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ABSTRACT

In 2000, Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to impose a surcharge on natural gas consumed in California. These monies funded energy efficiency programs and public interest research and development to benefit natural gas ratepayers. AB 1002 also required the CPUC to designate an entity to administer the research component of AB 1002. In 2004, the CPUC issued Decision 04-08-010, designating the California Energy Commission as the research fund administrator. In July of 2021, Section 25620.8 of the Public Resources Code was amended to provide further guidance on the preparation and submission of an annual report.

The *Natural Gas Research and Development Program 2021 Annual Report* highlights project successes and benefits, and covers results of completed projects and the progress of current research from July 1, 2020 through June 30, 2021. In fiscal year 2020-2021, the California Energy Commission administered $24 million in natural gas research, development, and demonstration projects geared toward improving natural gas system decarbonization, building decarbonization, industrial and agricultural innovation, low-emission transportation, entrepreneurial support, and resilience, health, and safety for natural gas in California.

Keywords: California Energy Commission, California Public Utilities Commission, natural gas, energy efficiency, pipeline safety, climate change, buildings end use energy efficiency, industrial, agriculture and water efficiency, renewable energy and advanced generation, energy infrastructure, natural gas pipeline integrity, energy-related environmental research, natural gas-related transportation, disadvantaged communities, low-income communities, strategic decommissioning, hydrogen, biomethane

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EXECUTIVE SUMMARY

California's climate and energy policies are driving the state to reach its ambitious emissions reduction goals and renewable energy targets that improve public health and safety while also addressing the pressing issue of climate change. Senate Bill 100 (De León, Chapter 312, Statutes of 2018) set the state on the path to achieve all renewable or zero-carbon retail electricity sales in California by 2045 while Executive Order B-55-18 positioned California's entire economy to achieve carbon neutrality by 2045. To meet these goals by 2045, California is assessing pathways to decarbonize across all sectors now, so that the state can transition to clean energy efficiently, safely, and equitably.

The role of natural gas must adapt to support the transition to carbon neutrality, since natural gas is an important component of California's current energy system. Public research is essential to building the technical foundation of natural gas's transition by supporting innovations that ensure the safety of the natural gas system, minimize environmental impacts, and enable cost-effective pathways for producing and using renewable gas, including hydrogen.

Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) created the California Energy Commission's Natural Gas Research and Development Program recognizing that natural gas has been an important energy resource for California. AB 1002 directed the California Public Utilities Commission to impose a surcharge on all natural gas consumed in California to fund public-interest research and development activities. The Natural Gas Research and Development Program invests $21.6 million annually in energy efficiency, renewable energy, and advanced generation; natural gas infrastructure safety and integrity; energy-related environmental research, transportation, and entrepreneurial support. As California transitions its gas system to meet the goals set in Senate Bill 100 and Executive Order B-55-18, the key priorities that drive the investments of the Natural Gas Research and Development Program continue to adapt to the changing landscape of the state's energy system.

Across the Natural Gas Research and Development Program, a key priority is to ensure that all Californians have access to and can benefit from clean, affordable, and safe energy. The program invests strategically to provide community-wide benefits to address gaps in energy equity. In addition, the program aims to increase engagement with and benefits to under-resourced communities to ensure that the transition to a decarbonized future does not burden California's most vulnerable residents and communities.

To accomplish the goals of decarbonization equitably and efficiently, the Natural Gas Research and Development Program has begun prioritizing the following critical research areas in its recent investment plans: green hydrogen and biomethane, decommissioning of aging natural gas generation, decarbonization of heavy-duty vehicles, and sectors that have been difficult to electrify. As investments and projects in these emerging areas of research kick off, the Natural Gas Research and Development Program's projects in areas such as natural gas infrastructure safety, building decarbonization, and low-emission transportation will help transition California's energy sector to a safe, reliable, and decarbonized system.

CHAPTER 1: Introduction

Aiming to ensure that California's gas system continually evolves to serve its ratepayers, the California Legislature passed AB 1002 (Wright, Chapter 932, Statutes of 2000), creating the Natural Gas Research and Development (R&D) Program in 2000. This enacted a surcharge on all natural gas consumed within the service territories of California's investor-owned utilities, which fund efforts such as energy efficiency programs, low-income assistance, weatherization programs, and public interest research. Since 2004, the California Energy Commission (CEC) has administered the Natural Gas R&D Program that emerged from this legislation and funds a range of public-interest R&D activities in energy efficiency, renewable energy and advanced generation, and energy infrastructure. The California Public Utilities Commission (CPUC) established a requirement that Natural Gas R&D Program projects meet the following criteria:

- Focus on energy efficiency, renewable technologies, conservation, and environmental issues.
- Support state energy policy.
- Offer a reasonable probability of providing benefits to the public.
- Consider opportunities for collaboration and co-funding with other entities.

The CEC is required to submit an annual report of the last fiscal year and a new budget plan for the upcoming fiscal year. The CEC engages with multiple stakeholders when creating its budget plans and works with entities such as the state's investor-owned gas utilities, state and federal agencies, industry experts, academic researchers, and other interested parties of the public. The CEC also conducts public workshops throughout the year to share project results, generate new research ideas, explore emerging topics, and create the best research industry practices. The workshops bring together utilities, researchers, manufacturers, end users, and policymakers from state and federal agencies, such as the California Air Resources Board (CARB) and the United States Department of Energy, to encourage knowledge sharing and collaboration.

The CEC has prioritized energy equity by working to ensure that the benefits from clean energy are equitably shared with under-resourced communities. The Natural Gas R&D Program has invested an estimated 67 percent of program funds in projects located in either a disadvantaged community or low-income community, or both, since fiscal year 2016-2017. The CEC has also invested 68 percent of demonstration funds under the companion electricity R&D program — the Electric Program Investment Charge Program (EPIC) — far surpassing the 35 percent legislative requirement.[1]

[1] Disadvantaged communities are those designated under to Health and Safety Code Section 39711 as representing the 25 percent highest-scoring census tracts in California Communities Environmental Health Screening (CalEnviroScreen) Tool 3.0. https://calepa.ca.gov/envjustice/ghginvest/. Low-income communities are those within census tracts with median household incomes at or below 80 percent of the statewide median income or the applicable low-income threshold listed in the state income limits updated by the California Department of Housing and Community Development (HCD).

