

Transitions

RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAM **2020 ANNUAL REPORT**





SoCalGas is boldly committed

to achieving net zero greenhouse gas emissions
in our operations and delivery of energy by 2045.

Innovation

and the rapid development of new technologies will be vital to our success.





The SoCalGas Research, Development, and Demonstration Program

plays a key role in this effort by developing and demonstrating transformational products and technologies that promote decarbonization across the natural gas value chain and a diversified portfolio of clean energy sources, distributed networks, tools, and applications.

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With reliance on renewable energy sources growing every year, the decarbonization of the energy sector is well underway.

SoCalGas is playing a pivotal role in this transformation by developing clean energy innovations and energy efficiency technologies as well as advancing hydrogen for use in both transportation and energy storage.”



MARYAM BROWN
President
SoCalGas

The vision, mission, and values of the SoCalGas Research, Development, and Demonstration Program align with SoCalGas' mission to build the cleanest, safest, and most innovative energy company in America.

Advancing innovative technologies for safer, cleaner, and more reliable energy.

OUR VISION

OUR MISSION

Identify transformational energy solutions. Build them. Share them with the world.

OUR VALUES

Science

Our experts in science, engineering, energy systems, and environmental policy seek answers to some of today's most pressing energy questions.

Synergy

We work with the world's finest researchers in universities, national labs, and industry to develop transformational technologies that support decarbonization, energy security, and economic development.

Equity

We champion technologies that support affordable access to clean, safe, and reliable energy for all Californians.



**OPERATIONAL
EFFICIENCY**
157 PROJECTS



RELIABILITY
226 PROJECTS



SAFETY
199 PROJECTS



**PROGRAM
BENEFITS**



ENVIRONMENTAL:
**IMPROVED AIR
QUALITY**
187 PROJECTS



ENVIRONMENTAL:
**REDUCED GHG
EMISSIONS**
229 PROJECTS



**IMPROVED
AFFORDABILITY**
144 PROJECTS

2020

A YEAR OF TRANSITIONS

“Oil and gas [have] incredible infrastructure, incredible capacity to move energy from one place to another... What if that happened for hydrogen?”

—JOHN KERRY
SPECIAL PRESIDENTIAL ENVOY
FOR CLIMATE

2020 was a year of transitions. The global COVID-19 pandemic brought sickness and tragedy into many lives and upended how we live, work, and play. For a time, modern life ground to a halt. Amidst the chaos, however, science, technology, and innovation were powerful forces that helped us adapt to the changes and come together as a community.

Digital collaboration tools brought families, friends, students, and co-workers together when they could not meet in person. Restaurants, grocery stores, and retailers began offering online ordering and curbside pickup. And around the world, teams of scientists and researchers worked day and night to develop effective vaccines against the coronavirus at a record-breaking pace.

At SoCalGas, we believe that science, technology, and innovation—as well as collaboration—can help solve another one of the world’s great challenges: climate change.

According to the International Energy Agency, global carbon dioxide emissions were expected to decline by a record 8% in 2020. Unfortunately, most of this reduction was driven by a temporary reduction in demand for energy rather than by real, large-scale structural changes to how we produce and utilize it. Supporting meaningful progress in the transition to lower-carbon forms of energy while ensuring safe, reliable, and affordable access to it are key goals of the SoCalGas Research, Development, and Demonstration (RD&D) Program.



THOUGHT-LEADERS, INNOVATORS, AND INDUSTRY EXPERTS

“Almost any objective analysis
for getting to zero emissions
includes hydrogen.”

—JACK BROUWER
DIRECTOR

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY OF CALIFORNIA, IRVINE

With more than 21 million customers and one of the nation’s largest networks of gas transmission, storage, and distribution infrastructure, SoCalGas is well-positioned to play a central role in the ongoing decarbonization of our energy industry and, ultimately, the state of California.

The RD&D Program is staffed with subject matter experts in science, engineering, industrial process technology, and environmental policy who collaborate with the world’s top institutions—including the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL), the California Energy Commission (CEC), Gas Technology Institute (GTI), Caltech, the University of California, and Stanford University—to develop and demonstrate transformational products and technologies that promote decarbonization across the entire natural gas value chain.

We communicate regularly with our colleagues around the nation and world, ensuring that the work we support supplements and complements their efforts and addresses the most pressing technological gaps in the field.

Each year, we support hundreds of projects along the commercialization pathway—from lab-scale R&D to multi-year precommercial demonstrations—with the ultimate goals of saving energy, reducing GHG emissions, improving air quality, and increasing energy safety, reliability and affordability.

And, when we finish a project, our work is not done. We share “lessons learned” widely to spur further innovation and advance products from lab- and demonstration-scale to market. In support of these goals, the RD&D Program invested almost \$15 million in energy technology projects in 2020.



CLEANER, MORE AFFORDABLE, & SAFER ENERGY FOR ALL

“I’m going to work with my new advisor for equity so that we can lead the way—by targeting disadvantaged communities for new clean energy investments, jobs, and businesses, doubling down on our commitments to racial justice, and developing policies that ensure the benefits of this emerging economy reach those on the front lines of climate change.”

**—SECRETARY JENNIFER GRANHOLM
U.S. DEPARTMENT OF ENERGY**

Science and technology helped many navigate the trials of the past year. But too many people have been left behind or never experienced the benefits of abundant energy and a prosperous economy in the first place. In California, millions of people live and work in areas categorized as Environmental or Social Justice (ESJ) communities, a designation that includes disadvantaged communities, tribal lands, and low-income households and census tracts.

All too often, people from ESJ communities suffer disproportionate environmental and socioeconomic impacts, including poverty, high unemployment, air and water pollution, and high incidences of asthma and heart disease. In many cases, ESJ community residents also suffer from reduced or less reliable access to energy. What energy they can access often represents a burdensome percentage of their household incomes.

The RD&D Program seeks to advance and champion technologies that support widespread access to clean, affordable, and reliable energy for all Californians, including those living and working in ESJ communities.

That is why equity is a factor we consider when deciding which products and technologies to support. Our short-term goals are to increase our engagement with residents and businesses from ESJ communities and to continually grow the number of projects we support in those locations. Ultimately, we want to ensure that the benefits of decarbonization and clean energy do not become luxuries for the wealthy but are widely available and accessible to all Californians.

RD&D Program

2020 EQUITY ACTIVITIES

We committed to **long-term relationship building** with key representatives of ESJ communities throughout California.

We prepared educational material about the RD&D Program for members of ESJ communities and, in collaboration with the Regional Public Affairs (RPA) team, co-launched our **ESJ outreach program**, identifying approximately 20 community-based organizations (CBOs) to target for 2021 presentations.

Our commitment to provide customers with safe, affordable, and reliable service goes beyond natural gas. We are also dedicated to **improving the quality of life in the communities we serve** by maintaining a diverse workforce and giving back through our charitable contributions and employee volunteer activities.

We **connected one-on-one** with organizations—including Hispañas Organized for Political Equity (HOPE)—in ESJ communities and sought input on potential research needs.

We began working with the SoCalGas Supplier Diversity group to identify resources available to **help diverse and minority-owned businesses** connect and work with SoCalGas RD&D. Supplier diversity can help culturally and ethnically diverse business owners navigate the paperwork required to obtain certification by the California Public Utilities Commission (CPUC) as a Diverse Business Entity (DBE).

We committed to **supporting supplier diversity** and actively sought collaboration with disadvantaged business enterprises and woman-, LGBTQ-, and disabled-veteran-owned businesses.

We interviewed experts, including researchers at the University of California, Los Angeles (UCLA) Luskin Center for Innovation and a Senior Equity Analyst at the CPUC, to seek guidance on developing the RD&D Program's **Equity Engagement Plan**.

Based on feedback submitted during our 2020 public workshop, RD&D staff started developing an **Equity Engagement Plan**. Like the other transitions we experienced in 2020, equity engagement is a new area for the RD&D program. At this early stage of development, the plan is devoted to connecting with and listening to stakeholders in ESJ communities.

