CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

Research and Development Division

STAFF REPORT

Gas Research and Development Program

Proposed **Updated** Budget Plan for Fiscal Year 2022–23

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program (Gas R&D Program), which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These research investments spur innovation in energy efficiency, renewable energy and advanced generation, energy and distribution, energy-related environmental research, and transportation.

The CEC Energy Research and Development Division conducts this public interest gas-related energy research by partnering with R&D entities, including public and private research institutions, businesses, utilities, and individuals. This program promotes greater gas reliability, lower costs, and increased safety for Californians.

The *Gas Research and Development Program Proposed Budget Plan for Fiscal Year (FY) 2022–23* is a staff report prepared by the CEC Energy Research and Development Division.

For more information about the Energy Research and Development Division, please visit the Research and Development webpage on the CEC website.

ABSTRACT

In 2000, Assembly Bill (AB) 1002 (Wright, Chapter 932, Statutes of 2000) was enacted, requiring the California Public Utilities Commission (CPUC) to add a surcharge on gas consumed in California. This surcharge funded various energy efficiency programs and public interest research and development (R&D) to benefit 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 (CEC) as the research fund administrator.

This Gas Research and Development (Gas R&D) Budget Plan describes the CEC's proposed gas R&D initiatives for FY 2022-23. The proposed R&D aligns with the themes of targeted gas system decommissioning, decarbonization of gas end-uses, energy efficiency, and gas pipeline safety and integrity. The initiatives support state energy policies and goals, with several initiatives directly benefitting underresourced communities. The proposed research funding for FY 2022-23 is $24 million, and the budget plan covers July 1, 2022, through June 30, 2023. The budget plan benefitted from input from representatives of the Disadvantaged Communities Advisory Group (DACAG), CPUC and other agency coordination, and a public workshop, among other input received on CEC's gas related efforts.

CEC staff appreciates the coordination with CPUC on the proposed research initiatives and CPUC's ongoing support to enable access to needed utility infrastructure data.

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

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As California progresses toward its clean energy and climate change mitigation goals, the role of the gas sector and the mix of fuels — including fossil gas, biomethane, and green hydrogen — will change. The Gas Research and Development (Gas R&D) Program supports this gas sector transition and cost-effective achievement of the state's clean energy and climate goals. R&D investments ~~lower the cost and improve the performance of low-carbon gas products, infrastructure, and services,~~ support~~ing~~ reductions in fossil gas consumption, **advance** the production and **use**~~tilization~~ of renewable, low-carbon fuels, and deliver~~ing~~ public health, environmental, and gas system safety benefits.

The CEC's Energy Research and Development Division staff develops the Gas R&D Budget Plan based on state energy policies, plans, and guidance; analysis of research gaps; coordination with the California Public Utilities Commission (CPUC) and other agencies; and stakeholder input. Key policies, plans, and guidance include Executive Order B-55-18, Integrated Energy Policy Reports, the California Energy Efficiency Action Plan, and CPUC decisions and resolutions, among others.

This proposed FY 2022–23 Gas R&D Budget Plan includes R&D funding for seven initiatives aligned with four themes (Table ES-1). The proposed R&D serves to support gas system planning; advance low-carbon hydrogen for hard-to-decarbonize applications such as in industry, dispatchable generation, and heavy-duty transport; and inform efficiency improvements in residential hot water distribution**. In response to CPUC guidance in Resolution G-3592, CEC is proposing to fund projects to improve gas pipeline safety and integrity in lieu of projects that would** support entrepreneurs in advancing their concepts to commercialized products and services.

The FY 2022–23 Gas R&D Budget Plan benefitted from input from representatives of the Disadvantaged Communities Advisory Group (DACAG), CPUC coordination, and a public workshop, among other input received on CEC's gas-related efforts. Following guidance from CPUC staff, if California's 2022–23 state budget includes funding for hydrogen storage, Gas R&D Program funding for the initiative on Large-Volume Hydrogen Storage for Targeted Use Cases ($3 million) is proposed to be redirected to augment the initiative on Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools.

Table ES-1: Proposed FY 2022–23 Gas R&D Budget Plan

Initiative Themes	Initiative Title	Proposed Budget
Targeted Gas System Decommissioning	Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools	~~$3,500,000~~ **$4,100,000**
Decarbonization of Gas End Uses	Large-Volume Hydrogen Storage for Targeted Use Cases	$3,000,000
	Industrial Clusters for Clean Hydrogen Utilization	$1,000,000
	Mitigate Criteria Air Pollutants in Hydrogen Combustion	$4,500,000
	Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport	$4,500,000
Energy Efficiency	Analysis of Residential Hot Water Distribution Designs	$1,500,000
~~**Entrepreneur Development**~~	~~California Sustainable Energy Entrepreneur Development (CalSEED) – Low Carbon Gas~~	~~$3,600,000~~
Gas Pipeline Safety and Integrity	**Gas Pipeline Safety and Integrity Research to Support Decarbonization**	**$3,000,000**
Program Administration		$2,400,000
TOTAL		$24,000,000

Source: California Energy Commission

CHAPTER 1: Introduction

Gas Sector Transition to Meet Decarbonization Goals

As California progresses toward its clean energy and climate change mitigation goals, the role of the gas sector and the mix of fuels — including fossil gas, biomethane, and green hydrogen — will change. Key policies driving this transition include Title 24 building standards, appliance standards, Senate Bill 350 (De León, Chapter 547, Statutes of 2015), Senate Bill 100 (De León, Chapter 312, Statutes of 2018), among others. As one example of progress, California's residential gas use was 9 percent lower in 2019 compared to 1990, despite the 33 percent growth in population.[1] However, fossil gas use remains significant; as of 2019, California gas still accounted for 28 percent of total energy consumption in the state.[2] Further, the overall gas demand in California could grow over the next decade in a business-as-usual scenario.[3] Continued technology and policy development are needed to cost-effectively meet the state's 2045 carbon neutrality goal, including through the advancement of renewable, low-carbon fuels and continued improvements in energy efficiency.

Gas R&D Program Background

The Gas Research and Development (Gas R&D) Program supports the gas sector transition and cost-effective achievement of the state's clean energy and climate goals. R&D investments ~~lower the cost and improve the performance of low-carbon gas products, infrastructure, and services~~,support~~ing~~ reductions in fossil gas consumption; ~~advancing~~**advance** the production and utilization of renewable, low-carbon fuels; and deliver~~ing~~ public health, environmental, and gas system safety benefits.

Recognizing the benefit of gas research to Californians, Assembly Bill 1002 (Wright, Chapter 932, Statutes of 2000) directed the CPUC to add a surcharge on all fossil gas consumed in California to fund research and development specific to gas. The 2004 CPUC Decision 04-08-010 designated the CEC as the administrator for the Research and Development (R&D) Program. The CPUC allocates $24 million annually and defines public interest gas research activities as those "directed towards developing science or technology, and 1) the benefits of which accrue to California citizens, and 2) are not adequately addressed by competitive or regulated entities."[4] The decision also provides direction that R&D projects focus on energy efficiency, renewable technologies, conservation, and environmental issues; support state energy policy; offer a reasonable probability of providing benefits to the general public; and

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1 Jones, Melissa, Jennifer Campagna, Catherine Elder, and Stephanie Bailey. 2022. *Final 2021 Integrated Energy Policy Report, Volume III: Decarbonizing the State's Gas System.* California Energy Commission. Publication Number: CEC-100-2021-001-V3.

2 U.S. Energy Information Administration. 2019. "California Energy Consumption Estimates." Available at https://www.eia.gov/state/?sid=CA.

3 Javanbakht, Heidi, Cary Garcia, Ingrid Neumann, Anitha Rednam, Stephanie Bailey, and Quentin Gee. 2022. *Final 2021 Integrated Energy Policy Report, Volume IV: California Energy Demand Forecast.* California Energy Commission. Publication Number: CEC-100- 2021-001-V4.

4 California Public Utilities Commission Decision 04-08-010. Available at https://docs.cpuc.ca.gov/PublishedDocs/WORD_PDF/FINAL_DECISION/39314.PDF.

consider opportunities for collaboration and cofunding with other entities, such as federal and local agencies.

In 2006, the California Legislature passed Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006),[5] which further outlines the goal of the Public Interest Research, Development, and Demonstration Program ("R&D program") to "develop, and help bring to market, energy technologies that provide increased environmental benefits, greater system reliability, and lower system costs, and that provide tangible benefits to electric utility customers." In addition to these goals, the CPUC has issued resolutions providing further guidance for implementing the Gas R&D Program.[6]

The Gas R&D Program has invested in R&D to develop technologies, tools, and strategies that increase energy efficiency, lower energy cost, reduce air pollutants and greenhouse gas (GHG) emissions, and improve the safety of gas infrastructure. Recent program achievements are included in the *Gas Research and Development 2021 Annual Report*.[7]

2022–23 Budget Plan Priorities and Development

The proposed FY 2022–23 Gas R&D Budget Plan continues to place emphasis on R&D areas that align with the state's priorities for decarbonization. The proposed R&D serves to support gas system planning; advance low-carbon hydrogen for hard-to-decarbonize applications such as in industry, dispatchable generation, and heavy-duty transport; inform efficiency improvements in residential hot water distribution; and **improve pipeline safety and integrity**. The CEC Energy Research and Development Division staff develops the Gas R&D Budget Plan based on state energy policies, plans, and guidance; analysis of research gaps; coordination with the CPUC and other agencies; and stakeholder input, as discussed further in Chapter 2.

5 Public Resources Code Sections 25620-25620.15 codifies **Senate Bill** 1250 (2006). Available at https://codes.findlaw.com/ca/public-resources-code/prc-sect-25620.html.

6 CPUC website for "Energy Research Development and Deployment," https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/energy-research-development-and-deployment.

7 Deng, Maggie and Braden Henderson. 2021. Energy Research and Development Division. Gas Research and Development 2021 Annual Report California Energy Commission. Publication Number: CEC-500-2021-047, Available at https://www.energy.ca.gov/publications/2021/natural-gas-research-and-development-program-2021-annual-report.

CHAPTER 2:
Developing Gas R&D Initiatives for Fiscal Year 2022–23

The research initiatives described in Chapter 3 of this report were informed by state policies, plans, and guidance — including in CPUC decisions discussed below — as well as the CEC's commitment to diversity and equity, stakeholder input, and state agency roadmaps, as discussed further below and in Appendices A–F.

CPUC Decision 04-08-10: Supporting State Policy

As called for in CPUC Decision 04-08-010, issued in 2004, the Gas R&D Program supports state energy policies and goals, such as achieving economywide carbon neutrality by 2045 (Executive Order B-55-18) [8] and doubling energy efficiency by 2030 (Senate Bill 350, De León, Chapter 547, Statutes of 2015).[9] The Gas R&D Program investments advance these objectives by supporting R&D for the production, use, and storage of renewable, low-carbon gas and developing decision-support tools for gas system transition. The Gas R&D Program supports efficiency improvements in areas such as high-temperature industrial processes and carbon capture and use.

The Gas R&D Program supports several other key energy and climate policies and goals, including:

- Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016), which establishes the state's goal for a 40 percent GHG emissions reduction below 1990 levels by 2030;
- CEC Integrated Energy Policy Reports (IEPRs), which assess major energy trends facing California's electricity, gas, and transportation fuel sectors and provide policy recommendations;[10] and
- Climate Change Scoping Plan, which underscores the pivotal role of innovative technologies in improving efficiency, increasing the production of renewable gas, and reducing leakage from gas infrastructure in meeting future climate change targets.[11]

The FY 2022–23 Gas R&D Budget Plan also specifically addresses the focus areas identified in CPUC Decision 04-08-10, including energy efficiency, renewable technologies (that is, with initiatives in ~~the areas of entrepreneur development and~~decarbonizing gas end uses), conservation (in other words, energy efficiency and decarbonizing end uses), and environmental issues (that is, decarbonizing end uses, energy efficiency, and targeted gas system decommissioning). Initiative themes of the budget plan also support sets of policies, as described in Appendix A.

