency of the energy system in the face of climate impacts**.

MORE RELIABLE

Undergrounding lines may mitigate PSPS activities in some areas, thereby **reducing customer disruptions and ensuring reliable energy flow**.

AFFORDABLE

The reduced need for vegetation management, coupled with the likelihood of lower ongoing maintenance costs and the longer expected useful life of underground assets, may reduce overall lifetime costs of the system, **enhancing our ability to provide affordable power into the future**.



What we need from you

In recent years, PG&E has made strides to implement its undergrounding plan using existing technology solutions; however, we still seek novel solutions and emerging technologies that have the potential to increase the speed, efficiency, and predictability of undergrounding.

We will continue to work closely with fellow **utilities**, the **vendor community**, and **academic institutions** to advance our undergrounding efforts, but we hope to engage the world's grittiest problem solvers to make our undergrounding vision a reality. **Our goal is to identify novel technologies that can help PG&E mitigate risk quickly while reducing the cycle time and cost of underground projects.**

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

THEME 1

Improve the efficiency of undergrounding civil construction from survey to installation

Novel subsurface mapping, soil analysis solutions, and innovative conductor and construction technologies can reduce spoils generation and associated handling and treatment costs, which together drive the majority of costs associated with the civil construction process.

Civil construction drives the majority of undergrounding costs, but these can be highly variable based on construction and installation methods and existing underground conditions.

The need to track, treat, 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.

To meaningfully reduce costs, we seek solutions capable of providing a detailed understanding of the subsurface terrain and soil composition to better plan routes, construction methods, and off-haul plans to minimize costs associated with spoils displacement and removal. While an understanding of soil composition is critical, novel methods for civil construction and removal/treatment of spoils at scale (including trenching, boring, at-surface solutions, etc.) will also be necessary, especially in areas where hazardous spoils cannot be avoided.

Finally, 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 conductors that can withstand longer pull lengths to reduce the frequency of splices and primary boxes, splicing technologies that reduce manual installation efforts, and other solutions that could enable direct burial to reduce overall effort, time, and materials associated with the underground process.

THEME 2

Identify scalable solutions for system components difficult to underground

As PG&E seeks to eliminate ignition risk via undergrounding electrical assets, there are hurdles that must be overcome to ensure that undergrounding rural distribution lines and customer service drops are technically and economically feasible.

While overhead service drops, which connect customer homes to distribution lines, are a relatively minor source of ignition risk, moving these connections underground would further enhance PG&E's ignition risk mitigation efforts.

However, moving service drops underground faces a variety of challenges. This process may involve significant customer impacts, such as digging through yards and updating electrical panels, among others. As we strive to provide reliable and safe power to all of our customers with minimal disruptions, we look to identify novel technologies that enable minimally disruptive, dramatically less expensive undergrounding or hardening of service drops.

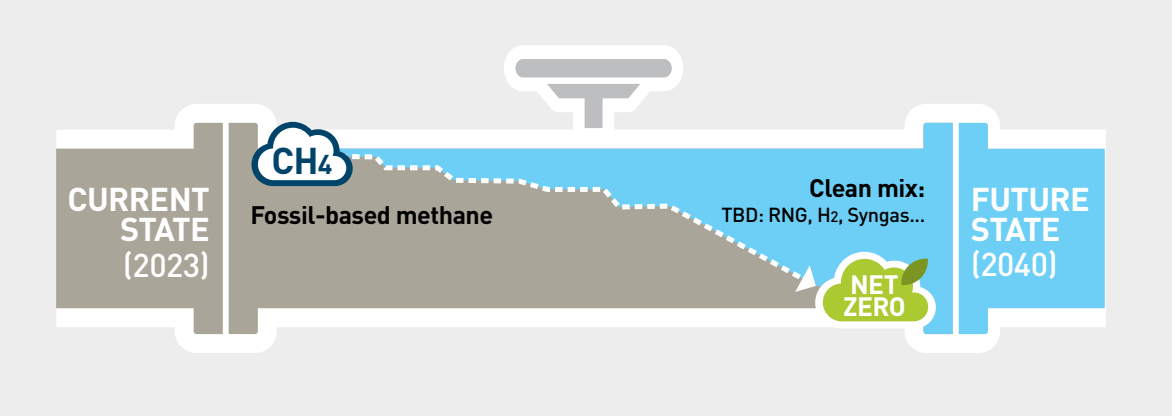
Gas

Gas

What is driving the need for innovation?

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 895,520 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. 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, maintain infrastructure cost effectively

A key challenge of the transition to net zero is the high degree of industry-wide uncertainty surrounding the road ahead. While there are a range of renewable alternatives to fossil-based methane, including **renewable natural gas (RNG)**, **hydrogen**, and **syngas**, none is presently cost-effective or commercially available at a scale capable of meeting the needs of PG&E, much less those of an entire nation seeking to decarbonize. Beyond these considerations of cost and scale, there are also many unknowns surrounding how well-suited existing operations are to the introduction of certain methane alternatives (e.g., hydrogen) and to what degree existing customer 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 away from natural gas by some of our customers will present a challenge to the economics of the system as the ongoing costs to maintain its safety and reliability will be spread over fewer ratepayers 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 material methane emissions reductions from ongoing operations. As outlined in our Climate Strategy, we have **committed to reduce Scope 1 and 2 emissions from natural gas operations by 45% by 2030**. While much work remains to be done, we have already made measurable progress against this goal.

In April of this year, we announced that we have **already achieved our 2025 target of reducing pipeline emissions by 20%—two years ahead of schedule**.

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.

Building the future: How does R&D help us deliver on our True North Strategy?

Investing in R&D to future-proof the gas system for the migration to green 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 green alternatives to natural gas, lowering emissions across the system, and ensuring the safety of our customers and co-workers.

CLEANER

Advancing the industry's foundational understanding of the full range of implications associated with integrating cleaner fuels into existing infrastructure will better **enable PG&E to determine the optimal path towards greening the gas supply**. Further, increasing the efficiency and effectiveness of our leak detection and repair capabilities **will help us deliver on our mission to heal the planet by reducing methane emissions from ongoing operations**.

SAFER

Enhancing our ongoing visibility into conditions across the system will allow us to address developing risks more proactively and respond to any imminent threats more rapidly, thereby **increasing the safety of our communities and our co-workers**.

MORE RELIABLE

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**.

AFFORDABLE

Efficiency gains across our inspection, monitoring, and maintenance programs will ensure that PG&E is able to **provide safe and reliable energy service, while minimizing the cost burden on remaining ratepayers**. Looking ahead, enhancing our understanding of which pathways represent the lowest cost-best fit options for greening the gas supply will help **optimize near-term investments in delivering a net zero future**.

Desired outcome

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. **We aim to engage with the scientific community to help direct the foundational research necessary** to better understand the dynamics and impacts of pursuing a range of decarbonization pathways.

We will also look 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 as we navigate this transition together. Additionally, we seek novel solutions and technologies from the innovation ecosystem that will enable PG&E to deliver on ambitious emissions reduction goals and to provide safe, reliable service more cost effectively than ever before.

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

THEME 1

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

Implementation of novel solutions that increase automation, data-driven decision making, and remote situational awareness can deliver numerous benefits across safety, reliability, and emissions reductions, while decreasing the overall cost burden to deliver these positive outcomes.

Both the scope and scale of our O&M programs, which entail ongoing work across the full extent of our 50,000 mile 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 ratepayers.

THEME 2

Reduce methane emissions from the gas system

Meeting our targets for methane emissions reductions will require investment in equipment upgrades and highly effective leak detection and repair technologies. Refining existing methane emissions calculations will enable PG&E to take a more targeted approach to prioritizing these investments, while novel technologies will enable PG&E to more effectively abate methane emissions across the system.

We recognize that avoiding the worst impacts of climate change will require bold action and fundamental changes to how the world, and PG&E, operates.

We have set ambitious targets for the transformation of our operations over the next 25 years in order to fulfill our purpose to help heal the planet. While we embark on the path of greening our gas operations by 2040, we are also pursuing aggressive measures to reduce methane emissions from our existing system in the interim. PG&E has committed to reduce Scope 1 & 2 emissions from natural gas operations by 45% by 2030. Delivering on this goal will require novel solutions that can be cost-effectively deployed at scale for the early detection and efficient remediation of leaks, as well as the mitigation of emissions during routine maintenance across the system. In order to effectively direct our efforts and track our progress, it is imperative that emissions calculations are able to provide accurate baselines and to precisely account for changes over time.

Definition	PG&E 2030 Goal/Initiative
SCOPE 1 EMISSIONS **Direct** emissions from PG&E's operations	Reduce Scope 1 & 2 emissions from natural gas operations **by 45%**
SCOPE 2 EMISSIONS **Indirect** emissions from facility electricity and electric line losses	
SCOPE 3 EMISSIONS Emissions resulting from **value chain activities** now owned or controlled by PG&E but that can be **indirectly** impacted through PG&E actions	• Reduce Scope 3 emissions from natural gas supply **by 20%** • Reduce cumulative carbon emissions **by 2.5MMT** by converting commercial and industrial (C&I) customers unable to electrify from dirtier fuels to natural gas • Deliver **15% RNG** in PG&E's core throughput • Operationalize hydrogen pilot by 2024 to inform safe levels of blending into the system **by 2030** • Pledge **$25M** towards sustainable uses for woody biomass with other partners
SCOPE 4 EMISSIONS An emerging term for categorizing emissions reductions enabled by a company. PG&E can make significant contribution by enabling these emission reductions in our service area	

We seek to identify novel solutions and approaches to both improve the accuracy of these existing emissions calculation methodologies and scale the impact of our emissions reduction efforts.

THEME 3

Decarbonize the gas system

Foundational research will better inform the industry's understanding of the challenges and impacts of integrating cleaner fuels into existing pipelines and system assets, and to customer applications and end uses.

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.

While it is widely accepted that hydrogen and other green alternatives will likely be important fuel 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 natural gas and other fossil-based fuels. 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.