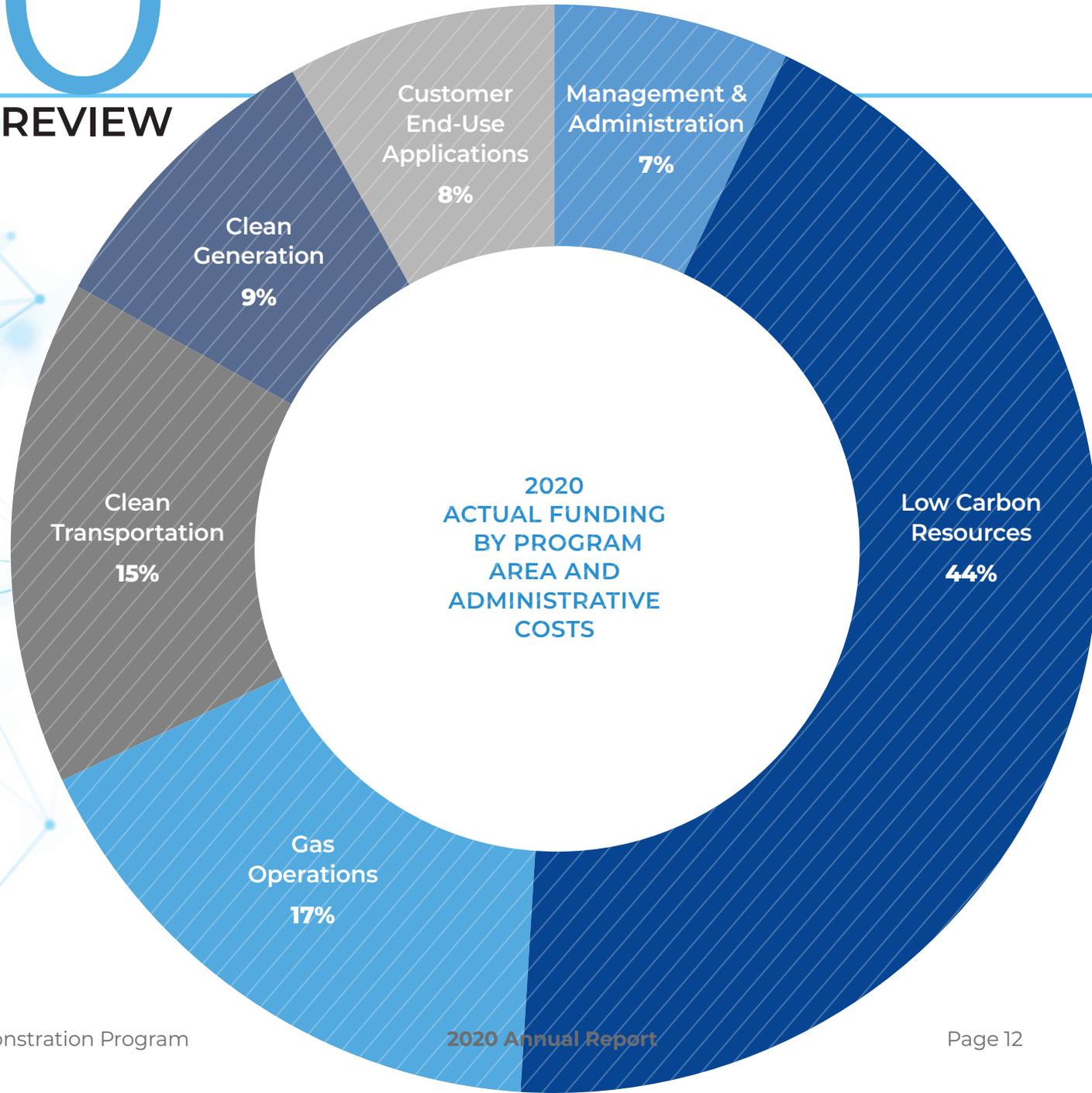
2020

IN REVIEW

FINANCIAL HIGHLIGHTS

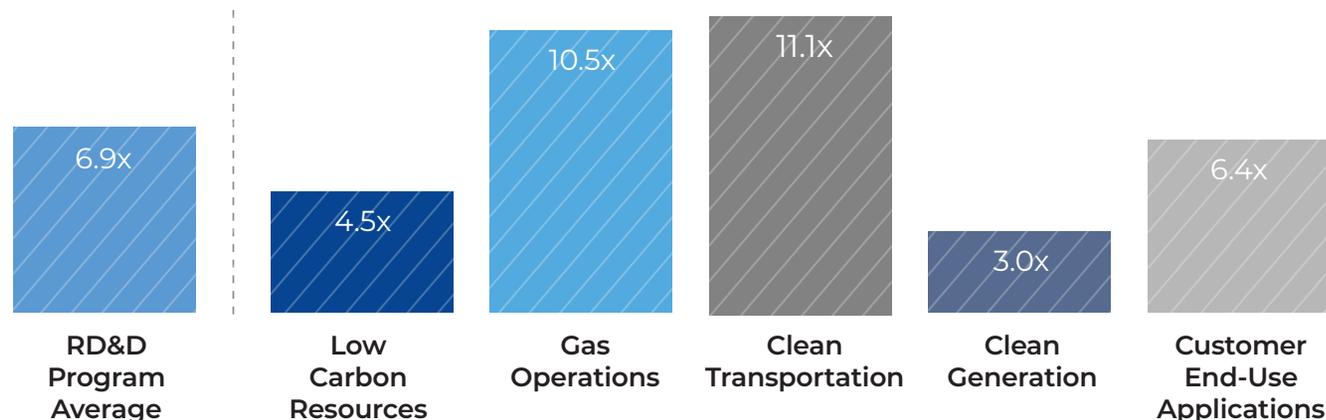
In 2020, the RD&D Program supported 386 active RD&D projects and distributed almost \$15 million to projects across the entire gas value chain in California.

In executing these projects, SoCal-Gas collaborated with many of the most forward-thinking research consortia, universities, national labs, public agencies, and entrepreneurs in the nation and the world. Collectively, these organizations provided significant leveraged funding, as well as invaluable guidance, review, technical expertise, and access to resources and infrastructure.



Split across five program areas—Low Carbon Resources, Gas Operations, Clean Transportation, Clean Generation, and Customer End-Use Applications—these projects encompassed everything from benchtop research efforts and pilot testing to demonstrations in real-world conditions. Importantly, they achieved substantial progress toward commercializing new safe, reliable, and affordable clean energy products and technologies.

RATIO OF OUTSIDE FUNDING TO SOCALGAS FUNDING



2020 Funds Expended

In 2020, the SoCalGas RD&D Program invested \$14,894,000 in numerous projects across the entire gas value chain. The RD&D Program allocated funding across the five programs and multiple subprograms. Collectively, these projects leveraged significant cofunding from businesses, research consortia, and other participating organizations. On average, every dollar of SoCalGas RD&D funds expended was matched by \$6.90 of funding from other sources in 2020.

PROGRAM	2020 ACTUALS
Low Carbon Resources	\$7,036,000
Gas Operations	\$2,677,000
Clean Transportation	\$2,363,000
Clean Generation	\$1,442,000
Customer End-Use Applications	\$1,376,000
Management & Administration	\$1,149,000
TOTAL	\$16,043,000

Royalties and Incentives

To maximize value, the RD&D Program is authorized to negotiate royalty and equity arrangements with companies participating in the program. For certain products or technologies nearing full commercialization, SoCalGas negotiates product royalty rights or equity interest in companies developing targeted technologies in exchange for RD&D funding used to support technology development and demonstration. When appropriate, SoCalGas may also negotiate post-commercial benefits on equipment and other technology developed with funding from the RD&D Program.

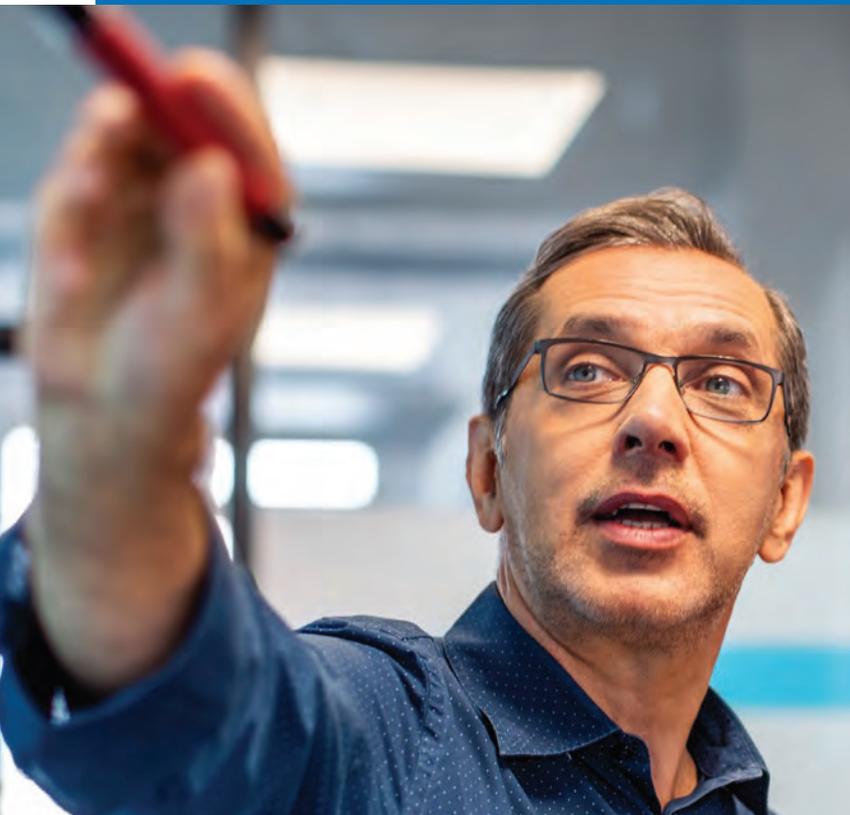
These arrangements provide an opportunity for SoCalGas ratepayers to receive a direct financial return should the technology development efforts prove successful. In 2020, past RD&D Program investments generated \$132,359 in royalties.

PROGRAM	2020 ACTUALS
2015	\$99,689
2016	\$90,882
2017	\$104,398
2018	\$100,849
2019	\$99,584
2020	\$132,359

SIGNIFICANT 2020 MILESTONES

2020 ANNUAL STAKEHOLDER WORKSHOP:

On April 24, 2020, RD&D Program staff hosted an online workshop attended by 148 individuals from a wide variety of organizations, including the CEC, GTI, HOPE, NREL, the University of California, and the National Fuel Cell Research Center. Program staff incorporated input received at the workshop into the 2021 RD&D Program Research Plan.



TOTAL ACTIVE PROJECTS IN 2020

386

SIGNIFICANT 2020 MILESTONES

Research Webinars

RD&D Program staff conducted two webinars to share information with industry stakeholders, the research community, and the general public about two recent successful projects. Recordings of the webinars are available on the SoCalGas RD&D webpage.

The first, a collaboration with Opus 12, explored how to utilize carbon dioxide emissions to produce renewable fuels and industrial chemicals. Among the 50 attendees were representatives from Lawrence Livermore National Laboratory, the American Gas Association, the National Aeronautics and Space Administration, and the Pipeline Research Council International (PRCI).

The second discussed a recent joint effort with GTI to develop a 4th-generation gas-fired heat pump water heater that reduces GHG emissions by 49% in comparison with conventional gas-fired water heaters. The 42 attendees included representatives from Pacific Northwest National Laboratory (PNNL), Rinnai, and Northwest Energy Efficiency Alliance.



TOTAL INITIATED
PROJECTS IN 2020

104

106

TOTAL PROJECTS
COMPLETED
IN 2020



LEVERAGED PUBLIC FUNDING

In 2020, program staff supported 19 proposals applying for public funding. These projects were awarded more than \$38 million in research funding from the DOE, CEC, and the National Science Foundation.

5 PROJECTS WON A TOTAL OF **\$11,922,984** FROM CEC IN 2020

PUBLICATIONS, PATENTS, AND CITATIONS

In 2020, projects cofunded or otherwise supported by the RD&D Program were featured in 55 articles, reports, and technology briefs. Projects supported by the RD&D Program were also associated with four patent applications.

See Appendix for more information.

DEPLOYED TECHNOLOGIES

A major goal of the RD&D Program is to bring technology from the lab to market. In 2020, organizations across California and throughout the nation deployed numerous products and technologies for real-world use as a direct result of the support they received from the RD&D Program. Examples from 2020 include:

- » Fracture Toughness via in-Ditch Non-Destructive Testing-Validation (NDE-2-9)
- » Polyethylene Saddle Heat Fusion Rounding Clamp Evaluation
- » Fiber Optical Systems at Montecito Creek
- » Risk Profile for Aldyl-A Piping System - Phase 3 - Squeeze Off Reinforcement Clamps (2.13.d.3)
- » Small Polyethylene Diameter Squeeze-Off - Phase 2 (2.14.c.2)
- » Gas Utility Threat Contextualization (Real-Time Visualization and Notification)
- » Demonstrate In-Line Inspection Tool for Gas Storage Piping
- » Heavy Hydrocarbon Compound Dew Point in Natural Gas Pipelines (MEAS-15-01)
- » Protect Tracer Wires from Corrosion (5.17.k)

Program

GOALS AND STRUCTURE

Improve the
environment

Develop
renewable
resources

Improve
safety,
reliability,
affordability

PROGRAM GOALS

The goals of the RD&D program are to identify, test, and commercialize transformational new energy technologies that will reduce GHG and criteria air pollutant emissions, maintain the energy affordability that natural gas has historically provided, and advance the safety and reliability of California's gas delivery networks and systems in an ever-changing operational environment.