In 2021, the CPUC set Resolution G-3571 which changes how the CEC develops and submits budget plans to the CPUC. The new resolution requests additional outreach with the CPUC, the Disadvantaged Communities Advisory Group (DACAG), and the public. In addressing the elements of CPUC Resolution G-3571, CEC staff conducted an outreach survey on natural gas research initiatives and presented the proposed budget plan for 2021-22 Natural Gas R&D Program at the January 2021 DACAG meeting to solicit feedback from disadvantaged community stakeholders. Additionally, in 2021 the legislature passed AB 148 (Ting, Chapter 115, Statutes of 2021) which requires the CEC to submit the annual report with additional content that includes the following:

- Recommendations for improvements in the program, addressed on pages 5-9.
- A summary of the Public Interest Research, Development, and Demonstration Program's impacts and benefits, addressed on page 3.
- A summary of how funding is allocated to each of the Public Interest Research, Development, and Demonstration Program's natural gas investment areas, addressed on pages 4-5.
- A description of successful or promising projects funded in each of the Public Interest Research, Development, and Demonstration Program's natural gas investment areas, addressed on pages 10-19.
- A summary of expected Public Interest Research, Development, and Demonstration Program funding initiatives and activities over the next year, addressed on pages 5-9.
- Information on Public Interest Research, Development, and Demonstration Program-approved project budgets and benefits, all active projects, and recently completed projects, which can be found on the CEC's Energize Innovation Project Showcase.
- A description of any recent changes to the Public Interest Research, Development, and Demonstration Program's spending guidelines or eligible projects, which is not applicable for fiscal year 2021-2022.

Program Investment and Impact

The CEC's Natural Gas R&D Program has invested in a wide variety of research projects and technologies to ensure that California's gas system is advancing to serve ratepayers. Figure 1 shows the locations of recipient headquarters and project sites. Natural Gas R&D Program impacts include:

- **$300 Million** invested to date through 286 projects.
- Project recipients have attracted **more than $5.1 billion in private investment** after being selected for a Natural Gas R&D Program award.
- About **67 percent of program funds have been invested in disadvantaged and low-income communities**, or both, since fiscal year 2016-2017.
- More than **23 projects informed codes, standards, proceedings, or protocols** (adopted or under consideration), providing an estimated **$65 million per year in energy cost savings**.
- More than **37 technologies or products have been commercialized** and many more are moving toward commercialization.

- More than **12,300 citations** have been made to publications referencing research results from CEC-funded natural gas projects (through September 2021).

Figure 1: Map of Natural Gas R&D Program Recipient Headquarters and Project Site Locations

Project site locations and prime recipient headquarters for CEC Natural Gas R&D projects.

Source: California Energy Commission staff

Entrepreneurial Ecosystem: $11.2 Million Invested

The growth of emerging clean energy start-ups is essential to commercializing technology advancements made through public interest research. Funding in the Entrepreneurial Ecosystem category supports clean-tech entrepreneurship, in part by providing small grants that invest in startups for early-stage research and prototype development. The CEC's previous small grants program, the Energy Innovation Small Grant Program (EISG), provided funding for electric and natural gas related technologies. The EISG Program ended in 2017 and was replaced with the California Sustainable Energy Entrepreneur Development Initiative (CalSEED) program. Previously, CalSEED was exclusively funded by the CEC's EPIC to support start-up companies advancing electricity related technologies for precommercial stage research and prototype development. This past year, CalSEED was awarded funding from the Natural Gas R&D Program to expand research areas to include natural gas related technologies. CalSEED anticipates selecting and funding their first group of natural gas start-ups in late 2022.

Resiliency, Health, and Safety: $74.1 Million Invested

The CEC's Natural Gas R&D Program helps Californians create a reliable, resilient, and safe energy system through state-of-the art research on pipeline storage and safety, climate and weather risk, indoor air quality and health, and forest biomass usage that reduces fossil-fuel reliance and wildfire risk.

Building Decarbonization: $56.6 Million Invested

The program invests in novel energy technologies to improve building decarbonization technologies, energy efficiency, affordability, health, and comfort of California's homes and businesses.

Natural Gas System Decarbonization: $24.8 Million Invested

As California approaches decarbonization policy goals, this investment category supports a safe, healthy, and equitable transition to a zero-carbon energy system through leading-edge studies on fugitive methane emissions, natural gas infrastructure decommissioning, renewable hydrogen, and biomethane.

Industrial and Agricultural Innovation: $76.9 Million Invested

The industrial and agricultural sectors are an essential part of California's economy but have been difficult to decarbonize. The CEC's Natural Gas R&D program is prioritizing the need to develop and scale technology solutions that decrease natural gas use, carbon emissions, and waste while increasing production of goods, such as biofuels from dairy digesters or wastewater treatment plants.

Transportation: $55.6 Million Invested

The program advances new technology solutions to increase the efficiency and clean operation of medium-, heavy-duty, and off-road vehicles. The program has advanced the applications of efficient and low emission vehicles and is actively researching hydrogen fuel advancements and applications.