8 Available at https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

9 Available at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350

10 Available at https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report

11 California Air Resources Board. California's AB 32 Climate Change Scoping Plan.

CPUC Resolution G-3584

As directed by CPUC Resolution G-3584, issued in 2021, the CEC considered the AB 3232 (Friedman, 2018) report in the development of the FY 2022–23 Gas R&D Budget Plan, specifically the seven key strategies to decarbonize residential and commercial buildings outlined in the 2021 report *California Building Decarbonization Assessment.*[12] For example, one strategy is to improve energy efficiency, which is addressed by the research initiative "Analysis of Residential Hot Water Distribution Designs." This research initiative can help implement the energy efficiency strategy by informing future codes and standards and is described in Chapter 3.

CPUC Resolution G-3584 calls for the CEC to consider, when available, the long-term research roadmap for gas technology development – currently titled "Establishing a Long-Term Natural Gas Research Strategy to Achieve Aggressive Statewide Carbon Neutrality Goals." While findings are not yet available for CEC to consider, the gas technology R&D roadmap is expected to be a valuable resource for program planning in future years.

CPUC Resolution G-3584 also requires that in the FY 2022–23 Gas R&D Budget Plan that the CEC review the unspent funds in the Public Interest Research Development and Demonstration Natural Gas Subaccount to identify research funds from FY 2014–15 to FY 2021–22 Gas R&D Budget Plans that were encumbered within two years of budget approval (Appendix B). Per the CPUC's request in Resolution G-3555, the CEC will ensure that for any use of encumbered and unspent funds that the CEC requests for new projects, the request will identify the respective research areas for which the CPUC originally authorized the funding.

CPUC Resolution G-3571

CPUC Resolution G-3571, issued in 2020, requires that if the CEC is unable to obtain data it deems necessary to complete any of the projects proposed in the FY 2021–22 Gas R&D Budget Plan, it must first consult with CPUC Energy Division staff overseeing this program before reallocating any funding. While CEC or its project recipients have not yet required data to complete the projects in the FY 2021–22 Gas R&D Budget Plan or projects proposed in the FY 2022–23 Gas R&D Budget Plan, the CPUC and CEC have an information-sharing agreement to support the Gas R&D Program and ensure confidentiality of the exchanged information will be maintained.[13] Should the CEC be unable to obtain the needed data, CEC staff will consult with CPUC Energy Division staff before reallocating any funding as required in the CPUC's resolution.

The resolution also calls for the CEC to consider "any research gaps that might emerge because of recent budget decreases or reallocations in response to COVID-related economic impacts and potential cofunding opportunities that the Gas R&D program can provide to limit the impact of these gaps on California energy goals." However, at this time, the CEC is not aware of budget decreases or reallocations that may result in research gaps.

For all Gas R&D Budget Plans, CPUC asked that the CEC coordinate with CPUC staff at least three weeks in advance of CEC's public workshop on the proposed budget plan. The goal of this additional step is to ensure the best possible use of funds across programs. In response,

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12 Kenney, Michael, Nicholas Janusch, Ingrid Neumann, and Mike Jaske. 2021. *California Building Decarbonization Assessment*. California Energy Commission. Publication Number: CEC-400-2021-006-CMF. Available at https://www.energy.ca.gov/publications/2021/california-building-decarbonization-assessment.

13 Available upon request.

CEC staff provided CPUC staff with summaries of the research initiatives December 27, 2021, and organized a staff coordination meeting on January 12, 2022. A summary of this meeting is provided in Appendix C.

The CPUC also included a requirement that — for all Gas R&D Budget Plans — the CEC post the budget plans publicly on the CEC's website before submitting an approval request to the CPUC and notify the CPUC of the web address when requesting approval of the plan. The CEC follows this practice, with Gas R&D Budget Plans posted to the CECs website, under Energy Research and Development investment plans and annual reports.[14]

For all Gas R&D budget plans, the CPUC called for the CEC to distribute the budget plan through the CEC's listservs and include the names of the distribution lists served when requesting CPUC's approval of the plan. The resolution also calls for the CEC to consult with Energy Division staff on which CPUC listservs from ongoing CPUC proceedings the CEC should notice its proposed plan. Addressing that request, the CEC notes that the CEC lists include Research, Natural Gas, Renewable, Transportation, Efficiency, Climate Change, Diversity, and DACAG listserv, and relevant CPUC listservs will be noticed.[15]

Moreover, the resolution asks that for all Gas R&D budget plans, the CEC consult with CPUC to allow the option to present the budget plan to the CPUC commissioners during a CPUC commissioner committee meeting. The CEC staff looks forward to consulting further with the CPUC and welcome the opportunity to present the budget plan to CPUC commissioners, if desired.

Commitment to Diversity and Equity

The Gas R&D Program is shaped by the CEC's commitment to diversity and equity. California is a diverse state in its people and geography. The CEC strives to increase opportunities for all Californians through its programs and advances equity through outreach, funding opportunities, and planning. In 2015, the CEC unanimously approved a formal Diversity Policy Resolution, consistent with state and federal law, to improve fair and equal opportunities for small businesses; women, disabled veteran-, minority-, and LGBTQ-owned business enterprises;[16] and economically disadvantaged and underserved communities to participate in and benefit from CEC programs. Assembly Bill 865 (Alejo, Chapter 583, Statutes of 2015) provided additional guidance, requiring the CEC to develop and implement a comprehensive outreach plan to broaden and diversify the applicant pool to CEC programs and track progress toward those objectives.

Some recent examples of outreach efforts to support diversity and equity commitments include improving the CEC's application and grant management processes to relieve administrative burdens for applicants. This improvement is particularly beneficial for new and underresourced

14 "California Energy Commission Annual Reports." Available at https://www.energy.ca.gov/data-reports/reports/energy-research-and-development-investment-plans-and-annual-reports.

15 CPUC listservs include A1704028, A1806015, A1902015, A1907006, A1910012, A1908015, A2106021, A1710008, A1807024, I1911013, R1602007, R1803011, R1804019, R1807006, R1810007, R1812005, R1812006, R1901011, R1211005, R1910005, R1302008, R2001007, R1407002, R2005012, R1503010, R2008020, R1505006, R2011003.

16 As defined by the investor-owned utilities in CPUC General Order 156: http://docs.cpuc.ca.gov/publisheddocs/published/g000/m152/k827/152827372.pdf.

entities. In collaboration with the CEC Grants Ombudsman, R&D staff obtain feedback from applicants and implement improvements to the grant application process.

- Continuing to ensure women, minorities, LGBTQ individuals, disabled veterans, and other underrepresented groups are informed of R&D program activities and encouraged to participate in R&D project funding opportunities through the Empower Innovation platform (EmpowerInnovation.net). This platform hosts live online events so community leaders and clean energy technology innovators can meet and learn from each other and start conversations that lead to effective collaboration. In 2021, more than 800 attendees participated in live events. Past events have focused on developing sustainable, affordable housing, providing how-to technical assistance, and navigating grant requirements.
- Continuing to advance efforts to address energy-related challenges and opportunities in underresourced communities by encouraging residents and interested members of these communities to participate in and share perspectives in community meetings on CEC-funded projects.
- Continuing to track, monitor, and provide findings in the Gas R&D Annual Report on the participation of California-based entities; women-, minority-, and disabled-veteran-owned businesses; and small businesses as recipients of R&D awards.

Senate Bill 350 (De León, Chapter 547, Statutes of 2015) also advanced equity in California's clean energy transformation. As outlined in **Senate Bill** ~~SB~~ 350, the CEC coestablished the Disadvantaged Communities Advisory Group (DACAG) in 2018 to advise the CEC and the CPUC on ways to help disadvantaged communities benefit from proposed clean energy and pollution reduction programs, expand access to clean energy technologies, and receive affordable energy services. Furthermore, in its **Senate Bill** ~~SB~~ 350 Barriers Report, the CEC recommended that the CEC and CPUC direct RD&D and market facilitation programs to include targeted benefits for low-income customers and disadvantaged communities.[17]

Since FY 2016–17, the Gas R&D Program has invested about 67 percent of its research funds to projects located in either a disadvantaged community, low-income community, or both. Recent program investments in disadvantaged and low-income communities are included in the *Gas Research and Development 2021 Annual Report*.[18] CEC staff activities specifically related to CEC's commitment to diversity and equity in the FY 2022–23 Gas R&D Proposed Budget Plan includes:

- Presenting and soliciting feedback on the R&D initiatives at the DACAG Electric Program Investment Charge (EPIC) subcommittee meeting January 13, 2022.
- Notifying the DACAG of the January 19, 2022, Gas R&D Plan — Stakeholders Workshop and offering the opportunity for public comment.

17 Scavo, Jordan, Suzanne Korosec, Esteban Guerrero, Bill Pennington, and Pamela Doughman. 2016. *Low-Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low-Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities.* California Energy Commission. Publication Number: CEC-300-2016-009-CMF.

18 California Energy Commission Energy Research and Development Division. 2020. 2020 *Natural Gas Research and Development Program Annual Report.* California Energy Commission. Publication Number: CEC-500-2020-073.

- Regularly meeting with DACAG members to receive recommendations on how to effectively address equity and improve benefits to low-income and disadvantaged communities through proposed R&D initiatives.

CEC staff has helped onboard underresourced entities to the platform, such as local governments and community-based organizations serving tribes, disadvantaged communities, low-income communities, and opportunity zones. As part of the recruitment, CEC staff held a webinar for tribes, partnered with the Institute for Local Government to support its BOOST program,[19] and supported the cities of Arvin and Paramount in creating their profiles. CEC staff is also coordinating additional webinars targeted at local governments and community-based organizations. CEC staff continues to share information on how to use the Empower Innovation Platform, including at preapplication workshops for Gas R&D Program funding opportunities. Empower Innovation technical assistance workshops also provide how-to knowledge to develop winning grant applications.

More information about these and other CEC activities that support equity and diversity are available on the CEC's website (https://www.energy.ca.gov/about/campaigns/equity-and-diversity).

Stakeholder Participation and Strategic Partnerships

CEC engages with stakeholders to develop a research portfolio responding to challenges in the gas sector. The CEC conducts outreach to a wide range of California stakeholders, including research institutions, governmental agencies, industry and utility representatives, and the public to incorporate diverse perspectives on gas public interest energy research projects. This outreach promotes program accountability, transparency, communication, and responsiveness. The CEC relies on these strategic partnerships to avoid duplication, build upon previous R&D work, generate new ideas, leverage public and private investments, and ensure the research portfolio delivers benefits to the state's gas ratepayers.

For developing the FY 2022–23 Gas R&D Budget Plan, the CEC conducted a public workshop January 19, 2022. The workshop was attended by 183 people, not including the CEC panelists, and the CEC received more than two dozen attendee questions and comments during the workshop discussion. The CEC considered and responded to stakeholder comments associated with budget plan development. (See Appendices C and D for the staff workshop presentation and a summary of public comments and CEC staff responses, respectively.) The CEC also engages a diverse set of stakeholders in R&D implementation, including grant funding opportunities and projects. This engagement includes broadening the use of social media platforms to educate and inform; collaborating with the CEC's public advisor to promote grant-funding opportunities; meeting with community leaders, stakeholders, and business leaders; and distributing R&D informational materials at conferences, meetings, workshops, and public events – including 22 events in 2021. (A list of 2021 public events is provided in Appendix E.)