Concurrent with the pursuit of these goals, SoCalGas also seeks to decarbonize its pipeline by replacing conventionally sourced, fossil-based natural gas with increasingly higher amounts of renewable natural gas (RNG) and hydrogen to benefit its customers and support California in the achievement of its ambitious climate change goals.

Consistent with the framework established in Public Utilities Code Section 740.1, program staff considers multiple factors when selecting projects to support. These factors include regulatory and policy drivers, input from knowledgeable industry stakeholders, equity, and corporate policy and goals, such as 20% RNG being delivered in our system by 2030.

PROGRAM STRUCTURE

In 2020, the RD&D Program allocated funding across five research program areas: Low Carbon Resources, Gas Operations, Clean Transportation, Clean Generation, and Customer End-Use Applications.

PROGRAM STRUCTURE

The five program areas and their respective sub-programs:



The RD&D Program follows three SoCalGas principles in its quest to achieve California's energy transition and net zero goals.

1

DECARBONIZATION

Reducing carbon intensity across all economic sectors is foundational to achieving net zero. It requires energy efficiency, renewable electricity, renewable gases, long duration storage, carbon management, and other technologies to be viable at scale.

2

DIVERSIFICATION

Developing a diversified portfolio of clean energy sources, distributed networks, tools, and applications is the only way to achieve society's clean energy goals. Diversification also serves as a necessary risk management tool, delivering resiliency to the system and protecting against the uncertainties of the future.

3

DIGITALIZATION

Deploying advanced technologies and analytics to improve planning, safety, resiliency, and the integration of real-time information to benefit participants across the energy value chain.

RESEARCH COLLABORATORS

“Decarbonized gas would let us take advantage of trillions of dollars of existing pipelines, equipment, and appliances, saving huge sums of money and years of time in creating a zero-carbon energy system.”

—MICHAEL WEBBER
SCIENTIFIC AMERICAN



The SoCalGas RD&D Program is a vital element of a much larger technology funding ecosystem that includes a variety of gas industry research consortia and numerous federal, state, and regional public agencies. Program staff works with leading industry professionals and subject matter experts from these organizations, as well as from universities, national labs, and businesses, to maximize the impact of their investments in promising technologies and products with clear commercialization pathways.

These relationships enable SoCalGas to engage science and technology experts, other utilities, and industry stakeholders in open dialogues to more effectively identify and close knowledge and research gaps, avoid duplication of previous and ongoing research, and mitigate technical, economic, and commercialization risks. This helps us in our quest to develop products and technologies that reduce customer costs, save energy, increase safety and reliability, improve air quality, and reduce GHG emissions.

Together, we exchange information and research concepts, collaborate on project development, establish partnerships, and actively seek public and private funding opportunities, with the goals of securing additional cofunding and assembling the most capable and impactful team of subject matter experts to work on any particular project.

Universities

SoCalGas regularly collaborates with scientists, engineers, and other academics at some of our nation’s most prominent universities, including Stanford University, the California Institute of Technology (Caltech), and the University of California at Davis, Riverside, and Irvine. These professionals perform fundamental science work through lab- and bench-scale applied research on a variety of critical energy topics, including fuel cell development, carbon-free hydrogen production and energy storage, and carbon capture and use. University collaborators also possess expertise in modeling, technoeconomic analysis, and lifecycle analysis—areas of immense importance to the evaluation, development, and demonstration of cleaner, safer, affordable, and more reliable energy solutions. On many projects, universities also serve as ideal technology demonstration sites.



National Laboratories

The U.S. National Laboratories and Technology Centers are a system of facilities and laboratories overseen by the DOE to advance science and technology. Researchers and scientists at the 17 national labs tackle the critical scientific challenges of our time—from combating climate change to discovering the origins of our universe—and possess unique instruments, equipment, and testing facilities.

National labs are unequalled in their ability to address large-scale, multifaceted, and complex research and development challenges with a multidisciplinary approach that emphasizes translating basic science to innovation. SoCalGas regularly engages national lab personnel for subject matter expertise, guidance, and collaboration in developing and executing research projects. Through collaboration with national labs, SoCalGas often cofunds projects supported by the DOE, amplifying the impact of RD&D funds for maximum leverage. In many cases, SoCalGas also obtains licensing or intellectual property (IP) rights, which can generate revenue and offset RD&D Program costs.

Public Agencies

At local, state, and federal levels, public agencies play a key role in driving the RD&D process, from disseminating project solicitations related to regulatory policy objectives to serving as thought leaders that help shape broad energy strategies. RD&D Program staff regularly work with numerous agencies, including the DOE, CEC, South Coast Air Quality Management District, the California Air Resources Board, and the Pipeline and Hazardous Materials Safety Administration (PHMSA).

For projects focused on early-stage technologies, public funding programs can significantly reduce many of the risks associated with deploying staff and resources on untested products. This, in turn, can attract high-caliber team members and other leveraged funding to compound the impact of invested dollars. Importantly, if successful, publicly funded projects can serve as springboards to additional public and private funding, larger demonstration projects and, ultimately, product and technology commercialization.



Businesses

At its core, the RD&D Program is about developing and promoting practical applications to overcome challenges facing the energy sector, in alignment with California's decarbonization goals. To help ensure that the new technologies and products supported by SoCalGas advance to real-world applications and markets, RD&D Program staff leverage their connections, knowledge, and expertise by working closely with leading equipment manufacturers and global technology developers to demonstrate new technologies in large-scale and/or long-term pilot demonstration projects under real-world conditions. These demonstrations constitute the final stages of validation before commercial launch.

Research Consortia

RD&D Program staff have developed strong ties with several research consortia focused on the gas energy industry. The membership of many of these organizations consists of utility companies across North America. Typically, these consortia serve member utilities by facilitating technical collaboration and pooling financial and technical resources to collectively address ongoing or anticipated challenges in the gas industry.

By working closely with these and other similar organizations, RD&D Program staff can share both knowledge and funding with other utilities and researchers to develop and execute impactful projects. Coordination of work between these organizations and access to technical libraries also greatly reduce the odds of reproducing previously completed work or work currently underway.

To facilitate collaboration with research consortia, the RD&D Program is a member of five subscription-based organizations: Northeast Gas Association (NGA)/NYSEARCH, Operations Technology Development (OTD), PRCI, Sustaining Membership Program (SMP), and Utilization Technology Development (UTD).



Northeast Gas Association/NYSEARCH: NGA/NYSEARCH is a collaborative research suborganization within the Northeast Gas Association that serves 20 gas utility member companies. Members of NYSEARCH, primarily North American gas distribution companies, voluntarily participate in projects focused directly on needs specific to the member companies and the gas industry as a whole.

Operations Technology Development: OTD is a not-for-profit organization, comprising 26 gas utility members that serve over 60 million gas consumers in the United States and Canada, representing 75% of the households served by gas. OTD combines the interests, expertise, and resources of its members to develop advanced operations and pipeline technologies for the gas industry.

Pipeline Research Council International: PRCI is a community of the world's leading pipeline companies, vendors, service providers, equipment manufacturers, and other organizations supporting the gas industry. PRCI's research focuses directly on gas and oil transmission pipeline issues.

Sustaining Membership Program: SMP is a collaborative research and development program with two segments, Utilization and Operations. Its 28 gas utility members support research projects focused on gas delivery, energy utilization, environmental science, and renewable energy. SMP develops technology through the "proof of concept" phase, at which point the most promising technologies are continued through short- to mid-term R&D programs, implemented by organizations such as OTD and Utilization Technology Development (UTD).

Utilization Technology Development: UTD is a 20-member consortium of utilities in the United States and Canada, representing 37 million gas customers in North America. Its goal is to develop new technologies that help gas consumers save money, reduce emissions, improve efficiencies, and optimize their gas use.

See Appendix for more information.

Programs

25 **LOW CARBON RESOURCES** 

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46 **CUSTOMER END-USE APPLICATIONS** 

LOW CARBON RESOURCES

The primary goal of the Low Carbon Resources program area is to decarbonize the gas supply while maintaining its affordability and reliability. To accomplish this goal, program staff members develop, promote, and advance new technologies aimed at increasing and expanding the production of renewable gas to displace conventionally sourced pipeline gas, while also limiting or recycling GHG emissions.

This program includes three subprograms:

Renewable Gas Production

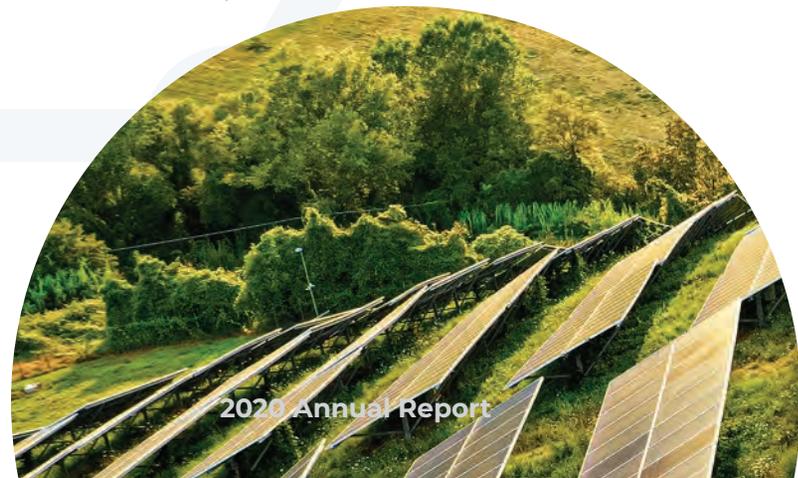
This subprogram focuses on the safe, reliable, and cost-effective production of renewable gaseous fuels—specifically, RNG and hydrogen—from various feedstocks and multiple technological pathways. Areas of focus include, but are not limited to, biomass processing and conversion, renewable hydrogen production from direct water splitting, and methanation pathways to produce RNG from captured carbon dioxide.