Shifting Research and Development Initiatives to Address California's Zero Carbon Policy Goals

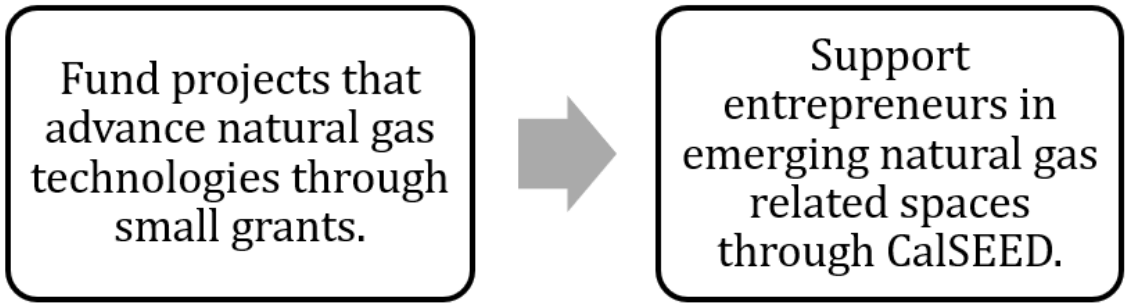
As California has set ambitious emissions targets through policies such as SB 100 (De León, Chapter 312, Statutes of 2018) and AB 32 (Núñez, Chapter 488, Statutes of 2006), the Natural Gas Research & Development Program has shifted its investment priorities to address these policy changes while continuing to meet core objectives for ratepayer benefits. For fiscal year 2021 to 2022, the program's proposed research initiatives are framed around decarbonization. The program's shifting priorities reflect that the gas system is important yet carbon intensive; to make progress towards a decarbonized economy in future years, research is essential in emerging spaces related to natural gas and its infrastructure such as strategic decommissioning, hydrogen integration, and industrial decarbonization.

Entrepreneurial Ecosystem

Commercialization of emerging technology is essential to realize benefits from research efforts. Funding opportunities can help entrepreneurs effectively develop their technologies from early-stage research to final products (Figure 2).

In 2021, the research program has contributed natural gas funding to the CalSEED program, which was initially developed under EPIC, to support innovations related to the natural gas program such as hydrogen, solar thermal, and carbon capture technologies.

Figure 2: Expanding Entrepreneurial Support



Source: California Energy Commission staff

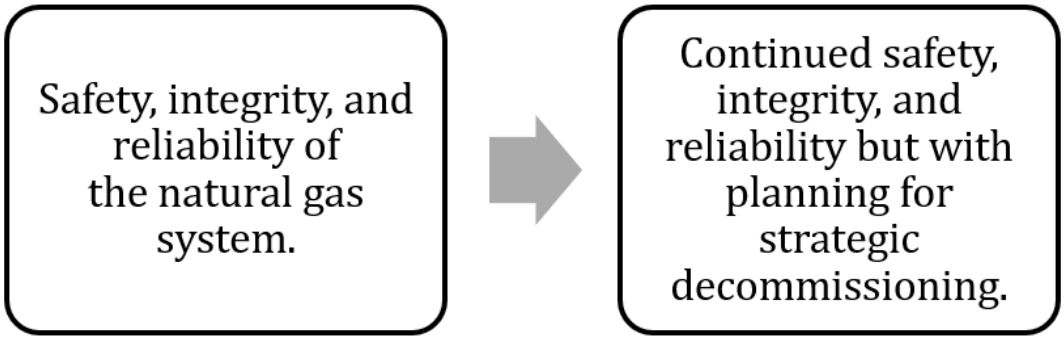
Natural Gas System Safety and Integrity

Dangerous events such as the San Bruno pipeline explosion in 2010 and Aliso Canyon gas storage facility leak in 2015 exposed the vulnerabilities of California's natural gas system and the need for more research to improve natural gas system safety and integrity. Furthermore, environmental changes such as prolonged drought, extensive tree mortality, climate-change-related subsidence, and sea level rise became key research areas to understand how climate change may affect the natural gas sector and how the system can be adapted to contribute to the state's greenhouse gas (GHG) reduction goals.

Safety and integrity of the gas system remains an essential research topic for maintaining infrastructure to avoid costly and potentially deadly accidents. At the same time, strategic decommissioning of gas infrastructure will be added as an area of study in upcoming initiatives. While infrastructure decommissioning supports decarbonization efforts overall, the transition must be done in a safe and equitable manner — ensuring that customers who remain connected to gas infrastructure are not burdened with high costs (Figure 3).

- 2021-2022 Research Initiatives:
    - Technologies for Monitoring Ground Movement Around Pipelines and Mitigating Natural Force Damages
    - Technology Development and Demonstration for Plastic Pipeline Repair and Integrity Improvement

Figure 3: Adapting Natural Gas System Safety and Integrity Research



Source: California Energy Commission staff

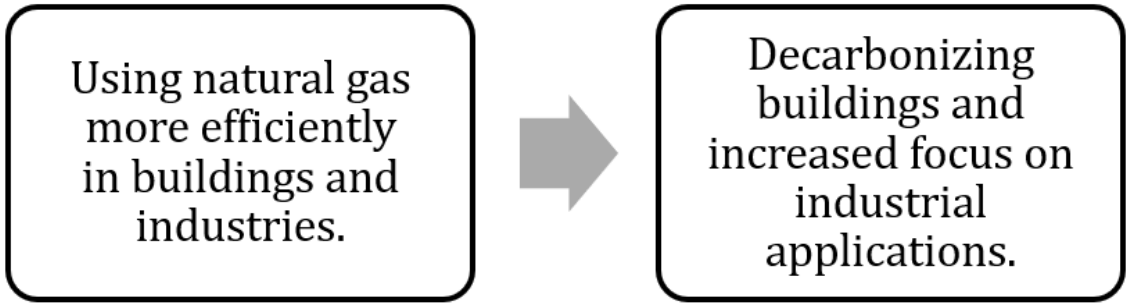
Energy Efficiency

Efficient use of natural gas has always been a priority research topic for the Natural Gas R&D Program, with a particular focus on reducing oxides of nitrogen (NOx) which are a main contributor to respiratory health problems from local emissions. With the advancement of technology through R&D alongside implementation of policy change, efficient and low NOx technologies have experienced successful entries to market. Increased uptake of these technologies, as well as electric alternatives, in residential and commercial sectors have helped drive emission reductions in these sectors.