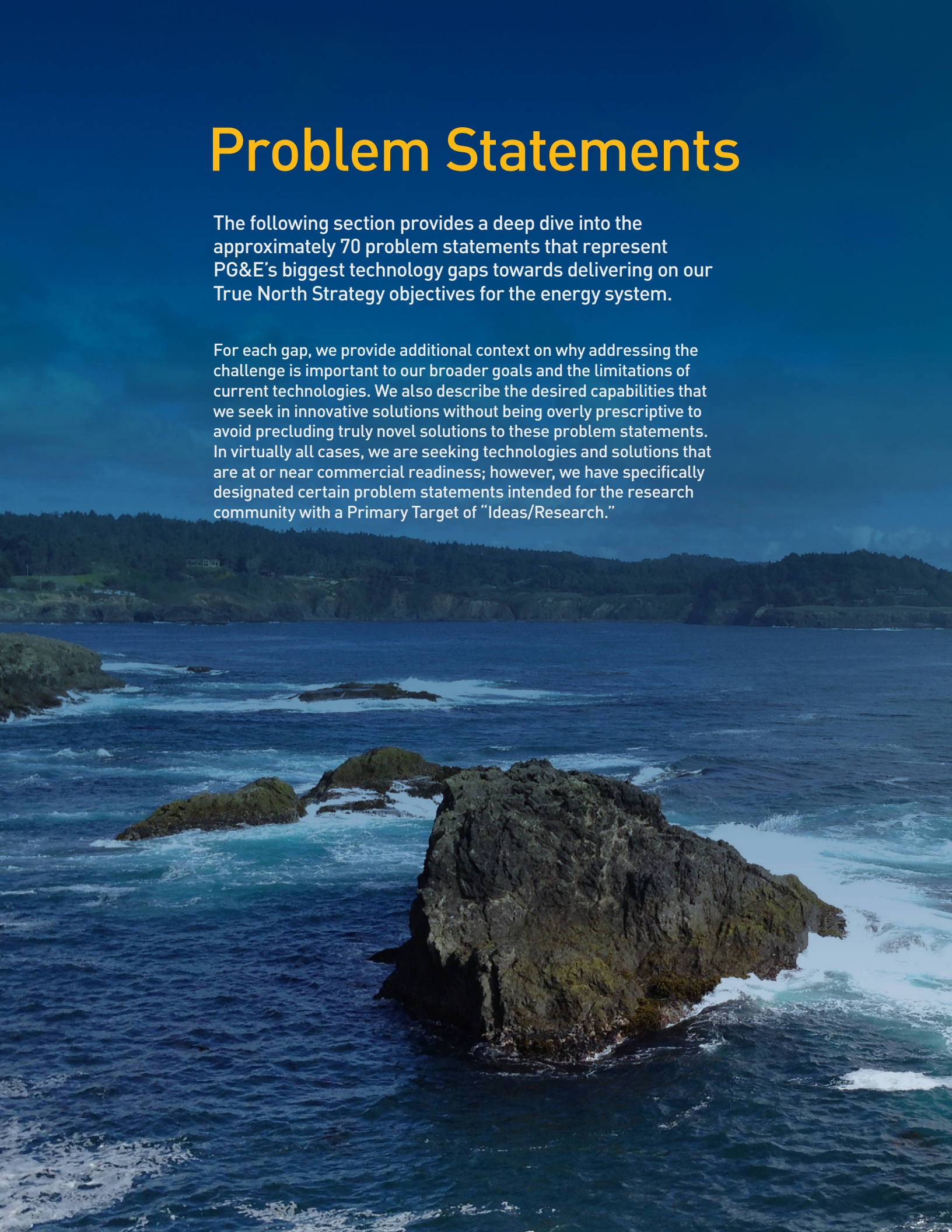
In order to determine the optimal path to a net zero future, PG&E is seeking the help of the scientific community to deepen the industry's understanding of the economics, properties, and interactions effects of cleaner fuels. Additionally, we seek avenues to extend this research beyond controlled laboratory 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 cost effective interconnection hardware to connect RNG supply to existing pipelines 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 affect the transition.

Problem Statements

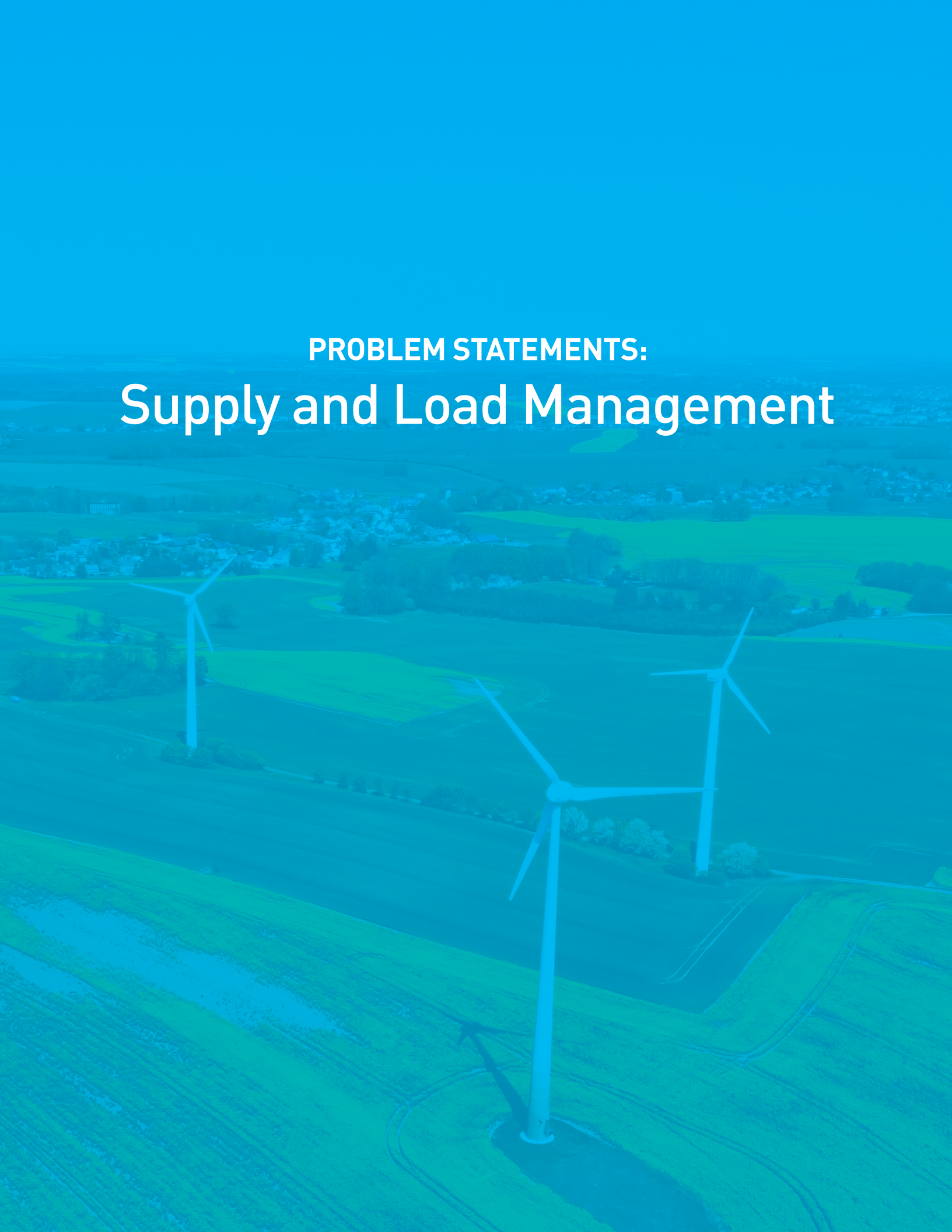
The following section provides a deep dive into the approximately 70 problem statements that represent PG&E's biggest technology gaps towards delivering on our True North Strategy objectives for the energy system.

For each gap, we provide additional context on why addressing the challenge is important to our broader goals and the limitations of current technologies. We also describe the desired capabilities that we seek in innovative solutions without being overly prescriptive to avoid precluding truly novel solutions to these problem statements. In virtually all cases, we are seeking technologies and solutions that are at or near commercial readiness; however, we have specifically designated certain problem statements intended for the research community with a Primary Target of "Ideas/Research."



PROBLEM STATEMENTS:

Supply and Load Management



THEME 1

Expand load management capabilities across all levels of the system

PROBLEM STATEMENT 1

Visibility into demand response (DR), DER, and EV Load Data

PG&E lacks consistent visibility into the device type, location, and energy usage data of existing and new DERs connecting to the grid. This poses a major challenge for distribution and transmission planning and operations and is a barrier to designing and implementing targeted demand management programs.

Why is this important?	PG&E's ability to predict demand is essential to maintaining a reliable grid both in the immediate-term and on a multi-year time horizon. As the share of supply and demand composed of DERs continues to rise, the need to understand and predict the behavior of these assets becomes increasingly important. This data must be taken into account for day-to-day system operations, long-term grid planning, and load management program design and execution.
What is the current state and its primary limitations?	While most DERs are connected to the internet and store location and usage data, this data is not consistently available to PG&E. Beyond site-level meter data on the hourly, or 15-minute interval, PG&E lacks a comprehensive way to collect essential demand data at the device-level. **Primary limitations include:** • A lack of visibility into the location and asset type for existing and new DERs connecting to the system • No standardized method for securely capturing electricity usage data at the device level
What are the desired outcomes from R&D?	**Novel solutions to:** • Comprehensively capture real-time DER-level location and usage data for all DERs on the network and store in a centralized depository

PROBLEM STATEMENT 2

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.

Why is this important?	Increasing DER penetration is driving significant load growth on the distribution network. Maintaining reliability while limiting expensive distribution service and substation capacity upgrades will require real-time, automated coordination of generation and load at the grid edge. These capabilities are essential to ensuring grid reliability, in addition to enabling continued customer electrification and higher penetrations of renewable supply.
What is the current state and its primary limitations?	PG&E's current grid monitoring and control rely largely on a centralized system to optimize power flows and detect and restore faults. As DERs proliferate on the distribution grid, coordinating these devices with real-time conditions on the grid becomes increasingly important to maintaining grid reliability. PG&E's current centralized control system was designed around last century's technology and is not equipped to coordinate flexible customer loads with local grid conditions across the entire distribution grid in a cost-effective and reliable way. **Primary limitations include:** • Lack of real-time data and analytics for detecting and addressing rapidly changing conditions on the distribution grid • Lack of capabilities to coordinate between customer sites with service transformer, conductors, substation transformers, substation banks, and local transmission
What are the desired outcomes from R&D?	**Novel solutions to:** • Automate power flow optimization on the distribution system • Automate fault detection, isolation, and service restoration • Coordinate between flexible customers loads and distribution grid assets in real-time

PROBLEM STATEMENT 3

Customer connection interface

PG&E lacks a consistent interface at customer sites capable of coordinating flexible loads with local conditions on the distribution system, thus limiting the potential for comprehensive load management on the distribution system.

Why is this important?	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. Not only does this interface have the potential to enable coordination between customer sites and real-time conditions on the distribution grid, but it can also minimize the need for expensive service upgrades by managing customer loads within service constraints. Further, this point of interface with the customer could have massively underutilized potential to provide additional value by avoiding the need for costly panel or service upgrades, by capturing insights that could be leveraged for bill savings, and a range of other novel applications.
What is the current state and its primary limitations?	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-sided flexible loads. Under the current technology regime, customers also may be required to pay for costly panel, wiring, or service upgrades when electrifying their homes and vehicles.
What are the desired outcomes from R&D?	**Novel solutions to:** • Monitor localized grid health • Receive and execute on direct control signals • Communicate customer usage patterns in real-time • Island customer sites • Enable secure loading of third-party applications • Cost-effectively scale across PG&E's entire system

THEME 2

Deploy new clean supply and energy storage technologies

PROBLEM STATEMENT 1

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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	**Long-duration assets are an important class of resources that may be transformative and disruptive at once. It is important to understand:** • The reliability and economic impacts on the aggregate portfolio of resources • The potential displacement (potential stranded investment) and utilization impacts on existing resources • The GHG and other environmental impacts • The impact on market prices and their uncertainties since these resources may be price makers (as opposed to price takers)
What is the current state and its primary limitations?	Current proprietary tools are not set up to address stochastic portfolio impacts of long-duration assets, including hydrogen, co-located (e.g., solar with batteries, offshore/onshore wind with batteries, etc.), pumped-storage, etc.
What are the desired outcomes from R&D?	**Desired outcomes include:** • Better understanding of the reliability, economic, and utilization impacts on the existing portfolio of resources • Ability to model potential GHG and other environmental impacts of long-duration assets • Enhanced ability to forecast market price implications associated with long-duration assets