Low-Carbon Hydrogen Production

This subprogram focuses on the production of low-carbon and emissions-free hydrogen from various methane feedstocks, including biomethane. Areas of focus include, but are not limited to, advanced steam methane reforming (SMR) and methane pyrolysis technologies.

Low-GHG Chemical Processes

This subprogram focuses on the design, development, and deployment of technologies that can minimize reliance on natural gas combustion, and on carbon capture utilization and sequestration (CCUS) technologies for the capture of GHG emissions and their conversion into valuable chemicals or sequestration.





INNOVATIVE PROCESS MAKES CLEAN CEMENT AND LOW- OR ZERO-CARBON HYDROGEN

New industrial process coproduces hydrogen and cementitious materials in a clean, cost-effective manner that also reduces energy consumption.

Industrial processes account for a significant portion of global GHG emissions, with four processes in particular—cement, hydrogen, steel, and aluminum production—accounting for roughly 16% of the annual total. These four carbon-intensive processes are particularly difficult to decarbonize because they use tremendous amounts of energy, resulting in large quantities of process emissions.

Recently, SoCalGas collaborated with Brimstone Energy on the development of a prototype system that, once fully commercialized, could dramatically reduce GHG emissions from two of these four major emitters, hydrogen and cement. The prototype builds on earlier proof-of-concept work completed by Brimstone’s founders while completing graduate research at Caltech.

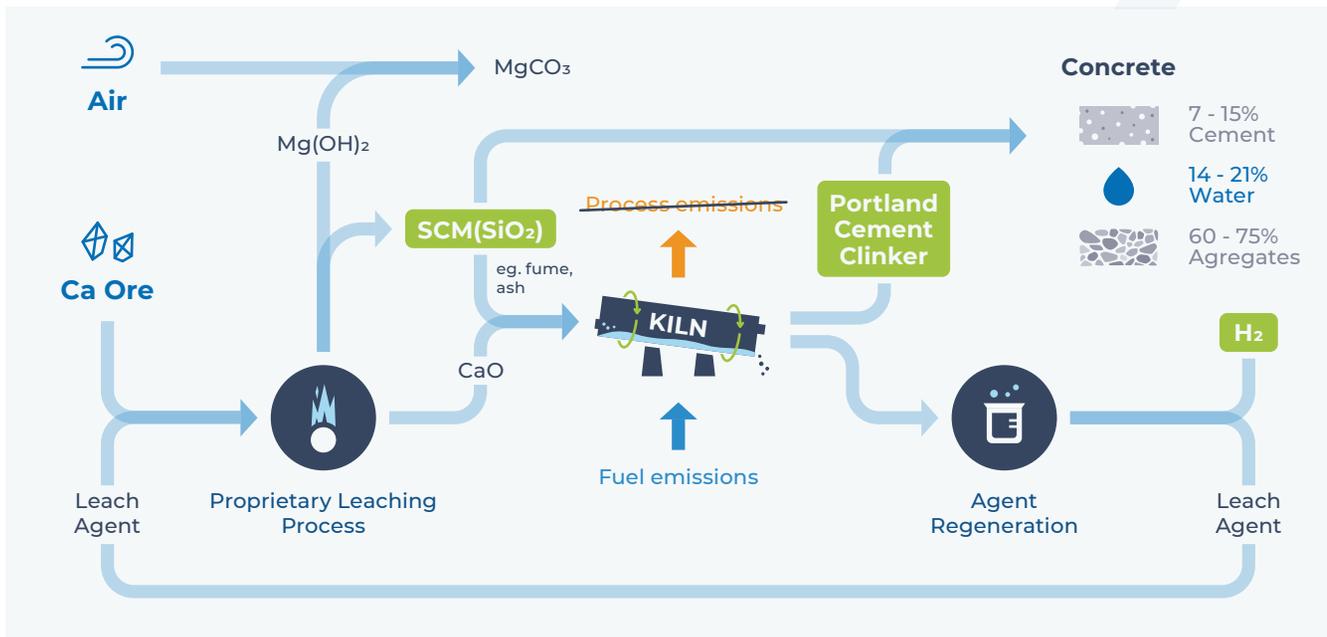
TOTAL PROJECT COST	\$3,525,000
SOCALGAS	\$50,000
COFUNDING	\$3,475,000

“Cement turns into concrete which is the most widely used material on the planet,” explained Cody Finke, CEO of Brimstone. “There is also tremendous industrial demand for hydrogen.” Collectively, the production of these two commodities accounts for roughly 3% and 8%, respectively, of annual global GHG emissions.

“Cement today is typically produced from limestone—CaCO₃—which is essentially solidified carbon dioxide,” said Finke. “When you heat limestone, it releases carbon dioxide. So, even if the energy used to produce cement is 100% clean,



Brimstone Energy sought to develop a batch-process system sulfuric acid electrolysis prototype capable of producing 1 kg of clean hydrogen, while consuming less energy than a comparable conventional water-only electrolysis process.



The new process does not start with calcium carbonate or natural gas and, thus, does not emit process carbon emissions. The only potential emissions associated with the technology depend on the source of the energy used to power the system.

the majority of emissions associated with concrete production would persist.”

The same is true for conventional hydrogen production, which most commonly uses steam methane reforming (SMR). “Basically, you heat up natural gas—methane or CH₄—in the presence of steam and it decomposes into hydrogen and carbon dioxide,” said Finke. “Again, even if the energy used to power SMR is completely carbon-free, you would still produce a lot of carbon dioxide.”

“The only way to decarbonize these industries is to improve their economics while lowering the associated emissions,” said Finke. “That’s why we developed an industrial process that can co produce both hydrogen and cementitious materials in a clean, cost-effective manner that also reduces energy consumption.”

“Essentially, the system uses sulfuric acid (H₂SO₄) to dissolve a calcium ore, which selectively extracts calcium sulfate (CaSO₄) and produces supplementary cementitious materials, such as ash and silica fume,” said Finke. The system then heats the calcium sulfate in a kiln, which produces sulfur dioxide (SO₂) and cement. “Finally, it combines the supplementary cementitious materials produced earlier with clinker to produce low-carbon concrete.”

To produce hydrogen, the system inputs the sulfur dioxide produced in the kiln and water into an electrolyzer, which produces hydrogen and sulfuric acid. The sulfuric acid is then recycled as an input into the cement production process described above.

“We don’t start with calcium carbonate, so there are no emissions in the cement-making process,” said Finke. “We don’t start with natural

gas, so there are no emissions from the hydrogen production step.” The only potential emissions associated with the technology depend on the source of the energy used to power the system.

In its collaboration with SoCal-Gas, Brimstone Energy sought to develop a batch-process system sulfuric acid electrolysis prototype capable of producing 1 kilogram (kg) of clean hydrogen, while consuming less energy than a comparable conventional water-only electrolysis process. “This exact electrolytic reaction has never been built at industrial scale before,” said Finke. “To better understand how to scale up, we plan on performing a lot of stability testing to ensure consistent energy consumption per unit of hydrogen produced.”

The next goal is to gather data for the near-term development of a skid-mounted, continuous-process pilot system capable of producing several kilograms of cement per day and tens of grams of hydrogen at an industrial facility. “If that proves successful, we hope to build a full-scale demonstration plant sometime in 2023,” said Finke.

As a small startup, Brimstone Energy initially had difficulty raising capital. With a contribution of \$50,000, SoCalGas’ RD&D Program

was the first organization to support Brimstone and recognize the technology’s potential. Leveraging that initial funding, Brimstone has since raised almost \$4 million from a variety of organizations, including Pacific Gas and Electric, Caltech’s Rocket Fund, the Chevron Catalyst Program, the DOE’s Advanced Research Projects Agency-Energy (ARPA-E) program, as well as additional private venture capital investors. The company also gained access to free lab space through a grant from the DOE and Cyclotron Road, a program that incubates advanced technologies in partnership with Lawrence Berkeley National Laboratory.

The process has incredible potential. Brimstone estimates that in a system configuration that uses solar- or wind-generated electricity and heat from natural gas, the carbon intensity of the process would be approximately 30 kg carbon dioxide per ton of cement produced along with 25 kg of hydrogen co-production. “To put that in perspective, using the same assumptions, a conventional approach would have a carbon intensity of roughly 1,000 kg of carbon dioxide per ton of cement produced,” said Finke. Using clean electricity and renewable natural gas, Finke estimates that carbon

intensity would further drop to approximately -620 kg of carbon dioxide per ton of cement produced.

The new process has one additional benefit. “Carbon emissions really depend on the rock we start with,” said Finke. Brimstone has chosen to work with a rock common to California, where the company is based. This rock is particularly rich in magnesium, which delivers additional environmental benefits. “One of the waste products of our process is magnesium dihydroxide, which naturally sucks carbon out of the atmosphere and converts it to magnesium carbonate. So even when the process uses heat from natural gas, there is a built-in mechanism for carbon capture.”

Finke anticipates participating in joint ventures with cement companies, concrete companies, or gas utilities in the future. “Our products would be clean cement and low- or zero-carbon hydrogen, depending on the source of electricity used in the electrolyzer,” said Finke. “If the entire cement industry used this process to produce 100% of the world’s cement, then we would produce enough hydrogen to fuel all of the world’s cars.”



NEW CO₂-FREE PROCESS PRODUCES HYDROGEN FROM NATURAL GAS

Thermocatalytic decomposition of methane yields CO₂-free hydrogen and high-value carbon coproducts for transportation and manufacturing industries

To cut its greenhouse gas emissions to 40 percent below 1990 levels, California seeks to put five million zero-emission vehicles on the state's roads by 2030. Many of these vehicles will obtain power from onboard battery-electric systems, but a significant fraction will utilize hydrogen fuel cells.

Both methods of powering zero-emission vehicles have their challenges. For hydrogen fuel cell vehicles, one of the biggest hurdles is obtaining a supply of hydrogen. One common source is methane (CH₄), the primary constituent of natural gas. Methane is both inexpensive and readily available.