Previous research focused on increasing the efficient use of natural gas in buildings by successfully developing and demonstrating technologies such as improved building envelope technologies, whole building retrofits, and low NOx alternatives for industrial equipment, water and space heating, and cooking appliances. With the increased focus on decarbonization, the program's strategies are shifting to address areas that have been more difficult to decarbonize, such as carbon capture and utilization in the industrial sector (Figure 4).

- 2021-2022 Research Initiatives:
    - Industrial Carbon Capture and Utilization

Figure 4: Adapting Energy Efficiency Research



Source: California Energy Commission staff

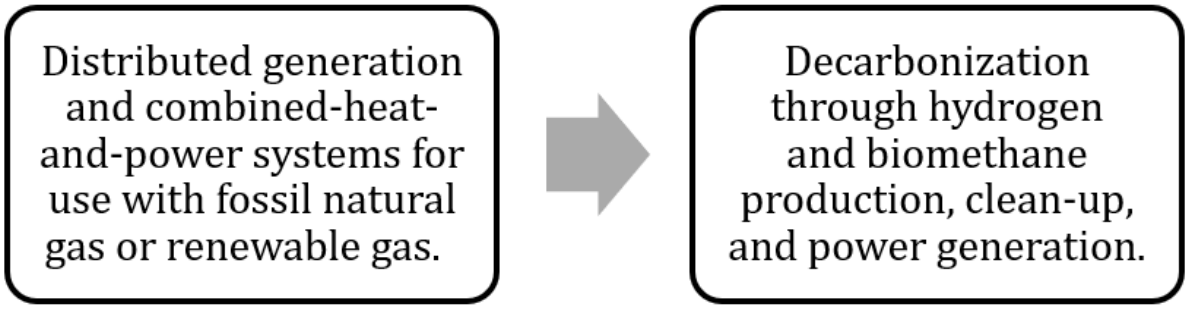
Renewable Energy and Advanced Generation

While California has added significant amounts of renewable energy resources to the grid, natural gas is still widely used for electricity and heat generation. Bioenergy offers a way to reduce emissions but has struggled with cost-competitiveness and access to feedstocks.

Prior research focused on developing distributed generation and combined-heat-and-power systems to help improve efficiencies and lower costs. Future research will focus on decarbonization through use of hydrogen and biomethane, which could reduce dependence on natural gas (Figure 5).

- 2021-2022 Research Initiatives:
    - Developing and Demonstrating Hydrogen-Based Power Generation Systems

Figure 5: Adapting Renewable Energy and Advanced Generation Research



Source: California Energy Commission staff

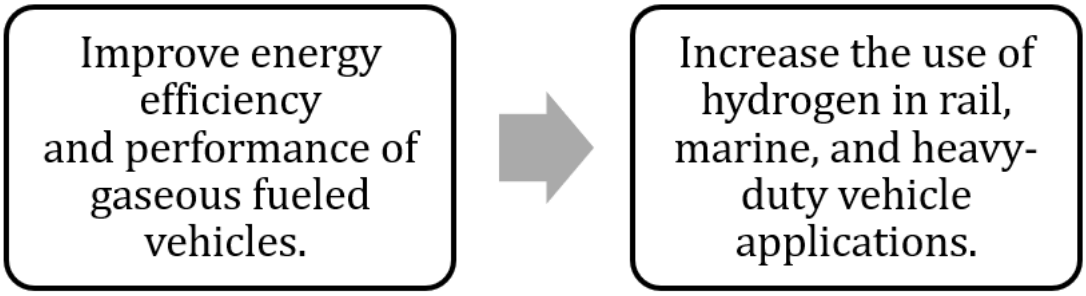
Transportation

California's largest source of carbon emissions and criteria pollutants is the transportation sector. While the passenger vehicle market has seen steady adoption of electric vehicles, heavy-duty vehicles still face significant challenges in decarbonization.

Previous research successfully helped commercialize natural gas vehicles with improved efficiency and reduced emissions in the light-duty and heavy-duty trucking sector. Future research will focus on utilizing hydrogen in heavy-duty applications such as trucks, rail, and marine vessels (Figure 6). Expanding availability of green hydrogen fueling infrastructure will improve air quality and the accessibility of zero-emission transportation.

- 2021-2022 Research Initiatives:
    - Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport

Figure 6: Adapting Transportation Research



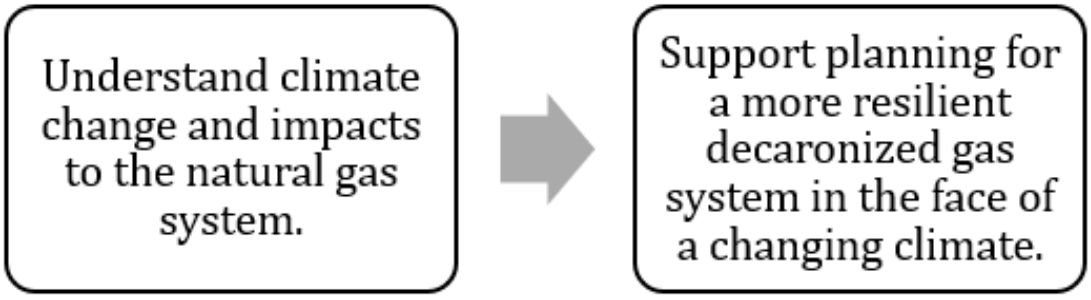
Energy-Related Environmental Research

Research on the adverse environmental and public health impacts of natural gas use and leaks, including the disproportionate impact felt by under-resourced communities, have underscored the need for zero- and near-zero emission technologies. At the same time, a changing climate also threatens to disrupt the gas system.

Previous research has supported greater understanding of how natural gas affects individuals and communities and how climate change may affect the gas system through changes such as sea level rise. With this understanding growing, future research priorities will support research into the potential health benefits of electrification as well as active planning of a more resilient gas system (Figure 7).