Roadmaps and Technology Assessments

Roadmaps and technology assessments are planning mechanisms and communication tools that establish a clear link between research and energy policy goals. Research roadmaps

19 The Institute for Local Government, in partnership with the California Strategic Growth Council, created the BOOST Pilot Program to help local governments build capacity and resources to develop projects and secure funding to increase access to clean air and water, clean transportation, affordable housing and economic opportunity.

define the topic area, significant issues and barriers, data gaps, information needs, research priorities, and potential partnerships. CEC staff and a wide range of energy researchers and consumers participate in "road-mapping" in many program areas to gather cutting-edge information that can help determine how to maximize the value of Gas R&D Program investments.[20] Participants help identify Gas R&D Program research needs in a range of program areas. Collaborative thinking about energy solutions that cut across policy boundaries is integral to leveraging research dollars. Bringing gas and electricity stakeholders together to develop roadmaps minimizes resource shifting, encourages innovation, and promotes transparency.

An example of a research roadmap from the Gas R&D Program is one for the chemical and allied products industry — the fourth largest consumer of gas among California industries — to identify technologies and approaches to reduce gas use.[21] This roadmap helped inform the research initiative "Industrial Clusters for Clean Hydrogen Utilization" proposed in this report. Some of the promising technologies identified for future R&D investments include advanced separations to replace distillation, improvements to hydrogen production and advancements to overcome issues with end-use of hydrogen, use of biomass as feedstock and fuel, among other areas.

In January 2021, the CEC released a solicitation to develop a roadmap on *Establishing a Long-Term Natural Gas Research Strategy to Achieve Aggressive Statewide Carbon Neutrality Goals.*[22] This roadmap will produce a long-term strategy to help decarbonize California by 2045 and is expected to identify prioritized research recommendations in all stages of the gas supply chain and all end-use sectors except utility-scale power generation. CEC selected a contractor in June 2021, and the study is underway. As the study develops, there will be several opportunities for expert stakeholder input through public workshops and expert stakeholder interviews. The results of the study are expected to be available by the end of 2022.

20 Various roadmaps can be found at the Energy Commission's publications database, https://www.energy.ca.gov/energy-rd-reports-n-publications.

21 Morrow, William, Ali Hasanbeigi, and John Marano. 2021. *Energy Efficiency Potentials and R&D Opportunities in California's Chemical Industry.* California Energy Commission. Draft final report. Publication Number: CEC- PIR-17-007.

22 "RFP-20-501 – Establishing a Long-Term Natural Gas Research Strategy to Achieve Aggressive Statewide Carbon Neutrality Goals." https://www.energy.ca.gov/solicitations/2021-01/rfp-20-501-establishing-long-term-natural-gas-research-strategy-achieve.

CHAPTER 3:
Proposed Initiatives for Fiscal Year 2022–2023

Proposed Budget

This proposed Fiscal Year 2022–23 Gas R&D Budget Plan includes funding for seven initiatives aligned with four program themes (Table 1). The proposed R&D serves to

- Support gas system planning;
- Advance low-carbon hydrogen for hard-to-decarbonize applications such as in industry, dispatchable generation, and heavy-duty transport;
- Inform efficiency improvements in residential hot water service; and
- **Improve gas pipeline safety and integrity** ~~entrpreneurs in advancing their concepts to marketable products and services.~~.

Following guidance from CPUC staff, if California's 2022–23 state budget includes funding for hydrogen storage, Gas R&D Program funding for the initiative on Large-Volume Hydrogen Storage for Targeted Use Cases ($3 million) is proposed to be redirected to augment the initiative on Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools. **This proposed budget plan was revised to address CPUC's direction in Resolution G-3592 by adding an initiative theme for Gas Pipeline Safety and Integrity and by adding funds to the Targeted Gas System Decommissioning initative. The initiative theme for Gas Pipeline Safety and Integrity was approved in the FY2021-2022 Budget Plan under the "Natural Gas Infrastructure Safety and Integrity" research area, and resulted in the release of solicitation GFO-22-503 Gas Pipeline Safety and Integrity Research to Support Decarbonization on November 29, 2022[23]. The solicitation included two project groups: 1) monitoring and risk assessment for natural force damage to gas pipelines and 2) plastic pipeline deficiency inspection for pipeline integrity management. CEC proposes to add funds to this solicitation to fully award high quality project proposals that passed the scoring phase. The solicitation application period closed on March 6, 2023, and selected projects would need to be approved at a Business Meeting. Added funds will be subject to approval of this Revised Budget Plan. If the full balance is not used for awarded projects from GFO-22-503, any remaining funds will be added to the initiative: Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools.**

[23] California Energy Commission. 2022. GFO-22-503 - Gas Pipeline Safety and Integrity Research to Support Decarbonization. https://www.energy.ca.gov/solicitations/2022-11/gfo-22-503-gas-pipeline-safety-and-integrity-research-support-decarbonization

Table 1: Proposed FY 2022–23 Gas R&D Budget Plan

Initiative Themes	Initiative Title	Proposed Budget
Targeted Gas System Decommissioning	Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools	~~$3,500,000~~**$4,100,000**
Decarbonization of Gas End Uses	Large-Volume Hydrogen Storage for Targeted Use Cases	$3,000,000
	Industrial Clusters for Clean Hydrogen Utilization	$1,000,000
	Mitigate Criteria Air Pollutants in Hydrogen Combustion	$4,500,000
	Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport	$4,500,000
Energy Efficiency	Analysis of Residential Hot Water Distribution Designs	$1,500,000
~~**Entrepreneur Development**~~	~~California Sustainable Energy Entrepreneur Development (CalSEED) – Low Carbon Gas~~	~~$3,600,000~~
Gas Pipeline Safety and Integrity	**Gas Pipeline Safety and Integrity Research to Support Decarbonization**	**$3,000,000**
Program Administration		$2,400,000
TOTAL		$24,000,000

Source: California Energy Commission

Proposed Research Initiatives

Initiative Theme: Targeted Gas System Decommissioning

As California moves toward a clean energy future, the role of gas in the state's energy system is changing. CEC's 2022 update to California's Building Energy Efficiency Standards encourages greater use of electric heat pump technologies in residential and select nonresidential building

categories statewide.[24] Complementing state actions, a growing number of California cities are adopting and implementing local building codes that mandate or encourage building electrification in new construction and major retrofits. Electrification of gas-fueled technologies is expected to accelerate over the next few decades and reduce demand for gas.[25] Management of this gas system transition is important to support consumer interests, system reliability, and safety.

Prior studies, including research funded by the Gas R&D Program, indicate that large reductions in fossil gas consumption in residential and commercial buildings are necessary to meet the state's climate goals.[26] For example, CEC's *California Building Decarbonization Assessment* finds that "accelerating efficient electrification of building end-uses in both new and existing buildings represents the most predictable pathway to achieve deep reductions in building emissions" and "electrification in the buildings sector appears to be the lowest-cost trajectory to meeting the state's climate change mitigation goals."[27] A growing body of literature on the future of California's gas system affirms and offers insights into the complex challenge of decarbonizing the gas system. Yet important gaps remain regarding how to scale up decommissioning efforts, how to chart a transition that addresses community and consumer priorities, and how to expand the purview of planning approaches to consider multiple factors exogenous to gas system infrastructure.[28] Prior research indicates that a managed gas transition is imperative to address issues related to cost and equity. A growing

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24 California Energy Commission. 2021. *Revised Proposed Changes to the 2022 California Building Energy Efficiency Standards (Energy Code).* https://efiling.energy.ca.gov/GetDocument.aspx?tn=238848. See also https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency, and https://efiling.energy.ca.gov/GetDocument.aspx?tn=239368&DocumentContentId=72826

25 California Public Utilities Commission. 2020. Order Instituting Rulemaking to Establish Policies, Processes, and Rules to Ensure Safe and Reliable Gas Systems in California and Perform Long-Term Gas System Planning. R.20-01-007. January 27, 2020. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M325/K641/325641802.PDF.

26 Mahone, Amber et al. 2018. *Deep Decarbonization in a High Renewables Future: Updated Results from the California PATHWAYS Model.* California Energy Commission. CEC-500-2018-012. https://www.energy.ca.gov/publications/2018/deep-decarbonization-high-renewables-future-updated-results-california-pathways.

Wei, Max et al. 2017. *Building a Healthier and More Robust Future: 2050 Low-Carbon Energy Scenarios for California.* California Energy Commission. CEC-500-2019-033. https://ww2.energy.ca.gov/2019publications/CEC-500-2019-033/CEC-500-2019-033.pdf.

Gridworks. 2019. *California's Gas System in Transition: Equitable, Affordable, Decarbonized, and Smaller.* https://gridworks.org/wp-content/uploads/2019/09/CA_Gas_System_in_Transition.pdf.

Aas, Dan et al. 2020. *The Challenge of Retail Gas in California's Low-Carbon Future: Technology Options, Customer Costs and Public Health Benefits of Reducing Natural Gas Use*. CEC-500-2019-055. https://ww2.energy.ca.gov/2019publications/CEC-500-2019-055/index.html.

27 Kenney, Michael, Nicholas Janusch, Ingrid Neumann, and Mike Jaske. 2021. *California Building Decarbonization Assessment*. California Energy Commission. Publication Number: CEC-400-2021-006-CMF. https://efiling.energy.ca.gov/GetDocument.aspx?tn=239311&DocumentContentId=72767

28 See, e.g., Bilith, Andy et al. 2019. *Managing the Transition: Proactive Solutions for Stranded Gas Asset Risk in California*. Environmental Defense Fund. https://www.edf.org/sites/default/files/documents/Managing_the_Transition_new.pdf.

The Greenlining Institute. 2019. *Equitable Building Electrification: A Framework for Powering Resilient Communities*. https://greenlining.org/wp-content/uploads/2019/10/Greenlining_EquitableElectrification_Report_2019_WEB.pdf

Ong, Alison et al. 2021. The Costs of Building Decarbonization Policy Proposals for California Natural Gas Ratepayers: Identifying Cost-Effective Paths to a Zero Carbon Building Fleet, Stanford Woods Institute Climate and Energy Policy Program White Paper. https://woodsinstitute.stanford.edu/system/files/publications/Building_Decarbonization_Policy_CA_Natural_Gas_Ratepayers_Whitepaper.pdf

body of literature on the future of California's gas system affirms and offers insights into the complex challenge of decarbonizing the gas system, but important gaps remain regarding how to scale up decommissioning efforts.

Recognizing the need to collaboratively chart a strategic transition that addresses cost, equity, reliability, and safety, the FY 2022–23 Gas R&D Budget Plan proposes an initiative to scale up pilots and advance integrated planning for gas system decommissioning.

Initiative Title: Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools

Initiative Description

This initiative will expand pilots and advance integrated planning for gas system decommissioning. To support the scaling up of decommissioning pilots, the initiative will design a large-scale pilot for decommissioning segments of the gas system that delivers cost, environmental, health, and equity benefits. To advance integrated planning for gas system decommissioning, the initiative will also expand and enhance a planning tool currently under development with support from the Gas R&D Program by integrating a more complete perspective on cost considerations and facilitating planning across short- and long-term time frames. Results will promote cost-effective, safe, and equitable decarbonization that is informed by consumer and community perspectives and priorities.

Background

Gas has been a dominant fuel in California for more than 80 years and remains prevalent. For example, 9 million homes in the state use gas for water heating,[29] and California's gas consumption levels across all sectors have remained fairly stable over more than two decades.[30] The strategies needed to reduce fossil gas use are just beginning to be developed. A successful transition will require scaling up from smaller-scale decommissioning pilots to larger-scale replicable projects. Achieving this expansion will require shaping technologies to suit the varied circumstances of gas system users and creating pathways that are attractive and actionable for a variety of consumers and communities.

Investor-owned utilities (IOUs) have identified a more complete assessment of gas sector decarbonization pathways as an important knowledge gap that needs to be addressed to chart a decarbonization path that is robust, cost-effective, and aligned with California's energy goals across the entire energy system. For example, integrated approaches must simultaneously address the timing of infrastructure investments and the pragmatics of upgrades. Examples include electrical panel upgrades or workarounds, financing, supply chain and workforce dynamics, and field-vetted replacement technologies and upgrade packages that are attractive to consumers. At the same time, vulnerable consumers should be shielded from cost shocks, and efforts must be coordinated with energy infrastructure transition timelines and associated vulnerabilities (for example, gas system trimming, escalating costs).[31]

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29 *California Residential Appliance Saturation Survey, 2019* (California Energy Commission), accessed through DNV Reporting Center tool (https://webtools.dnv.com/CA_RASS/Default.aspx).