Unfortunately, conventional methods of producing hydrogen from methane, such as steam methane reforming (SMR), come at a steep environmental cost, emitting roughly 11 g of carbon dioxide (CO₂)

TOTAL PROJECT COST	\$3,200,000
SOCALGAS	\$700,000
COFUNDING	\$2,500,000

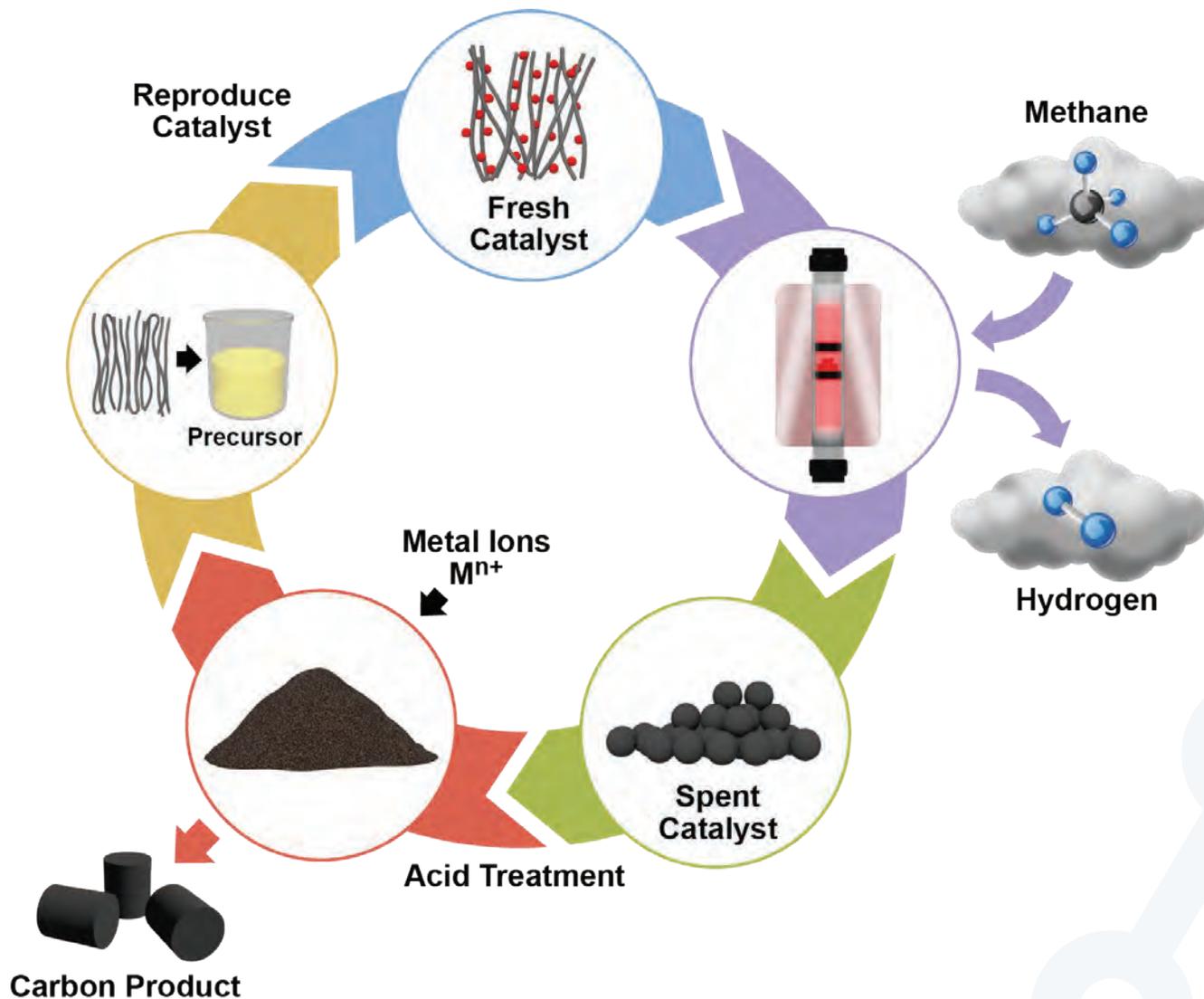
for every gram of hydrogen produced.

Methane pyrolysis, the non-oxidative thermal decomposition of methane, is an alternative to SMR and can produce CO₂-free hydrogen. However, commercial methane pyrolysis technologies are largely nonexistent. In fact, today, only one pilot-scale plant exists in North America.

To address this critical gap, SoCalGas recently cofunded the development of a novel patent-pending methane pyrolysis process for producing CO₂-free hydrogen while simultaneously producing highly



A research team from PNNL and WVU developed and demonstrated a thermocatalytic decomposition process to convert methane into hydrogen at a bench scale. The process also yields a high-value solid carbon co-product suitable for a variety of manufacturing applications.



The PNNL-WVU thermocatalytic decomposition process uses a novel bimetallic catalyst to produce hydrogen. Solid carbon that accumulates on the catalyst is washed and separated for commercial use, while the metallic precursors are re-synthesized and recycled back into the reactor. The closed-loop cycle allows for continuous catalyst replacement while emitting zero carbon dioxide emissions.

valuable carbon coproducts. Originally cofunded by the U.S. Department of Energy (DOE) in 2018, the project sought to develop a new thermodynamic catalytic deposition (TCD) process with lower operating temperatures and, therefore, reduced energy consumption.

Importantly, this approach would also enable plant operators to sell the process's valuable carbon fiber and carbon nanotube (CNT) coproducts, further reducing the net cost of hydrogen production. Carbon nanotubes and carbon fibers have desirable mechanical and chemical properties and can be used in a variety of manufacturing applications ranging from electronics and medical devices to composites for aerospace structures and building systems.

This approach has several advantages over other methane pyrolysis technologies, which typically require high operating temperatures and produce a less valuable, non-crystalline solid carbon product. Other research teams exploring TCD were unable to develop an efficient regenerable catalyst or methods to separate the solid carbon coproducts from the catalyst.

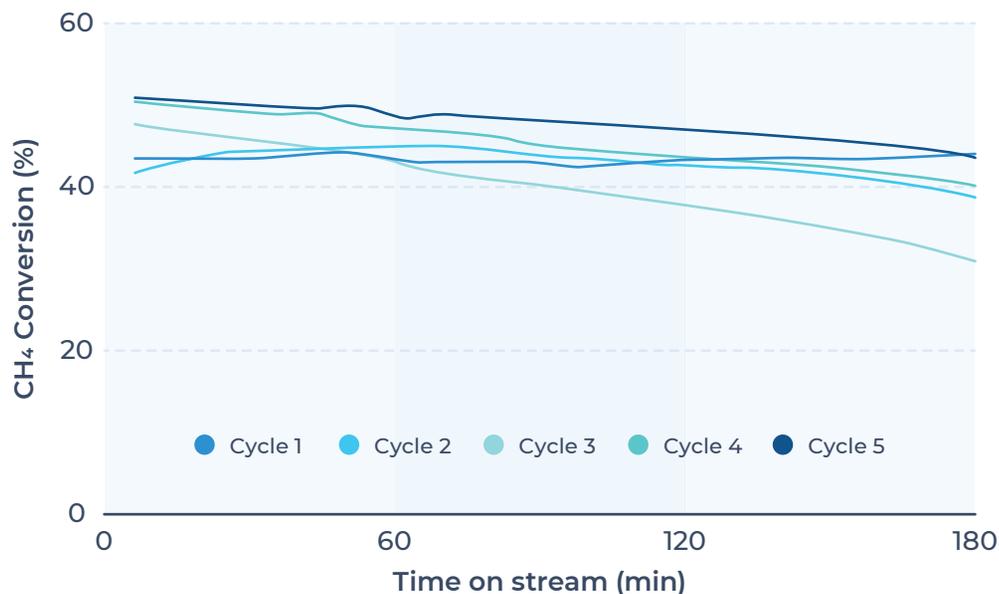
To address these challenges, a team from West Virginia University (WVU) and Pacific Northwest National Laboratory (PNNL) first developed a highly efficient bimetallic catalyst—active, stable, and selective toward desirable carbon and hydrogen coproducts—for the TCD reaction. Second, they developed a way to separate the carbon product from the catalyst and

demonstrated that process at the bench scale.

The TCD process starts by flowing methane gas through a patent-pending bimetallic catalyst inside a reactor vessel operating at approximately 600°C. The chemical reaction produces hydrogen as solid carbon accumulates on the catalyst. An acid wash then separates the carbon products from the metallic catalyst precursors, which are then resynthesized using some of the carbon product as catalyst support. The recycled catalyst then re-enters the reactor, completing the loop for continuous catalyst replacement. The high-value carbon coproducts gleaned from the wash process remain separate and available for industrial use.

Using this new method, PNNL techno-economic analyses project a net hydrogen production cost of \$2.0/kg at 40,000 – 140,000 tons/year, assuming a solid carbon credit price range between \$0.7/kg - \$1.2/kg. PNNL also projects a decrease in carbon dioxide emissions of at least 85% compared to conventional SMR for hydrogen production.

Southern California tech startup C4-MCP LLC is participating as a commercialization partner, providing cost-share funding and in-kind resources to identify market



Through five cycles of the TCD process, with each cycle lasting three hours, the bimetallic catalyst sustained reactivity and selectivity for producing both CO₂-free hydrogen and high-value solid carbon coproducts.

opportunities for the solid carbon coproducts. The global CNT market was estimated at approximately \$3.5 billion in 2016 and is expected to increase to \$8.7 billion by 2022, with robust growth rates of over 17 percent annually. C4-MCP is also identifying additional, new market opportunities made possible with the production of the unique crystalline carbon co-product produced in this process.

The next step in the research proposed to the DOE involves scaling up the TCD process for a pilot-scale demonstration in a fluidized bed reactor. The fluidized bed reactor technology is a key step that enables continuous replacement of the catalyst, as well as the removal

of solid carbon co-product. During this second phase, PNNL and WVU will advance the fluidized bed technology by evaluating higher operating temperatures (>650°C) that enable higher-per-pass yields and develop strategies that are increasing catalyst stability.

With successful technology scaleup and envisioned cost offsets from sales of carbon coproducts, the new methane TCD process provides a pathway for fuel cell-powered vehicles to close the cost gap with conventional gasoline and diesel vehicles and pave the way for carbon-free, fuel cell-based micro-grid systems that move California closer to its ambitious emissions reduction goals.

GAS OPERATIONS

The Gas Operations RD&D program supports pipeline transportation and storage operations through innovations that enhance pipeline and employee safety, maintain system reliability, increase operational efficiency, and minimize GHG impacts to the environment.

The program also supports technology development driven by emerging regulatory requirements. Its primary goals are to develop, test, and introduce new gas operations technologies that are beneficial to ratepayers through improvements in public and pipeline safety, system reliability, operational efficiency, and environmental benefits

The program invests in technology development projects that are divided into the following subprograms:

Environmental & Safety

This subprogram seeks to advance the environmental integrity of the pipeline network and the safety of those who live and work in proximity to it. Environmental projects focus on developing technologies that also support state goals. Safety projects are concerned with protecting the pipeline from intentional and unintentional damage and with improving the safety of the general public and company employees or contractors working on or around the pipeline. Projects include exploring how blending hydrogen into the pipeline impacts the operation and maintenance of the pipeline system regarding safety, reliability, integrity, and environmental impacts.

