CALIFORNIA STATIONARY FUEL CELL

ROADMAP

BENEFITS AND VISION THROUGH

2050

NATIONAL FUEL CELL RESEARCH CENTER
UNIVERSITY OF CALIFORNIA • IRVINE

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EXECUTIVE SUMMARY

FUEL CELLS CREATE RESILIENCY AND VALUE THROUGHOUT THE ENERGY SYSTEM

Stationary fuel cell systems are a **non-combustion** energy resource that generate clean, high efficiency, 24/7 power and heat, with virtually **zero emissions of criteria air pollutants** and **net zero water use**.

Fuel cell systems are today operating in microgrids and providing primary and backup power around the country. Able to island from the grid and provide power to sustain loads for prolonged duration outages, **fuel cells secure communities, critical facilities and infrastructure and ensure reliability**.

Fuel cell systems also significantly reduce the land footprint required for power generation in areas with high density and vulnerable populations.

FUEL CELLS REDUCE GREENHOUSE GASES AND IMPROVE AIR QUALITY

Fuel cell systems for power and heat generation are unique non-combustion solutions that **reduce greenhouse gas ("GHG") emissions** and decarbonize in commercial, industrial, multi-unit residential and other buildings. Many areas of California also face major challenges and health effects of air pollution. With high-efficiency and zero-emission of criteria pollutants, stationary fuel cell systems bring **environmental, health, and economic benefits** to communities that are disproportionately burdened by air pollution.

FUEL CELLS SUPPORT AND ENABLE A 100% RENEWABLE GRID

As the grid evolves, California will require zero net carbon energy that also provides clean, firm, load-following power to complement intermittent and diurnal varying renewable power sources like solar and wind. Stationary fuel cells provide these attributes and merit consistent short- and long-term policy to enable robust integration into California's energy and environmental strategies.

The **fuel flexibility** of fuel cells allows for a **seamless transition** from natural gas to **renewable fuels**. Policies that provide support to the use of fuel cell systems today facilitate this transition, while continuing the development of zero net carbon fuels is critical to realizing the benefits of stationary fuel cells for a 100% decarbonized future.

Photo: Bloom Energy Fuel Cell System
Courtesy of Bloom Energy, www.bloomenergy.com

STATIONARY FUEL CELL ROADMAP

2025 NEAR-TERM STATUS AND VISION TO 2025

State energy policy must recognize stationary fuel cells as a critical resource to meet 2030 air quality, climate and resiliency goals with consistent state incentives such as net energy metering, feed-in tariffs and reduced demand charges.

These incentives will sustain the evolution of the fuel cell market and accelerate cost and performance improvement.

Fuel cells are a ***non-combustion*** energy resource that today **reduces greenhouse gas (GHG)** emissions and produces negligible criteria and toxic air pollutants in either electric-only or combined heat and power modes.

Fuel cell systems today provide **primary** and **backup power** for communities, microgrids, industrial and commercial facilities. Their high reliability and grid independent operation increase resiliency and eliminate the need for combustion-based backup power generation.

Fuel cells today are the most efficient, load-following distributed energy resource to generate electricity and heat from the existing infrastructure using **conventional or renewable fuel**, and complement the increasing use of intermittent renewable wind and solar power.

Fuel cell systems are **fuel flexible**, operating on **hydrogen, biogas, or natural gas** depending on fuel availability. Biogas can be produced from a variety of sources including water resource recovery facilities, landfills, food processing plants, dairies and other organic waste via anaerobic digestion.

Fuel cells are ideal for the **clean, resilient power generation** that is required in emerging microgrid systems both behind and on the utility-side of the meter.

To harness the full value and potential of fuel cells to **support the grid and accelerate renewable deployment**, incentive programs should be maintained and supportive microgrid, net metering and interconnection policies should be expanded.

> ***Fuel cells are ideal for clean, resilient power generation***

MEDIUM-TERM VISION TO 2035

2035

Fuel cells emerge in the evolving energy ecosystem as a predominantly renewable resource-of-choice in the expanding networks of microgrids, distributed energy resources and utility-scale generation. Existing and newly installed stationary fuel cells operate on renewable fuel as it becomes available.