30 US Energy Information Administration, "Natural Gas Delivered to Customers in California," 12/30/2021. Includes residential, commercial, industrial, electric power, and vehicle fuel.

31 For example, SMUD Comments on "Data-Driven Tool to Support Strategic and Equitable Natural Gas Decommissioning" (September 2, 2021, CEC 19-ERDD-01 Docket, TN# 239580); SoCalGas comments on

To date, government-sponsored energy technology research has not been positioned to consider in depth the role of communities and consumers in large-scale energy transitions, and no large-scale pilots of gas decommissioning have been planned or executed in the state. Recognizing that large-scale energy transitions are also social transitions, this initiative includes a social scientific research component that addresses perspectives, circumstances, and needs of prospective adopters of electrification and the supply chain that serves adopters. This social scientific research will assess barriers and opportunities related to technological aspects of gas system decarbonization, including those related to optimizing technology designs, community reactions, and transition rollout strategies.

Existing research shows that small-scale pilot projects seem cost-effective and less risky, but large-scale deployment is required to achieve California's goals for decarbonization. There are unique challenges related to large-scale pilots that require detailed engineering review and analysis and must overcome barriers such as the obligation-to-serve requirement and funding availability for electrification. These technical, policy, regulatory, and funding obstacles must be addressed before actual large-scale pilots become feasible. Further, while a Gas R&D-funded planning tool is under development[32] and expected to substantially enhance the state's capacity for planning a strategic transition based on consideration of gas infrastructure data, major gaps remain. These gaps include integration of a more complete accounting of decommissioning costs, consideration of emerging clean energy options, and planning across a range of timescales.

This research initiative has been informed by ongoing interagency coordination between CPUC and CEC staff regarding gas R&D and related policy priorities. A public workshop will inform solicitation development to ensure this initiative is focused for maximum impact in this rapidly evolving space. Research is expected to commence during the latter stages of CPUC's long-term gas planning rulemaking (R.20-01-007), as well as CPUC's rulemaking to modernize the electric grid for a high distributed energy resources future (R.21-06-017), to be responsive to discussions and decisions associated with those rulemakings.

Expected Initiative Outcomes

Findings from this initiative are expected to be used by state energy planning and regulatory agencies, local governments, utilities, and other key stakeholders in California's clean energy transition. The potential pilot project will build on existing research on gas decommissioning[33] and leverage insight from stakeholders, including utilities, local governments, environmental and community-based organizations, customers, and property owners. The research will identify and collect data (for example, infrastructure condition, capacity for electrification, current and projected gas throughput, acquisition costs for consumers, consequences accruing

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Decommissioning Workshop (Nov. 30, 2021, CEC 19-ERDD-01 Docket, TN# 240743); Building Decarbonization Coalition's *The Flipside Report: A White Paper on Targeted Geographic Electrification in California's Gas Transition* (2021), Greenlining's *Equitable Building Electrification: A Framework for Powering Resilient Communities* (2019).

32 Supported by GFO-21-504, "Development of a Data-Driven Tool to Support Strategic and Equitable Decommissioning of Gas Infrastructure." https://www.energy.ca.gov/solicitations/2021-11/gfo-21-504-development-data-driven-tool-support-strategic-and-equitable.

33 GFO-20-503 - Strategic Pathways and Analytics for Tactical Decommissioning of Portions of Natural Gas Infrastructure, available at: https://www.energy.ca.gov/solicitations/2020-12/gfo-20-503-strategic-pathways-and-analytics-tactical-decommissioning-portions; GFO-21-504 - Development of a Data-Driven Tool to Support Strategic and Equitable Decommissioning of Gas Infrastructure, available at: https://www.energy.ca.gov/solicitations/2021-11/gfo-21-504-development-data-driven-tool-support-strategic-and-equitable

to consumers, critical fossil gas dependencies) to inform the design of a real-world, large-scale gas system decommissioning pilot. Analyses may include detailed engineering review of electrical and gas systems, safety implications, building electrification, energy equity for underresourced communities, improved design of consumer technology and supply chain dynamics, and cost savings by avoiding stranded assets. Underresourced communities will be prioritized in site selection. The research will promote a large-scale decommissioning pilot to support a cost-effective, equitable gas transition and inform stakeholders on financial, programmatic, legal, and regulatory actions.

A complementary applied research component will build on analyses of large-scale pilots as well as ongoing development[32] of a data-driven tool to identify promising decommissioning sites. Enhancements to the data-driven tool to identify promising decommissioning sites will:

- Ease planning across a range of time horizons,
- Consider cost impacts associated with gas and electricity system interactions,
- Analyze potential roles of emerging zero-carbon energy sources, and
- Assess consumer and community-level energy choices.

Ratepayer Benefits

- **Safety:** Aging gas infrastructure in California poses safety and integrity risks and challenges. Electrification and decommissioning of gas infrastructure are key strategies for addressing aging gas system infrastructure and avoiding future stranded assets.
- **Affordability:** This initiative contributes to strategic planning of gas sector decommissioning, which is critical for managing costs and maintaining affordable rates through gas system transition.
- **Environmental Sustainability:** Applied research to support implementation of decarbonization options for the gas sector is urgent given the accelerated pace needed to meet 2030 and 2050 emissions reductions goals. Decommissioning part of the gas system lowers end-use emissions and can reduce methane leakage. It also helps reduce in-home pollution and detrimental health impacts of gas appliances through electrification.
- **Equity:** The proposed research supports proactive decommissioning and helps reduce the risk to vulnerable communities from potentially volatile costs that could arise as the number of gas ratepayers' declines. The research will prioritize transitioning underresourced communities off the gas system and develop strategies and resources to address equity impacts of potential rate changes.

Initiative Theme: Decarbonization of Gas End Uses

Executive Order B-55-18 established a goal for statewide carbon neutrality by 2045. New energy technologies and strategies are needed to achieve this goal cost-effectively, especially for those gas end uses that are difficult to decarbonize – including segments of the industrial sector, dispatchable generation, and heavy-duty transport. Switching to low-carbon fuels, such as green hydrogen, is one potential decarbonization pathway. The production of green hydrogen is energy-intensive, and its usefulness in helping the state meet its energy and climate goals will depend on how the gas is produced, stored, distributed, and integrated with the state's energy ecosystem, including industry, power generation, and transportation. Further R&D is required to address cost, safety, reliability, and operational requirements.

California's industrial sector accounts for over one-third of the state's fossil gas consumption, produces more than 20 percent of California's GHG emissions, and represents the second largest source of emissions in California. Decarbonization of the industrial sector is challenging – both technically and economically. High-temperature requirements of some industrial processes and the level of systems integration needed are major challenges. Most industrial equipment is highly specialized, and field deployment experience cannot be easily transferred between industries. These factors impede wide adoption of state-of-art energy-efficient equipment. The development of new decarbonized process heating technologies can eliminate a large portion of industrial emissions because process heat accounts for about 85 percent of industrial fossil gas use. However, heavy GHG-emitting subsectors, such as cement production, are more difficult to electrify due to high heat requirements (>800° C or 1,472° F) and the need for a consistent energy source. Green hydrogen is one potential fuel switching option that may be applicable for segments of the industrial sector, but it requires further development associated with cost, safety, and retrofit requirements.

The electricity sector represents more than 14 percent of California's GHG emissions. More than half of this GHG footprint comes from in-state fossil gas-fired power generation, while most of the remainder from electricity imports also generated by fossil gas. Fossil gas-fired electricity generation is also a source of criteria pollutants such as oxides of nitrogen (NOx). Achieving the state's 100 percent clean electricity goal requires reducing dependence on fossil gas while providing grid support to complement increases in variable solar and wind generation. Renewable hydrogen can support these needs but has not yet been commercially demonstrated in California. Moreover, addressing issues of performance, cost, safety, and NOx emissions is needed to enable increased deployment of hydrogen-based generation.

Emissions from vehicle tailpipes alone represent nearly 40 percent of the state's GHG emissions. When combining fuel consumption with petroleum processing and extraction, these transportation-related emissions total more than 50 percent of the state's GHG emissions. The transportation sector is also a leading source of air pollutants, with mobile sources responsible for nearly 80 percent of NOx and 90 percent of diesel particulate matter emissions. Executive Order N-79-20[34] set ambitious statewide targets for 100 percent of passenger vehicle sales to be zero emission by 2035, for all off-road and drayage operations to be zero emission by 2035, and for all medium- and heavy-duty vehicle fleets to consist of zero-emission vehicles by 2045, where feasible. Hydrogen fuel cell technology can complement battery-electric technology as a zero-emission pathway to decarbonize operationally challenging transportation subsectors, such as heavy-duty vehicles and off-road operations.

In alignment with the state's carbon neutrality targets for 2045, this Budget Plan includes initiatives to assess opportunities for geological storage of hydrogen, shared clean hydrogen infrastructure for the industrial sector, develop emission mitigation technologies for hydrogen-based power generation, and improve the performance and cost-effectiveness of hydrogen refueling infrastructure for heavy-transport applications. Solicitations will be developed with coordination across initiatives, as appropriate.

Initiative Title: Large-Volume Hydrogen Storage in California for Targeted Use Cases

[34] Available at: https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

Initiative Description

This initiative aims to assess the technical and cost feasibility of geological hydrogen storage opportunities in California that support targeted, hard-to-decarbonize use cases such as high-temperature industrial processes, peaking power generation, and heavy-duty transport. Geological storage options may include salt caverns, depleted oil and gas reservoirs, aquifers, and hard rock caverns, among other sites. Potential research topics may include (1) fluid flow properties and behavior of hydrogen in underground reservoirs, (2) geochemical reaction, (3) biotic reaction, (4) geomechanical considerations for integrity, (5) operation and safety, and (6) cost-effectiveness. The research will fill knowledge and technology gaps, evaluate and advance emerging technologies, and inform decision-making to enable the safe and efficient implementation of geological hydrogen storage in California for these targeted use cases.

Background

Hydrogen is emerging as a low-carbon fuel option for certain hard-to-decarbonize applications in industry, dispatchable electricity generation, and heavy-duty transport. Infrastructure is required to store large volumes of hydrogen to serve these various applications at scale, buffer seasonal gas demands, and provide continuity in case of disruptions in the supply chain. Large-volume storage options for hydrogen will promote a stable hydrogen supply that could support achievement of **Senate Bill** 100 and carbon-neutrality goals.

Storing large-volume hydrogen as a liquid or in some other form is a challenge, requiring significant energy in the form of work, heat, or, in some cases, hydrogen-binding materials. While geological storage of hydrogen offers a relatively low-cost solution with significant storage capacity to meet the needs of consumers, experience with hydrogen storage in geological formations is limited. Suitable sites will require specific investigation and characterization to ensure safety and economic performance. Uncertainties related to potential leakage as well as other risks, such as the loss of hydrogen because of microbial activities, need to be investigated and quantified. New monitoring systems with advanced sensors are required to help reduce those potential risks. The proposed research initiative will assess the opportunities and technical challenges associated with geological storage for renewable, low-carbon hydrogen.

Expected Initiative Outcomes

The research will investigate the technical and economic viability of large-volume geologic storage opportunities to help meet the state's climate goals. Projects under this research initiative could develop a framework for policy makers, regulators, and utilities to identify the main options for geologic hydrogen storage in California that match the needs of emerging hydrogen industry applications, considering the economic, social, and environmental constraints. The research could conduct technoeconomic analysis for geological storage sites, considering the hydrogen supply chain including production, transport, storage, and end use.