Further gas emissions monitoring and reduction research is being supported by the SoCalGas Natural Gas Leakage Abatement R&D Program under the SB 1371 compliance plan, pursuant to the Gas Leak Abatement OIR (R.15-01-008).

Operations Technology

This subprogram supports technologies that improve employee training; efficiency of construction; and operation/maintenance/rehabilitation of gas pipelines, as well as systems that facilitate continued safe and reliable service. This subprogram also explores how best to prevent gas leaks that result from blending hydrogen into the pipeline.



System Design & Materials

The objectives of this subprogram are to advance materials and materials science, materials tracking and traceability, and technical tools for designing pipeline systems and infrastructure for safety, reliability, efficiency, and maintainability throughout the lifecycle of pipeline assets. Projects include research to advance engineering design standards and models, developing risk analytical tools to comply with pipeline integrity regulations, modeling operational efficiencies of gas storage and compressor station assets, and assessing the effects of incorporating gas from non-traditional sources (biogas and hydrogen-blend) on overall natural gas quality and system integrity.

System Inspection & Monitoring

The objectives for this subprogram include developing technologies and methods for inspection, monitoring, and testing of pipelines and pipeline components to assess the condition and performance of pipeline facilities. The goal is to improve system performance, reliability, safety and operational efficiencies through data management to identify precursors to failures or incidents. Projects in this subprogram area leverage artificial intelligence, machine learning, and preventive and predictive maintenance technologies, including data analytic models and data lakes, and includes innovative data sources such as Crowd Source and the Internet of Things. This subprogram also seeks to explore tools for managing the potential impacts of blending hydrogen into the gas pipeline.



SOCALGAS IDEA LEADS TO ADOPTION OF NEW EMISSION TESTING METHODS

Industry collaboration and funding resulted in U.S. Environmental Protection Agency posting of simplified test methods that reduce environmental compliance costs.

The U.S. National Ambient Air Quality Standards require that the U.S. Environmental Protection Agency (EPA) and state and local agencies regulate the exhaust emissions of criteria pollutants, including nitric oxide (NO), nitrogen dioxide (NO₂), and carbon monoxide (CO). Within the gas industry, natural gas boilers and the compressor engines used to maintain pressure and flowrates in gas transmission lines are a source of such emissions.

To verify compliance with the emission limits, facilities conduct expensive and complicated tests using EPA Reference Methods with analyzers in a large trailer or truck. However, plant and facility operators also rely on portable, handheld, electrochemical analyzers to verify compliance using EPA-approved testing methods, as well as to perform operational diagnostics and engine tuning.

TOTAL PROJECT COST	\$301,916
SOCALGAS	\$36,806
COFUNDING	\$265,110

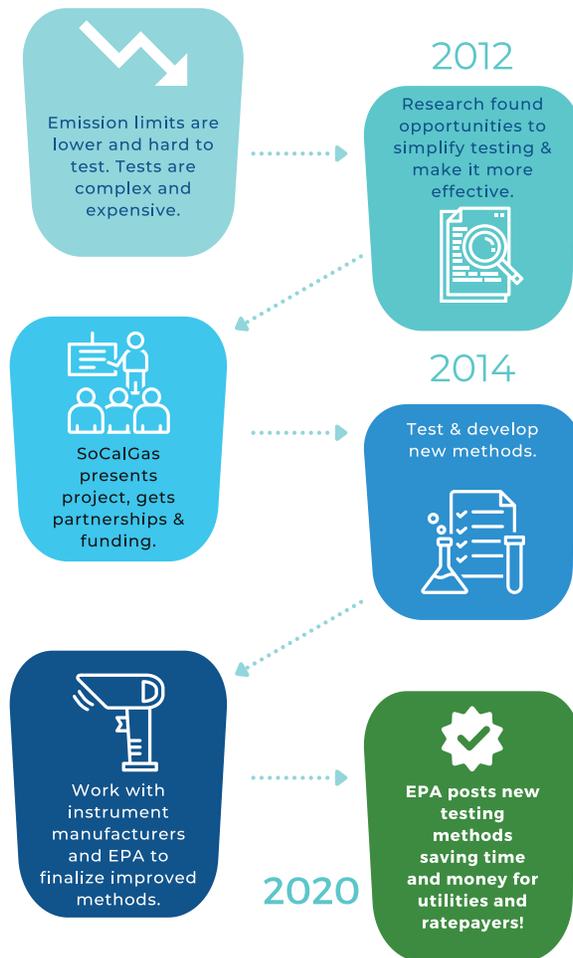
Although highly effective, the EPA-approved test methods for portable analyzers were complex and time consuming, which added significant cost to the compliance process. Developed many decades ago, the test methods did not take advantage of technology advancements that could be used to simplify the method. They were also optimized for much higher emissions targets—hundreds of parts per million (ppmv)—instead of today’s much lower numbers, which can require exhaust emission concentrations of less than 20 ppmv.

Research published in 2012 by Gregg Arney and Firas Hamze of



To verify compliance with emission limits, plant and facility operators conduct expensive and complicated tests using EPA Reference Methods with analyzers in a large trailer or truck or handheld, electrochemical analyzers.

HOW IT HAPPENED



SoCalGas confirmed that it was possible to simplify test methods for the portable electrochemical analyzers for emissions at low levels. If implemented, such changes could result in significant cost reductions for utility companies and, by extension, their ratepayers.

To develop a practical, simplified and cost-effective test method, SoCalGas turned to the Pipeline Research Council International (PRCI), a community of the world’s leading pipeline companies, vendors, service providers, equipment manufacturers, and other organizations supporting the gas industry. To support this important work, the RD&D Program committed \$50,000 toward the \$300,000 project across all phases.

Between 2014 and 2020, the PRCI’s Compressor Group worked closely with SoCalGas and other utilities, Innovative Environmental Solutions (IES), and various instrument manufacturers to develop the new testing methods. This collaboration resulted in the development of a rigorous technical whitepaper, comprehensive laboratory and field testing at SoCalGas’ Pico Rivera and Whittier bases, and field testing at a Dominion Energy gas compressor station near Pittsburgh, Pennsylvania. In 2017, the project team presented its results at the Air Quality Measurement Methods and Technology Conference in Long Beach, California—a presentation that caught the attention of the EPA.

PRCI, SoCalGas, IES, and the industrial instrument manufacturers then began a multi-year process of seeking formal EPA approval for

two new testing methods. Conducting extreme due diligence, EPA staff scrutinized every line of the proposed methods, looking for loopholes that might enable a non-compliant compressor, boiler, or other gas-fired equipment to mistakenly pass required compliance or period testing.

In August 2020, after three years of deliberation and review, the EPA formally posted two new test methods, OTM-38 and OTM-39, and approved their use as alternatives to ASTM International methods. These two methods minimize the costs associated with performance testing, while ensuring equivalent or improved data quality compared to the existing method. For example, the new methods reduced the number of gas calibration cylinders required for a typical test setup from 12 to four.

Support from utilities and industry for the new EPA testing methods is resounding. “It’s been common knowledge for decades that new electrochemical testing protocols were needed,” said Craig McKim, Business Unit Manager, Energy Division, of Testo North America, a prominent portable analyzer manufacturer. “The EPA’s new testing protocol is shaking up the compliance testing world by saving testers time and money.”



DRONES INSPECT DIFFICULT-TO-ACCESS GAS FACILITIES, PIPELINES, AND METERS

Small Unmanned Aerial System (sUAS) and aerial photography provide safer and more efficient access to remote or difficult-to-access gas facilities.

Every year, SoCalGas delivers approximately 1 trillion cubic feet of natural gas to 22 million residential, industrial, and commercial customers across a service territory encompassing more than 20,000 square miles. To deliver such vast quantities of gas—5% of total U.S. gas deliveries—SoCalGas maintains a network that includes roughly six million gas meters, 3,385 miles of transmission pipeline, and 103,477 miles of distribution mains and service lines.

To maintain the safety, integrity, and reliability of this network, SoCalGas inspects each meter and every inch of pipeline. This is a monumental task, especially using conventional approaches such as foot patrols or vehicle-based surveys, which often require visiting facilities that are difficult to access.

In response to this challenge—as well as the requirements of Califor-

TOTAL PROJECT COST	\$440,248
SOCALGAS	\$440,248
COFUNDING	\$0

nia’s SB 1371, which mandated the adoption of procedures to reduce methane emissions from pipeline facilities—the SoCalGas RD&D Program created an Aviation Services Group (AS) in 2015.

AS sought to advance the development of a small Unmanned Aerial System (sUAS) for use in the inspection of gas facilities, meters, and pipelines that are remote or difficult to access. When AS first began work, the technology platform as a whole was immature, with numerous technology challenges, including a chaotic wiring system that at times could facilitate miswiring. “At best, the unit failed to function,” said tech-



The SoCalGas Aviation Services Group operates small Unmanned Aerial Systems for use in the inspection of gas facilities, meters, and pipelines that are remote or difficult to access.



Aviation Services used the sUAS to conduct a virtual “job walk” along Line 1008A, a pipeline with many hidden and hazardous spans.

nician Mike Watkins. “At worst, there was the potential for damage to a component from making incorrect connections.”

During the project, AS evaluated the aerial platform, identified key challenges, and solved numerous payload functionality, system interaction, and application-specific problems. AS tested the sUAS at various SoCalGas operating facilities and in the field, demonstrating aerial photography, videography, and aerial methane detection in the SoCalGas service territory.

After initial success with demonstrations using the Avyon Micro-drone MD4-1000, AS began work on the DJI Matrice 210 RT quadcopter in 2018. With a maximum allowable payload of just over five pounds, the DJI Matrice 210 RT is equipped with a Zenmuse Z30

versatile integrated HD camera and gimbal for aerial photography and video. It has a maximum flight time of approximately 17 minutes.

AS assessed the obstacle sensing capability of the DJI Matrice 210 RT during inspections of difficult-to-access residential Meter Set Assemblies. Under overcast skies, the sUAS was able to take images that clearly showed metallic debris that could compromise the electrical isolation of the natural gas piping system. Each image was tagged with date, time, and location stamps.

AS also tested the quadcopter in the inspection of a supply line in the dimly lit environment under a steel-reinforced concrete bridge spanning the Los Angeles River. Any loss of the GPS signal under the bridge could have resulted in loss of the sUAS. AS carefully managed the signal and maintained control of the aerial platform through constant monitoring of the number of available satellites and their corresponding signal strength. “Doing it that way was a challenge, but it was far easier and more affordable than the conventional alternative of sending in a crew on a cherry picker to capture multiple images,” said Watkins.

