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Establishing a Long-Term Gas Research Strategy to Achieve Aggressive Statewide Carbon Neutrality Goals

Recommendations Webinar

December 12, 2022

Agenda

Time	Items
10 minutes	**Background** • Purpose and Policy Drivers • Gas Research Strategy Project
90 minutes (including 10-min. break)	**Research Recommendations** • Structure of Initiatives Characterization • *Communities, Equity, and Environment* • *Gas End Use* • *Gas Supply – Production, Transport, and Storage*
20 minutes	**Closing and Q&A**

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Background

Purpose of R&D Strategy Project

- The purpose of this project for the California Energy Commission (CEC) Gas Research and Development (R&D) Program is to produce a long-term research strategy to help decarbonize California's gas system by 2045.
- The strategy project produced priority research recommendations that include all stages in the supply chain (production, transmission, storage, and distribution for low carbon fuels) and all gas end use sectors, except for utility-scale power generation.
- These recommendations will inform future research on technology development, deployment, and demonstration in the CEC's Gas R&D Program to help transition to a net-zero carbon gas system.

CA Decarbonization Policy Goals Timeline

2023: 1 million ZEVs on the road (EO N-79-20 / ACC II)

2023: Incorporate hydrogen into planning (SB1075)

2024: Prepare evaluation of H_2 use in helping achieve state climate, clean energy, and clean air objectives (SB1075)

2025: Reduce organic waste disposed in landfills by 75% from 2014 levels (SB1383)

2025: 1.5 million ZEVs on the road (EO N-79-20 / ACC II)

2030

2030: GHG emissions 40% below 1990 levels (SB 32) and specifically for buildings (AB 3232)

2030: Reduce methane (CH_4) and hydrofluorocarbons (HFCs) by 40% from 2013 levels (SB1383)

2030: 5 million ZEVs on the road (EO N-79-20 / ACC II)

2030: 60% renewables for electricity (SB 100)

2035: 100% ZEVs for light duty vehicles and drayage trucks (EO N-79-20 / ACC II)

2045

2045: Carbon neutrality and net negative emissions thereafter (EO B-55-18 / AB 1279)

2045: 100% zero-carbon electricity (SB 100)

Scope and Approach

Baseline Assessment	Evaluate Technologies & Barriers	Stakeholder Input	Recommend Strategies	Knowledge Transfer
• Reviewed existing decarbonization scenarios • Prioritized and selected three scenarios to inform rest of study • Conducted comprehensive technology assessment for 170+ challenges and technologies	• Established criteria to screen technologies considering multiple factors • Screened technologies from baseline assessment • Identified barriers to adoption and gaps • Developed preliminary performance, cost, and benefit targets	• Identified stakeholders beyond the Technical Advisory Committee (TAC) • Conducted in-depth interviews with stakeholders to corroborate and supplement prior findings • Held public workshops	• Developed research recommendations to support deep decarbonization • Characterized CEC Gas R&D's potential roles and timing considerations • Factored in stakeholder input before finalizing recommendations	• Developed knowledge transfer plan • Present recommendations in a public webinar • Develop recommendations report
Period of Activity: *Aug. 2021 – Nov. 2021*	*Period of Activity:* *Oct. 2021 – Mar. 2022*	*Period of Activity:* *Feb. 2022 – May 2022*	*Period of Activity:* *Apr. 2022 – Sep. 2022*	*Period of Activity:* *Jul. 2022 – Jan. 2023*

Technical Advisory Committee (TAC) engagement throughout project

- *TAC Meeting #1 was held Nov. 9-10, 2021*
- *TAC Meeting #2 was held July 12-13, 2022*

The Technical Advisory Committee (TAC) was actively engaged.

Meeting #1 was held Nov. 9-10, 2021. Meeting #2 was held July 12-13, 2022.

TAC Member Organization	TAC Member Name and Title
Advanced Energy Economy (AEE)	**Ryan Katofsky** – Managing Director
Building Decarbonization Coalition	**Jose Torres** – California Director
California Public Utilities Commission (CPUC)	**Karin Sung** – Chief of Staff and Legal Advisor to Commissioner Houck
U.S. Department of Energy (DOE)	**Jared Ciferno** – Program Manager, Methane Mitigation Technologies
Google	**Adam Forni** – Technical Program Manager, Energy Development
GTI Energy	**Ryan Kerr** – Emerging Technologies Manager, End Use Solutions
Pacific Gas and Electric (PG&E)	**Danielle Mark** – Senior Gas Engineer, R&D and Innovation
SoCalGas (SCG – a subsidiary of Sempra)	**Hugo Mejia** – Engineering Hydrogen Manager
University of California, Irvine (UCI)	**Jeff Reed** – Chief Scientist, Advanced Power and Energy Program

Principles Guiding Long Term CEC Gas Decarbonization Research Strategy

The CEC's Gas Research Program has an annual **budget of $24 million** to support California's gas decarbonization efforts, focusing on addressing strategic technology-oriented challenges.

Communities, Equity, and Environment

Examples of CEC RD&D Areas of Study:

- Environmental and equity impacts of hard-to-electrify sectors and applications across CA's communities
- Determine attractiveness of clustering strategies for hard-to-decarbonize sectors in communities (jobs, economic impacts, vs. risks)

CEC RD&D Does Not Focus On:

- Developing new policy or regulations
- Operating educational programs to inform community members
- Running workforce training and development programs

Gas End Use

Examples of CEC RD&D Areas of Study:
Research for end uses that are and will remain critical to California's decarbonized economy, including:

- Industry
- Transportation
- Distributed power

CEC RD&D Does Not Focus On:

- Implementing technologies at scale
- Transition cost support for end users
- Sourcing fuel to end user
- Implementing safety protocols/standards
- Providing cost support for stranded assets

Gas Supply (Production, Transport, and Storage)

Examples of CEC RD&D Areas of Study:

- Support determination of viability of using existing gas infrastructure to support decarbonization
- Ensure the resilient and sustainable operation of the gas supply chain with minimal leakage loss

CEC RD&D Does Not Focus On:

- Implementing technologies at scale
- Implementing safety protocols and standards
- Implementing operation and maintenance requirements and standards

Gas Decarbonization Strategies

Electrification

Using electricity to fuel technologies that currently use gas

CEC electricity research program (EPIC) leads work in this area

Emissions highly dependent upon electricity generation mix

Preferred solution for:

- New residential and commercial buildings
- Light and medium duty vehicles
- Commuter rail

Clean Hydrogen (H_2)

Using low-carbon hydrogen for select gas end-uses

Emissions highly dependent upon H_2 production process

H_2 could potentially be blended with fossil or renewable gas in limited quantities using current gas infrastructure

Preferred solution for:

- Industrial process heating
- Select transportation applications
- Some distributed generation

Renewable Gas (RG)

Methane from renewable sources, reducing dependence on fossil gas

Fuel produced from biomass and waste sources, such as landfill gas and agricultural feedstocks

Limited by the amount of **readily available feedstock**

Can be a **carbon neutral fuel**

Preferred solution for:

Industrial processes designed to operate using methane

Carbon Capture and Utilization (CCU)

Capture CO_2 to mitigate impacts of emissions

Captures CO_2 before it is released to the atmosphere.