Experiments and simulations will be conducted to research pure hydrogen and blended hydrogen impacts on underground storage systems. Research results could help facility operators

- Quantify the compatibility of materials;
- Characterize microbial interactions;
- Identify technical requirements such as storage volume, frequency of cycling of the storage, and maximum and minimum operating pressures and temperatures;
- Develop mitigation strategies associated with technical and operational risks; and

- Evaluate emerging technologies to enable a safe and reliable hydrogen storage system.

The research will form the basis for determining how large-volume geological storage technologies can support targeted end uses for renewable, low-carbon hydrogen.

Ratepayer Benefits

- **Safety:** This initiative will address safety risks for hydrogen storage, including evaluation of storage integrity and leveraging emerging technologies such as monitoring sensors and reservoir modeling software.
- **Affordability:** Cost-effective storage options at scale are essential to realizing the full potential of hydrogen as an energy carrier. Underground geological storage of hydrogen could offer substantial storage cost reductions as well as buffer capacity to meet possible disruptions in supply or changing seasonal demands, contributing to the affordability and stability of hydrogen supplies.
- **Environmental Sustainability:** The proposed research will enable low-cost storage opportunities for renewable, low-carbon hydrogen in California at scales that could contribute to a 100 percent renewable and zero-carbon grid and decarbonization of hard-to-electrify segments of the economy.

Initiative Title: Industrial Clusters for Clean Hydrogen Utilization

Initiative Description

This initiative will identify and characterize the optimal colocation of industries ("clusters") to share hydrogen infrastructure and reduce costs for hydrogen producers and users. This initiative will consider the number of industries to be colocated, the most promising locations, the types of industries most compatible for regional hydrogen deployments, and the best ways to ensure safety of the neighboring communities. This initiative aims to improve cost-effectiveness of replacing fossil gas with hydrogen for industrial use by:

- Evaluating safety, risks, benefits, and technical advancements needed for using hydrogen in industrial applications.
- Identifying and characterizing optimal colocation of industries to drive down costs by sharing hydrogen infrastructure, engaging with stakeholders, and addressing safety.
- Identifying the feasibility and cost savings opportunities of repurposing existing gas infrastructure.

Background

California's industrial sector is responsible for more than 35 percent of the state's gas use and contributes nearly 100 million metric tons of CO_2 equivalent emissions (MMT CO_2e), which is more than 20 percent of the state's GHG emissions.[35] Process heating accounts for about 85 percent of industrial sector gas use. Decarbonizing process heating is challenging due to technical and cost limitations and the need to meet high-temperature industrial demands. Green hydrogen can replace fossil gas and is a promising decarbonization pathway to reduce GHG emissions from high-temperature industrial processes. However, hydrogen is relatively costly to produce and transport to industrial facilities.

35 California Air Resources Board. 2021. "Current California GHG Emission Inventory Data." https://ww2.arb.ca.gov/ghg-inventory-data.

Sharing hydrogen infrastructure could improve overall economics for cluster participants by distributing costs, reducing the learning curve, and improving economies of scale. For example, by sharing infrastructure and colocating end users, scale and capacity factor can be increased to improve the economics. Furthermore, use of by-products from hydrogen production, such as pure oxygen and waste heat that are conventionally vented to the atmosphere, could improve economics of hydrogen deployment. For instance, food processing plants use low-temperature processes and are more suitable for waste heat reuse, while high-temperature facilities like glass manufacturers may benefit from oxygen for combustion.

This study will also evaluate potential safety concerns, such as explosions and fire hazards, associated with producing, storing, and transporting hydrogen. Mitigation options for minimizing these risks will be included in this research. This initiative will be informed by the current research solicitation, GFO-21-503, Examining the Effects of Hydrogen in End-Use Appliances for Large Commercial Buildings and Industrial Applications.[36] This solicitation will fund a study to examine the effects of hydrogen in end-use commercial and some generic industrial heating applications. The results could provide insights on the technical potential of hydrogen use in various equipment associated with the industrial sector.

Expected Initiative Outcomes

Research conducted under this initiative is expected to:

- Identify technical advancements needed for using hydrogen in industrial applications.
- Identify potential locations for clustering hydrogen-using industrial facilities and assess opportunities to share hydrogen infrastructure.
- Identify the feasibility and cost savings opportunities from repurposing segments of existing gas infrastructure compared to constructing new dedicated hydrogen infrastructure.
- Support safety measures for the communities located around prospective hydrogen deployments.

A successful study would establish a method to assess whether a specific location might be feasible for clustering, provide information on the technical, geospatial, safety, and economic feasibility related to industrial hydrogen clusters, and advance the level of understanding of hydrogen's potential role in decarbonizing the industrial sector. Findings may be used by utilities, industries, hydrogen producers, and policy makers to inform future decision making and build-out related to hydrogen infrastructure.

Ratepayer Benefits

- **Affordability:** Sharing infrastructure has the potential to drive down the cost of hydrogen, making it more affordable for industries to reduce GHG emissions.
- **Environmental Sustainability:** Replacing fossil gas with green hydrogen could play a role in reducing both GHG and criteria air pollutant emissions in the industrial sector.
- **Equity:** This research will examine the implications of hydrogen use in industrial clusters, including for air quality, local community safety, and economic benefits such as local job creation and workforce development.

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36 California Energy Commission. "GFO-21-503 — Examining the Effects of Hydrogen in End-Use Appliances for Large Commercial Buildings and Industrial Applications."

Initiative Title: Mitigate Criteria Air Pollutants in Hydrogen-Based Power Generation

Initiative Description

This initiative aims to reduce emissions of NO_x and potentially other criteria air pollutants, such as carbon monoxide, from the combustion of high percentages of hydrogen in fuel — approaching and including 100 percent — in power generation applications. The implications of this mitigation for surrounding communities are of particular interest. Technology advancements that control emissions before, during, or after hydrogen combustion may include:

- Stationary system pre-intake strategies (for example, optimizing air-fuel ratio or integrating water and steam injection).
- Combustor control strategies (for example, varying compression ratio).
- Post-combustion emission-mitigating technologies (for example, improving catalyst design and performance or modifying emissions control system design and operation).

Background

Hydrogen-based gas-fired generation technologies can reduce the consumption of fossil gas and GHG emissions from power generation, but these technologies are in early stages of development. To examine hydrogen in the power sector, the CEC focused the Renewable Energy and Advanced Generation research area in the FY 2021–2022 Gas R&D Program Budget Plan on hydrogen-based power generation systems that can run efficiently on high percentages of hydrogen in the fuel stream. However, hydrogen-based gas-fired generation technologies can result in increased NO_x emissions because of higher flame temperatures and increased water content as a result of combusting high percentages of hydrogen.[37]

This research builds upon the FY 2021–22 Gas R&D Budget Plan initiative by advancing the technologies to reduce such emissions and meet criteria air pollutant standards.[38] The current emission control strategies can be advanced in several ways, such as using control scheme optimization, system redesigns for the gas burners, and new catalytic materials, to accommodate high blends of hydrogen for fossil-based power generation. Barriers include validating designs and components for hydrogen use; maintaining performance, safety, and energy output when NO_x mitigating technologies are integrated into the gas systems, and minimizing cost of aftertreatment technology additions. Upon approval of the FY 2022–23 Gas R&D Budget Plan, the CEC may consider combining the FY 2021–22 and FY 2022–23 Gas R&D initiatives to provide technology development opportunities to accommodate higher percentages of hydrogen and emission reductions simultaneously.

Technology advancements that control emissions before, during, or after hydrogen combustion will enable adoption of hydrogen-blended gas-fired systems, thus reducing consumption of fossil gas. Moreover, the research from this initiative will help address pollution impacts to

37 U.S. Department of Energy. 2020. *Hydrogen Program Plan.* https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf.

38 California Air Resources Board. 2021. "Current Air District Rules." https://ww2.arb.ca.gov/current-air-district-rules.

surrounding communities — a concern identified by representatives of the Disadvantaged Communities Advisory Group (DACAG).[39]

This initiative complements the *Electric Program Investment Charge Proposed 2021–2025 Investment Plan* (EPIC 4) initiative on Advancing Clean, Dispatchable Generation[40] to support grid reliability and complement intermittent renewables such as solar and wind. While EPIC 4 helps advance hydrogen generation technologies, the proposed Gas R&D initiative supports deeper examination of emission-mitigating technologies to increase safety and advance equity. This initiative also complements the U.S. Department of Energy (DOE) Hydrogen Program Plan,[37] which focuses on other aspects of hydrogen combustion, such as enabling wider ranges of hydrogen percentages and developing advanced combustor manufacturing techniques. Projects funded under this initiative would leverage DOE efforts to improve understanding of combustion behavior and further develop technologies for low NO_x emissions.

Expected Initiative Outcomes

Projects under this initiative seek to develop emission-mitigating technologies for using high percentages of hydrogen — approaching and including 100 percent — for power generation. Projects will improve air quality and seek to meet or exceed power output and performance compared to market-available fossil gas technologies. Projects must also prove feasibility and system durability by demonstrating safe operation of the technologies with hydrogen blends or 100 percent hydrogen. Although this initiative would fund technology development in labs, projects would be required to measure and quantify anticipated air-quality improvements and community health benefits of adopting advanced mitigation technologies. The innovations developed under this initiative could assist with deploying hydrogen-blend or 100 percent hydrogen power generation systems. Technology developers and operators would be able to integrate these technologies for using high percentages of hydrogen and benefit from the research by lowering emissions.

Ratepayer Benefits

- **Affordability:** This initiative aims to adapt emission-mitigating technologies for hydrogen combustion, increasing market adoption of hydrogen and reducing the cost of air-quality mitigation in hydrogen power generation.
- **Environmental Sustainability:** This initiative will support the transition to hydrogen blending and 100 percent hydrogen for power generation, helping reduce statewide consumption of fossil gas, thereby lowering GHG emissions. This initiative would also advance technologies that lower criteria air pollutants from hydrogen combustion and improve air quality by reducing NO_x emissions.
- **Equity:** Half of all fossil gas power plants and most industrial plants in California are in underresourced communities. Residents of these communities have historically suffered from health disparities and vulnerabilities linked to local pollutant emissions. The researched technologies support air quality improvements in hydrogen combustion.

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39 California Energy Commission. 2021. *Natural Gas Research and Development Program,* Appendices A-C, p. B-27. https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2021-022-APA-C.pdf.

40 California Energy Commission. 2021. *The Electric Program Investment Charge Proposed 2021–2025 Investment Plan.* https://www.energy.ca.gov/publications/2021/electric-program-investment-charge-proposed-2021-2025-investment-plan-epic-4.

Initiative Title: Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport

Initiative Description

This initiative augments the Transportation research initiative of the same name in the FY 2021–22 Gas R&D Budget Plan with additional funds for projects to address key barriers and stimulate early markets by improving the cost-effectiveness and performance of hydrogen refueling infrastructure technologies for heavy transport. In the context of this initiative, "heavy transport" broadly includes heavy-duty trucks, off-road agricultural and construction equipment, cargo-handling equipment, rail, and marine (at ports and other in-state facilities). Technology advancements may include:

- Improving the efficiency and reliability of hydrogen refueling station components and designs to reduce delivery and refueling costs (for example, improved compressors, cryopumps, chillers, innovative station configurations to reduce footprint, increase utilization, or integrate on-site renewable hydrogen production or a combination thereof.
- Demonstrating high-flow-rate systems for economical fast refueling of larger hydrogen fuel cell vehicles.
- Developing flexible mobile refueler technologies to enable hydrogen fuel cell adoption for off-road, rail, and marine end uses that rely on diesel mobile refuelers.

Background

Hydrogen fuel cells can complement batteries as a zero-emission technology option for heavy transport applications that may be challenging to electrify directly. However, commercial adoption of hydrogen fuel cells for heavy transport is limited by the lack of an extensive hydrogen refueling infrastructure network in California. With additional advancements, emerging hydrogen refueling infrastructure technologies can address performance and cost barriers to better support the transition of heavy transport applications to zero emissions.