As a further demonstration of the versatility of the sUAS, AS con-

ducted a virtual “job walk” along SoCalGas’ Line 1008A, a gas pipeline east of Morro Bay. “This line covers a large area with many hidden and hazardous spans,” said Watkins. AS wanted to record high-quality video coupled with still photographs, but the onboard Z30 HD camera was temporarily unable to concurrently capture video and stills.

To resolve this challenge, AS surveyed each location twice, with the second flight utilizing a dedicated Zenmuse X4S still photography camera. Utilizing approved AS contractors, the massive video file was edited to enable the addition of span markers to the video and the extraction of still photography close-ups. “Those capabilities are extremely useful to bidding contractors and the SoCalGas operations team,” concluded Watkins.

With this project, the RD&D Program advanced the development of practical unmanned aerial monitoring technology for use in both compliance and emergency inspection of difficult-to-access gas infrastructure. The new systems provide a safer and more efficient method of access to remote or dangerous locations, and also produce a time-and-location-stamped digital image that becomes part of a facility’s permanent maintenance record.

CLEAN TRANSPORTATION

The Clean Transportation subprogram supports activities that minimize environmental impacts related to the transportation sector through the development of low-carbon fuels, zero- and near-zero-emissions drivetrains, fueling infrastructure, and on-board storage technologies.

This program includes four subprograms:

On-Road

This subprogram targets emissions reductions from medium- and heavy-duty on-road vehicles. The focus is on-road transportation technologies using hydrogen, RNG, and natural gas.

Off-Road

This subprogram targets emissions reductions from off-road vehicles such as rail, ocean-going vessels and commercial harbor craft, and construction and cargo handling equipment, where gaseous fuels can reduce emissions. Subprogram staff have also begun to explore aviation applications, including hydrogen fuel cell aircraft and drones. The subprogram focuses on developing zero- and near-zero emission off-road transportation solutions using hydrogen, RNG, and natural gas.

Refueling Stations

This subprogram targets the development, demonstration, and deployment of technologies and systems that support refueling for alternative fuels, including hydrogen, RNG, and compressed natural gas (CNG)/liquefied natural gas. The subprogram seeks to identify and manage concerns and issues arising from refueling of gaseous fuels—from storage to safety and standardization.

Onboard Storage

This subprogram targets the development, demonstration, and deployment of cost-effective technologies and systems that improve onboard storage for gaseous transportation fuels. Areas of focus include advanced materials, low-pressure systems, and conformable tanks for both CNG and hydrogen. Onboard storage, which requires compressed storage and/or the use of advanced adsorption technologies, is a critical element needed for increased utilization of low-carbon, low-emission gaseous fuels.





ZERO-EMISSIONS FOR CALIFORNIA PORTS



GTI leads development of hydrogen fuel cell yard tractors for reductions in GHG, criteria pollutant, and diesel particulate matter emissions.

TOTAL PROJECT COST	\$12,055,413
SOCALGAS	\$322,500
COFUNDING	\$11,732,913

Ports are a vital part of the United States economy, serving as gateways for moving freight and passengers across the country and around the world. Seaports alone account for more than 23 million jobs and seaport cargo activity accounts for 26% of the United States economy.

Because they rely to a tremendous degree on diesel-powered cargo handling equipment and vehicles, ports are also a massive source of harmful emissions, including criteria pollutants and greenhouse gases (GHG). The single largest source of port-related cargo handling emissions is the diesel yard



The project team configured two diesel-powered Capacity Trailer Jockey Series TJ9000 gliders (above) with with an electric drive powertrain and a hydrogen fuel cell.



Port of Los Angeles

truck—also known as the terminal tractor. These workhorses of the port put in as many as 20 hours per day, lifting and moving heavy cargo trailers, stopping only once daily for refueling.

In 2019, SoCalGas, GTI, ZEN Clean Energy Solutions, and several technology developers and equipment manufacturers began collaborating on the Zero-Emissions for California Ports (ZECAP) project—funded in part by the California Air Resources Board—to develop and demonstrate two zero-emission hydrogen fuel cell yard trucks at port terminals operated by TraPac at the Port of Los Angeles.

“The primary goal is to demonstrate a novel and unique application of fuel cell technology—the yard truck—in port operations,” explained Bart Sowa, a Senior Project Manager with GTI. For each unit, the team configured a Capacity Trailer Jockey Series TJ9000 glider with a BAE Systems electric drive powertrain and an FCvelocity®-HD85 fuel cell from Ballard Power Systems, as well as onboard hydrogen storage tanks.

“Finding room for all of that on the base truck, while staying within the wheelbase constraints and keeping the storage vessels accessible was quite a challenge,” said Sowa.

“It was also important that the yard trucks could work long hours without refueling and could refuel quickly when required.” For refueling, GTI chose to deploy mobile but permanently installed storage tanks, as well as a custom fueling infrastructure designed and built by Hydrogen Technology & Energy Corporation.

SoCalGas provided \$300,000 in cofunding and also offered valuable perspective about infrastructure utilization and product commercialization. “The participation of a large utility like SoCalGas shows this is not a science project but a technology on the path to commercialization,” said Sowa.

In 2020, the project team completed engineering design on the hydrogen fuel cell yard trucks, overcoming key constraints related to vehicle wheelbase constraints and storage vessel accessibility. The team also finished engineering design for the custom fueling infrastructure, applied for the permits necessary to install the hydrogen storage tanks and dispenser, and procured all long-lead vehicle components. Assembly of the yard trucks began in late 2020.

Despite some COVID-related delays to the manufacturing and delivery of the onboard storage tanks, deliv-

ery of the two zero-emission yard trucks is scheduled for late April 2021.

Prior to delivery, Frontier Energy will conduct surveys of TraPac operations staff to better understand attitudes toward the new technology. “Equipment operators and maintenance personnel are often apprehensive about trying out new technologies,” said Sowa.

Demonstration of the two zero-emission yard trucks is scheduled for 12 months. Frontier Energy will conduct post-demonstration surveys to assess end user experiences with vehicles. “We believe they will appreciate being able to work without all of the noise, vibration, and odor associated with diesel,” said Sowa.

Successful project completion will result in many benefits and advance hydrogen fuel cell yard truck technology toward commercialization. “If all goes as expected, immediate benefits will include improved operator satisfaction, a quieter and cleaner port environment, and reduced emissions of GHGs, criteria pollutants, and diesel particulate matter,” said Sowa. Importantly, the areas surrounding the Port—many of which are disadvantaged communities—will also experience these benefits.

Further, the project will help fleets around the state better understand how hydrogen fuel cell yard trucks could fit into their business operations. “It will give Capacity and BAE Systems the real-world experience they need to see what works and what doesn’t in this first iteration of a hydrogen fuel cell yard truck,” said Sowa. “So far, everything has been based on engineering simulations.”

“Yard trucks in a port environment have very difficult duty cycles,” said Ted Barnes, Director of R&D at GTI. “In this project, we anticipate being able to prove out the reliability and maintainability of zero-emissions yard trucks in day-to-day port operations. Getting that information is a critical next step in the commercialization of these vehicles.”

“Having SoCalGas on the team has been very valuable,” continued Barnes. “Their involvement shows terminal operators, truck manufacturers, and technology developers that a major gas utility believes that hydrogen fuel cell technology has a place in our nation’s demanding port environments.”

ZECAP is part of California Climate Investments, a statewide initiative that puts billions of Cap-and-Trade dollars to work reducing greenhouse gas emissions, strengthening the economy, and improving public health and the environment—particularly in disadvantaged communities.

www.calclimateinvestments.ca.gov



CLEAN GENERATION

This program targets the development and demonstration of high-efficiency products and technologies associated with the generation of power for the residential, commercial, and industrial market segments in order to reduce emissions, lower customer costs, integrate renewable fuels, and improve energy reliability and resiliency.

Clean Generation is composed of two subprograms:

Distributed Generation

This subprogram develops and enhances distributed generation technologies. Microgrids and the increasing availability of RNG and hydrogen offer new opportunities for the deployment of low-emission and renewably fueled distributed generation technologies.

Integration & Controls

This subprogram develops, enhances, and demonstrates technologies and control systems that integrate distributed generation resources and thermal loads. The focus is on enabling low-emissions, distributed generation, and storage technologies to provide energy resilience and affordability to customers.





BREAKTHROUGH AC SYSTEM REDUCES ELECTRICITY CONSUMPTION BY 60–80%

Florida technology company integrates revolutionary air conditioning system with fuel cells for massive energy savings and reduced cost.

Modern air conditioning (AC) provides comfort and drives productivity and commerce. Unfortunately, it comes at a high cost, producing GHG emissions and utilizing harmful refrigerants. To address this cost, Blue Frontier is developing an innovative AC system that will eliminate some of the most harmful side effects of conventional AC, while keeping buildings more comfortable.

The company's first product is a drop-in replacement for the rooftop AC units found on 97% of all commercial buildings under four stories. Currently under development, it's designed to provide 30% fresh air, offer independent control of humidity and temperature, and reduce energy consumption by 60 to 80% when compared to today's best available technology.

TOTAL PROJECT COST	\$540,000
SOCALGAS	\$540,000
COFUNDING	\$0

Blue Frontier designed the system to incorporate heat recovered from gas-fueled combined heat and power (CHP) units—including fuel cells—via a load-shifting thermochemical energy-storage system that uses a liquid desiccant to store energy. When recovered heat is readily available, the system stores this energy by increasing the concentration of the liquid desiccant.

The opportunity for integration with fuel cells caught the eye of staff at the SoCalGas RD&D Program.