Captured CO_2 can be **utilized as carbon feedstocks**

Retrofitted or built out at **industrial sites** or large **gas-fired generators**

Preferred solution for:

Hard to decarbonize industrial processes

Gas Technology Efficiency Improvements

Gas System Strategic Decommissioning (*connected to Electrification*)

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Structure of Initiatives Characterization

The Initiatives

Communities, Equity, and Environment (C)

- C1: Develop Optimal Decommissioning Practices and Considerations for Legacy Gas System
- C2: Develop Interdependencies Modeling Between Gaseous Fuels and Electric Systems to Guide Systems Planning Decisions
- C3: Improve Gas Leakage Prevention, Detection, and Other Risk Mitigation Solutions

Gas End Use (U)

- U1: Demonstrate H_2 Heating Solutions to Meet Industrial Requirements
- U2: Develop and Demonstrate Off-road Hydrogen Transportation Vehicles
- U3: Develop and Demonstrate Fuel Flexible Distributed Generation Technologies
- U4: Demonstrate Industrial Sector Point Source Carbon Capture Co-located with Utilization Opportunities

Gas Supply - Production, Transport, and Storage (S)

- S1: Develop and Demonstrate Solutions to Mitigate Non-energy Impacts of Renewable Gas Production
- S2: Investigate and Develop CA Geologic Formations Suitable for Storing H_2
- S3: Research Hydrogen Pipeline-related Distribution Options
- S4: Examine and Develop Hydrogen Demand Clustering to Enable Efficient H_2 Distribution

Reference for the Upcoming Initiative Characterization Slides

Summary and contextual overview of the research initiative.

0 yrs. — Short Term — 5 yrs. — Medium Term — 10 yrs. — Long Term

The black arrow to the left will be filled in based on the key to the right

- CEC Leads
- CEC Supports
- CEC Monitors

Key Research Elements

Required Resources

Below is the scoring rubric:

$: <5% of Annual Budget
$$: 5-9% of Annual Budget
$$$- 10-19% of Annual Budget
$$$$- 20% or More of Annual Budget

Performance Metrics

Each section will include a unique set of performance metrics relevant to the initiative

Variables & Interdependencies

Each section will include unique variables and interdependencies based on the nature of the research initiative

Community and Equity Benefits

Health & Safety Rubric:

□□□	Some potential for negative health & safety impacts on the community
■□□	Neutral potential for positive health & safety impacts on the community
■■□	Some potential for positive health & safety impacts on the community
■■■	Large potential for positive health & safety impacts on the community

Financial & Accessibility Rubric:

□□□	Expected to significantly impact the affordability of energy solutions without additional measures taken
■□□	Expected to be somewhat affordable and accessible to under-resourced communities
■■□	Expected to be readily affordable and accessible to under-resourced communities
■■■	Expected to improve the affordability and/or accessibility of energy solutions to under-resourced communities

Environmental Rubric:

□□□	Significant and difficult to resolve non-CO_2 related environmental issues
■□□	Some non-CO_2 related environmental issues with some promise for these issues to be resolved
■■□	Minimal non-CO_2 related environmental issues that are expected to be easily addressable
■■■	Directly reduces negative non-CO_2 related environmental issues

CA Decarbonization Potential

Annual Emissions Reduction Rubric:

□□□	Purely indirect emissions reductions
■□□	0-10 MMT CO2e
■■□	10-30 MMT CO_2e
■■■	>30 MMT CO_2e

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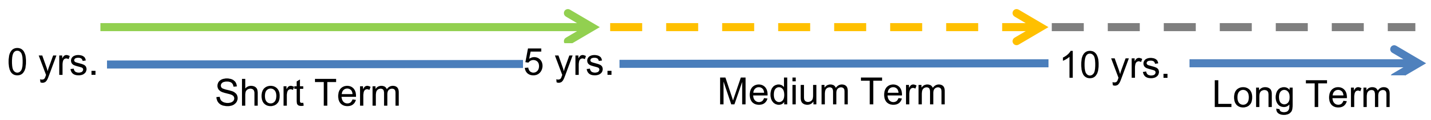
Communities, Equity, and Environment Initiatives and Recommendations

C1: Develop Optimal Decommissioning Practices and Considerations for Legacy Gas System (1/2)

Previous efforts have focused on the cost minimization of the decommissioning of legacy gas system while future efforts will also need to emphasize steps needed to avoid harmful environmental impacts and garner support of affected communities.

CEC Research Role Over Time:



CEC Leads *Short Term* — **Lead** research addressing remaining gaps on community and environmental risks from decommissioning.

CEC Supports *Medium Term* — **Support** pilots and demonstrations of pipeline decommissioning.

CEC Monitors *Long Term* — **Monitor** the successes of decommissioning pilots and capture community feedback and concerns.

Key Research Elements

Required Resources

Previous CEC efforts included $2M for decom. research and $3.5M for pilots.

CA Decarbonization Potential

Annual Emissions Reduced: Entirely indirect emissions reductions.

Performance Metrics

Community Acceptance: Qualitative and quantitative following pilots.

Transition Cost: Costs incurred to customer within 10% of BAU.

Upfront Cost: Some governments have set goals to reduce by 30%.

Environmental Data: Readily available data with minimal concerning observations.

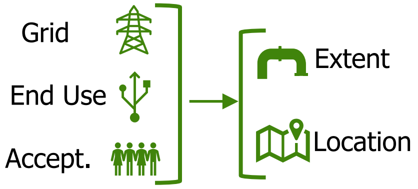
Community and Equity Benefits

Financial & Accessibility: High electricity rates vs. volatile gas prices.

Environmental: Aging gas infrastructure poses risk to communities.

Health & Safety: Reduced in-home exposure to methane.

Variables & Interdependencies:



(1) Technical feasibility to ramp up grid capacity, (2) expanded end uses for electric tech., and (3) community acceptance of total electrification all impact extent and location of decom.

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C1: Develop Optimal Decommissioning Practices and Considerations for Legacy Gas System (2/2)

Research Recommendations to Consider

C1.1 Quantify and Identify Potential Environmental & Human Safety Hazards

Impact: Minimize the risk of environmental harm from pipeline decommissioning, improper purging and cleaning, and monitoring for soil & water contamination.

Timing Focus: Short term. Expand best practices research on cost effectiveness and include community safety and environmental hazard research in parallel.

C1.2 Conduct Decommissioning Pilots

Impact: Understand impacts on electric system upgrades, potential savings, community concerns, and changes in ongoing energy costs.

Timing Focus: Short and medium term. Pilots occur after significant progress in best practices research.

C1.3 Long Term Impact Analysis and Customer Feedback

Impact: Customer feedback will consider lifestyle change, support received, resource availability, and financial impacts from the transition.

Timing Focus: Short through long term. First round of feedback collected after pilot completion. Second round collected 1-2 years after completion.

External Factors to Watch

- **Consider the success of H_2 blending and retrofit into gas pipelines.** If Investor-Owned Utilities (IOUs) successfully integrate/blend H_2 within existing pipelines, decommissioning may be delayed.
- **Monitor cost impacts on fully-electrified communities.** If energy costs meaningfully rise, the financial impacts on communities may delay decommissioning as this would add to the cost burden.

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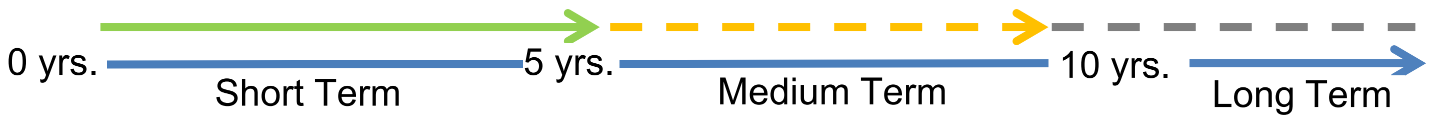
C2: Develop Interdependencies Modeling Between Gaseous Fuels and Electric Systems to Guide Systems Planning Decisions (1/2)

Research is needed to better integrate strategic decisions of gas and electric system planners. Outputs from this research are tools or models for system planners and utilities to design California's energy systems to be efficient, safe, and reliable.