This initiative will support efforts to achieve cost parity between hydrogen fuel cell and internal combustion engines by reducing hydrogen delivery and refueling costs, which represent roughly 60 percent of the price of hydrogen at the pump.[41] DOE has set a target of $2/kilogram (kg) for hydrogen delivery and refueling costs to reduce the price of hydrogen at the pump to levels equivalent to conventional gasoline or diesel.[42] Furthermore, improving hydrogen refueling infrastructure reliability to minimize downtime is critical for acceptance of hydrogen fuel cell vehicles by commercial fleets. This initiative will seek to advance technologies to achieve high flow rates (for example, 8-10 kg/minute at 700 bar for long-haul heavy-duty trucks)[43] needed for fast refueling of larger vehicles that require storing an order of magnitude more hydrogen on-board than light-duty vehicles (for example, 60 kg for heavy-

41 Based on data from Satyapal, Sunita. 2021. "2021 AMR Plenary Session." https://www.hydrogen.energy.gov/pdfs/review21/plenary5_satyapal_2021_o.pdf.

42 U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. "Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan – Section 3.2 Hydrogen Delivery."

https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-delivery.

43 Marcinkoski, Jason, et al. October 2019. "DOE Advanced Truck Technologies Subsection of the Electrified Powertrain Roadmap: Technical Targets for Hydrogen-Fueled Long-Haul Tractor-Trailer Trucks." https://www.hydrogen.energy.gov/pdfs/19006_hydrogen_class8_long_haul_truck_targets.pdf.

duty trucks compared to 5 kg for light-duty vehicles). Lastly, advancing flexible mobile hydrogen refueling to emulate diesel mobile refueling or "wet hosing" practices can address operational barriers of using hydrogen fuel cells in off-road, rail, and marine applications where access to permanent refueling infrastructure is less practical. Research funding is needed to address these barriers and stimulate early markets.

This research initiative augments the approved FY 2021–22 Gas R&D Budget Plan to conduct a broader solicitation to attract more applicants and fund additional projects. This initiative expands upon the FY 2021–22 Gas R&D Budget Plan by derisking innovative hydrogen refueling solutions across a broader range of applications (including off-road, rail, and marine). The resulting projects will complement CEC's Clean Transportation Program investments from the *2021–2023 Investment Plan Update*, which allocates $695 million to future medium- and heavy-duty deployments, prioritizing refueling infrastructure to enable the replacement of drayage trucks, transit buses, and school buses with zero-emission alternatives.[44] The topics in this initiative bridge the technology gap between DOE's research on low-technology-readiness-level (TRL) materials and components[45] and CEC's Clean Transportation Program investments in high-TRL deployments.

Expected Initiative Outcomes

Projects funded under this initiative will demonstrate hydrogen refueling infrastructure solutions to reduce hydrogen delivery and refueling costs from $5 to $11/kg today toward a goal of $2/kg. Projects will also address performance barriers specific to heavy transport applications advancing technologies to improve reliability, increase flow rates toward suitable refueling times for larger vehicles (for example, 8–10 kg/min at 700 bar for long haul heavy-duty trucks), and better support operators that rely on mobile refuelers. Demonstrations of actual refueling in real-world conditions will validate improvements over existing technology and toward key targets. Research results and technology advancements will assist hydrogen station developers, commercial fleets, utilities, industrial hydrogen suppliers, and complementary funding programs such as the Clean Transportation Program by improving accessibility of hydrogen as a fuel for heavy transport. This research will support accelerated adoption of zero-emission vehicles powered by hydrogen fuel cells following goals established under Executive Order N-79-20 and forthcoming regulations such as the California Air Resources Board's Advanced Clean Fleets rule.

Ratepayer Benefits

- **Affordability:** Reducing costs of delivering and refueling hydrogen will lower the price of hydrogen at the pump for transportation end uses. Benefits could transfer to other sectors that may rely on similar methods of hydrogen distribution (for example, industrial).
- **Environmental Sustainability:** Improving the feasibility of adopting hydrogen fuel cells for heavy transport will lead to GHG and air pollutant emission reductions. Increasing demand for renewable hydrogen in the transportation sector can drive low-

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44 Brecht, Patrick. December 2021. *2021–2023 Investment Plan Update for the Clean Transportation Program.* California Energy Commission. Publication Number: CEC-600-2021-038-CMF. https://www.energy.ca.gov/publications/2021/2021-2023-investment-plan-update-clean-transportation-program.

45 Stetson, Ned. 2021. "H2 Technologies Overview." https://www.hydrogen.energy.gov/pdfs/review21/plenary7_stetson_2021_o.pdf.

carbon hydrogen production at scale, which can support decarbonization of other fossil gas end uses.

- **Equity:** Underresourced communities near ports, railyards, warehouses, and highways experience higher concentrations of air pollution compared to other areas due to oxides of nitrogen and particulate matter emissions from mobile sources such as diesel trucks, off-road equipment, locomotives, and marine vessels.[46] Improving the cost-effectiveness and performance of hydrogen refueling infrastructure for these end uses can accelerate a transition to zero-emission alternatives.

Initiative Theme: Energy Efficiency

Energy efficiency continues to be important in reducing energy demand and GHG emissions in buildings and the industrial, agriculture, and water sectors. Residential and commercial buildings and the industrial sector together represent 69 percent of gas consumption in California. As a result, past energy efficiency research has focused on developing, testing, and demonstrating precommercial and emerging technologies, strategies, and tools to reduce gas use in buildings and the industrial, agriculture, and water sectors.

AB 3232[47] requires the CEC to assess the potential to reduce GHG emissions from homes and businesses by 40 percent of 1990 levels by 2030. As a result, the CEC prepared and adopted the *California Building Decarbonization Assessment*, which identifies seven strategies, including building end-use electrification, electricity generation decarbonization, energy efficiency, refrigerant leakage reduction, distributed energy resources, decarbonizing the gas system, and demand flexibility.[48] The assessment shows that California can achieve more than a 40 percent reduction by 2030 by implementing these strategies.[49] Efficient electrification of space and water heating in buildings combined with refrigerant leakage reduction can provide a greater than 40 percent reduction in GHG emissions by 2030.[50]

In alignment with the state's carbon-neutrality goal for 2045, the proposed FY 2022–2023 Gas R&D Budget Plan includes an initiative to analyze residential hot water distribution designs that could increase efficiency of hot water delivery for gas and electric water heating while reducing water waste.

Initiative Title: Analysis of Residential Hot Water Distribution Designs

Initiative Description

This initiative aims to identify technological advancements for on-demand hot water recirculation pumps. These advancements include smart controls and electronically commutated motors to reduce energy and water use for water heaters in existing and new single-family homes. Research conducted under this initiative will:

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46 California Air Resources Board. 2021. *2020 Mobile Source Strategy.* https://ww2.arb.ca.gov/sites/default/files/2021-12/2020_Mobile_Source_Strategy.pdf.

47 Assembly Bill 3232, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB3232.

48 Kenney, Michael, Nocholas Janusch, Ingrid Neumann, and Mike Jaske. 2021. *California Building Decarbonization Assessment.* California Energy Commission. Publication Number: CEC-400-2021-006-CMF. https://www.energy.ca.gov/publications/2021/california-building-decarbonization-assessment.

49 Ibid.

50 Ibid.

- Identify technological advancements for reducing energy and water consumption for on-demand hot water recirculation pumps.
- Demonstrate promising technological advancements for on-demand hot water recirculation pumps to improve performance, energy savings, and cost-effectiveness on various types of water heaters.
- Assess the value proposition of using on-demand recirculation pumps in comparison to other hot water distribution design methods.
- Document real-world field data to inform future updates to codes and standards.

Background

Hot water recirculation pumps move previously heated, unused hot water in pipes back to the water heater to be reheated before flowing to the faucet as hot water. This recirculation allows residents to have readily available hot water at the tap and reduces the amount of water wasted down the drain as a user waits for hot water to arrive at a faucet.

About half of the circulator pumps currently sold on the market are uncontrolled, continuous recirculation pumps. Another 25 percent of circulator pumps are timer-based and typically operate 16 hours per day, or longer in cases where a homeowner has bypassed the timer. The convenience and water-saving benefits of standard circulator pumps come with a sizable energy penalty, as these pumps operate much longer than needed — wasting electricity to operate the pump and requiring the water heater to operate more often to reheat the hot water that continually cools down in the pipes.

On-demand circulator pumps using the latest technologies — such as electronically commutated motors and smart controllers — reduce energy usage. Activated using a push-button or smart control, the pump primes the hot water line only when needed and then automatically shuts off. Demand-activated circulator pumps typically operate in the range of 10–15 minutes per day and offer similar convenience and water-saving benefits as standard models. While on-demand circulators come with a modest incremental cost over standard circulator pumps, the market share of on-demand models was less than 1 percent in 2011 and continues to lag standard models, with less than 5 percent of sales in 2021.

Research data on hot water recirculation systems generally reflect technologies from 10 to 15 years ago. Recent modeling analyses indicate that on-demand circulator pumps can save substantial energy and water. In addition, there are no current energy efficiency standards on different types of recirculation pumps that could be installed in homes. There may be a need for standards due to the potential issues with heat pump water heaters that are expected to be the primary type of water heater in the coming decades. Issues such as disruption of thermal stratification in the tank with continuous recirculation could potentially cause the heat pump water heater to operate in the electric resistance mode much of the time[51] and substantially increase energy use. Real-world field data on water and energy consumption of advanced on-demand circulator pumps are needed to develop performance standards and possibly inform energy codes.

Expected Initiative Outcomes

[51] Energy Solutions. October 2021. Research and Analysis of the Benefit of Appliance Standards for Domestic Hot Water Circulator Pumps, Report to NRDC

Findings will apprise utilities, builders, consumers, and policy makers of the benefits and costs of adopting advanced on-demand recirculation pumps and inform future appliance standards and energy code updates for new and existing single-family homes.

Ratepayer Benefits

- **Affordability:** On-demand circulator pumps are an easy and cost-effective retrofit option (roughly $1,000 installed) with an estimated economic payback period of 2–6 years compared with continuous pumps and have an expected useful life of 15 years.
- **Environmental Sustainability:** Circulator pumps save an estimated 1,100 gallons of water per person annually and, when compared to continuous operation, on-demand circulator pumps, reduce electricity and gas consumption, resulting in lower GHG emissions and saving an estimated $500 per household annually.
- **Equity:** Homeowners, builders, and contractors need to be informed that standard circulators incur a sizable energy penalty and that on-demand circulator pumps are a cost-effective option. Code updates requiring advanced controls on recirculation pumps have the potential to reduce energy and water bills and could alleviate financial stress for residents in low-income multifamily housing.

~~Initiative Theme: Entrepreneur Development~~

~~California's statutory energy policies have put the state on an accelerated timeline to decarbonize its energy sector. Independent studies have found electrifying traditionally nonelectric end uses to be a promising pathway for decarbonizing the energy sector. While some end uses can more easily and cost-effectively electrify, such as space and water heating in new building construction, other end uses such as industrial process heating and heavy-duty transportation will be more challenging. For California to successfully decarbonize these end-uses in a manner that aims to make them cost-competitive with fossil fuels, continued innovation and entrepreneurship are needed to introduce new technology solutions to the market.~~

~~Large energy corporations have mostly forgone in-house R&D activities, instead finding it more cost-effective and opportunistic to strategically partner with or acquire start-up companies with new technology solutions. Without a prospering portfolio of clean energy start-up companies to partner with, large energy corporations would have to develop and scale up their own internal R&D activities as well as build up their internal capacity and expertise to launch these new technology products. That timeline can take several years or more, with a risk profile that most large companies are not willing to accept.~~

~~Over the past several years, the EPIC Program has developed a robust statewide entrepreneurial ecosystem to support innovators through the early to middle stages of the technology development pipeline. These start-up companies have since raised more than $2 billion in subsequent private sector investment to bring new technology solutions to commercial fruition for the electric sector. Similar support to entrepreneurs for gas-related technologies can support decarbonization goals while also improving safety and affordability.~~

~~Initiative Title: California Sustainable Energy Entrepreneur Development – Low-Carbon Gas (CalSEED — LCG)~~

~~**Initiative Description**~~

This initiative builds upon the California Sustainable Energy Entrepreneur Development (CalSEED) efforts established under the first three EPIC investment plans by funding a complementary small grants program for technologies that decarbonize existing uses of fossil gas. The small-scale funding provided by the CalSEED initiative gives entrepreneurs starting capital to develop their ideas into proof-of-concepts and early prototypes. This funding fills a crucial niche in the financing landscape for clean energy entrepreneurs because venture capital firms typically favor later-stage companies and technologies, where there is less risk. Technology areas of focus may include carbon capture, hard-to-electrify end-uses such as industrial process heating and heavy-duty transportation, and producing low-carbon alternatives to fossil gas such as green hydrogen and biomethane.