- 2021-2022 Research Initiatives:
    - Quantify Exposures to Indoor Pollutants in Multi-Family Homes that Cook with Natural Gas or Alternatives
    - Location-Specific Analysis of Decommissioning to Support Long-Term Gas Planning

Figure 7: Adapting Energy-related Environmental Research



Source: California Energy Commission staff

CHAPTER 2
Project Highlights

This chapter highlights projects that have demonstrated promising results or are beginning to produce important work from the Natural Gas R&D Program's previous investment initiatives. More information is available on these projects, in addition to all active CEC R&D projects funded through the Natural Gas Research Program, on the CEC's Energize Innovation Project Showcase.

Natural Gas System Decarbonization

Project Title: High Efficiency and Ultra-Low Emissions Linear Generator Demonstration Project in Southern California

Project Description

Resilient power solutions for commercial and light industrial facilities — such as small-scale combustion engines and microturbines — are typically costly. When those solutions rely on combustion-based generators, they can emit significant local air pollutants as well as greenhouse gases. This prompts the need for low-cost, low-emission, small-scale power generation technologies that can reliably meet facility loads, including critical loads during grid outages.

Mainspring Energy (formerly EtaGen, Inc.) addressed this demand by developing and demonstrating a highly efficient linear generator for application in commercial and light industrial facilities (Figure 8). Their state-of-the-art and fuel-flexible system operates with different fuel types, such as natural gas, renewable biomethane, and hydrogen blends. Unlike combustion engines, this technology uses a non-combustion, low-temperature reaction of air and fuel to drive magnets through copper coils to efficiently produce electricity with near-zero NOx emissions. Its innovative architecture uses only two moving parts, resulting in lower operational and maintenance costs compared to conventional spark plug systems that require regular oil changes and replacing mechanical parts. The linear generator power output can be quickly adjusted to follow building load or complement intermittent renewable generation.

Mainspring Energy has successfully installed its linear generator at a Kroger Grocery Store in Colton, California, and demonstrated 41.5 percent electric efficiency. The linear generator technology achieved ultra-low emissions and low operational and maintenance costs. Additionally, the linear generator demonstrated the ability

> "Many commercial and industrial customers as well as utilities want clean, reliable power production, with the capability to switch to 100% renewable fuels like biogas and hydrogen as they become available. Mainspring is able to integrate clean onsite generation with both renewables and the grid and we're pleased to support bringing this innovative product to market."
>
> *- John Ketchum, President and CEO, NextEra Energy Resources*

to operate flexibly and provide reliable backup power. The successful demonstration attracted a $150 million agreement with NextEra Energy Resources, a company that provides energy-related products and services, to purchase linear generator units for 30 grocery stores.[2]

Figure 8: Mainspring Energy's Linear Generator

Mainspring Energy's project team with linear generator installed at the Kroger Grocery Store in Colton, CA.

Source: Mainspring Energy

Project Title: Demonstration of 4.5- and 25-kW CARB-compliant Reciprocating Engine Micro-CHP Systems

Project Description

Micro-CHP systems can support energy resilience and greenhouse gas emissions reductions for commercial and industrial facilities by efficiently providing water heating and electricity. Although reciprocating engines can reliably power micro-CHP systems, their use has been limited due to their cost and NOx emissions levels that do not meet CARB requirements. If overcome, the technical market potential for micro-CHP in commercial facilities in California is significant — up to 3,000 megawatts (MW) of capacity across about 100,000 potential sites, for systems sized 10-50 kilowatts (kW).

To address these issues, Gas Technology Institute (GTI) is developing and demonstrating two reciprocating engine-based, micro-CHP systems to be low-cost and high efficiency with near-

[2] California Energy Commission. March 2019. *A Comprehensive Assessment of Small Combined Heat and Power Technical and Market Potential in California*. Publication Number CEC-500-2019-030. https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-030.pdf.

"This advanced efficiency, near-zero-emission technology meets key benefit-to-cost metrics that would allow California to tap into the approximately 3,000 MW of micro-combined heat and power potential in the state, capturing cost and energy savings for ratepayers. And when operated with propane, this technology can be a totally resilient system."

- Joseph Calhoun, Associate Director of Business Development for the Propane Education and Research Council

zero NOx emissions: a 4.5kW system designed by subcontractor Marathon Engine Systems and a 25-kW system designed by the subcontractor Lochinvar. These micro-CHP systems incorporate emissions control equipment (three-way catalyst) and novel engine controls that optimize the combination of fuel and air in combustion to reduce air pollutant emissions.

GTI's laboratory testing showed total system efficiencies much greater than the standalone generation 4.5 kW and 25 kW systems for a range of conditions and loads. The two systems also met CARB distributed generator emissions limits for NOx, carbon monoxide, and volatile organic compounds in laboratory testing. Building on this laboratory testing, GTI installed the 25-kW micro-CHP system to meet electricity and hot water needs for baking and cleaning at an Einstein Noah Restaurant Group Inc. food production facility in City of Industry, California; GTI is in the process of commissioning and collecting data on output, efficiency, and emissions. GTI is currently preparing to install the 4.5-kW micro-CHP system at a Buzzbox drink manufacturing facility in Indio, California. Both demonstrations will inform future installations at additional facilities, such as commercial office buildings, retail services, schools, and multifamily homes.

Project Title: Multitiered Greenhouse Gas Emissions Measurements of California's Natural Gas Powered Industrial and Fueling Infrastructure

Project Description

Fugitive emissions of natural gas that occur on the customers' side of the system can contribute substantially to inventories of methane, which is a climate pollutant that California's policies have prioritized for reduction. Statewide methane emissions for primary emitting sectors are estimated to be more than 4.3 million metric tons of carbon dioxide equivalent per year. This project investigates methane emissions from sources that were previously uncharacterized, such as power plants, food processing plants, and compressed natural gas (CNG) vehicle fueling stations. Using a multi-tiered measurement method, this field research effort provided preliminary data to: (1) characterize methane and NOx emissions from these sites downstream of the customers' meters; and (2) provide insights regarding the use of multitiered measurement approaches for emission sources that span a broad geographic scale and vary in time.