PROBLEM STATEMENT 2

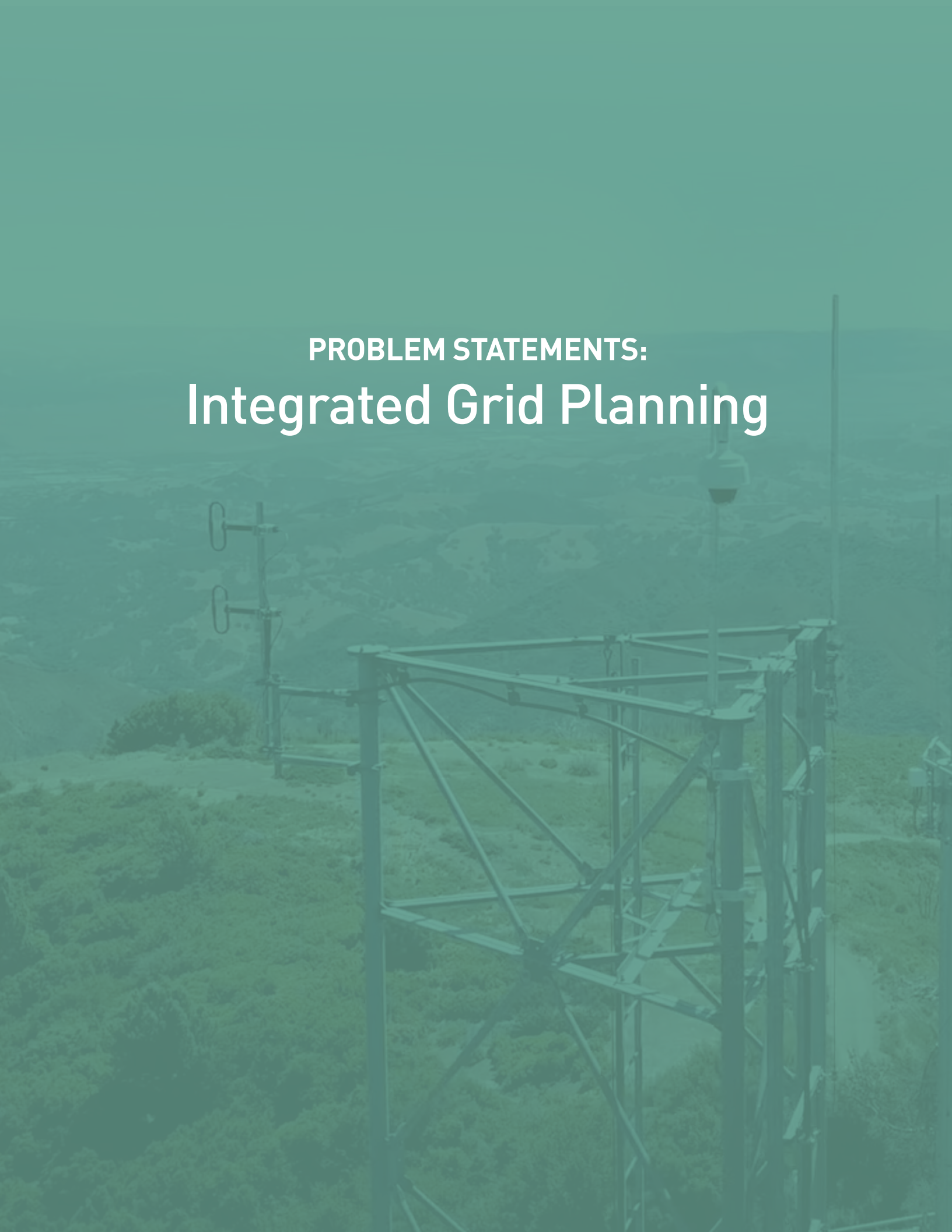
Deploying new clean supply and energy storage technologies

Relying solely on existing clean generation and storage technologies to support the transition to a net zero grid by 2040 will likely yield suboptimal results in terms of reliability and affordability.

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. For example, the CPUC estimates that California will need 1,000 MW of long-duration energy storage resources by 2030 and upwards of 4,000 MW by 2045. While PG&E will not fund the development of these technologies, we seek to demonstrate promising new technologies to understand the use cases, interconnection processes, and operational characteristics of these technologies.
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?	PG&E seeks to demonstrate the safe integration of new zero-carbon supply and storage technologies in order to validate use cases for these technologies and establish roadmaps to broader grid implementation. **Desired solution capabilities include, but are not limited to:** • Technologies that flatten the "duck curve" and/or provide ancillary services • Firm renewable generation

PROBLEM STATEMENTS:

Integrated Grid Planning



THEME 1

Reduce the need for conventional capacity upgrades

PROBLEM STATEMENT 1

Underutilized T&D infrastructure

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

Why is this important?	Electrification is expected to increase load across PG&E's service area by ~70% over the next 20 years, 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 lowering customer rates.
What is the current state and its primary limitations?	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 expense 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 the existing assets, further increasing project costs and timelines. **Primary limitations include:** • 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 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 reliability

THEME 2

Optimize prioritization and reduce costs of unavoidable capacity upgrades

PROBLEM STATEMENT 1

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.

Why is this important?	The electrification of transportation, buildings, and industrial processes will require connecting thousands of new loads to the distribution system over the next decade. In parallel, PG&E will need to prioritize and plan hundreds of capacity upgrades across the T&D system based on the evolving dynamics of customer load growth. Providing time and cost-efficient pathways to connect these new loads is necessary to achieve PG&E's emissions reduction and electrification goals, while optimizing the scale and priority of investments in grid infrastructure is key to ensuring affordable rates for all customers. We are seeking new tools to increase the pace, decrease the cost, and improve the customer experience of connecting new loads to the grid.
What is the current state and its primary limitations?	Under the current process, customers apply for new or upgraded service based on their maximum expected load with limited visibility into the available feeder capacity or length/composition of the existing queue. PG&E's review process uses a somewhat static model to identify constraints and plan necessary upgrades. **Primary limitations include:** • Lack of visibility into constraints and secondary effects of potential new loads • A highly manual and time-intensive application and review process that doesn't consider the queue of projects seeking capacity on the same feeder • Lack of tools to dynamically model power flows based on all loads seeking connection to the system • Limited ability for customer to change project scope during review process, leading to wasted time and cost for studies
What are the desired outcomes from R&D?	**Novel technologies to:** • Streamline application and review process (and automate where possible) • Help customers make informed decisions on where to locate and how to size new loads • Provide visibility into real-time feeder capacity limits and iterative power flow analysis tools • Optimize T&D buildout based on load profiles and resource flexibility of connecting loads

PROBLEM STATEMENT 2

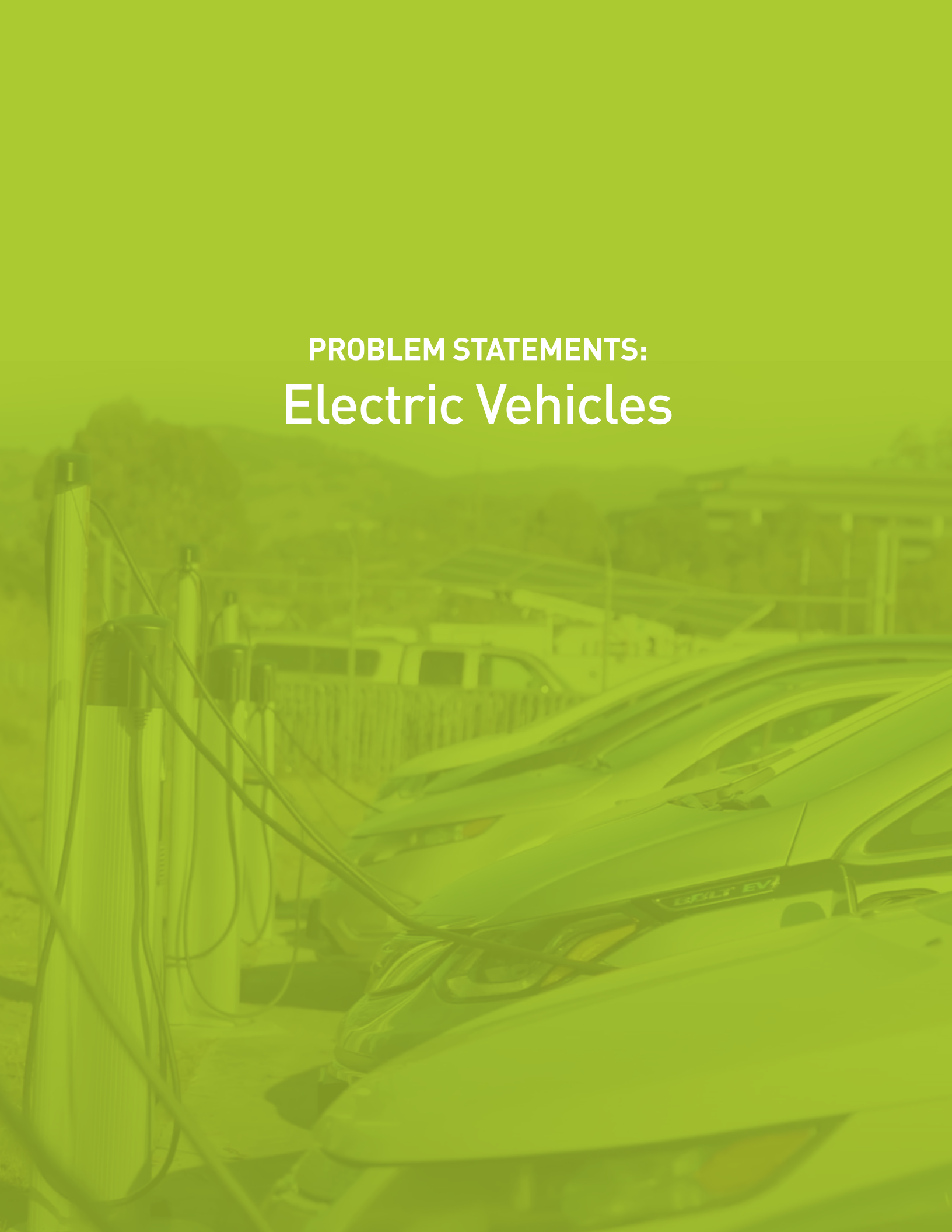
T&D asset replacements and upgrades

Upgrades to the T&D system typically require up-rating existing infrastructure which may 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 its 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.
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. **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)
What are the desired outcomes from R&D?	**Novel technologies to:** • Maximize the safe reuse and/or extend the useful life of existing assets • Test and qualify existing T&D equipment for reuse

PROBLEM STATEMENTS:

Electric Vehicles



THEME 1

Ensure affordable and timely connection for every customer

PROBLEM STATEMENT 1

Multi-family connections

Connecting an EV charger at a multi-family home can be a lengthy and costly process that is further complicated by the need for a third party (i.e., property owner/manager) to undertake these investments and provide ongoing operational support for billing and maintenance.