CEC Research Role Over Time:



CEC Leads *Short Term*	**Lead** with EPIC to develop tools to inform strategic decarb. plans while considering systems and infrastructure.
CEC Supports *Medium Term*	**Support** in adjusting the developed tools as needed for them to be useful.
CEC Monitors *Long Term*	**Monitor** and encourage the use of developed tools to effectively plan and transition California to an efficient, decarbonized energy system.

Key Research Elements

Required Resources

Previous CEC efforts included $1.5M for tool development on separate topic

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CA Decarbonization Potential

Annual Emissions Reduced: Entirely indirect emissions reductions.

Performance Metrics

System Costs: System-wide savings outweigh investment costs of efforts.

Reliability: Improved SAIFI and SAIDI; expanded DR capabilities.

Resiliency: Reduced average time to resolve outage.

Decarbonization Impact: Reduces emissions impact vs. BAU system planning.

Community and Equity Benefits

Financial & Accessibility: Reduced energy system costs.

Environmental: Loosely driven by a need to decarbonize, not a primary goal.

Health & Safety: Improved reliability and resiliency for gas and electric systems.

Variables & Interdependencies:

Decarbonized Gas

Clean H_2

RG

CCU

Interdependency Modeling

Viability of decarbonized gas strategies impacts the ability of gas to support electricity and increases need for this research

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C2: Develop Interdependencies Modeling Between Gaseous Fuels and Electric Systems to Guide Systems Planning Decisions (2/2)

Research Recommendations to Consider

C2.1 Develop a Robust Model for Capacity, Resilience, and Load Flexibility

Impact: Enables greater efficiency with system planning and infrastructure buildout that fits within existing planning processes and requirements.

Timing Focus: Short term. This is crucial as soon as possible to ensure planning is efficient and optimized between gas and electric systems. It is also a large effort requiring significant collaboration.

C2.2 Evaluate the Value and Need for Gas Demand Response (DR) Programs

Impact: Gas DR offers some potential to minimize system costs and avoid catastrophic price spikes on the system. Research on this topic will explore value for California and identify potential strategies to effectively integrate it within the state.

Timing Focus: Medium term. This should be pursued as a secondary item to the model, if necessary and load flexibility initiatives prove costly in initial models.

External Factors to Watch

- **Monitor progress and viability of different gas decarbonization strategies (e.g., clean H_2, RG, CCU).** This will inform the level that gas can support electricity in interdependency models.
- **Monitor developments in areas where electricity can support new applications cost effectively, compared to gaseous alternatives.** This also impacts the development of the interdependent planning tool by deprioritizing gas use.

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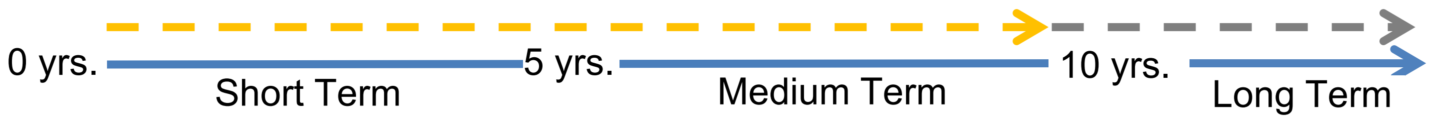
C3: Improve Gas Leakage Prevention, Detection, and Other Risk Mitigation Solutions (1/2)

The introduction of hydrogen into the gas system will present new challenges as the properties of hydrogen are different than methane. Research into leakage prevention, detection, and risk mitigation will facilitate clean hydrogen adoption.

CEC Research Role Over Time:



CEC Supports *Short Term* — **Support** by enabling third parties to use Gas R&D pilots to gather data on gas leakage, including blended and pure H_2.

CEC Supports *Medium Term* — **Support** by enabling third parties to use gas R&D pilots to test H_2 and legacy methane leakage detection equipment.

CEC Monitors *Long Term* — **Monitor** gas leakage research for a consensus on optimal solutions to pursue.

Key Research Elements

Required Resources

Previous CEC efforts included $4M for pipeline monitoring and retrofit, end use research may require less capital

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CA Decarbonization Potential

Annual Emissions (2020): Fossil gas leaks has an impact of 8.12 MMT CO_2e.

Performance Metrics

System Leakage: Decrease leakage from 8.03 MMT CO_2e/ yr. Also achieve Columbia's 2050 low risk center case of 2.9% H_2 leakage rate.

Household CH_4 Leakage: Emissions factor per household decreased from 2.08 to 0.64 lbs. CH_4/ meter-yr. from 2008 to 2020. Further reductions should be the goal.

Community and Equity Benefits

Financial & Accessibility: Reduced gas costs with more commodity delivered.

Environmental: Reduced fugitive leakage that contributes to climate change.

Health & Safety: Reduced in-home gas exposure and ignition incidents.

Variables & Interdependencies:

H_2 Deployment

H_2 Blended

$H_2 + CH_4$

Pure H_2

H_2

H_2 GWP

The extent of H_2 deployment in the gas system is uncertain and the Global Warming Potential (GWP) of H_2 continues to be debated.

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C3: Improve Gas Leakage Prevention, Detection, and Other Risk Mitigation Solutions (2/2)

Research Recommendations to Consider

C3.1 Valve, Seal, and Gasket Design and Operation with H_2

Impact: Improves resistance to H_2 leakage.

Timing Focus: Short and medium term. High priority in the short term if H_2 blending is pursued.

C3.2 Prevent H_2 Leaks with Materials and Microstructural Traps

Impact: Improved resistance to H_2 leakage.

Timing Focus: Medium term. Most relevant for pipelines.

C3.3 Sensors and Drones for Gas Leakage

Impact: Improves effectiveness of technologies that detect gas leakage.

Timing Focus: Short term. Important for CH_4 & H_2.

C3.4 H_2 Odorization for Safety

Impact: Enables H_2 to be deployed at various end uses and improves leakage detectability by nearby people.

Timing Focus: Short and Medium term.

C3.5 H_2 Flame Visibility for Safety

Impact: Improves H_2 combustion viability and worker safety for industrial applications.

Timing Focus: Medium and Long term.

C3.6 Impact Analysis of H_2 Leaks in the Supply Chain

Impact: Improve understanding of the extent and consequences of H_2 leakage in the supply chain.

Timing Focus: Short and Medium term. High priority in the short term if H_2 blending is pursued.

External Factors to Watch

- **Track progress of clean H_2 deployment at scale.** The level of H_2 deployment influences the need for H_2 leakage research.
- **Monitor discussion of the GWP of H_2.** If H_2 GWP is agreed to be higher than previously thought, even greater emphasis must be placed on leakage mitigation.