The Electric Power Research Institute (EPRI) led the team with substantial expertise and facilitated data collection with collaborating organizations. The project included intensive week-long monitoring, ground measurements of CNG stations, and aircraft monitoring. Investigating specific site types and previously under-sampled types of emissions sources in California's natural gas infrastructure has provided a first look at detailed surveys of emission points, magnitudes, and potential drivers from a variety of component and equipment types

across several high throughput facilities and CNG fueling stations. The diversity of measurement instrument platforms also provides greater context and detail on the emission profiles for each site, as compared with previous studies that have relied on one measurement platform.

At both industrial sites and compressed natural gas fueling stations, emissions were dominated by a small fraction of components. Total methane emissions from industrial sites monitored by this study represented a small fraction of total natural gas throughput, ranging from less than half a percent to less than one thousandth of a percent. For these facilities, methane emissions peaked during start-up mode and emissions from non-combustion equipment such as compressors contributed the majority of emissions. With more than 90 sites monitored by various methods, companies that directly participated in this study as well as some who were uninvolved in the research are already using project results and lessons learned to make operations, maintenance, and leak detection and repair programs more effective. Based on the insights from this project, industrial facilities could leverage targeted leak detection and repair activities and mitigate potential risks to system reliability. This in turn will lead to further reduced GHG emissions, improved worker and public safety, reduced risk of damage to infrastructure, improved system efficiency, reduced natural resource loss, and lower net costs to California ratepayers.

Building Decarbonization

Project Title: Advanced HVAC Technology Demonstration Project to Reduce Natural Gas Use in Hospitals

Project Description

Hospitals are among the most energy intensive commercial buildings due to high heating and reheating loads, and the average U.S. hospital consumes about 1.5 million therms of energy per year.[3] Hospitals comply with ventilation rules where the air is being continuously ventilated and new air is reheated. The project team estimates that forty percent more natural gas is being used through this requirement than is necessary to meet ventilation needs and indoor air quality standards.

With the goal to achieve significant energy reduction while maintaining safe and acceptable indoor airborne contaminant levels, Mazzezeti, Inc. demonstrated a variable air volume (VAV) system to provide the required ventilation or air changes needed at the Kaiser South Bay Medical Center located in Harbor City, California. This technology allows the individual zones to be controlled when needed, rather than all at the same time. The project used building energy management equipment to conduct real-time monitoring of the hospital's heating, ventilation, and air conditioning (HVAC) systems, indoor air quality, and energy use while also measuring environmental contaminants and ventilation rates. Airflow in hospital zones in patient rooms and administrative areas were converted to variable air volume with safety precautions in place to study the system's effect. The team was able to safely demonstrate a 21 percent

[3] Energy Use in Hospitals (energystar.gov)

reduction in natural gas consumption through ventilation control, resulting in an estimated 2,480 metric tons of avoided carbon emissions.

This project generated the largest dataset of airborne contamination measurements in a hospital on record. While it was assumed that lower ventilation rates and VAV systems would increase airborne contaminant levels, the actual results showed no change in contaminant levels, and therefore no findings of correlation to the levels of ventilation rates. The project demonstrated that VAV systems can be safe and effective in reducing energy consumption and carbon emissions. This data will inform future ventilation requirements specified by the state and the American Society of Heating, Refrigerating and Air-Conditioning Engineers and could overcome barriers to adopting of VAV systems in hospitals.

"We have tremendous support from the industry in developing this package including insulation manufacturer, Owens Corning; phase change material manufacturer, Insolcorp; aeroseal ceiling manufacturer AeroSeal; and thermostat manufacturer EcoBee, […] and also support of SoCalGas."

- Theresa Pistochini, WCEC University of California, Davis

Project Title: Phase Change Material-Enhanced Insulation for Residential Exterior Wall Retrofits

Project Description

Single family homes built before the 1978 building codes generally have uninsulated exterior walls that contribute to unwanted thermal exchange and air leakage, wasting energy and introducing outdoor air pollutants. It is estimated that 2.5 million single-family homes in California do not have wall insulation. Existing retrofit solutions struggle to be adopted because of cost and intrusive installation process.

Researchers at the University of California, Davis are developing and testing an enhanced building envelope retrofit solution that has the potential to be more cost effective and less intrusive through a phase change material (PCM) and aerosol sealing technology. The retrofit wall package will seal the interior wall cavity with an aerosol sealant, fill the cavity with loose-fill cellulose or fiberglass insulation, and cover the interior wall surface with a layer of phase change material, which aids temperature control through heat absorption. Through modeling and laboratory testing, the team plans to identify the most cost-effective applications of PCMs for wall retrofits in various California climate zones.

With the project underway, the research aims to validate the technology and evaluate its effectiveness in various California climate zones. Progress on the project includes securing three single-family homes for the demonstration, installation of laboratory equipment, and initial market analysis. This technology has the potential to reduce natural gas use for heating homes by 62 to 80 percent and achieve an estimated average simple payback of less than 10 years.

The project will enhance conventional low cost blown-in insulation with PCMs then aerosol the wall cavity sealing to reduce natural gas use. This process will increase the thermal storage capacity of the building, reduce the total heating energy requirement, including the summer peak late afternoon air conditioning energy costs, and control electric demand.

Industrial and Agricultural Innovation

Project Title: Demonstrating Replicable, Innovative, Large-Scale Heat Recovery in the Industrial Sector

Project Description

An estimated 20 to 50 percent of industrial energy input is lost as waste heat. Recovering waste heat losses generates cost savings, reduces environmental impact, and improves workflow and productivity. However, the waste heat recovery field is plagued by high-cost capital equipment with long payback periods. It is challenging to install cost-effective, scalable, large-capacity heat-recovery technology in the industrial sector for low-level waste heat of less than 400^{o}Fahrenheit (F). Traditional heat recovery exchangers made from stainless steel or titanium are capital intensive and subject to fouling and corrosion.