Background

The CEC initiated the CalSEED — LCG program in 2021, and it will be modeled after the successful CalSEED program established under the EPIC program in 2016. Each year, CalSEED receives between 200 to 400 applications, of which only 25–28 are selected for a CalSEED award. This oversubscription shows not only the popularity of the program, but indicates the lack of alternative funding opportunities at this early stage. Through November 2020, CalSEED has provided funding for 91 start-up companies, which have gone on to receive more than $37 million in public funding and $28 million in private investment. An example of a successful CalSEED recipient is Cuberg, a start-up developing a novel electrolyte for use in advanced lithium-ion batteries. Cuberg received a CalSEED award in 2017 and has since received subsequent investment from entities such as the National Science Foundation, the U.S. Army, the U.S. Air Force, and Boeing. In 2021, Cuberg was acquired by Northvolt, a European supplier of battery systems to partners such as BMW and Volkswagen Group. Northvolt seeks to scale Cuberg's innovation into its next generation of lithium batteries.

Expected Initiative Outcomes

This initiative will attract and support early-stage breakthrough innovations resulting in a robust pipeline of entrepreneurs developing the next generation of technologies to decarbonize existing uses of fossil gas. CalSEED is often the CEC's first touchpoint for many clean energy start-up companies. Providing small amounts of funding can set up these companies to be successful when applying to larger funding opportunities and attracting interest and investment from the private sector. In addition, CalSEED provides a path for intellectual property (IP) developed at research institutions to spin out of the lab and into commercial ventures. IP refers to product concepts protected by law such as copyrights, trademarks, and patents.

Ratepayer Benefits

- **Safety:** CalSEED-LCG may award funding to projects developing innovations to improve product or infrastructure safety, including solutions that can predict, detect, and repair infrastructure threats and vulnerabilities with greater speed and precision.
- **Affordability:** CalSEED-LCG may award funding to projects developing innovations that can cost-effectively decarbonize hard-to-electrify existing uses of fossil gas such as industrial process heating and heavy-duty transportation.
- **Environmental Sustainability:** CalSEED-LCG may award funding to projects that result in improved air quality by developing alternatives to fossil gas.

Initiative Theme: Gas Pipeline Safety and Integrity

California's gas infrastructure covers most of the state and includes production wells, treatment plants, transmission lines, compressor stations, distribution lines, meters, and small pipes inside homes and buildings. California's gas system consists of more than 100,000 miles of gas transmission and distribution pipelines and more than 11 million services.[52] Gas delivered by the system is highly combustible, contains toxic compounds, and has a very potent greenhouse gas, methane, as one of the main components. California's fossil gas wells and pipelines face risks that could cause damage or catastrophes. Five years of extreme drought exacted a toll on transmission pipelines, prompting the CEC to research drought-induced subsidence impacts on gas pipelines. Incidents such as the 2015 Aliso Canyon leak and the 2010 San Bruno explosion are reminders that public safety, public health, and greenhouse gas emissions are major guiding principles for gas research. Climate change exacerbates risks, such as exposing gas infrastructure directly or indirectly to wildfires, landslides, coastal and inland flooding, and ground subsidence due to overdrafting of groundwater. Furthermore, gas pipeline and storage-related incidents and constraints can impact affordability for ratepayers, as observed in the 2022-23 winter when combined with below-normal temperatures and high gas demand.[53] Finally, the gas system must evolve substantially to contribute to the state's goals for economy-wide carbon neutrality by 2045.

The CEC has previously funded research to assess the vulnerabilities of the gas system to prevent damages from excavation, corrosion, and other threats. This work includes developing and demonstrating risk management tools and monitoring technologies to improve cost-effectiveness and efficiency of evaluating and maintaining gas system integrity. Research funded by the CEC complements research conducted by industry, helping address public safety issues and developing preventative measures against catastrophic failures with a long-term, systemwide view and a focus on achieving the state's GHG reduction goals. Recognizing the need to advance technologies to increase safety, support cost effective integrity management, and reduce GHG emissions, the FY 2022–23 Gas R&D Budget Plan proposes an initiative to develop technologies for improved natural force damage monitoring and risk assessment and for plastic pipeline deficiency inspection.

Initiative Title: Gas Pipeline Safety and Integrity Research to Support Decarbonization

Initiative Description

This initiative augments the "Technologies for Monitoring Ground Movement Around Pipelines and Mitigating Natural Force Damages" and "Technology Development and Demonstration for Plastic Pipeline Repair and Integrity Improvement" initiatives in the FY 2021-22 Gas R&D Budget Plan with additional funds for projects proposed for award under GFO-22-503: Gas Pipeline Safety and

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[52] CPUC. *Natural Gas and California*. https://www.cpuc.ca.gov/industries-and-topics/natural-gas/natural-gas-and-california

[53] U.S. Energy Information Administration. *Daily natural gas spot prices in western United States exceed $50.00/MMBtu in December*. January, 2023. https://www.eia.gov/todayinenergy/detail.php?id=55279

Integrity Research to Support Decarbonization. These projects may focus on research to improve monitoring and risk assessment for natural force damages to gas pipelines or plastic pipeline deficiency inspection for pipeline integrity management.

Background

Pipeline age can affect safety and reliability, both because of the increased frequency of natural force exposure and the degradation of the pipeline materials over time. On January 9, 2018, a pipeline failure incident occurred in Montecito, California, caused by heavy rains and localized flooding resulting in a fire and explosion due to the failure of a 22-inch transmission pipeline. The pipeline failure resulted in the release of 12 million cubic feet of gas. Pipelines impacted by natural force damages, such as the incident in Montecito, are particularly concerning because these large and unpredictable natural forces are difficult to anticipate.[54] Pipeline and Hazardous Materials Safety Administration (PHMSA) data show that approximately seven percent of incidents for both gas distribution and transmission pipelines can be attributed to natural force damages from 2010 to present. Reporting data shows that these natural forces include temperature extremes, heavy rains and flooding, earth movement, lightning, intrusive tree root growth, snow or ice accumulation, or high winds.[55] Pipeline design and construction regulations require pipeline operators to identify, assess, and design for geotechnical conditions and anticipated meteorological events. Meanwhile, integrity management regulations require risk assessments in the form of in-person patrol programs conducted on an ongoing basis to identify all potential threats and integrity risk factors. These patrols are often conducted on a quarterly basis, and timing depends on the size of the line, operating pressures, class locations, terrain, seasonal weather conditions, and other relevant factors, which means that operators may not be able to locate leaks or ruptures until the line is physically inspected. Advanced monitoring technologies and data analytics are needed to assess the integrity of the gas system more efficiently and remotely in response to natural force damages and reduce the frequency of costly repairs and service interruptions.

Plastic pipelines are most frequently used for gas distribution networks due to favorable mechanical characteristics that include elasticity, tearing strength, and resilience to shocks and vibrations. [56] By the end of 2021, there were over 802,937 miles of plastic main and over 53.4 million plastic services installed in distribution systems in the United States.[57] Over 90 percent of plastic pipe gas distribution

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[54] Federal Register, 2022, *Pipeline Safety: Potential for Damage to Pipeline Facilities Caused by Earth Movement and other Geological Hazards*. https://www.federalregister.gov/documents/2022/06/02/2022-11791/pipeline-safety-potential-for-damage-to-pipeline-facilities-caused-by-earth-movement-and-other

[55] PHMSA, 2022, Gas Distribution and Gas Transmission Data.

[56] Sustainable and safe in exploitation of gas networks. Part 1. Stress factors of plastic pipelines, 2018, Electrotehnica, Electronica, Automatica (EEA), 2018, vol. 66 no. 4, pp. 66-72, ISSN 1582-5175.

[57] Plastic Pipe Database Committee, 2022, Plastic Piping Data Collection Initiative Status Report. https://www.aga.org/wp-content/uploads/2022/12/PPDC-October-2022-Status-Report-final-tracked-12072022.pdf

mains consists of polyethylene (PE) pipes with a wide range of pipe diameters. Like steel pipelines, the safety and integrity of plastic pipelines are significantly impacted by a broad range of risks and threats. For plastic pipelines, these risks and threats include third-party damages, natural hazards, age hardening of plastic material and components, and degradation of repairs over time. Typical plastic pipeline failures include slow crack growth, ductile rupture, and rapid crack propagation, all of which have the potential to contribute to fugitive methane emissions or result in catastrophic ignitions. Failure may also occur at the location where plastic pipes are joined together by fusion welding, with the main causes of failure being poor scraping, misalignments and contamination.[58] In particular, California's vintage plastic pipelines made with a type of PE called Aldyl-A have been identified by the CPUC as a major potential hazard due to their propensity for embrittlement, cracking, and rupture.[59]

The current practice for assuring the quality of plastic pipe systems relies on pressure testing and visual inspection of the pipes, fittings, and joints. These tests and inspections only examine the external surface and cannot provide evidence of embedded flaws or defects in plastic material. Non-destructive evaluation (NDE) methods have been developed to help bridge the knowledge gap and to retain the integrity of the pipeline. A substantial amount of research has been undertaken on the use of NDE to inspect steel pipelines. The application of NDE for plastic pipe inspection, on the other hand, is still in its early stages. Furthermore, the technology developed for inspecting metal pipe systems is not always applicable to plastic pipe systems. There is a need to accelerate the development and demonstration of advanced NDE technologies for plastic pipeline inspection.

Conclusions drawn from gas pipeline accidents and incident data from PHMSA illustrate the importance of pipeline safety research to improve the safety and reliability of the gas system. Pipeline safety research will also inform the role that existing gas infrastructure will play in the transition to a decarbonized future and accelerate California's effort to decarbonize the state's gas system. This initiative aims to advance technologies to better evaluate the safety and integrity of existing gas infrastructure, which will serve as a basis to inform gas system decarbonization strategies such as broad electrification and targeted use of renewable gas.

Expected Initiative Outcomes

The initiative will support the development and demonstration of novel technologies for geotechnical pipeline monitoring that include remote sensing or embedded sensing technologies that will inform long-term gas system planning. Sensors and sensor data may be employed to directly measure or predict mechanical loads along gas pipelines and assess potential damages or failures before they occur. Modeling approaches and field sensor data may be used to simulate the mechanical loads in pipeline systems subjected to natural forces and to determine potential damages or leakage rates. Additional modeling

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[58] California Public Utilities Commission (CPUC), 2014, Hazard Analysis and Mitigation Report – Aldyl A Polyethylene Gas Pipelines.

[59] The University of Sheffield, 2015, Fatigue Failure of Polyethylene Electrofusion Joints Subject to Contamination.

investigations may be conducted to estimate geotechnical changes using field-test-based methods in combination with laboratory tests.