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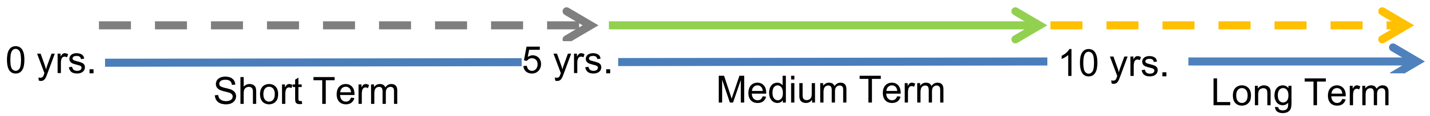
Gas End Use Initiatives and Recommendations

U1: Demonstrate H_2 Heating Solutions to Meet Industrial Requirements (1/2)

Explore hydrogen fueled alternatives to meet high-temperature industrial heating requirements. This initiative focuses on processes that have heating needs that are difficult to electrify.

CEC Research Role Over Time:



- **CEC Monitors** *Short Term* — **Monitor** the development of industrial hydrogen heating solutions developed by laboratories and manufacturers.
- **CEC Leads** *Medium Term* — **Lead** demonstrations of H_2 heating within California industrial processes.
- **CEC Supports** *Long Term* — **Support** scale up and adoption of H_2 heating solutions across California's industry.

Key Research Elements

Required Resources

CEC has allocated $1.77M to examine effects of H_2 in industry, demonstrations will likely require more capital.

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CA Decarbonization Potential

Annual Emissions (2020): Fossil gas in industry contributes about 32.7 MMT CO_2e.

Performance Metrics

Pollutants: Reduced NO_x emissions below CEQA target, ~30 ppm.

Safety: Minimal risk of leakage, flashback, and embrittlement.

CAPEX: Similar to fossil gaseous heating solutions, varying by application and size.

OPEX: Similar to current fossil gaseous solutions, including labor, fuel, maintenance, retrofit, etc.

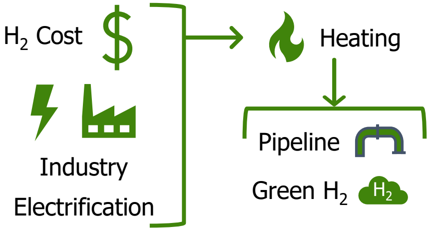
Community and Equity Benefits

Financial & Accessibility: New equipment and fuel transition is costly, not directly impacting communities.

Environmental: Can increase NO_x emissions, burner design can address.

Health & Safety: Increased need for H_2 handling, but less exposure to fossil emissions.

Variables & Interdependencies:



***(1)** Initiative costs depend on cost targets of clean H_2. **(2)** Research depends on areas where electrification isn't viable. **(3)** Success of demonstrations influences H_2 supply needs.*

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U1: Demonstrate H_2 Heating Solutions to Meet Industrial Requirements (2/2)

Research Recommendations to Consider

U1.1 Testing Different H_2 Burner Types

Impact: Evaluate success and compatibility of H_2 burner designs with CA industrial processes and goals.

Timing Focus: Short term. Burners are essential components for combustion processes.

U1.2 Mitigate NO_x Emissions

Impact: Evaluate the success of NO_x emissions control and mitigation strategies.

Timing Focus: Short term. NO_x is a large concern with H_2 combustion that needs to be resolved.

U1.3 Evaluate Industrial Material Compatibility with H_2

Impact: Understand the need for equipment and material replacement to achieve compatibility with H_2 handling and combustion.

Timing Focus: Short term. Before scaling, there needs to be an understanding of material and costs.

U1.4 Combustion and Flame Control Systems

Impact: Understanding the necessary control systems for H_2 combustion to ensure effective and safe operation in industrial settings.

Timing Focus: Medium term. Builds upon insights from the other recommended research.

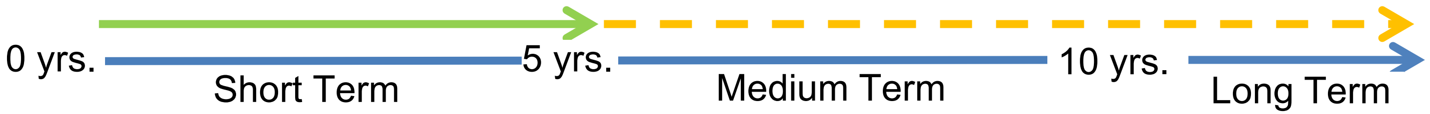
External Factors to Watch

- **Monitor the cost and availability of clean H_2 in state.** This determines the speed and extent of adoption of H_2 end use technologies at scale.
- **Understand heating end uses that can be electrified** and focus funds on those less electrification potential alternatives.
- **Monitor end use H_2 demand and progress on relevant infrastructure** necessary to support demand.

U2: Develop and Demonstrate Off-road H_2 Transportation Vehicles (1/2)

Validate the viability of H_2 fuel cell (FC) powered vehicles for various off-road, rail, and harbor craft applications in California. Mobile fueling and powertrain solutions that enable these applications may also receive support.

CEC Research Role Over Time:



CEC Leads *Short Term* — **Lead** by demonstrating FC agricultural work vehicles, and if needed, mobile refueling solutions.

CEC Supports *Medium Term* — **Support** follow-up from past efforts on targeted demos of harbor crafts to address gaps found for CA.

CEC Supports *Long Term* — **Support** follow-up from past efforts on targeted demos of rail to address gaps found for CA.

Key Research Elements

Required Resources

Proposed 2022-23 plan outlines $4.5M for transportation initiatives. This is on par with past CEC funding.

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CA Decarbonization Potential

Annual Emissions (2020): Relevant vehicle types contribute 7.47 MMT CO_2e.

Performance Metrics

Refueling: Less than 10 mins for a full tank, up to 8kg/ min by 2030.

Thermal Mgmt.: Cold start-up time to 50% power at +10°C reduced from 10 to 5 seconds by 2025.

Durability: 35,000- and 100,000-hour lifetime for rail and marine FC, respectively by 2050.

Costs: For agricultural vehicles, reduction by 62%, 20%, and 38% respectively for CAPEX, OPEX, and total cost of ownership (TCO).

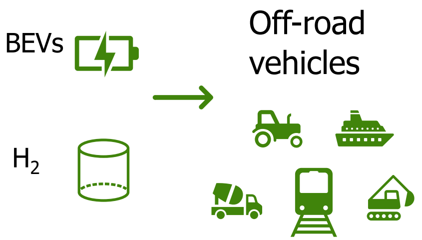
Community and Equity Benefits

Financial & Accessibility: Off-road vehicles offer value to under-resourced communities, some additional costs.

Environmental: Replaces existing diesel solutions that release criteria pollutants.

Health & Safety: Reduces worker emissions exposure, minimizes fossil fuel reliance.

Variables & Interdependencies:



*Successful BEV research on charging speeds and battery cost informs: **(1)** Extent of off-road vehicle decarbonization and **(2)** Necessity for further research to scale solutions*

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U2: Develop and Demonstrate Off-road H_2 Transportation Vehicles (2/2)

Research Recommendations to Consider

U2.1 Demonstrate H_2-powered Vehicles for Agriculture, Construction, Emergency Vehicles, and Mining with Refueling Solutions

Impact: Understand the viability of H_2 FC vehicles and refueling solutions to decarbonize these subsectors.

Timing Focus: Short term. Often high-visibility areas where Gas R&D funding can provide strong impact.

U2.2 Demonstrate H_2-powered Harbor Craft

Impact: Understand the viability of H_2-powered harbor crafts to decarbonize this subsector of transportation.

Timing Focus: Medium term. Consider lessons learned from existing efforts before further investments.

U2.3 Demonstrate Non-electrified Rail

Impact: Understand the viability of non-electric rail solutions to decarbonize this transportation subsector.