> "We believe Trevi's advanced heat recovery system can curb significant quantities of natural gas as well as natural gas fueled electricity usage in our facility. This will help our operation become more sustainable and push us to exceed CA's clean energy requirements for industrial facilities."
>
> *- Julie Cooper, Associate Winemaker, DuMOL Winery*

Recent developments in enhanced thermal conductivity of plastics have opened new pathways to cost-effectively recover low-level heat. Trevi's polymer heat exchanger (P-HEX) technology has the potential to provide a robust, cost-effective solution by integrating high-performance plastics with high-speed manufacturing. P-HEX's thin walls, made of conductive polymer composites fabricated using high-speed extrusion, make the technology more efficient and affordable for heating and cooling applications.

This technology has the potential to recover up to 95 percent of waste heat for industrial sector applications and current estimates show over 50 percent lower cost than conventional metallic heat exchangers, with significantly enhanced manufacturability and scalability using polymers.

Trevi Systems successfully designed, built, and tested a prototype P-HEX unit and are in the process of starting a manufacturing system for limited production. The P-HEX technology will be demonstrated at sites in the rapidly growing industries of microbrewing and winemaking where heat recovery has been limited in use. The recipient estimates California's wine and microbrewery industries produce a considerable amount of recoverable waste heat from natural gas use each year, creating more than 2.6 million therms and 1 million therms respectively. The demonstrations aim to validate amount of heat recovery potential and energy and cost savings from their natural gas-based operations.

Low-Emission Transportation

Project Title: CNG Hybrid Power System for Mobile Vehicles

Project Description

Off-road agricultural equipment, such as tractors and harvesters, mostly rely on diesel engines which significantly contribute to California's air quality issues and greenhouse gas emissions. Annually, off-road agricultural equipment in California consumes 238 million gallons of diesel, resulting in significant emissions and criteria air pollutants.[4] Without further progress to transition to electrified alternatives or improving efficiency of current technology, off-road diesel consumption is expected to increase by approximately 40 percent by 2045.

To help address this challenge, Terzo Power Systems developed a modular hybrid-electric power system for agricultural equipment and demonstrated it in an existing nut harvester (Figure 9). The power system uses batteries, electrohydraulic pumps, and a downsized, low-carbon CNG engine as an alternative to conventional diesel prime movers. Taking advantage of hybridization, Terzo Power Systems electrified all hydraulic and auxiliary functions of their technology. The CNG engine was operated for optimal efficiency and functioned as a generator for charging the batteries and avoiding idle and partial loads. The hybrid nut harvester delivered a 27 percent CO_2 emission reduction compared to equivalent diesel-powered equipment while also reducing costs by 43 percent.

> "Innovation with purpose is a keystone of Vanguard* and we are proud to work with Terzo, a company that shares that same value… Their mission to electrify hydraulic systems with pioneering technology is an exciting project to be a part of and is sure to bring new energy to all markets they touch."
>
> *- Chris Davison, Briggs & Stratton Senior Marketing Manager, Commercial Power.*

The hybrid power system could be adapted for a range of off-road equipment – including hybrid-electric and all-electric technology – to improve efficiency, lower fuel costs, and reduce CO_2 and other air pollutants. Going forward, Terzo Power Systems is planning to commercialize the high-voltage safety subsystem, electrified cab comfort subsystem, and electrohydraulic pump technology advanced under this project to support electrification of other agricultural and off-road equipment.

[4] https://www.arb.ca.gov/orion/

Figure 9: Terzo Power System Prototype CNG Hybrid-Electric Nut Harvester

Mike Terzo, CEO of Terzo Power Systems, with lithium-ion battery packs in front of a prototype CNG hybrid-electric nut harvester.

Source: Terzo Power Systems, LLC.

Resilience, Health, and Safety

Project Title: Barrier-Based Quantitative Risk Management Approach for Underground Storage of Natural Gas

Project Description

Following the Aliso Canyon leak and other previous failures of gas storage systems in the United States, regulators and stakeholders have been reviewing regulatory requirements to ensure the safe management of underground storage systems. As a result, California's regulations were updated in 2019 to require a risk management plan to be in place for each natural gas storage project, including a quantitative risk assessment.

The risk assessment model developed by DNV GL, USA, Inc. combines a simple qualitative method for risk assessment, known as Bow Ties, and a more complex quantitative approach, known as Bayesian networks. The methods were developed, tested, and validated using inputs from two Californian gas utility partners – Sothern California Gas Company and Pacific Gas and Electric Company. The new

"Quantification of risk of threats and hazards for underground gas storage facilities is of a great importance for the State of California and Californians. In this research project, a state-of-the-art probabilistic risk analysis is carried out to address this important issue and develop a quantitative risk assessment approach that can be used by the industry."

- Yousef Bozorgnia, Ph.D., P.E., F.ASCE Professor, Department of Civil and Environmental Engineering, University of California, Los Angeles

method allows engineers to compare threats or various mitigation actions and their effects on the overall risk of a natural gas storage project.

The combined approach of the risk assessment provides transparency and flexibility. First, the model describes the various scenarios leading to gas release in the storage project and the safety barriers that prevent gas release and related consequences. The assessment then provides a visualization of the hazards, the probabilities of occurrence, and the potential consequences, allowing natural gas companies to anticipate threats and respond in a timely manner.

> "Seismic risk analysis of natural gas infrastructure is an important issue that is being addressed by the UCLA team. This state-wide comprehensive, yet applied, research is investigating multi-hazards due to ground shaking, fault rupture, landslides, and liquefaction, all very important hazards for geographically distributed systems."
>
> - Dr. Kenneth Campbell, Principle, Science & Analytics, CoreLogic, Inc., Oakland, California

Project Title: Seismic Risk Assessment and Management of Natural Gas Storage and Pipeline Infrastructure in California

Project Description

California's seismic hazard is one of the highest in the world and is a challenge for the state's distributed natural gas infrastructure. Any moderate-to-major earthquake in the state may affect the gas infrastructure in terms of safety and functionality of the system (Figure 10).