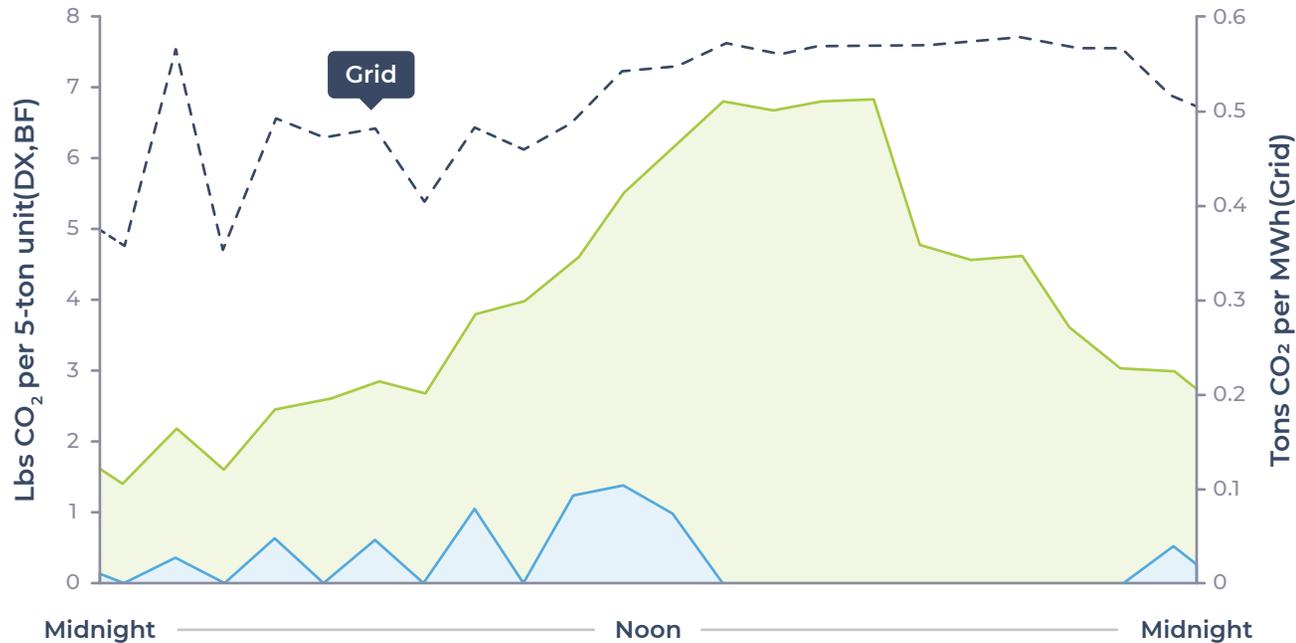
“They saw the potential our technology has to work with fuel cell systems using hydrogen or natural gas



The innovative A/C system incorporates heat recovered from gas-fueled CHP units—including fuel cells—via a load-shifting thermochemical energy-storage system that uses a liquid desiccant to store energy.

Hourly CO₂ Profiles Conventional AC vs BF AC

● Conventional AC ● Blue Frontier AC



Blue Frontier reductions in carbon dioxide emissions compared to those from a conventional AC system.

to generate electricity and produce waste heat,” said Dr. Daniel Betts, CEO of Blue Frontier. “Traditionally, buildings use the heat from CHPs to heat water or building spaces. Our system can use this heat to regenerate the liquid desiccant, displacing more costly grid-sourced electricity and delivering low-cost air conditioning when electricity rates are at their highest.”

To advance this technology, Blue Frontier collaborated with SoCal-Gas, Energy and Environmental

Economics, and the National Renewable Energy Laboratory on a multi-phase project.

In phase one, they established the value proposition for the product by developing baseline models and exploring energy cost savings across various building types and locations throughout California. SoCalGas offered perspective on fuel cells, technology rollouts, and the target market and customers.

Initial models indicated a high likelihood of commercial success. Using grid-sourced electricity to recharge the liquid desiccant, the models showed the potential to reduce air conditioning energy consumption by an average of 81%, resulting in carbon dioxide emissions reductions averaging 12% in residential buildings and 15% in commercial buildings. System performance further improved when the models assumed utilization of waste heat from a fuel cell to regenerate the liquid desiccant, offsetting cooling-related electrical consumption. “That effectively increases the electrical efficiency of the fuel cell and improves its economics,” said Dr. Betts.

Phase two is underway, with testing scheduled for April to June 2021. “We are completing assembly of the first prototypes and plan to

evaluate their performance in multiple simulated climate conditions,” said Dr. Betts. “Ultimately, we hope to validate the phase-one models and identify ways to improve performance and design.”

By helping eliminate peak demand on the grid, this technology could reduce ratepayer costs. “We could actually eliminate or significantly reduce the need for battery storage, peaking plants, and transmission and capacity upgrades,” said Dr. Betts. “Take away the need for grid-sourced electricity and transfer it to the natural gas supply in a super-efficient way and it actually creates dramatic reductions in carbon dioxide compared to any other piece of equipment you could buy.”

By reducing peak demand, the technology delivers another benefit. “One of the main causes of forest fires is the sagging of power lines during peak demand, which is largely driven by the demand for air conditioning,” said Dr. Betts. “By eliminating this demand, this technology could reduce the risk of fires and provide reliable electricity and air conditioning service when it’s needed most.”

Blue Frontier anticipates pursuing customers in the commercial building market first. “U.S. commercial building owners buy roughly

300,000 rooftop units every year—it’s a robust and large market, with millions of units nationwide nearing the end of their useful lifetimes,” said Dr. Betts. Ultimately, Blue Frontier seeks to deploy 1,000 units by 2024 as a first phase of product commercialization.

Following this project, Blue Frontier plans to conduct dynamic testing at the UC Davis Western Cooling Efficiency Center through the CalTestBed program. “That will enable us to finalize unit controls, demonstrate it in actual field trials, and deploy it in a statistically significant field trial,” said Dr. Betts. “With that completed, we could ramp up manufacturing quickly and go to market with real accuracy.”

The RD&D Program was an essential component of the project’s success. “SoCalGas is an extremely innovative gas company seeking to solve some of California’s most significant obstacles on the path to reducing GHG emissions,” said Dr. Betts. “They helped convene the right team and made sure that the project met appropriate levels of engineering rigor before financing its development with a clear, strategic path. California is lucky to have a company like SoCalGas.”



Blue Frontier anticipates pursuing customers in the U.S. commercial building market first, which purchases roughly 300,000 rooftop units per year. In the near term, Blue Frontier seeks to deploy 1,000 units by 2024 as a first phase of product commercialization.

CUSTOMER END-USE APPLICATIONS

This program focuses on developing, demonstrating, and commercializing technologies that cost-effectively improve the efficiency and reduce the environmental impacts of gas equipment used in residential, commercial, and industrial settings

This program includes five subprograms:

Commercial Food Service

This subprogram develops and enhances technologies and advancements related to commercial food service. This includes restaurants, catering services, and institutional kitchens that primarily rely on fuel supplied by SoCalGas for cooking and water heating. In response to the COVID-19 pandemic, this subprogram may also explore new solutions, such as adapting to increased outdoor dining.

Residential Appliances

This subprogram develops, demonstrates, and enhances technologies and advancements related to gas-consuming appliances in residences. Subprogram staff also seek to adapt proven European technologies to the California market. Relevant appliances include furnaces, hot water heaters, stoves, ovens, and dryers.

Commercial Applications

This subprogram develops and enhances technologies and advancements related to gas consumption and end-uses in the commercial sector. Relevant applications include commercial HVAC, hot water service, and commercial laundry.

Industrial Process Heat

This subprogram develops advanced heating technologies and systems for use in the industrial sector. Relevant applications include food processing, textile drying, chemical processing, and other process heat needs.

Advanced Innovation

This new subprogram seeks to develop new technologies to increase energy efficiency and decrease emissions.





INNOVATIVE RESIDENTIAL WATER HEATER MOVES TOWARD COMMERCIALIZATION

Gas-fired heat pump saves energy, cuts homeowner costs, and reduces GHG emissions by 49%.

Water heating accounts for 7% of residential carbon dioxide emissions. A new generation of gas-fired water heaters that utilize a heat pump to capture ambient heat and preheat the water could substantially reduce those emissions and achieve greater than 100% energy efficiency.

With its aggressive decarbonization goals and widespread deployment of conventional residential gas-fired water heaters, California is an ideal market for such a technology. Recognizing this opportunity, GTI—one of the nation’s leading gas R&D firms—collaborated with SoCalGas and other industry stakeholders on a project funded by the California Energy Commission (CEC), Stone Mountain Technologies, Inc. (SMTI), and the Utilization Technology Development consortium.

TOTAL PROJECT COST	\$1,272,355
SOCALGAS	\$188,125
COFUNDING	\$1,084,230

“Our primary goal was to field-test 4th-generation gas-fired heat pump water heater prototypes in five single-family homes in the Los Angeles basin,” said Merry Sweeney, senior market analyst at GTI. The team also conducted market research to better understand the path to commercialization.

SoCalGas believes this technology has the potential to deliver significant energy savings to its ratepayers. To support the project, SoCalGas performed simulated extended life and performance testing on the prototype. “They also helped us secure the five residential demonstration sites,” said Sweeney.



GTI field-tested 4th-generation gas-fired heat pump water heater prototypes in five single-family homes in the Los Angeles basin.

The project kicked off in 2017 with the placement of five hand-tooled, precommercial prototypes in homes in the Los Angeles basin. Building on work begun in 2011 with SMTI, the prototype was designed as a drop-in replacement for conventional gas-fired water heaters, requiring only minor building modifications.

The idea behind the technology is simple. “The gas-fired heat pump draws heat from the ambient space and uses it to pre-heat the water in the tank,” said Sweeney. Less gas is required to heat the water to the set-point temperature. “You actually get more energy—hot water—out of the system than you put in because of the boost provided by the ambient heat.”

During 12 months of field and lab testing, GTI faced several challenges, including minor mechanical failures and a lack of installation guidelines addressing venting, electrical service, and space requirements. “We addressed these challenges and also identified two critical challenges to explore—how to design the units for safe, damage-free shipment and how to address high-draw events that can drain the tank faster than it can heat new water.”

Upon project completion, GTI believed it had demonstrated a product ready for the market, and also proved there was a market for the product. “We demonstrated very strong energy, cost, and emissions savings, and clearly established the technical viability of the product,” said Sweeney. “The homeowners and installation contractors were also very satisfied with it.”

Gas-fired heat pumps represent a huge opportunity. “In comparison to conventional water heaters, this technology can reduce GHG emissions by roughly 49%,” said Sweeney. “When deployed widely, it represents a real opportunity for gas to play a key role in building decarbonization.”

GTI and SoCalGas plan to use this project as a springboard to a larger, bi-national demonstration effort through the North American Gas Heat Pump Water Heater Demonstration Collaborative. “We will perform field, lab, and market evaluations of next-generation gas-fired heat pump water heaters manufactured by Rinnai, a global manufacturer,” said Sweeney. The project plans to deploy 55+ near-commercial units across the United States and Canada, including 15 within SoCalGas territory.

The potential benefits are significant. “For each gas-fired heat pump water heater installed, we saw a reduction in GHG emissions of approximately 2,200 lbs. per year,” said Sweeney. “If this technology could achieve 10% market penetration in California, we’d be looking at annual emissions reductions of roughly half a million metric tons.”



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