Timing Focus: Medium term. Consider lessons learned from efforts already underway.

U2.4 Evaluate FC Durability and Suitability for Off-road Operating Environments

Impact: Understand the suitability of hydrogen for various off-road operating environments.

Timing Focus: Short and Medium term. It is key to monitor lab-scale efforts in short and medium term in conjunction with pilots and demonstrations.

External Factors to Watch

- **Monitor significant advancements in battery and BEV technologies.** This determines the necessity of H_2 FC vehicles for off-road applications.
- **Monitor fleet owner and customer sentiment on both BEV and H_2 FC vehicles.** This informs the favorability of both options in the marketplace.
- **Monitor liquid and cryo-compressed H_2 feasibility.** These may ultimately play a greater role in H_2-powered vehicles.

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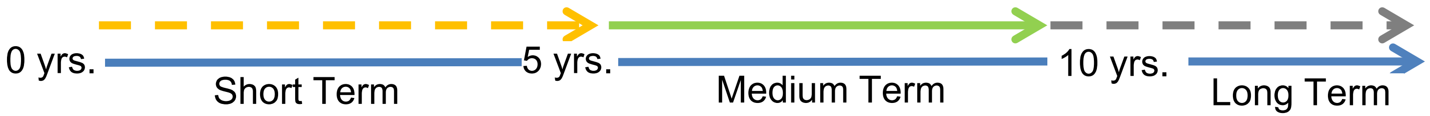
U3: Develop and Demonstrate Fuel Flexible Distributed Generation Technologies (1/2)

Gas fueled distributed generation (DG) technologies may see supplies with varying fuel mixes such as blends of H_2 and CH_4. These systems need to be durable, adaptable, and modular to gain widespread use.

CEC Research Role Over Time:



CEC Supports *Short Term* — **Support** the development of power generation technologies while potential to integrate DR technologies is understood.

CEC Leads *Medium Term* — **Lead** demonstrations of DG technologies in identified end use clusters.

CEC Monitors *Long Term* — **Monitor** development of cluster and installed DG systems for further modifications and improvements.

Key Research Elements

Required Resources

CEC has allocated \$4M to H_2 based power generation, demonstrations will likely require more capital.

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CA Decarbonization Potential

Annual Emissions (2020): CHP accounted for 10.8 MMT CO_2e, which is about 20% of the state's electricity gen.

Performance Metrics

Flexibility: Ability to run on multiple fuels and variable fuel quality & flow.

Dispatchability and Reliability: Power demand met and operated independent of centralized system.

Durability: Expected operation for about 20 years.

Ease of Integration: Modular design to reduce installation barriers and costs.

Costs: Fuel flexible options with max 25% premium with eventually no premium of fuel flexibility

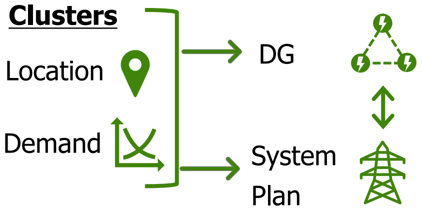
Community and Equity Benefits

Financial & Accessibility: New equipment and distributed operation may be reflected in electricity costs.

Environmental: Decreased fossil fuel reliance, introduces potential NO_x emissions from H_2.

Health & Safety: Reduces exposure to fossil gas combustion.

Variables & Interdependencies:



*Geographic clustering of end uses and energy demand **(1)** Determines viability of DG near clusters and **(2)** Impacts system planning and DG alignment*

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U3: Develop and Demonstrate Fuel Flexible Distributed Generation Technologies (2/2)

Research Recommendations to Consider

U3.1 Develop Flexibility to Variation in Fuel Supply

Impact: Understand and develop fuel flexibility and technology resistance of DG technologies.

Timing Focus: Short term. Evaluation of limits could be led by CEC Gas R&D with technology development being led by manufacturers.

U3.2 Testing Under Range of Operating Conditions

Impact: Understand optimal operating conditions and durability in changing conditions.

Timing Focus: Medium term. Demonstrations led by CEC Gas R&D with some understanding of realistic operating conditions.

U3.3 Evaluate Modularity and Dispatchability

Impact: Understand dispatchability of technologies and costs associated with installation and operation.

Timing Focus: Medium term. Demonstrations may be led by CEC Gas R&D.

U3.4 Alternative Distributed Generation Technologies

Impact: Monitor the extent of renewable DG technology deployment and role for gaseous DG.

Timing Focus: Monitoring across all timeframes.

External Factors to Watch

- **Understand energy demand fluctuation in CA and opportunities for DG.** Identification of end use clusters where it is favorable to decentralize electricity supply.
- **Identify areas where gaseous fuels will still be supplied** considering decommissioning. Will require coordination with utilities.
- **Coordinate with utilities to determine how DG resources integrate or replace grid resources.**

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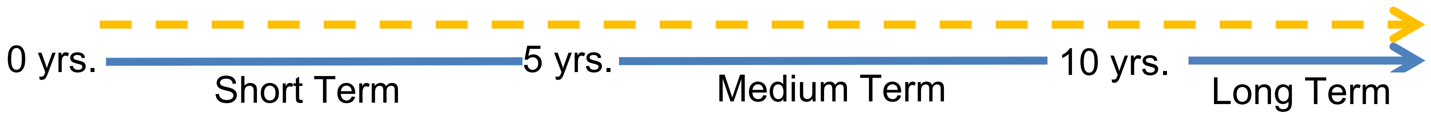
U4: Demonstrate Industrial Sector Point Source Carbon Capture Co-located with Utilization Opportunities (1/2)

Apply carbon capture (CC) technologies at industrial sites with CO_2 utilization technologies (CCU) located on the same site to recue need for CO_2 transportation infrastructure.

CEC Research Role Over Time:



CEC Supports *Short Term*: **Support** development of CCU demonstrations within CA.

CEC Supports *Medium Term*: **Support** demonstration of CCU and expansion of CO_2 utilization opportunities.

CEC Supports *Long Term*: **Support** the adoption of CCU technologies and their role in decarbonized CA economy.

Key Research Elements

Required Resources

CEC has allocated $6.1M industrial CCU research, demonstrations will likely require more capital.

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CA Decarbonization Potential

Annual Emissions (2020): Industrial processes emitted 65.5 MMT CO_2e.

Performance Metrics

Efficiency: Capture efficiency of at least 90%. Utilization close to 100% of CO_2 captured.

Energy Consumption: Reduced energy needed for capture, currently 250-300 kWh/t CO_2 captured.

Safety: Reduced capture material toxicity and limited CO_2 transport.

Total Costs: DOE cost target of less than $30/t CO_2 by 2030.

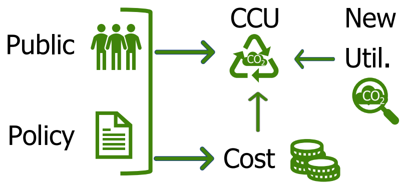
Community and Equity Benefits

Financial & Accessibility: Costs are high, but there could be economic support. Minimal direct impact on customer.

Environmental: Maintained fossil fuel consumption which can lead to CH_4 leakage. Increased energy consumption.

Health & Safety: Direct exposure to CO_2. Reduces air pollution form industry.

Variables & Interdependencies:



(1) Public perception, (2) Policy and market support (financial and barrier reduction), (3) Identification of new utilization pathways, and (4) Achieving cost targets affect CCU adoption.