The installed base approaches 6GW and the fleet average GHG emissions reflect a 50% renewable fuel composition. Scaling of regional and global adoption brings annual installations to the GW scale and drives costs to less than half current levels.

The **fuel flexibility** of stationary fuel cells enables the transition to a decarbonized economy. The existing and expanding number of fuel cell systems have the **capability to operate on natural gas, renewable hydrogen, biogas or combinations of all three.**

Distributed stationary fuel cell systems are operating to **support capacity and distribution deferral** throughout the utility grid network, replace combustion systems and improve the reliability and stability of the network's high use of renewable power generation.

The current gas distribution system continues to be a resource to store and distribute renewable hydrogen from electrolysis of over-generation of renewable power. Storage and conveyance of ***renewable hydrogen*** begins to utilize dedicated hydrogen pipelines in addition to the natural gas infrastructure.

Tri-generation fuel cell systems have become prevalent, providing electrical power, thermal power for cooling and heating, and hydrogen for industrial, commercial, transportation, campuses, and microgrids.

In addition to generating clean electricity for plug-in electric vehicles, stationary fuel cells **produce renewable hydrogen** for fuel cell electric vehicles via tri-generation, and utilize stored renewable hydrogen, generated from otherwise curtailed renewable resources, to power loads on-demand.

The fuel flexibility of stationary fuel cells enables the transition to a decarbonized economy

2050 VISION FOR DEPLOYMENT TO 2050

Stationary fuel cells and a renewable hydrogen infrastructure enable a high penetration of renewables. Fuel cells are fundamental to a deeply de-carbonized energy sector utilizing 100% renewable fuel and serving as the primary dispatchable and load-following resource to support a resilient, renewable grid.

Microgrids anchored by fuel cells are a dominant element of the energy ecosystem. Reversible fuel cell systems and fuel cells designed for direct utilization of hydrogen fuel make possible the long-duration storage and load shifting needed over days, weeks and seasons. Wide-scale global deployment brings cost levels below 25% of current levels.

Fuel cell systems anchor California's **resilient and reliable power generation**, renewable fuel, and transportation networks enabling the proliferation of plug-in electric and hydrogen powered fuel cell electric vehicles, achievement of emission reduction targets, new levels of energy efficiency, and an integrated 100% renewable electric grid and transportation system.

> ***Fuel cells are fundamental to a deeply de-carbonized energy sector utilizing 100% renewable fuel and serving as the primary dispatchable and load-following resource to support a resilient and renewable grid.***

Electrolysis of water emerges to **generate renewable hydrogen** and to (1) capture and store energy that would otherwise be curtailed, (2) directly fuel stationary fuel cells, and (3) fuel difficult to electrify heavy duty transportation, aviation, and industrial energy requirements.