Why is this important?	Many multi-family home dwellers, which account for approximately half of California's population, do not have access to an at-home charger, thus limiting EV adoption. Multi-family charger installation often requires upgrades to a building's electrical system, as well as local utility service, both of which can be costly and time-consuming. A unique challenge for multi-family residences is that electrical work may be required in a common space such as a garage or parking lot, presenting further coordination challenges. Third-party property managers may lack sufficient incentive to undertake this complex and costly upgrade and installation work, especially if the building is older and requires substantial updates. Beyond the technical limitations, there are additional ongoing economic and support considerations that are specific to shared infrastructure and further complicate the build-out of multi-family charging infrastructure. These include uncertain utilization rates, managing tenant access to charging ports, and handling customer billing for charger use. In spite of these challenges, increasing multi-family charger accessibility, especially to disadvantaged communities, is paramount to meeting California's aggressive EV goals.
What is the current state and its primary limitations?	Currently, the property owner/manager works with electricians and PG&E to assess the building's existing electrical setup and the capacity of the local utility service to determine the extent of upgrades needed to support the installation of charging equipment. If constraints exist on the local service level, PG&E must complete grid upgrades prior to the installation of the charging equipment. Once completed, property owners/managers then obtain the necessary permits and bear the associated expense to complete necessary upgrades at the building. Property managers are responsible for determining the number of plugs required, how to manage access to charging equipment, ongoing maintenance, and customer billing. **Primary limitations include:** • High costs and extended wait times associated with lower utilization multi-family charging infrastructure installation and necessary electrical upgrades • Ambiguity 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 the common spaces
What are the desired outcomes from R&D?	**Novel technologies to:** • Adapt current chargers or design a new charger to meet multi-family residence needs • Reduce costs and timelines associated with the installation of multi-family charging infrastructure • Eliminate the need for costly electrical upgrades • Facilitate seamless billing at the customer level, removing coordination burden on property managers

PROBLEM STATEMENT 2

Capacity constraints for Direct Current Fast Chargers (DCFC) and fleets

PG&E is deploying systems that are able to dynamically limit power flow to DCFCs 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 efforts, but capacity constraints on the electrical system can lead to delays in connection times for customers while upgrades take place. To alleviate this constraint, PG&E is deploying systems to enable dynamic management of new loads within the capacity limits of existing infrastructure. These dynamic management systems require that customer charging equipment understand and respond to signals to modulate load as capacity fluctuates. Ensuring that circuits are prepared to manage the load that large-scale charging infrastructure requires and that charging hub customers are able to manage within dynamic constraints are both key to enabling fleet electrification at scale to support California's goal of transitioning 100% of medium- and heavy-duty vehicles to zero emissions vehicles (ZEVs) by 2045.
What is the current state and its primary limitations?	Currently, PG&E is deploying systems to dynamically manage capacity on constrained circuits to enable interconnection of new DCFC infrastructure while larger-scale capacity upgrades are in progress. In order to capitalize on this potential to connect to these constrained circuits sooner, all charging equipment must have maximized flexible capabilities to modulate power draw as system constraints evolve. Depending on the timing of vehicle charging needs, it might also be necessary that alternate power sources (e.g., storage) are available to meet the load during times when grid power is limited or unavailable. **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 to:** • Enable customers to adjust consumption based on a real-time or near real-time signal 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

Single-family connections

Customers connecting an EV charger at a single-family home may encounter unanticipated and significant costs and wait times to complete the on-site electrical work and may unknowingly create challenges for the broader system as service transformers become increasingly constrained, resulting in added costs to PG&E to upgrade existing infrastructure.

Why is this important?	Prior to purchasing an EV, PG&E customers are often unaware of whether their current electric systems and utility service can support EV charging infrastructure—from limits on the customers' panels, to limits on the utility wires and transformers themselves. Lack of visibility into consumption and a clear understanding of the load impact may leave customers waiting for months or facing extremely high and unexpected costs depending on the scale of required upgrades. The desire to avoid high costs and long wait times in these cases may increase the risk that some customers resort to completing unpermitted upgrades to connect their EVs, limiting PG&E's visibility into local service transformer loading. As EV adoption spreads, increasing charging load can lead to service transformer failures that can cause widespread outages and costly repairs for PG&E. Improving the existing connection process and the ability to manage newly connected EV load can remove critical barriers to customer adoption of EVs and can enhance PG&E's ability to provide a more orderly, streamlined, and transparent experience through the transition.
What is the current state and its primary limitations?	Currently, home charger installation is a timely process and can cost thousands of dollars, depending on the scale of upgrades required. To avoid these high costs and long wait times, customers in some cases may bypass the permitting process and install EV charging equipment without permits, necessitating PG&E to take a reactionary and costly approach to the problem. Required work to install an EV charge 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:** • Customers lack visibility into their home electrical system and utility service constraints that will require remediation in order to support EV, which limits their ability to accurately understand installation costs prior to EV purchase • High costs and long timelines associated with electrical upgrades necessary to install EV equipment • PG&E lacks visibility into increasing charging loads and evolving constraints at the service transformer level, leading to costly and reactive repairs
What are the desired outcomes from R&D?	**Novel technologies to:** • Increase customer visibility into the constraints that exist on their current system and improved flow throughout the process to help customers identify the best approach for their system to better plan for fully loaded cost of EV purchase • 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 to avoid transformer failures and costly repairs for PG&E

THEME 2

Unlock potential of EVs as grid assets

PROBLEM STATEMENT 1

V2X connections

Technologies required to enable V2X are costly and time-consuming to install for both the utility and customer.

Why is this important?	EV ownership is increasing across the country, thus leading to heightened stress on the grid and creating challenges and costs for both customers and PG&E alike. Increasingly, EVs are equipped with vehicle-to-grid (V2G) capabilities, which enable electric vehicles to provide power back to the electrical grid. V2G enablement has the potential to reduce grid stress by making use of EVs' high-capacity batteries when not in use to provide power to the grid during peak demand events or to serve as a critical backup power source during outages. Assuming each EV will have 60–80 kWh of capacity in the future, reaching PG&E's goal of serving 3 million EVs by 2030 would imply a total of 180–240 GWh of EV battery capacity that could be tapped to support the grid. Additionally, V2G can create an additional value stream for customers in the form of value-based payments from the utility for power provided to the grid, lowering the total cost of EV ownership, and encouraging wider EV adoption. Addressing existing barriers to broader V2G enablement can help unlock the full potential of vehicle-to-grid capabilities for both the customer and the utility.
What is the current state and its primary limitations?	Enabling V2G capabilities requires incremental investment from both the utility and the customer above any costs for foundational upgrades to support one-way charging that have already been incurred. These additional upgrades can include the purchase and installation of a new panel and costly on-site work to add new system wires/components and relocate loads. **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 remain costly • Installing V2G infrastructure is time consuming due to the often necessary electrical upgrades
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce the cost or the need for electrical and panel upgrades when installing a bi-directional charger • Enable more rapid installation of V2G equipment • Decrease the cost of V2G charging equipment to lower the total upfront expense of enabling V2G

PROBLEM STATEMENT 2

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.

Why is this important?	The fundamental designs of America's grid infrastructure were conceived contemporaneously with the invention and adoption of the gas-powered automobile. While both have evolved significantly over the last 130 years, the eventual transition to and widespread adoption of electric vehicles was not a consideration along this path. As such, the designs of today's grid infrastructure were not conceived to support the type of rapid and widely dispersed load growth characteristic of today's EV transition, nor were they optimized to capture the opportunity inherent in the introduction of millions of distributed, highly mobile, and highly flexible energy resources at the customer level. Breakthrough thinking that takes a first principles approach to reimagining the foundational designs and operating models of the grid with today's evolving dynamics in mind could fundamentally alter how we at PG&E serve our customers in the decades ahead.
What is the current state and its primary limitations?	Given the pace of EV adoption across our service area, much of today's focus is necessarily centered on adapting and enhancing today's infrastructure to accommodate the transition as seamlessly as possible. While this work is exceedingly important and will continue, it is also critical that we simultaneously seek ideas and technologies that could enable us to leverage EVs as grid resources in new and previously unimagined ways.
What are the desired outcomes from R&D?	Given the broad scope of this problem statement, the solution set is less clearly defined. However, our desired outcome is to identify ideas, technologies, and solutions that will enable PG&E to unlock the full potential of EVs as a resource to support our mission to provide clean, affordable, and reliable energy to our customers. **Example solutions and technologies may include:** • Second life for EV batteries: identify novel means for collecting and repurposing used EV batteries to provide a second life as energy storage for the grid • EVs as distribution assets: enable the utilization of EVs as mobile distribution assets to transfer energy from centralized charging hubs to remote customer loads

PROBLEM STATEMENTS:

Wildfires

THEME 1

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

PROBLEM STATEMENT 1

Asset lifetime prediction

Current technologies lack the ability to determine the expected safe lifetime of transmission assets once degradation has been documented, leading to unpredicted, continued asset degradation and potential risk of failure, as well as additional costs when assets are unnecessarily replaced prematurely.

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 transmission assets once degradation has been documented or estimate how repairs will impact the remaining useful life. PG&E takes a proactive approach to managing potential asset failures, realizing a 58% decrease in reportable ignitions due to equipment failure in 2022 relative to the latest 3-year annual average. Technological improvements in available diagnostic technologies and/or predictive solutions could help PG&E achieve its goal of zero reportable ignitions moving forward. These innovations could also improve electric service reliability and cost, as the inability to predict safe asset lifetime after degradation has been observed may result in unexpected customer outages or the costly premature replacement of assets with remaining useful life.
What is the current state and its primary limitations?	PG&E's transmission assets degrade over the course of decades as a result of both environmental and non-environmental factors. PG&E inspects its transmission assets on a regular annual cycle via visual inspections, augmented by remote sensing technology in certain instances. The data that is collected 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 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
What are the desired outcomes from R&D?	**Novel technologies to:** • Improve accuracy of PG&E's asset degradation assessments • Enable more accurate understanding or prediction of assets' remaining safe and useful lifetime

PROBLEM STATEMENT 2

Limitations of overhead inspections

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 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 automated, efficient, and systematic review of data collected by routine inspections

PROBLEM STATEMENT 3

Continuous monitoring

There is currently no cost-effective method for ubiquitous and continuous monitoring of the entire overhead system, limiting visibility into asset conditions and PG&E's ability to proactively remediate evolving threats between inspection cycles.

Why is this important?	While PG&E completes comprehensive routine inspections of its overhead system, there is not a scalable solution for continuous system-wide monitoring. Given that our assets exist in a dynamic environment and conditions can evolve rapidly, risks can develop between cycles that were not apparent during the most recent inspection. Continuous, comprehensive monitoring of the overhead system would provide better ongoing visibility into evolving conditions and help to further reduce the ignition risk.
What is the current state and its primary limitations?	PG&E currently conducts periodic inspections of its overhead network utilizing a wide range of methods, from ground surveys to drone and helicopter inspections, to collect photos, videos and LiDAR data. PG&E is exploring other monitoring options and has deployed both a limited network of line-mounted sensors that monitor voltage and current and substation-based solutions that monitor circuits and is also conducting limited pilots of pole-based sensors. Comprehensive communications solutions to enable the timely relaying of information of system conditions and alerts are also not currently scalable at cost. **Primary limitations include:** • Lack of scalable solutions for ongoing asset health monitoring • High costs of deploying continuous monitoring at scale • Insufficient communications capabilities to provide real-time systemwide connectivity, including the most remote areas of the grid • Lack of a single, comprehensive device/solutions 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)
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable ongoing visibility into a wide range of local conditions impacting asset health between inspection cycles • Reduce costs of deploying and maintaining monitoring system at scale • Provide real-time communications connectivity for sensors in the field capable of relaying ongoing information

PROBLEM STATEMENT 4

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 of data • Expand types and scale of data collected beyond photos and videos submitted through external app

THEME 2

Eliminate ignitions with improved protection schemes

PROBLEM STATEMENT 1

Eliminating ignitions

While EPSS is enabled on all circuits in HFTDs, there are still reportable ignitions occurring on EPSS-enabled circuits and gaps in the abilities of this technology.

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 68% reduction in ignitions on EPSS-enabled power lines compared to the 2018–2020 yearly average, PG&E is targeting zero total ignitions. Further enhancing the abilities of existing ignition prevention systems will enable PG&E to more proactively address developing risks and 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. But despite a drastic reduction there were still 31 reportable ignitions on EPSS-enabled circuits in 2022, indicating that gaps in EPSS capability still remain. Further analysis may be required to determine the specific nature of the gaps in the ignition prevention capabilities of the existing system. **Primary limitations include:** • Inability of existing EPSS technology to comprehensively eliminate all ignitions on enabled circuits • Gaps in technologies that are used alongside EPSS. The Down Conductor Detection (DCD) program may be helpful in addressing some of the gaps in EPSS, but its sensitivity may limit its applicability
What are the desired outcomes from R&D?	**Novel technologies to:** • Achieve zero total ignitions across PG&E's entire system

PROBLEM STATEMENT 2

Fault energy

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 to deploy.

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 may be limited due to the difficulty 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. REFCL is currently projected to be costly to scale and is complex to implement and operate. 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 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 3

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.