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U4: Demonstrate Industrial Sector Point Source Carbon Capture Co-located with Utilization Opportunities (2/2)

Research Recommendations to Consider

U4.1 Carbon Capture Cost Effectiveness Demonstrations

Impact: Improve the cost effectiveness and presence of CC technologies in CA industries.

Timing Focus: Short and Medium term. This will likely be led by industry and other entities; CEC Gas R&D could support.

U4.2 Carbon Utilization Demonstrations

Impact: Understand the effectiveness of CO_2 utilization within CA industries and further potential.

Timing Focus: Short and Medium term. Existing utilization pathways led by other entities and new utilization pathways supported by CEC Gas R&D.

U4.3 Optimization of Capture and Utilization Via Co-Location

Impact: Identify CCU co-location industries in CA and understand how optimization impacts CCU cost.

Timing Focus: Medium term. CEC Gas R&D to identify locations and support projects more directly.

U4.4 CCU Alternatives in California

Impact: Monitor the development of DAC and sequestration options within CA and determine potential within CA.

Timing Focus: Medium to Long term. CEC Gas R&D to monitor progress and adoption of technologies.

External Factors to Watch

- **Monitor public acceptance of CCU technologies.** Ensure understanding of CCU as a supporting resource for decarbonization when fuel-switching and efficiency efforts are insufficient in achieving progress toward net zero carbon goals.
- **Track policies and market incentives that support CCU technology development** given the large upfront cost and long-term investments required.

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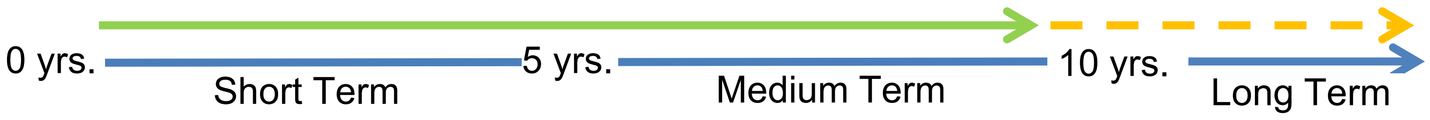
Gas Supply (Production, Transport, and Storage) Initiatives and Recommendations

S1: Develop and Demonstrate Solutions to Mitigate Non-energy Impacts of Renewable Gas Production (1/2)

Research will help improve renewable gas (RG) production, especially from anaerobic digestion (AD) and codigestion, by exploring solutions to mitigate undesired impacts, such as odor, biosolid waste, and increased resource consumption.

CEC Research Role Over Time:



CEC Leads *Short Term* — **Lead** the evaluation of community and environmental impacts and develop mitigation strategies. Evaluate potential for organic and woody biomass waste in CA.

CEC Leads *Medium Term* — **Lead** demonstrations of mitigation technologies. Evaluate potential of RG based on feedstock availability.

CEC Supports *Long Term* — **Support** improvements of RG production implemented in CA. Monitor availability of feedstocks.

Key Research Elements

Required Resources

CEC has allocated $1.2M to AD projects, demonstrations will be conducted at existing AD facilities.

CA Decarbonization Potential

Annual Emissions (2020): Landfills and manure contribute about 20.1 MMT CO_2e.

Performance Metrics

Odor: Reduce release of odorous compounds (H_2S and NH_3), keep H_2S concentration below 0.47 ppb.

Biosolid waste: Proper management and processing to avoid emission of toxic compounds.

CAPEX: Minimal additional cost for mitigation technologies on facilities.

OPEX: Minimize additional operational costs on facilities.

Community and Equity Benefits

Financial & Accessibility: Increased costs may be reflected in RG prices. New biosolid uses could mitigate costs.

Environmental: Decreased emissions of toxic and polluting compounds from biosolids.

Health & Safety: Reduced worker exposure to odor and toxic emissions

Variables & Interdependencies:

*AD and RG production growth depends on: **(1)** Policy support for RG from various feedstocks **(2)** Ongoing methane demand.*

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S1: Develop and Demonstrate Solutions to Mitigate Non-energy Impacts of Renewable Gas Production (2/2)

Research Recommendations to Consider

S1.1 Odor Control and Mitigation

Impact: Reduce the unpleasant odor associated with AD facilities that affect communities.

Timing Focus: Short term.

S1.2 Biosolids Management

Impact: Reduce disposal of potentially toxic or harmful waste from AD, codigestion, and gasification facilities.

Timing Focus: Short term. Medium term may include exploring utilization of this waste beyond fertilizer.

S1.3 Reduce Excess Resource Consumption

Impact: Reduce consumption of community resources, fuel, water, and organic products.

Timing Focus: Short term.

S1.4 Evaluate Feedstock Potential

Impact: Improve understanding of feedstock potential within the state and determine updated renewable gas production potential.

Timing Focus: Short and Medium term.

S1.5 Renewable Gas Production Technologies

Impact: Improve renewable gas production technologies and their scaling potential to meet potential demand.

Timing Focus: Medium and Long term.

External Factors to Watch

- **Track development of state policies that address organic waste and RG production.** SB 1383 aims to reduce organic waste disposal in landfills. Success of bills like this determine availability of organic feedstock.
- **Monitor the increased woody biomass feedstock availability** from forest resiliency programs.
- **Monitor gas to H_2 technologies** as these could increase the demand for RG.
- **Monitor CA decarbonization.** It may result in lower CH_4/ RG demand.

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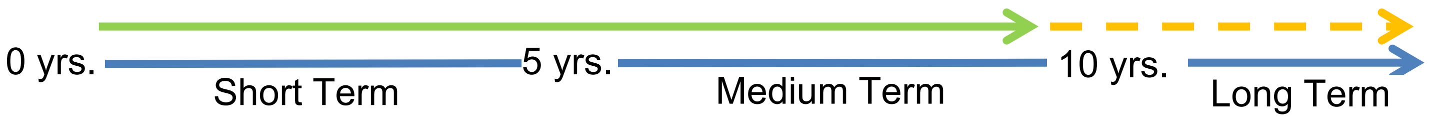
S2: Investigate and Develop CA Geologic Formations Suitable for Storing H_2 (1/2)

Study and develop new geologic storage facilities for hydrogen in California to meet fuel demand and provide reliability for a decarbonized energy system. Depleted oil and gas fields will likely be the focus of geologic storage options in CA.

CEC Research Role Over Time:



CEC Leads *Short Term*		**Lead** analysis of geologic formations in CA and grade for H_2 compatibility.
CEC Leads *Medium Term*		**Lead** testing of hydrogen storage in expanding number of candidate sites.
CEC Supports *Long Term*		**Support** scale up and responsible expansion of H_2 storage capacity.

Key Research Elements

Required Resources

CEC has allocated $3M for large-volume H_2 feasibility studies, demonstrations will need more funds.

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CA Decarbonization Potential

Annual Emissions (2020): Fossil gas contributes 105 MMT CO_2e systemwide*, could be mitigated with H_2.

* Includes power generation

Performance Metrics

Capacity: Sufficient to meet sustained H_2 demand and season energy needs.

Safety: Minimal risk of leakage, contamination, pressure buildup, injection, and extraction.

CAPEX: Comparable to existing facilities, estimates at around $1.29/kg of H_2 in depleted fields.

OPEX: Comparable to existing facilities, estimates at around $0.11/kg of H_2 in depleted fields.