Figure 10: Earthquake Fault Rupture

2019 Ridgecrest Earthquake in Southern California

Source: United States Geological Survey

To address this, the University of California, Los Angeles (UCLA) Natural Hazards Risk and Resiliency Research Center (NHR3) is working to quantify the risk of damage to the natural gas infrastructure from moderate and severe earthquakes in the state and provide an interactive computer tool to the stakeholders for the planning and mitigation of seismic risk.

Building upon the risk assessment model developed by DNV GL, USA, Inc., the project carries out hundreds of thousands of simulations that cover wide variations in the characteristics of earthquakes and natural gas pipelines throughout California. The project is coordinated through the UCLA NHR3, and involves California Institute of Technology, University of Southern California, and University of Texas. To ensure the practicality of the final product, in addition to academic researchers, numerous practicing professionals with decades of experience in natural gas transmission are also involved. Other ongoing initiatives at UCLA, such as those investigating liquefaction resulting from earthquakes, have also contributed to this project.

LIST OF ACRONYMS

Term	Description
AB	Assembly Bill
CalSEED	California Sustainable Energy Entrepreneur Development Initiative
CARB	California Air Resources Board
CEC	California Energy Commission
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CPUC	California Public Utilities Commission
EPIC	Electric Program Investment Charge Program
EPRI	Electric Power Research Institute
EISG	Energy Innovation Small Grant Program
F	Fahrenheit
GTI	Gas Technology Institute
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
kW	Kilowatts
MW	Megawatts
NHR3	Natural Hazards Risk and Resiliency Research Center
NOx	Nitrogen Oxide
PCM	Phase Change Materials
P-HEX	Polymer Heat Exchanger
R&D	Research and Development
SB	Senate Bill
UCLA	University of California Los Angeles
VAV	Variable Air Volume

APPENDIX A:
Investment Areas and Related Portfolio Topics Align to State Policies and CPUC Proceedings

The CEC's current Natural Gas R&D program was established through Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) and is further shaped by more recent policies such as Senate Bill (SB) 100 (De León, Chapter 312, Statutes of 2018). The program's research priorities change as knowledge is gained and policies evolve.

Resiliency, Health, & Safety

- SB 887 (Pavley, Chapter 673, Statutes of 2016) issues requirements to ensure the safety and integrity of natural gas storage facilities.
- SB 1371 (Leno, Chapter 525, Statutes of 2014) requires the CPUC to determine whether existing practices are effective at reducing methane leaks and promoting public safety, and whether alternative practices may be more effective.
- SB 380 (Pavley, Chapter 14, Statutes of 2016) determines the feasibility of minimizing or eliminating the use of the Aliso Canyon natural gas storage field in Los Angeles County while maintaining energy and electric reliability for the region.
- SB 901 (Dodd, Chapter 626, Statutes of 2018) directs revisions to fuel or feedstock procurement requirements for generation from bioenergy projects intended to reduce wildfire risks.

Building Decarbonization

- SB 350 (De León, Chapter 547, Statutes of 2015) establishes targets for statewide energy efficiency savings and demand reduction that will achieve a cumulative doubling of statewide energy efficiency savings for retail customers by 2030.
- 2019 California Energy Efficiency Action Plan addresses existing buildings, low-income barriers to energy efficiency, agriculture, industry, newly constructed buildings, conservation voltage reduction, and electrification.
- Integrated Energy Policy Report assesses major energy trends facing California's electricity, natural gas, and transportation fuel sectors and provides policy recommendations.

Natural Gas System Decarbonization

- SB 1383 (Lara, Chapter 395, Statutes of 2016) requires reductions in statewide emissions of methane by 40 percent, hydrofluorocarbon gases by 40 percent, and anthropogenic black carbon by 50 percent below 2013 levels by 2030.
- AB 1496 (Thurmond, Chapter 604, Statutes of 2015) requires the state to monitor methane hotspots.
- Short-Lived Climate Pollutant Reduction Strategy recommends actions to reduce emissions of short-lived climate pollutants, including from dairies, organics disposal, and wastewater.

- SB 32 (Pavley, Chapter 249, Status of 2016) requires California to reduce GHG emissions to 40 percent below 1990 levels by 2030.

Industrial and Agricultural Innovation

- AB 1613, the Waste Heat and Carbon Emissions Reduction Act (Blakeslee, Chapter 713, Statutes of 2007) requires an electrical corporation to purchase excess electricity from CHP systems that comply with sizing, energy efficiency, and air pollution control requirements.
- SB 1122 (Rubio, Chapter 612, Statutes of 2012) requires the CPUC to direct the electrical corporations to collectively procure at least 250 megawatts from eligible bioenergy projects, including projects using biogas (bio-fuel produced from decomposition of organic waste) from wastewater treatment plants, municipal organic waste diversion, food processing, and co-digestion; dairy and other agricultural bioenergy; and bioenergy using by-products of sustainable forest management.

Low-Emission Transportation

- Sustainable Freight Action Plan establishes targets to improve freight system efficiency by 25 percent by 2030, deploy more than 100,000 freight vehicles and equipment capable of zero-emission operation, and maximize near-zero freight vehicles and equipment powered by renewables by 2030.
- Mobile Source Strategy reduces emissions from the heavy-duty truck sector with cleaner combustion engines, renewable fuels, and zero-emission technology to meet GHG-reduction targets and attain federal health-based air quality standards for ozone and particulate matter.
- Low Carbon Fuel Standard reduces the full fuel-cycle carbon intensity of the transportation fuels pool used in California by encouraging the transition to fuels that have a lower carbon footprint.