Why is this important?	Mainstream electrical equipment is not primarily designed to fail safely and thus poses a significant ignition and wildfire risk. There were an estimated 14 reportable ignitions in 2022 as a result of equipment failure. This results in additional costs, as it is crucial for PG&E to invest in monitoring and fault mitigation that will avoid dangerous equipment failure. If electrical equipment could be relied upon to fail safely, it would be possible to avoid ignitions from equipment failures, as well as reduce system-wide costs associated with the mitigation of asset failure risk.
What is the current state and its primary limitations?	Today's electrical equipment was fundamentally not designed to fail safely (e.g., without sparking, flaming, etc.). 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. PG&E invests heavily in additional monitoring, inspections, and supplemental technologies intended to mitigate the risks associated with unsafe failures. 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:** • Distributed nature of equipment design and manufacture that is owned by a variety of third-party equipment manufacturers and suppliers • 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 to:** • Re-imagine failure behavior of electrical equipment so as to limit outcomes that could lead to ignitions • Reduce the necessity of frequent asset monitoring by targeting the source of the risk

PROBLEM STATEMENT 4

Gaps in ignition notification

Today's ignition monitoring and notification technologies are limited in their ability to provide highly accurate and locationally precise information across PG&E's system on a real-time basis, leaving room for improvement in ignition response times.

Why is this important?	While PG&E utilizes several different methods and technologies as a part of their ignition monitoring and notification system, today's technologies have significant gaps. PG&E is therefore limited in its ability to provide expedited responses targeted to the sites of ignitions, increasing the risk of wildfires. An improved ignition notification system would help to improve response times and to direct resources to a more precise location, thereby increasing the likelihood of containing 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. **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
What are the desired outcomes from R&D?	**Novel technologies to:** • Expand real-time notification capabilities across all applicable assets on PG&E's network • Reduce latency and improve precision of alerts • Enable PG&E to more efficiently direct response resources so as to more effectively eliminate the risk of ignition events and the spread of fires

PROBLEM STATEMENT 5

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.

Why is this important?	While there are numerous technologies to detect faults deployed across PG&E's system, they generally are limited in their ability to provide highly accurate locational information. As a result, PG&E must spend considerable time locating the fault in the field before power can be restored to customers, extending disruptions that can have economic or safety related consequences. Additionally, current technologies generally lack the ability to locate and alert to deterioration and faults within assets, such as partial discharges, which can introduce safety and reliability risks to the system. Enhancing the ability to better understand when and where faults or pre-fault conditions are occurring will improve overall system safety and reliability.
What is the current state and its primary limitations?	PG&E employs multiple technologies across its system to quickly and accurately alert when a fault occurs. While the current state-of-the-art is able to successfully identify when a fault has occurred, the majority of these solutions are limited in their ability to also precisely locate the fault on a circuit. As such, resources deployed in the field to address the issue must spend valuable time identifying the precise location of the fault before work can begin to restore service. **Primary limitations include:** • Ability to precisely identify and communicate the geographic location of faults and incipient faults • Ability to identify the location of deterioration and faults within assets (e.g., partial discharges) to enable proactive maintenance prior to failure
What are the desired outcomes from R&D?	**Novel technologies to:** • Provide highly accurate and precise location information associated with faults across both overhead and underground assets • Expand the scope of faults and asset degradation that current technologies are able to identify, including those occurring with assets such as transformers • Cost effectively scale across PG&E's system

THEME 3

Eliminate customer impacts from PSPS/EPSS

PROBLEM STATEMENT 1

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.

Why is this important?	Public Safety Power Shutoffs and Enhanced Powerline Safety Settings are tools that remain important in reducing wildfire and ignition risk; however, service outages present significant risks to human health and safety, in addition to posing economic consequences to customers. Given that these programs at this time are critical to eliminating wildfire risk across PG&E's system, it is imperative that we are able to mitigate any negative impacts on customers associated with planning for and managing through these events. In order to provide reliable electricity and positive experiences for its customers, PG&E must reduce the personnel resource intensity and completion times of PSPS and EPSS patrols in order to restore power in a timelier manner.
What is the current state and its primary limitations?	PSPS and EPSS are programs aimed at reducing wildfire risk in targeted areas of PG&E's system through targeted de-energization of electrical equipment during times of elevated wildfire risk (PSPS) or when a suspected electrical issue has been detected (EPSS). While these measures have proven very effective at decreasing ignition risks, they also cause outages that are impactful to our customers. Once an event has occurred, PG&E must perform on-site patrols of impacted areas to ensure that any risk has been remediated prior to re-energizing the affected section of the system. The average restoration time for PSPS events in 2021 was 12 hours. PG&E continues to install sectionalization devices, which separate the electric grid into smaller sections, to allow for more targeted de-energization and to narrow the scope of outages. While these and other measures have proven effective at reducing the number and scope of PSPS and EPSS events without increasing risk, we are looking for solutions to further limit the impact of these events on our customers. **Primary limitations include:** • Resource and time intensity of required PSPS and EPSS patrols, especially in hard-to-reach locations • Restriction of patrols to daylight hours in rural or difficult terrain, further delaying restoration timelines • Inability to accurately determine the root cause of an outage, in spite of resource intensity of patrols • Limited ability to precisely target the impacts of these outages, and therefore the scope of the patrols necessary to restore power
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce patrol times and significantly expedite power restoration for PSPS/EPSS events • Improve communication with customers around outage occurrences and restoration times • Improve visibility into outages to eliminate more difficult and resource-intensive aspects of patrols (e.g., hiking)

PROBLEM STATEMENT 2

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.

Why is this important?	EPSS is enabled on all circuits in high fire risk areas and reduces wildfire risk by de-energizing a line within one-tenth of a second of contact with an object. While EPSS has been effective in many circumstances, current response rates are not sufficient to enable micro-targeted EPSS activations when there are multiple protective devices on the feeder. Improvements to relay rates and line recloser configurations could allow for more targeted EPSS activations that impact fewer customers while maintaining safety benefits.
What is the current state and its primary limitations?	The current EPSS relays activate in approximately 35 milliseconds, which is insufficient to enable micro-targeted activations when there are multiple protective devices on the feeder. Faster recloser response rates could enable PG&E to achieve better coordination of protective devices across a wider range of circumstances. **Primary limitations include:** • Insufficiently fast relay response rates when multiple protective devices are present on a feeder • Continued occurrence of customers experiencing multiple EPSS-related outages per year
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable faster relay response rate of 20 milliseconds or below • Improve coordination amongst multiple protective devices present on a given feeder • Limit the scope of EPSS activations and the number of customers affected

PROBLEM STATEMENT 3

PSPS/EPSS customer outages

While highly effective at reducing wildfire risk, PSPS and EPSS programs are also highly impactful to customers, resulting in potentially lengthy electrical outages that can be disruptive and costly and may impact the same customer multiple times throughout the course of the year.

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 time 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. Additionally, back-up generation is often provided by diesel generators which increase system emissions. **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 to:** • Eliminate customer impacts resulting from PSPS and EPSS events

THEME 4

Optimize vegetation management (VM)

PROBLEM STATEMENT 1

Accuracy of vegetation management patrols

Current modeling and analytics solutions are insufficient for precisely targeting and prioritizing vegetation management patrols based on evolving conditions across the system.

Why is this important?	Vegetation contact with electrical assets is a primary cause of ignitions across PG&E's service area, resulting in 38 reportable ignitions in HFTDs in 2022. PG&E therefore invests extensive time and resources in managing vegetation to minimize this risk. Vegetation management patrols are conducted system-wide on a fixed schedule, as current technology does not support the ability to tailor this approach at a hyper-local level. Improved analytics, modeling, or other solutions to provide a more granular understanding of evolving risks in terms of both time and location 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 performs an annual vegetation management patrol to ensure all vegetation is at least 18 inches away from primary lines and is not straining or abrading secondary lines. For HFTDs, the frequency of these patrols is increased to semi-annually. While comprehensive in scope, the vegetation management scheme is not targeted based on hyper-localized risks as current technologies to collect, analyze, and model this data are not commercially available. **Primary limitations include:** • Lack of highly geographic specific data on wildfire risk, vegetation conditions, etc. • Insufficient capabilities for modeling wildfire risks related to vegetation at a hyper-local level to inform prioritization of vegetation management efforts
What are the desired outcomes from R&D?	**Novel technologies to:** • Optimize the frequency and geographic specificity of patrols based on local conditions • Collect and analyze data to inform the targeting of vegetation management controls

PROBLEM STATEMENT 2

Gaps in moisture monitoring

The industry's current understanding of how various moisture readings impact tree health and associated ignition and propagation risks is limited and industry standard techniques to assess live fuel moisture content are subject to high degrees of variability based on factors unrelated to risk (e.g., time of day for sampling).

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. 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?	While PG&E monitors tree moisture, technical capabilities and foundational research is lacking across the industry to ensure accurate readings across a variety of conditions and a complete understanding of how various outputs should be interpreted in the context of risk of ignition or propagation. **Primary limitations include:** • A lack of data and research into the exact moisture sources that are most indicative of ignition risk • Inability to perform live fuel moisture calculations without the need for off-site analysis
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable live fuel moisture sampling on-site • Improve ability to model tree health based on a variety of conditions, including moisture

PROBLEM STATEMENT 3

Healthy tree failure

Green healthy trees can fail despite having no visible defects, thus creating an ignition risk in HFTDs that PG&E cannot currently 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 in order 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 green 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 identification of dead and dying trees that could fail and come into contact with assets, creating an ignition risk. However, current vegetation management procedures for trees at PG&E rely heavily on the outward appearance of trees. They cannot accurately determine when healthy-looking trees may fail, meaning that green healthy trees can still be a wildfire risk that PG&E currently cannot abate. **Primary limitations include:** • Inadequate research into why green healthy trees fail, limiting PG&E's ability to reduce this risk • Lack of technologies capable of 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 to:** • Improve ability to determine when healthy-looking trees should be abated or removed • Reduce the number of ignitions from trees falling unexpectedly and reduce costs from damaged assets when this happens

PROBLEM STATEMENT 4

More targeted 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 its vegetation management practices, PG&E removes trees that have been damaged by fires, as they are presumed to be weakened and likely to present a further risk to assets and ignitions. However, many tree species in California are fire-adapted, meaning that they are able to sustain fire damage and continue to grow and thrive without introducing incremental risk to the system. The ability to better understand the condition of fire-damaged 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 its removal of fire-damaged 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 actually an ignition risk and the level of risk posed • Inability to perform these assessments at scale in the field
What are the desired outcomes from R&D?	**Novel technologies 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

THEME 5

Enhance and standardize forest management practices

PROBLEM STATEMENT 1

Wood management and conversion

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

Why is this important?	PG&E manages large amounts of wood debris across its 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 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 manages 52,000 acres of forested land and expects to generate up to one million tons of wood debris of material in 2023 alone with tens of millions of dollars in associated direct costs. Using machinery 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 experimented with creating biochar through burning wood and carbonizing wood waste, which could have significant environmental benefits, though current methods are not 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 to:** • Cost effectively densify close to the wood source • Improve the safety of existing wood management methods, including reduction in 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)