The initiative will also support the development of innovative laboratory and field tested NDE technologies that could provide a measure of the structural integrity of PE pipes and assess the structural health of in-situ conditions. The reliability of NDE technologies will be improved to identify different types of damages such as internal cracks, as well as different flaws or defects in material or from installation. Additionally, the initiative will improve replicability of results and account for differences in equipment, materials, joint configurations, and flaw types that may require distinct practices, procedures, and trainings to reliably interpret the measurement results. The initiative aims to result in low-cost, high-precision non-destructive inspection technologies to evaluate the status of PE pipes, fittings, and joints. The prospective research findings should aid in assessing system integrity and informing strategic gas decommissioning opportunities.

Ratepayer Benefits

- **Safety: With improved remote sensing and monitoring technologies, pipeline operators can monitor ground movement around pipelines and develop strategies to reduce the risk of potential natural force damages. NDE technologies for PE pipelines will support improved integrity management and help prevent incidents due to PE pipeline embrittlement, cracking, and rupture.**
- **Affordability: Technologies developed under this initiative will help prevent pipeline failures, decrease system downtime, and avoid the associated cost impacts to ratepayers.**
- **Environmental Sustainability: Preventing and mitigating natural force damages to gas pipelines and improving integrity management of gas mains and service lines will help reduce fugitive methane emissions.**
- **Equity: Underserved communities are usually more vulnerable to natural disasters and incidents such as gas leaks and pipeline ruptures. This research will inform engineering measures to protect these communities from being negatively impacted by natural force damages. This research will also enhance the safety, reliability, and resiliency of gas infrastructure and gas service in these communities.Equity Benefits of Proposed Initiatives**

Equity Benefits of Proposed Initiatives

CEC applies the DACAG Equity Framework[60] to help guide its R&D investments toward equity. Table 2 shows the application of the DACAG Equity Framework in CEC Gas R&D initiatives by illustrating their potential direct and indirect benefits. The framework outlines the key principles of equity for state investments and interventions, including (1) health and safety, (2) access and education, (3) financial benefits, and (4) economic development (see Appendix F for definitions of these principles). A fifth principle, consumer protection, is not applicable to the Gas R&D Program and is not included in the table. Direct impacts are expected as a direct

60 California Energy Commission. 2018. Disadvantaged Communities Advisory Group Equity.

result of project implementation, whereas indirect impacts are expected from the research and technology innovation advancements more broadly.

Table 2: FY 2022–2023 Gas R&D Plan Equity Framework Matrix

#	R&D Topic	Health and Safety	Access and Education	Financial Benefits	Economic Development
1	Scaled-Up Gas Decommissioning Pilots and Integrated Planning Tools	Direct Benefits	Direct Benefits	Direct Benefits	
2	Large-Volume Hydrogen Storage for Targeted Use Cases	Indirect Benefits	Indirect Benefits	Indirect Benefits	Indirect Benefits
3	Industrial Clusters for Clean Hydrogen Utilization	Indirect Benefits			Indirect Benefits
4	Mitigate Criteria Air Pollutants in Hydrogen Combustion	Direct Benefits		Indirect Benefits	Indirect Benefits
5	Advanced Hydrogen Refueling Infrastructure Solutions for Heavy Transport	Indirect Benefits	Indirect Benefits	Indirect Benefits	Indirect Benefits
6	Analysis of Residential Hot Water Distribution Designs			Direct Benefits	
~~7~~	~~California Sustainable Energy Entrepreneur Development – Low Carbon Gas~~				
7	**Gas Pipeline Safety and Integrity Research to Support Decarbonization**	**Direct Benefits**	**Indirect Benefits**	**Indirect Benefits**	**Indirect Benefits**

Next Steps

Upon review and approval of the Gas R&D Budget Plan by the CPUC, CEC staff will begin conducting additional research scoping, which may include hosting public workshops to develop these initiatives into competitively available grant solicitations.

LIST OF ACRONYMS

Term	Definition
AB	Assembly Bill
CEC	California Energy Commission
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
DACAG	Disadvantaged Communities Advisory Group
DOE	U.S. Department of Energy
EPIC	Electric Program Investment Charge
FY	Fiscal year
GFO	Grant funding opportunity
GHG	Greenhouse gas
GWh	Gigawatt-hour
IEPR	Integrated Energy Policy Report
IOU	Investor-owned utility
IP	Intellectual property
NOx	Oxides of nitrogen
R&D	Research and development
SB	Senate Bill
TDD	Technology demonstration and deployment
Title 24 Energy Code	California Code of Regulations, Title 24, Parts 6 and 11

GLOSSARY

For additional information on commonly used energy terminology, see the following industry glossary links:

- California Air Resources Board Glossary, available at https://ww2.arb.ca.gov/about/glossary
- California Energy Commission Energy Glossary, available at https://www.energy.ca.gov/resources/energy-glossary
- California Public Utilities Commission Glossary of Acronyms and Other Frequently Used Terms, available at https://www.cpuc.ca.gov/glossary/

Carbon dioxide (CO2): A naturally occurring gas, CO2 is also a by-product of burning fossil fuels (such as oil, gas, and coal), of burning biomass, of land-use changes, and of industrial processes (for example, cement production). It is the principal anthropogenic greenhouse gas (GHG) that affects the Earth's radiative balance. It is the reference gas against which other GHGs are measured and therefore has a global warming potential (GWP) of 1.

Carbon neutrality: CO2 and other greenhouse gas (GHG) emissions generated by sources such as transportation, power plants, and industrial processes must be less than or equal to the amount of CO2 that is stored, both in natural sinks such as forests and mechanical sequestration such as carbon capture and sequestration. Executive Order B-55-18 established a target for California to achieve carbon neutrality by 2045 and maintain net negative emissions thereafter. For more information, see the CARB Carbon Neutrality web Page.

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change: Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean or variability (or both) of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic (human induced) changes in the composition of the atmosphere or in land use. Anthropogenic climate change

is defined by the human impact on Earth's climate while natural climate changes are the natural climate cycles that have been and continue to occur throughout Earth's history. Anthropogenic climate change is directly linked to the amount of fossil fuel burning, aerosol releases, and land alteration from agriculture and deforestation.

Decarbonization: The process by which countries, individuals or other entities aim to reduce or achieve zero fossil carbon emissions. This typically refers to a reduction of the carbon emissions associated with electricity, industry, and transport. Decarbonization involves increasing the share of no- or low-carbon energy sources (renewables such as solar and wind) and decreasing the use of fossil fuels.

Demand flexibility is the ability of customers to reduce or increase load in response to grid conditions, usually through a proxy price signal or system operator or utility signal and facilitated by automation.

Disadvantaged community: Disadvantaged communities refer to the areas throughout California that most suffer from a combination of economic, health, and environmental burdens. These burdens include poverty, high unemployment, air and water pollution, presence of hazardous wastes, as well as high incidence of asthma and heart disease. One way that the state identifies these areas is by collecting and analyzing information from communities all over the state. CalEnviroScreen, an analytical tool created by the California Environmental Protection Agency, combines different types of census tract-specific information into a score to determine which communities are the most burdened or "disadvantaged." For more information, see the California Office of Environmental Health Hazard Assessment's CalEnviroScreen Web page.

Disadvantaged Communities Advisory Group (DACAG): The Clean Energy and Pollution Reduction Act of 2015 (also known as Senate Bill 350) called upon the CPUC to help improve air quality and economic conditions in disadvantaged communities by, for example, changing the way the state plans the development and future operations of power plants, or rethinking the location of clean energy technologies to benefit burdened communities. In addition, Senate Bill 350 required the CPUC and the CEC to create a group representing disadvantaged communities to advise the agencies in understanding how energy programs impact these communities and could be improved to benefit these communities. For more information, see the CPUC Disadvantaged Communities Advisory Group web page.

Distributed energy resource(s) (DER): Distributed energy resources are any resource with a first point of interconnection of a utility distribution company or metered subsystem.

Distributed energy resources include:

- Demand response, which has the potential to be used as a low-greenhouse gas, low cost, price-responsive option to help integrate renewable energy and provide grid stabilizing services, especially when several distributed energy resources are used in combination and opportunities to earn income make the investment worthwhile.
- Distributed renewable energy generation, primarily rooftop photovoltaic energy systems.
- Vehicle-grid integration, or all the ways plug-in electric vehicles can provide services to the grid, including coordinating the timing of vehicle charging with grid conditions.
- Energy storage in the electric power sector to capture electricity or heat for use later to help manage fluctuations in supply and demand.

Electric Program Investment Charge Program (EPIC): The CEC's Electric Program Investment Charge (EPIC) Program invests in scientific and technological research to accelerate the transformation of the electricity sector to meet the state's energy and climate goals. Investments of approximately $150 million annually support research and development in areas including renewable energy, energy storage, electric system resilience, and electric technologies for buildings, businesses, and transportation. For more information, see the CEC EPIC web page and the CPUC Energy Research, Development, and Deployment web page.

Energy efficiency: Energy efficiency means adapting technology to meet consumer needs while using less energy. The CEC adopts energy efficiency standards for appliances and buildings, which reduces air pollution and saves consumers money. The CPUC regulates ratepayer-funded energy efficiency programs and works with the investor-owned utilities, other program administrators, and vendors to develop programs and measures to transform technology markets within California using ratepayer funds. For more information, see the CEC Energy Efficiency web page and the CPUC Energy Efficiency web page.

Equity (energy equity): Energy equity is the principle of fairness in burden sharing and is a basis for understanding how the impacts and responses to climate change, including costs and benefits, are distributed in and by society in more or less equal ways. It is often aligned with ideas of equality, fairness, and justice and applied with respect to equity in the responsibility for, and distribution of, climate impacts and policies across society, generations, and

gender, and in the sense of who participates and controls the processes of decision-making.

Gas End Uses: Final applications of gas for energy use, such as heating, power generation, and transportation.

Greenhouse gas (GHG): GHGs are those gaseous constituents of the atmosphere, natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds. This property causes the greenhouse effect. Water vapor (H2O), CO2, nitrous oxide (N2O), methane, and ozone are the primary GHGs in the Earth's atmosphere. Moreover, there several entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and methane, the Kyoto Protocol deals with the GHGs sulfur hexafluoride, HFCs, and perfluorocarbons. In response to Assembly Bill 32 (California Global Warming Solutions Act of 2006), the definition of GHGs defined in Health and Safety Code Section 38505 includes nitrogen trifluoride in addition to those defined under the Montreal and Kyoto Protocols.

Investor-owned utility (IOU): Investor-owned utilities (IOUs) provide transmission and distribution services to all electric customers in their service territory. The utilities also provide generation service for "bundled" customers, while "unbundled" customers receive electric generation service from an alternate provider, such as a community choice aggregator (CCA). California has three large IOUs offering electricity service: Pacific Gas and Electric, Southern California Edison, and San Diego Gas & Electric.

Methane: Methane, also known as CH4, is one of the six GHGs to be mitigated under the Kyoto Protocol and is the major component of natural gas. Emissions also occur as a result of dairy and livestock operations and disposal of organics in landfills, and the management of these organics represents a major mitigation option. Methane is a short-lived climate pollutant. Unlike CO2, which lasts for about 100 years in the atmosphere, reductions of methane can create a relatively quick reduction in global warming.

Metric ton: A metric ton is a unit of weight equal to 1,000 kilograms (or 2,205 pounds).

Particulate matter (PM): Any material, except pure water, that exists in the solid or liquid state in the atmosphere. The size of particulate matter can vary from coarse, wind-blown dust particles to fine particle combustion products.

Sustainability: A dynamic process that guarantees the persistence of natural and human systems equitably.

Utility: An organization supplying the community with electricity, gas, water, or sewerage.

APPENDICES: A-F

- Appendix A: Policies Supported by 2022-23 Gas R&D Program Initiative Themes
- Appendix B: CPUC Resolution G-35484 Funding Encumbrance — Unspent Funds
- Appendix C: Public Comment and CEC Responses
- Appendix D: Gas R&D Stakeholders Workshop Presentation
- Appendix E: List of 2021 Gas R&D Events
- Appendix F: FY 2022-2023 Gas R&D Plan Equity Framework Topic Definitions