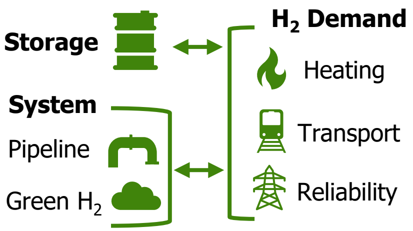
Community and Equity Benefits

Financial & Accessibility: Costs broadly shared across market. Can provide backup to hedge against price volatility.

Environmental: Potential leakage and contamination, addressed before scaling.

Health & Safety: New H_2 storage need to consider safety of nearby communities.

Variables & Interdependencies:



*Research informs **(1)** Viability of large scale H_2 storage in CA **(2)** Extent to which H_2 can be used. Other factors to consider are **(3)** H_2 demand **(4)** H_2 production and transportation.*

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S2: Investigate and Develop CA Geologic Formations Suitable for Storing H_2 (2/2)

Research Recommendations to Consider

S2.1 Location and Size of Formations

Impact: Develop baseline understanding of formations with potential for storage across CA.

Timing Focus: Short term.

S2.2 Testing Injection and Extraction Protocols

Impact: Evaluate compatibility of formations with injection and extraction protocols.

Timing Focus: Medium term. Will require identifying promising formations as a prerequisite.

S2.3 H_2 Stability and Reactivity in Formations

Impact: Evaluate the potential for successful storage of H_2, ensuring purity and volume losses are minimal.

Timing Focus: Short term. Will require evaluating formation porosity, chemical makeup, and residual compounds.

S2.4 Compatibility of Existing Infrastructure

Impact: Evaluate the potential to use existing infrastructure for H_2 reducing the cost of development.

Timing Focus: Medium term.

S2.5 Alternative H_2 Storage Options

Impact: Evaluate the potential for energy carriers for long term H_2 storage in CA.

Timing Focus: Medium and Long term.

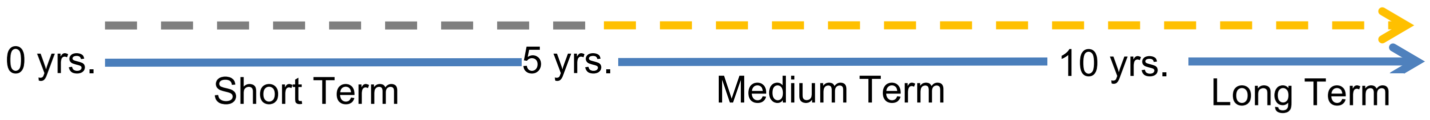
External Factors to Watch

- **Monitor H_2 demand.** Increased viability of hydrogen end uses will increase demand and the need for storage.
- **Monitor H_2 pipeline development.** Transport infrastructure can impact cost and viability of certain geologic formations and gas blends.
- **Track clean H_2 production.** CA needs enough storage capacity to address state's fuel production. Storage capacity will not grow until production capacity is established.
- **Monitor existing fossil gas storage.** Repurposed existing infrastructure may reduce costs and need for new formations.

S3: Research Hydrogen Pipeline-related Distribution Options (1/2)

Research is needed to explore pipeline options to deliver H_2 to end use and storage and must prioritize community health and safety as well as cost effectiveness. This research is essential for the deployment of H_2 at a large scale.

CEC Research Role Over Time:



CEC Monitors *Short Term* — **Monitor** external efforts to inform the scope and priority of other research initiatives that CEC Gas R&D leads.

CEC Supports *Medium Term* — **Support** external research that addresses pipeline research gaps, possibly through demonstrations needing add'l. funding.

CEC Supports *Long Term* — **Support** external research that addresses pipeline research gaps, possibly through demonstrations needing add'l. funding.

Key Research Elements

Required Resources

2020-21 Budget outlined $5.7 M for H_2 blending, may need similar funding for future pipeline-related efforts

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CA Decarbonization Potential

Annual Emissions (2020): Fossil gas pipelines contribute 6.3 MMT CO_2e, which can be mitigated by transition to clean H_2.

Performance Metrics

H_2 Permeation: Reduce difference in pipeline permeation from H_2 vs. CH_4, H_2 rates currently 4-5x greater.

Pipeline Lifespan: Comparable H_2 pipeline lifetime to fossil gas, ~50 yrs.

CAPEX: Reach or exceed reduction targets of $432/m for H_2 pipelines.

OPEX: Similar maintenance costs to incumbent fossil gas pipelines.

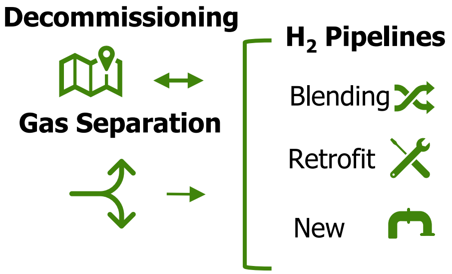
Community and Equity Benefits

Financial & Accessibility: Doesn't improve affordability and requires substantial investment.

Environmental: H_2 leakage from pipelines could contribute to climate change.

Health & Safety: Addresses safety concerns of retrofitting existing pipelines for H_2.

Variables & Interdependencies:



Success of decom. and H_2 pipeline research informs the importance one another. Gas separation research informs viability of HENG blends.

S3: Research Hydrogen Pipeline-related Distribution Options (2/2)

Research Recommendations to Consider

S3.1 Demonstrate Pipeline Gas Blending

Impact: Informs the viability of blending into existing pipelines as-is or transporting HENG blends or pure H_2 in existing pipelines with coatings or retrofit.

Timing Focus: Short term.

S3.2 Develop Gas Separation and Metering Technologies

Impact: Sheds light on viability of H_2 blending with CH_4 at small and large concentrations.

Timing Focus: Short term.

S3.3 Research Efficient and Cost-Effective H_2 Compressor Station Technologies

Impact: Informs the viability of blending into existing pipelines as-is or with retrofit and via dedicated H_2 pipelines.

Timing Focus: Medium term.

S3.4 Research New, Dedicated H_2 Pipelines

Impact: Determine viability of dedicated H_2 pipelines.

Timing Focus: Medium term. Research into dedicated H_2 pipelines should occur after exploring blending and fossil gas pipeline retrofit in the short term.

External Factors to Watch

- **Monitor research into existing pipeline suitability for H_2 blending or retrofit.** Pipelines identified as viable for these solutions may need to remain in place.
- **Monitor progress on electrification and gas decommissioning.** Strong progress here can minimize available pipelines for H_2 deployment.
- **Monitor progress on gas separation technologies.** Gas separation can enable higher H_2 concentrations in blends so disaggregated gases can be delivered.

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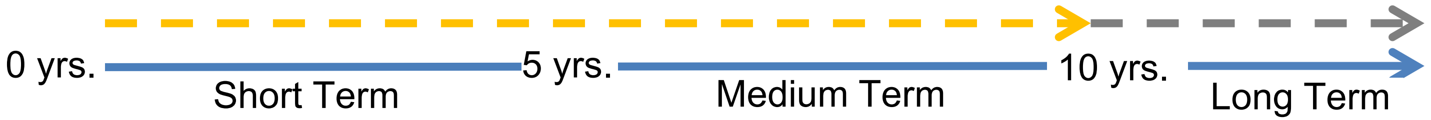
S4: Examine and Develop Hydrogen Demand Clustering to Enable Efficient H_2 Distribution (1/2)

Research is needed to identify viable co-location or clustering of H_2 end users based on its geographic demand in order to more efficiently integrate enabling systems for clean H_2 adoption in sectors such as transportation and industry.