PROBLEM STATEMENT 2

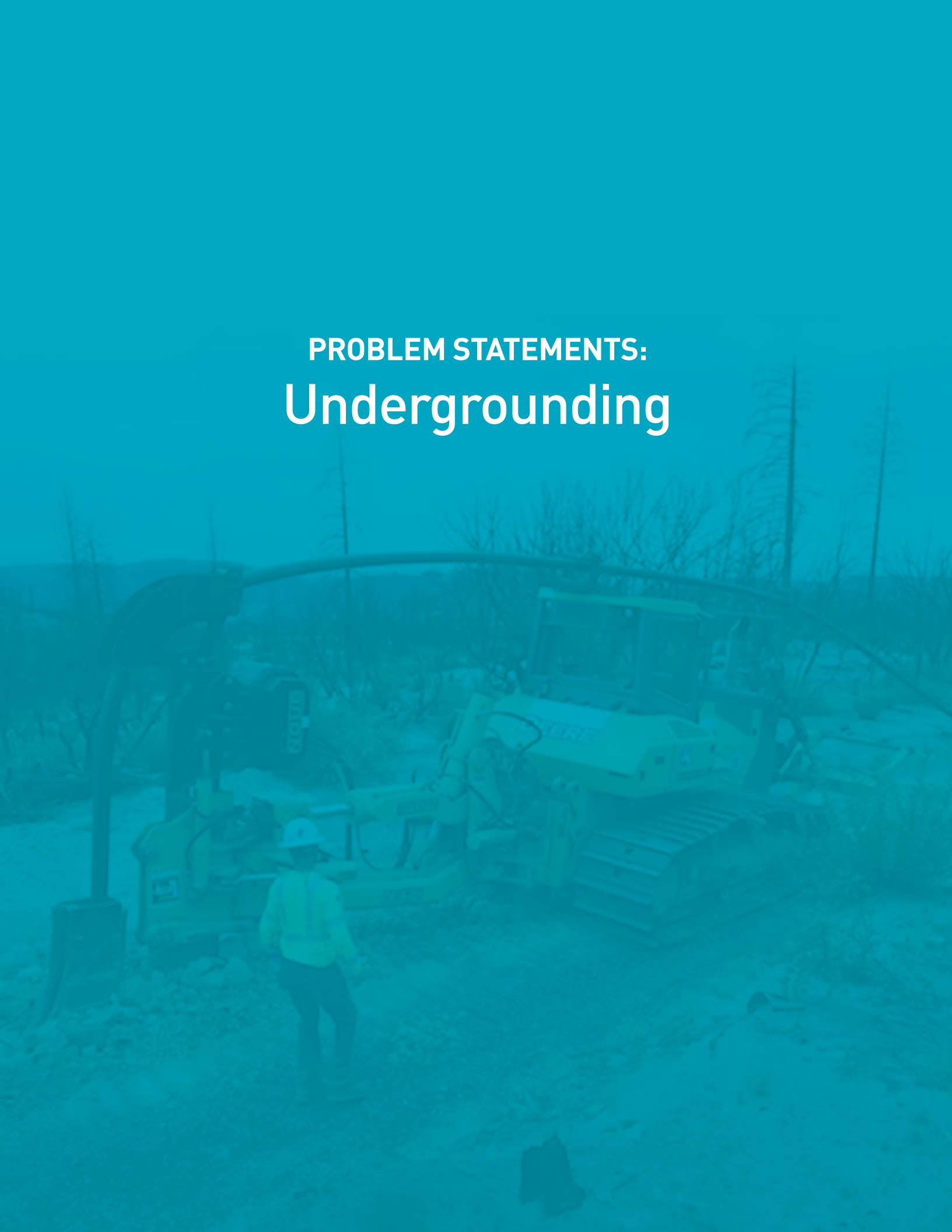
Targeted forest management

PG&E is unable to analytically prioritize potential land use treatment investments due to the lack of relevant advanced analytics and valuation capabilities.

Why is this important?	Healthy forest ecosystems can reduce wildfire risk by increasing forest resilience and reducing spread and consequences risk. PG&E does not currently have the ability to evaluate where healthy forests beyond rights of way would provide the most mitigation value and how much value that could create relative to other risk mitigation options. The ability to adopt a more targeted, data driven approach to targeting forest management for potential support and collaboration could 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, scalable optimization and valuation methodology for the values that healthy forests can provide for an electric utility, and how forest restoration investments might compare against other wildfire mitigation alternatives. **Primary limitations include:** • Lack of generally agreed upon optimization and valuation methodology • Lack of tool equipped for this utility use case
What are the desired outcomes from R&D?	**Novel technologies to:** • Optimize land management prioritization and value in PG&E supporting, collaborating, and/or advising on work on third party lands near assets • Value the return on investment of potential utility forest health restoration support and outcomes

PROBLEM STATEMENTS:

Undergrounding



THEME 1

Improve the efficiency of underground civil construction from survey to installation

PROBLEM STATEMENT 1

Construction methods

Converting overhead lines to underground has a high unit cost per line mile due to challenging environmental conditions (e.g., soils, rock, accessibility), lack of space and presence of existing underground facilities, and the need to cross canyons, creeks, and other challenging terrain.

Why is this important?	Civil construction comprises a significant 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, difficult to access areas, crosses through extremely hard rock (i.e., granite), and may traverse steep grades or require water crossings. Addressing these challenging use cases is essential to the cost-effective completion of the 10K 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. There is currently no one-size-fits-all approach that can be easily deployed across the 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 • Generation of spoils that are costly to remediate and off haul • Inability to easily maneuver in locations that are difficult to access and where space is constrained by difficult topography or existing underground facilities
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable cost effective undergrounding in remote, rocky, and steep terrain • Reduce the generation of spoils, minimize costs and time associated with treatment and disposal, and maximize the opportunity for productive reuse on-site • Enable efficient water crossings, compliant with all applicable regulations *Note: at surface alternatives to undergrounding are also in-scope*

PROBLEM STATEMENT 2

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.

Why is this important?	Accurate subsurface surveying and mapping are critical tools for PG&E to identify underground obstacles and soil characteristics before finalizing route design and beginning underground construction. When obstacles and ground characteristics are known early in the design process, routes can be optimally planned and costly re-work due to unexpected obstacles (i.e., boulders, third-party utilities, etc.) and terrain conditions can be avoided. Working in rural areas presents a greater challenge as less data is available, and obstacles can be difficult to identify in rural and uneven terrains. Spoils management is one of the largest drivers of cost within civil construction for undergrounding assets. Soil characteristics must be understood prior to digging to enable planners to optimize routes avoiding hazardous or sensitive terrain, to select the most effective construction equipment and techniques, and to develop detailed spoils management plans.
What is the current state and its primary limitations?	PG&E utilizes a range of subsurface mapping technologies based on the project setting. Advanced technologies, including ones that utilize Ground Penetrating Radar (GPR) and AI, are not currently sensitive, accurate, and fast enough to be used consistently in a production environment. While able to provide a more comprehensive subsurface picture of underground obstructions, these tools lack the ability to also generate a clear understanding of soil composition, making pot-holing necessary to obtain this information. **Primary limitations include:** • Inability to provide accurate map of soil composition and type • Inability to provide accurate readings at all applicable depths and across all soil conditions (e.g., unreliable readings when soil has high moisture content) • Difficulty locating unmarked third-party utilities and other obstacles, depending on material composition (e.g., polyvinyl chloride (PVC) pipes without tracing wires) • Difficulty generating readings on uneven terrain, due to push-cart construction or lack of effective aerial-platform-based solutions
What are the desired outcomes from R&D?	**Novel technologies to:** • Identify underground obstacles and soil composition quickly and accurately • Operate effectively across rocky and uneven terrain • Generate readings across the full range of PG&E use cases, including various depths, soil compositions, and third-party utility materials • Aggregate underground obstacle data in an accessible platform for vendors to reference while planning underground routes

PROBLEM STATEMENT 3

Conductor and splice technologies

Current conductors are limited in their pull lengths, requiring frequent installation of primary boxes, generating spoils, and necessitating splices, which are a common failure point for underground networks due to their complexity and reliance on manual workmanship.

Why is this important?	Existing conductor and splice technologies impose limitations on the undergrounding construction process that render it more costly and time consuming. Notably, concerns around the integrity of conductor casings prevent the adoption of direct burial construction methods and limit pull lengths for existing cable-in-conduit installations. Current splice technology also presents time and cost challenges to the undergrounding program, as splices must be installed manually and housed in enclosures that require additional construction efforts and generate spoils that must be remediated. Additionally, manual splicing techniques may result in workmanship errors that can lead to cable degradation over time. The ability to adopt direct burial methods, extend current pull lengths, or automate splicing could result in significant cost and time savings across the entire underground portfolio.
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 and sometimes High-Density Polyethylene (HDPE) conduit with maximum pull lengths ranging from 800–1200 feet to avoid excess strain on the casing of the conductor. Splices connecting adjoining runs of cable are installed manually and are housed in concrete primary boxes. **Primary limitations include:** • Shorter pull lengths result in an increased for need splices and splice enclosures • Complicated, manual splicing methods are time-consuming, error prone, and result in a common driver of maintenance and repairs
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable longer pull lengths and reduce the number of connections, while maintaining a similar load profile • Reduce the complexity of traditional splicing methods, enable direct burial, or reduce the overall time and cost associated with connections • Automate splicing to meaningfully reduce the level of manual effort associated with current splicing and splice monitoring methods

THEME 2

Identify scalable solutions for system components difficult to underground

PROBLEM STATEMENT 1

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.

Why is this important?	Service drops are a critical and ubiquitous component of the electrical system that connect from the service transformer to the customer's connection point. Ignition risk from service drops accounted for approximately 3% of reportable distribution system ignitions in high fire threat areas over the last three years. Additionally, leaving these connections above ground after distribution undergrounding can also trigger a PSPS event when customer expectation in the area may be that PSPS events should have ceased with the completion of the undergrounding of the distribution system. Connecting a customer's service drop from the newly installed underground distribution infrastructure is often difficult, time-consuming, and can cost tens of thousands of dollars. In addition, the process can negatively impact customers, requiring trenching through property and/or require panel or service upgrades and relocations that increase costs and extend customer disruptions. The lack of technology to cost effectively and non-invasively underground this critical component limits PG&E's ability to mitigate risk across the entirety of its distribution infrastructure.
What is the current state and its primary limitations?	The current process for undergrounding a service drop involves trenching through customers yards, which poses risks to customer's existing third-party utilities (e.g., water, septic). Once wires have been buried, additional work to upgrade or relocate customer panels may be required in order to complete the connection. **Primary limitations include:** • Need to trench through customer property • Compatibility issues with older customer electric panels that may require upgrades to complete connection • Need for panel relocations based on the position of the existing panel in relation to where the newly undergrounded connection reaches the customer connection point
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce cost, risk, and complexity associated with undergrounding service drops • Streamline/remove permitting process by avoiding digging altogether (at-surface technologies are a viable solution) • Reduce customer disruption by avoiding the need for a panel or service upgrade or relocation • Harden overhead service drops with a similar wildfire risk reduction outcome as undergrounding

PROBLEM STATEMENTS:

Gas

THEME 1

Maintain and continually improve system safety and reliability, while reducing O&M costs

PROBLEM STATEMENT 1

Meter set 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.

Why is this important?	Meter set leaks contribute to 11% of total baseline emissions from PG&E's gas system. Many meter sets are added to the repair queue during the course of a year, potentially resulting in a backlog awaiting service at any given time. Existing time-consuming repair technologies impede progress against this backlog and delay addressing associated emissions.
What is the current state and its primary limitations?	Current state leak repair technologies require shutting off service to the meter and fully breaking down the meter set in order to complete the repair. This process can be extremely time consuming to complete, often taking up to an hour to break down and repair a single meter and may pose a safety risk to co-workers completing repairs in the field. **Primary limitations include:** • Lengthy process to repair meter set leaks requiring temporary service shut off and full meter set disassembly and reassembly • 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 to:** • Shorten repair times 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 • Ensure co-worker safety while assessing meter set and completing repairs

PROBLEM STATEMENT 2

Crack assessment and monitoring for small pipes

State of the art crack detection and monitoring technologies used widely in industry are not suitable for smaller diameter pipes (6" or less), making compliance with regulations to complete these processes very costly.

Why is this important?	Requirements for the Pipeline and Hazardous Materials Safety Administration's (PHMSA) 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 extend its periodic crack assessment processes to additional sections of pipeline, which include networks of smaller pipes. No economical solution to perform these assessment processes currently exists.
What is the current state and its primary limitations?	Existing technologies capable of performing newly required crack detection inspections for smaller pipes are costly, intrusive, and require that segments of pipeline be taken out of service during inspection. In some cases, these methods rely on iterative test and repair cycles that may extend over a prolonged period, requiring significant resources and resulting in negative impacts to customers. **Primary limitations include:** • Inability to scalably and cost-effectively perform crack assessments in smaller diameter pipes • Need to take segments of pipeline out of service, sometimes for extended periods
What are the desired outcomes from R&D?	**Novel technologies to:** • Complete crack detection inspections across all sections of PG&E's transmission pipeline system in compliance with regulation • Reduce the costs and timelines associated with performing these inspections • Eliminate customer impacts or significantly reduce their scope and duration

PROBLEM STATEMENT 3

Material properties verification for existing pipe

New regulations require that PG&E verify the actual Yield Strength (YS) and Ultimate Tensile Strength (UTS) of pipeline across its existing network of installed underground assets; however, existing verification processes are costly and disruptive or lack accuracy and repeatability.

Why is this important?	Requirements for the Pipeline and Hazardous Materials Safety Administration's (PHMSA) 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 verify and record several different materials properties across its pipeline network, including Specified Minimum Yield Strength (SMYS), actual Yield Strength and Ultimate Tensile Strength. While compliance is relatively straightforward for new pipe installed going forward, PG&E has tens of 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.
What is the current state and its primary limitations?	Currently, destructive testing is the only highly accurate method for verifying YS and UTS. This method requires digging to locate the existing pipes in order to remove a cross section, which is then sent to the lab for testing. Performing this process requires shutting down the impacted section, releases GHG emissions into the atmosphere, and disrupts customers. While there are in-situ technologies available on the market, they currently provide mixed results. **Primary limitations include:** • Lack of consistent, reliable nondestructive testing methods capable of verifying YS and/or UTS • Lack of accurate and repeatable in-situ testing methods • Environmental and customer impacts inherent to destructive testing methods
What are the desired outcomes from R&D?	**Novel technologies to:** • Ability to verify Yield Strength and Ultimate Tensile Strength for existing pipes via non-destructive method that is accurate, repeatable, and reliable • Significantly reduce costs and timelines associated with verification process • Avoid negative environmental and customer impacts

PROBLEM STATEMENT 4

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.

Why is this important?	Requirements for the Pipeline and Hazardous Materials Safety Administration's (PHMSA) 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 determine and record the material toughness of pipes across its network. Compliance with this mandate for the installed base of assets requires either (1) the verification of actual toughness measures utilizing existing destructive methods, or (2) updating existing models used to drive maintenance and repair decisions with extremely conservative 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, destructive testing methods are the only option available to verify material toughness for installed steel transmission pipelines. This method requires excavating the existing pipes in order to remove a cross section, which is then sent to the lab for testing. Performing this process requires shutting down the impacted section, releases GHG emissions into the atmosphere, and disrupts customers. The alternative option for verification requires the use of conservative toughness 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 any nondestructive testing methods capable of verifying toughness • Costly and resource intensive nature of existing process • Inability to avoid environmental and customer impacts inherent to destructive testing methods
What are the desired outcomes from R&D?	**Novel technologies to:** • Verify 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 is also of interest*

PROBLEM STATEMENT 5

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.

Why is this important?	PG&E utilizes crack detection technologies across vast sections of its natural gas transmission network. These assessments are performed as part of periodic safety and maintenance routines and 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. 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 can 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 its transmission network. While existing methods are capable of identifying cracks across a variety of use cases, improving the accuracy, efficiency, and cost profile of these processes could increase overall system safety and cost effectiveness. **Primary limitations include:** • Costly and resource intensive nature of existing processes
What are the desired outcomes from R&D?	**Novel technologies to:** • Locate and size cracks in steel pipes • Reduce the cost and time associated with performing crack assessments • Improve the accuracy of crack detection and sizing

PROBLEM STATEMENT 6

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 introduces high risk operations that often impose damage to the wells being inspected, are disruptive to reliability with the need to take wells out of service to perform inspection activities, and are costly (ranging up to $3M per well). Current regulations drive to perform 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 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 being pulled out to complete the inspection. • Medium-resolution in-line thru-tubing inspection can avoid the extremely high-cost 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 also 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 the fiber optic sensor technology • 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 to:** • Cost-effectively meet regulatory requirements for periodic in-line inspections that are as or more accurate compared to existing methods • Reduce the installation and real-time monitoring costs of continuous monitoring solutions, while ensuring high quality, ongoing data transmission

PROBLEM STATEMENT 7

T&D leak detection

The current leak detection methods rely heavily on human effort to complete surveys (on foot or by vehicle/air) and on human judgment to identify issues and anomalies, resulting in a significant time and cost burden and a suboptimal approach to deploying additional resources for foot patrols.

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 and distribution systems totals a combined ~50,000 miles, completing these surveys requires a massive mobilization of resources and adds significant cost to 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 Picarro vehicles. While helicopters and vehicles quicken the process, completing these surveys over thousands of miles of pipeline requires a tremendous amount of resources. Further, additional foot patrol resources must be deployed to any areas where leak indications were identified during the initial surveys. **Primary limitations include:** • Costliness and labor-intensiveness of current initial survey methods • Inability for some technologies to precisely pinpoint the location of a leak, requiring surveyors to walk the swath with additional tools that can identify the source
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce costs and human effort necessary to maintain compliance with leak detection survey regulatory requirements • Increase the accuracy and effectiveness of leak detection technologies to direct deeper inspection efforts more precisely

PROBLEM STATEMENT 8

Reducing false positive on leak detection surveys

Foot patrol leak surveys often result in false positives on low-level leaks as determined upon re-check/further investigation, resulting in the unnecessary deployment of resources to conduct follow-up surveys.

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 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 Remote Methane Leak Detector 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, as opposed to methane from other naturally occurring sources • Unnecessary deployment of additional resources to completed deeper field inspections and surveys as a result of inaccurate reading
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable personnel completing initial foot patrol surveys to accurately distinguish between methane leaks and naturally occurring methane based on the presence of other trace gasses only present in pipelines or other viable method • Reduce the incidence of false positives that result in the needless deployment of additional survey and inspection resources

PROBLEM STATEMENT 9

Corrosion inspections

Spans of exposed pipeline subject to corrosion inspection requirements are often in remote locations that are difficult to access, making the process difficult, very time consuming and potentially dangerous based on local conditions.

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 our co-workers operating in hazardous conditions on-site.
What is the current state and its primary limitations?	Currently, PG&E co-workers travel to exposed spans, often in remote locations, to visually inspect and assess corrosion conditions. These visits are completed every three years on a given span, resulting in approximately 300 inspections per year. **Primary limitations include:** • Difficulties traveling to and accessing exposed spans in remote locations and in difficult terrain • Necessity for PG&E co-workers 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 to:** • Reduce costs associated with corrosion inspections on exposed spans • Limit the need for co-workers 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 10

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?	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

PROBLEM STATEMENT 11

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).

Why is this important?	Gas Field Services is responsible for performing shutoffs and re-connections of gas meters today as properties are vacated and subsequently re-occupied. They complete tens of thousands of shut offs per year with many jobs in the queue at any given time. Field Services must travel to customer sites as the process lacks automation and requires a physical visit to complete. Beyond a lack of efficiency, the existing manual shut-off process can also present safety concerns when required in emergency situations (e.g., flooding), as Field Services personnel must perform the process on-site in impacted areas.
What is the current state and its primary limitations?	Currently, customers notify PG&E when vacating a property, and the meter is added to a backlog of shut-off requests. Field Services must then travel to the vacated property to manually shut-off service at the meter set. Once the property is occupied by a new tenant/owner, another site visit is required to reconnect service. Similarly, when an emergency situation necessitates the disconnection of gas service across an impacted geography, PG&E personnel must manually complete these temporary disconnections. **Primary limitations include:** • Inability to remotely disconnect and/or reconnect gas service for residential and commercial customers without requiring a site visit
What are the desired outcomes from R&D?	**Novel technologies to:** • Enable the remote control of gas service to customer meters • Target individual meters for one-off service shut offs, or geo-target all meters within a specific area

PROBLEM STATEMENT 12

Accuracy of well-life estimation

Current technologies and methodologies to estimate the safe and useful remaining life of an existing well 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 a new well.

PRIMARY TARGET: IDEAS/RESEARCH

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?	**Desired outcomes include:** • Identification of the critical determinants of well longevity • Ability to 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 • Provision of better substantiated estimates of remaining useful life for existing wells

PROBLEM STATEMENT 13

Geohazard risk assessment

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

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 naturally occurring 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. Emerging threats resulting from subtler or more gradual changes to the local topography can be more difficult to proactively identify before a problem develops. **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 process • 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 to:** • 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 14

Accuracy of 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 is 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. 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, 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 depths greater than 9–10 feet, soil with high moisture content, and non-metallic pipelines • Inability to accurately assess the location of assets on the vertical plane (i.e., how deep is the pipe)
What are the desired outcomes from R&D?	**Novel technologies to:** • Address the use cases noted above where locating remains particularly challenging • 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 15

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 and potentially missing issues that develop during the interim period.

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 system 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 customer sites and visually inspecting the meter set every three years. **Primary limitations include:** • Costliness and inefficiency in current meter set corrosion inspection techniques • Challenges accessing customer premises
What are the desired outcomes from R&D?	**Novel technologies to:** • Reduce the necessity of in-person, visual inspections of meter sets • Monitor meter sets remotely or proactively detect and alert for corrosion • Introduce situational awareness at the meter set to alert when elevated corrosion risk is detected or automatically shut off if failure is imminent

PROBLEM STATEMENT 16

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.

Why is this important?	Long segments of Aldyl-a pipe, used for a substantial portion of PG&E's gas system, have a tendency to become brittle over time. This embrittlement can lead to leaks that may occur at many points throughout the main, but particularly at saddles. These leaks need to be repaired to ensure safety and reliability of the gas system, but the current methods that PG&E uses to repair these leaks are limited to full replacements of the saddle. This method is not cost-efficient and requires complete shutdown of the affected area to complete the repair. Alternative repair methods that are less intrusive and time consuming could ensure the continued safety and reliability of the system, while also enhancing efficiency in repairing our assets.
What is the current state and its primary limitations?	Current repair methods for saddle leaks on Aldyl-a pipe require the complete removal and replacement of the damaged section. To complete the repair utilizing this method, the impacted section of the pipeline must first be shutdown to remove the affected area. This further adds to the costly and time-consuming nature of these repairs. **Primary limitations include:** • Costliness of remediating leaking Aldyl-a pipes through full segment replacements • Gas line shut offs required to complete saddle replacements
What are the desired outcomes from R&D?	**Novel technologies to:** • Repair saddle leaks on Aldyl-a pipe using non-intrusive, in-service techniques, avoiding the need to remove and replace the affected segment • Reduce the overall cost and time to complete repair

PROBLEM STATEMENT 17

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.