CEC Research Role Over Time:



CEC Supports *Short Term*		**Support** in identifying demand clusters for transportation, DG, and industry. Develop strategies and best practices.
CEC Supports *Medium Term*		**Support** demonstrations for clustered H_2 DG, industrial use, and transportation based on identified clusters.
CEC Monitors *Long Term*		**Monitor** the successes of clustering demonstrations and determine if additional funding is necessary.

Key Research Elements

Required Resources

CEC has allocated $1M for industrial clusters for H_2 usage, demonstrations will likely require more capital.

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CA Decarbonization Potential

Annual Emissions Reduced: Entirely indirect emissions reductions.

Performance Metrics

OPEX: Reduced operating costs of energy delivered vs. status quo.

Infrastructure Cost: Reduce costs to produce, transport, and store clean H_2.

Demand Met: Near 100% of H_2 demand at clustering locations met.

H_2 Losses: Minimal losses via inefficient production, leakage, and unconsumed fuel.

Community and Equity Benefits

Financial & Accessibility: Clustering optimizes cost effectiveness of H_2 deployment.

Environmental: Clustering can strain water supply of nearby communities; NO_x emissions are of concern as well.

Health & Safety: Pipelines that run through communities are minimized.

Variables & Interdependencies:

Electrification, Distribution, Policy, Infrastructure

Research will be influenced by: ***(1)*** *The progress of electrification and the overall demand of H_2,* ***(2)*** *H_2 deployment policies that facilitate adoption,* ***(3)*** *extent of infrastructure changes from decarbonization, and* ***(4)*** *geographic distribution of H_2 demand.*

S4: Examine and Develop Hydrogen Demand Clustering to Enable Efficient H_2 Distribution (2/2)

Research Recommendations to Consider

S4.1 Identify Geographic Spread of Potential H_2 Demand

Impact: Develops an understanding of where the most critical H_2 demand will be located to inform where California should consider beginning H_2 deployment.

Timing Focus: Short term. Expand on current industrial clustering efforts and consider similar research for transportation and DG.

S4.2 Optimization of H_2 Infrastructure for Clusters

Impact: Develops a strategy for clustering that minimizes costs and effort of H_2 deployment by leveraging shared infrastructure and economies of scale.

Timing Focus: Medium term. Optimal after potential sites have been identified and H_2 demand and infrastructure development is better understood.

S4.3 Demonstrate H_2 Deployment for Identified Clusters

Impact: Verify performance metrics on costs and efficiency and determine the feasibility of H_2 clustering strategies in practice throughout California.

Timing Focus: Long term. After successful demonstrations from other entities to identify optimal clustering locations for further demonstrations.

External Factors to Watch

- **Monitor alternative electric end use development** compared to H_2 as this affects H_2 demand and the need for clustering.
- **Track geographic spread of H_2 end uses.** This will determine feasibility of clustering strategies. Some end uses could be moved for optimization but is challenging for industrial facilities.
- **Track policies that support decarbonization efforts, especially H_2.**

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Closing and Q&A

Closing

- We outlined 11 research initiatives corresponding recommendations for each of them that cover short (less than 5 years), medium (5-9 years), and long timeframes (≥10 years).
- As the landscape continues to evolve, the CEC Gas R&D Program’s application of the initiatives and recommendations from this effort should remain adaptable.
  - Stay vigilant on how the “technologies to watch” emerge over time
  - Stay engaged with researchers and stakeholders at the state, national, and international levels

Technologies to Watch (1/3)

Technology	Description
Liquid Hydrogen (LH_2)	Higher volumetric density of LH_2 enables grater efficiency in delivering fuel to end use and can increase vehicular range for transportation. Limitations still exist with high energy inputs required for liquefaction and challenges related to storage.
Clean Ammonia	Alternative to gaseous H_2 for direct use or as hydrogen carrier. Major limitations of ammonia include the toxicity, handling challenges (e.g., gaseous state at room temperature), and energy losses when acting as a hydrogen carrier.
Methanol as a liquid organic hydrogen carrier (LOHC)	Methanol can be easily stored and transported under ambient conditions, is already an industrial feedstock, and is currently the most cost competitive LOHC with highest storage capacity. Limitations include energy required to produce and emission of CO during decomposition.
Hydrogen Storage within Existing Fossil Gas Infrastructure	Transitioning existing fossil gas storage infrastructure to store H_2 could be promising instead of developing new geologic formations and infrastructure. Limitations include infrastructure retrofitting and compatibility, contamination, and prolonged fossil gas demand.
Low GWP Drop-in replacement for Fossil Gas	Development of a novel fuel that can be integrated into legacy gas infrastructure and direct end use replacement. Hydrogen requires too many modifications and has lower volumetric density. This topic is under consideration for support by U.S. DOE ARPA-E.

Technologies to Watch (2/3)

Technology	Description
Gas Equipment Technologies for Space and Water Heating in Buildings (H_2)	While electrification is the most pursued pathway for decarbonization of buildings there is still potential for gas equipment to meet demand in large commercial, multifamily and industrial buildings.
Non-electrolytic H_2 production	Emerging H_2 production technologies such as photocatalytic water splitting, bio methanation, and microbial electrolysis could develop to be competitive with electrolysis.
Codigestion	Simultaneous anaerobic digestion of multiple organic wastes in a single digester is promising to increase renewable gas production. Not a new topic but faces challenges related to feedstock compatibility, availability and cost.
Gasification and Pyrolysis	These solutions produce renewable gas from organic waste at high temperatures without combustion. This is a mature technology but is still not cost competitive or widely used, but it could have large potential in CA given biomass resource.
Geologic CO_2 Sequestration	There is a preference for CO_2 utilization as a method for sequestration, but geologic sequestration is still a viable option when environmental, cost, and permitting limitations are addressed.

Technologies to Watch (3/3)

Technology	Description
Direct Air Capture (DAC)	Capturing CO_2 directly from the atmosphere can function as a negative emission technology and could have a large impact on decarbonization efforts, but still faces significant technoeconomic limitations with high costs associated with the technology.
Hydrogen On-road Trucks	Hydrogen allows for faster refueling speeds and greater range than other decarbonized alternatives. Advanced demonstration and early commercial systems are being fielded.
Hydrogen Aviation	High on-board storage capacity is needed for aviation to meet large energy needs. Other sustainable aviation fuel options still result in pollutant emissions and involve higher costs.
Hydrogen Ocean Vessels	Large marine vessel demonstrations require large investments, but there could be further investigation into refueling barges and harbor crafts if alternative fuels gain traction in marine vessels.
Hydrogen Airport Ground Support Equipment (GSE)	There is investment into H_2 powered GSE but incorporating another fuel type at airports may increase complexity of energy consumption and safety. If H_2 becomes more popular in aviation aircrafts H_2 fueled GSE could develop further.

Feedback

Please submit comments to the relevant docket here: https://efiling.energy.ca.gov/Lists/DocketLog.aspx?docketnumber=16-PIER-01 by **December 20, 2022** and indicate “Guidehouse Long Term Study” in the subject line (comments will not be responded to directly).

Public Comment

Zoom:

- Use the “raise hand” feature

Telephone:

- Dial *9 to raise your hand
- *6 to mute/unmute your phone line. You may also use the mute feature on your phone.

Zoom/phone participants, when called upon:

- Your microphone will be opened
- Unmute your line
- Spell your name for the record, begin comments

Limited to 1 representative per organization.

2-Minute Timer

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Thank you!

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