Why is this important?	Gas construction crews must check for plastic inserts when welding or tapping on steel pipelines to avoid inadvertently cutting into these live inserts. While this process is a critical safety measure to avoid dangerous leaks, current technologies to perform these assessments are generally intrusive, costly, and time-consuming. Improved methods for detecting plastic inserts could help streamline the workflow of the construction crews, while ensuring the safe completion of their work.
What is the current state and its primary limitations?	When working on steel pipelines, construction crews test for the presence of plastic inserts before work may begin. Current state detection methods rely primarily on radiographic testing and bolt-on-tee technologies to determine whether a plastic insert is present within the steel pipe. **Primary limitations include:** • High cost and time-intensity of current methods • Delay of continued work on steel pipelines until testing is completed • Not all locations are suited to either technology. For example, when using radiographic technology there may not be enough physical clearance around the pipeline to use the tool and/or meet the required safety distance between people and the tool itself when operated
What are the desired outcomes from R&D?	**Novel technologies to:** • Detect plastic inserts in steel pipelines in a cost-effective, non-intrusive manner that improves the efficiency and safety of this construction work

THEME 2

Reduce methane emissions from the gas system

PROBLEM STATEMENT 1

Revised 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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	PG&E has set ambitious goals to reduce emissions from its 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. 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.
What is the current state and its primary limitations?	Emissions calculations at transmission M&R stations, compressor stations, and underground storage facilities are not based on actual recorded emissions levels over the course of a year. Rather, population-based factors, which assume a given annual quantity of emissions per component, or single point-in-time measurements, which are then annualized, are used to approximate emissions across the system. While these approaches are efficient, they do not provide accurate emissions information at the individual asset level. **Primary limitations include:** • Inability to create accurate emissions baselines based on actual emissions data at the individual site level • Lack of on-site technology 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?	**Desired outcomes include:** • 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 2

Transmission pipeline blowdown methane emissions

Blowdowns are often necessary to depressurize a pipeline for testing or other purposes, but they release methane directly into the atmosphere, or flare it to emit CO_2 instead. PG&E has decreased blowdown emissions in the past decade but needs to further abate these emissions in order to meet climate goals.

Why is this important?	To deliver on our 2030 goal of reducing overall gas systems 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. While effective technologies to abate blowdown emissions exist, current options are very costly, resource intensive to implement, and require heavy equipment.
What is the current state and its primary limitations?	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, 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 to:** • Reduce cost and size of required equipment relative to current state of the art cross-compression technologies • Prevent emissions from entering the atmosphere

THEME 3

Decarbonize the gas system

PROBLEM STATEMENT 1

Costly and unstandardized interconnection skids

Interconnection skids for biomethane projects lack standardization and scaled production and are therefore very costly. As a result, the costs of interconnection skids can materially impact the overall project economics for biomethane interconnection.

Why is this important?	Interconnection skids connect RNG from production plants to the natural gas system. These mechanisms contain complex equipment for measurement, pressurization, and odorization to enable the safe introduction of biomethane into PG&E's gas system. PG&E currently utilizes an in-house designed biomethane interconnection skid, as a commercially available option does not currently exist. Given that PG&E's custom-designed interconnection skid is not produced at scale, the unit cost remains very high, materially increasing the total cost of interconnection for new biomethane supplies. Novel solutions to reduce this component cost could therefore materially reduce the overall cost of providing clean and reliable energy service to 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 pressurization mechanisms, and other technologies to ensure RNG is compliant with a range of standards specific to PG&E's gas system. PG&E currently utilizes a skid based on in-house designs that is calibrated to our system's unique specifications. The lack of scale in producing this custom component renders it costly relative to overall project costs. **Primary limitations include:** • Current in-house design biomethane interconnection skid costs over $500,000 • Lack of standardization and scale for interconnection skid technology
What are the desired outcomes from R&D?	**Novel technologies to:** • Standardize biomethane interconnection skids • Significantly reduce costs relative to current levels ($100–$200k range) • Enable a plug and play componentry where utilities may utilize their own analyzers and metering devices in conjunction with more standardized piping

PROBLEM STATEMENT 2

Uncertainty about 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.

PRIMARY TARGET: IDEAS/RESEARCH

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 its use 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, environment considerations, and human health and safety.
What are the desired outcomes from R&D?	**Desired outcomes include:** • 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 3

Hydrogen embrittlement

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 pipeline infrastructure can suffer from embrittlement and cracking 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 various thresholds for hydrogen blending at which embrittlement may begin to pose a serious threat to pipeline integrity. 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?	**Desired outcomes include:** • Cost effective and scalable solution to protect existing pipelines from embrittlement • Research to determine the optimal blend rate of hydrogen to avoid structural shortcomings due to 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 4

Safety risks of hydrogen blend leaks

Different blends of hydrogen, RNG, and natural gas 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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	As PG&E prepares to introduce blending of hydrogen, RNG, and other renewable gasses into natural gas pipelines to decarbonize the gas system, safety risks associated with different blend rates must be investigated and understood. Based on the percentage of 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 and RNG blending and to determine whether safety protocols and equipment need to be modified for a mixture of hydrogen and natural gas.
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, of different blends needs to be more fully developed before introducing blending at scale across the system. **Primary limitations include:** • Incomplete understanding of how varying percentages of hydrogen blending 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?	**Desired outcomes include:** • Deeper understanding of safe hydrogen and RNG blend rates to avoid safety risks and any associated impacts to customers or co-workers • Determination whether the safety zones for natural gas need to be modified for a mixture of hydrogen and natural gas • Investigation of effectiveness and safety of odorants for detecting and repairing leaks

PROBLEM STATEMENT 5

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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	Increased hydrogen blending in the natural gas system will alter the physical properties of the combined gasses, 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 in current understanding include:** • The effectiveness of analyzers measuring the calorific value of blended gas above 10% hydrogen by volume • Effects of hydrogen blending on across different meter types, 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?	**Desired outcomes include:** • 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 • Test/understand accuracy of existing metering equipment under 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 6

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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	There are multiple renewable gasses (i.e., hydrogen, syngas, RNG) that could be used to decarbonize PG&E's natural gas system, but limited research has been conducted to evaluate the costs and benefits of each solution. Due to the size and scale of PG&E's gas system, a slight decrease in unit cost for the renewable fuels could result in massive cost savings for PG&E and ratepayers. Determining which renewable gasses offer the lowest cost/best-fit profiles for PG&E's system will better direct where we should focus efforts and resources to accelerate decarbonization efforts. PG&E plans to have 15% of the gas throughput from RNG by 2030, thus determining the optimal renewable gas is paramount.
What is the current state and its primary limitations?	While basic research into each renewable natural gas and hydrogen exists, cost-benefit analyses comparing each gas to determine which gas is best suited to enter PG&E's network is lacking. **Primary limitations include:** • Lack of techno economic analysis to determine best suited and lowest cost pathway to decarbonize PG&E's gas system • Incomplete understanding of how various dynamics of the broader system may evolve over time to influence the optimal mix of renewable gasses of the short- and medium-term • Inability to appropriately set prices of renewable gasses to avoid burdens on both PG&E and ratepayers
What are the desired outcomes from R&D?	**Desired outcomes include:** • A holistic cost-benefit analysis of each type and subtype of RNG and hydrogen to determine the lowest cost and best fit solution, taking into account emission reduction potential, existing system constraints and compatibility, time and resources constraints, and potential interactions with PG&E's electric system

PROBLEM STATEMENT 7

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.

PRIMARY TARGET: IDEAS/RESEARCH

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/ end-uses that may be impacted with the introduction of gas blends. The lack of renewable 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 residential 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 are likely 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 range existing end uses and appliances for hydrogen blend compatibility
What are the desired outcomes from R&D?	**Desired outcomes include:** • 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 mixed gasses

PROBLEM STATEMENT 8

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.

PRIMARY TARGET: IDEAS/RESEARCH

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 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?	**Desired outcomes include:** • Improved understanding of the impacts of hydrogen on underground storage facilities • Identification of components, interaction effects, etc. that pose the largest challenges to seasonal storage of hydrogen

PROBLEM STATEMENT 9

Limited RNG capacity from traditional sources

Traditional RNG feedstocks do not exist in sufficient volume to replace the entire throughout of PG&E's gas system, making it critical to identify alternative methods of RNG production in order to achieve climate commitments.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	PG&E aims to source 15% of gas throughput for core customers from RNG by 2030 as part of its efforts to achieve a net zero energy system by 2040. However, RNG production capacity has not been commercialized and 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. Due to the limited number of landfills and farms that could be used to produce RNG directly from biogas, alternative sources are needed to fill this gap and meet decarbonization goals.
What is the current state and its primary limitations?	Methane potential from biogas sources in the entire US is roughly 420 billion cubic feet per year, which is five times PG&E's 2021 production capacity, but 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. **Primary limitations include:** • High cost of RNG based on current production methods • Low quantity/scale of RNG production • Low throughput of RNG at production plants • Limited availability of feedstock to support current methods of RNG production
What are the desired outcomes from R&D?	**Desired outcomes include:** • Research and quantify the potential of alternative RNG production sources, such as woody (or other) biomass, wastewater treatment plants, and Power-to-Methane • Accelerate development of the Power-to-Methane solution utilizing already captured CO2 at RNG production plants to create green methane • Source 15% of gas throughput from RNG by 2030

PROBLEM STATEMENT 10

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.

PRIMARY TARGET: IDEAS/RESEARCH

Why is this important?	There is a tremendous volume of woody biomass in California that must be managed to decrease wildfire risk throughout our service area and California more broadly. Current management methods include controlled burning which releases large amounts of GHG emissions into the atmosphere. Identifying cost effective methods to convert existing woody biomass into RNG could provide the multiple benefits, including converting the cost center of woody biomass management into a potential source of revenue generation, avoiding emissions from controlled burning, and supporting PG&E's goals to decarbonize the gas system.
What is the current state and its primary limitations?	Currently, prescribed burning is used on about 125,000 acres per year in California. These controlled burns are preferable to massive wildfires, but emit CO2 and other pollutants nonetheless, and are a wasted potential source of value which could offset the cost of wildfires that do occur or help bring down the cost of RNG. The CPUC has directed PG&E under SB 1440, the biomethane procurement program, to conduct pilot projects for woody biomass pyrolysis or gasification which will be submitted in the summer of 2023. Though these and other studies have been undertaken by PG&E, cost effective means for converting woody biomass to RNG are not currently available at scale. **Primary limitations include:** • High financial investment to develop woody biomass to RNG pilot plants • Low technology readiness level (TRL) of existing solutions to convert woody biomass to RNG
What are the desired outcomes from R&D?	**Desired outcomes include:** • Evaluation of pathways for developing viable processes to convert woody biomass to RNG • Successful demonstration of technology capable of converting woody biomass to RNG at competitive unit cost

PROBLEM STATEMENT 11

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 by RNG or hydrogen in the future 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 also pose a potential risk to customer trust in the gas system. Eliminating NOx emissions from natural gas end uses (and ultimately RNG and hydrogen) 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 hydrogen also produce NOx emissions when combusted. 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 RNG/hydrogen end uses that would comply with zero-NOx standard
What are the desired outcomes from R&D?	**Novel technologies 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 RNG and hydrogen compatible appliances

PROBLEM STATEMENT 12

Lack 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, and changing supply and demand dynamics affect how hydrogen blends perform in an actual pipeline setting.

PRIMARY TARGET: IDEAS/RESEARCH

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 percentages of hydrogen blends. However, data collected in a controlled environment 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 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 its plans to build a hydrogen testing facility with an estimated cost of $350M. Identifying the most critical test cases ahead of design and construction will be essential to ensuring the facility is capable of handling the full range of scenarios that must be explored prior to adoption of hydrogen blending at scale.
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 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?	**Desired outcomes include:** • Field demonstrations to provide operational data from a real-life environment with variations in temperature and humidity; pressure and volume fluctuations due to changes in supply and demand; and true gas quality representations • 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

PROBLEM STATEMENT 13

Need to develop cost-effective and safe deblending technologies

Various end use applications may require pure natural gas or hydrogen to operate, requiring the deblending of gas-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. 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 a solution 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 to:** • Cost-effectively separate hydrogen-methane blends into component streams at the point of demand with a small physical footprint • Provide a viable option for deblending even at very low concentrations of hydrogen