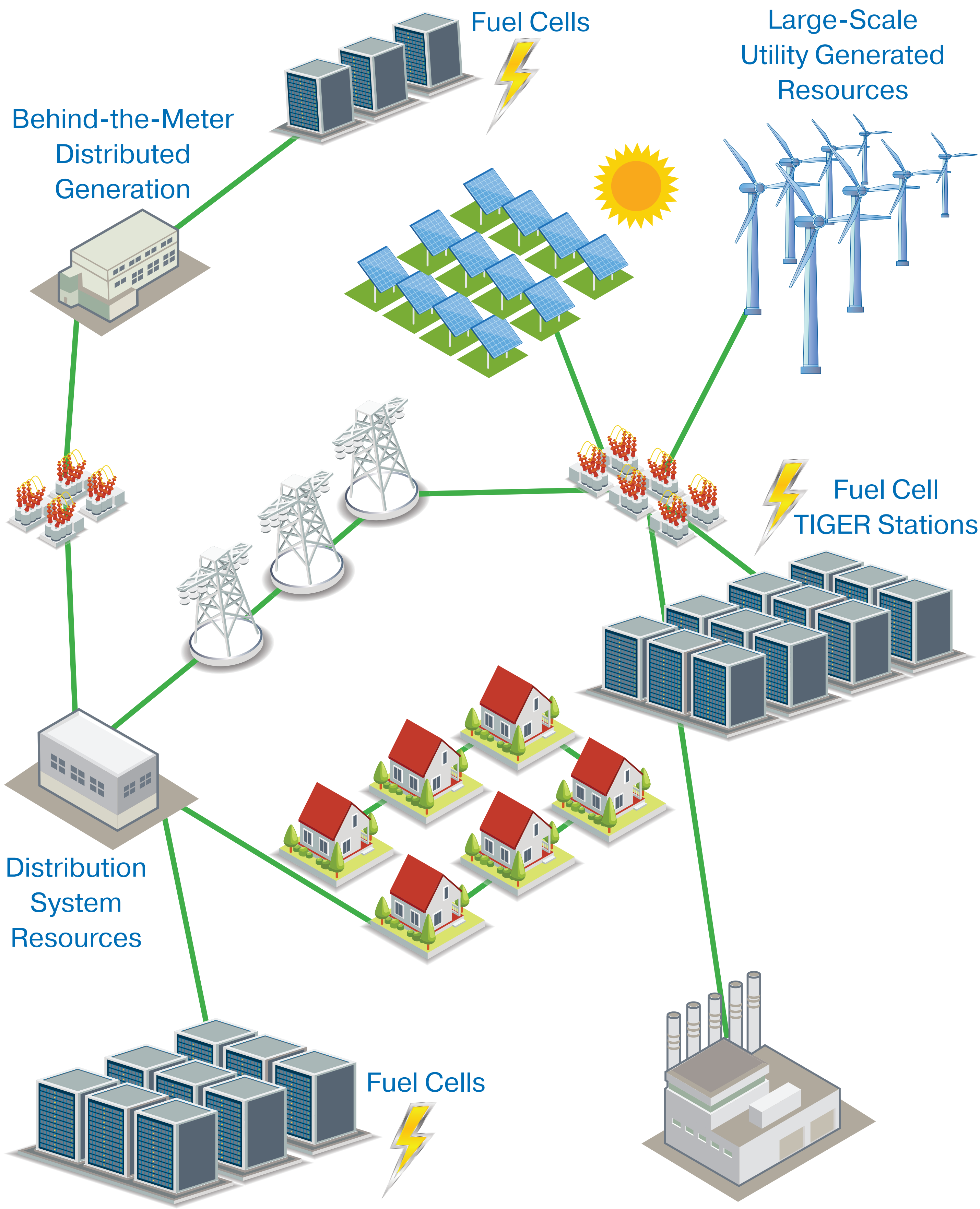
Dedicated hydrogen pipelines and infrastructure serve as a **massive energy storage** and distribution resource.

Deployment of fuel cell systems for large-scale, **100 MW-class power generation** at central plants is realized. Fuel cell modules facilitate scalability and carbon capture.

Local and utility-scale fuel cell generation enables long-term resiliency and improves air quality from the power generation sector.

Photo: Fuel Cell System
Courtesy of Altergy, www.altergy.com

ROLE OF FUEL CELLS IN THE ELECTRIC GRID



KEY ACTIONS FOR THE NEXT TEN YEARS

1 CREATE A CONSISTENT POLICY AND REGULATORY FRAMEWORK

Objective policies that value distributed energy resources for their distinct attributes must be established to realize California's environmental and economic goals with clean energy.

Microgrid and net energy metering tariffs and interconnection rules must be developed and maintained to incentivize the unique benefits and resiliency provided by distributed energy resources, rather than rewarding specific types of energy conversion technologies.

Fuel cell and electrolyzer systems must be provided access to markets that enable compensation for delivering increasingly valuable ancillary services such as ramping, capacity, voltage and frequency support to the utility grid network.

Policies must increasingly value the reduction of criteria air pollutants and short-lived climate pollutants in addition to carbon reduction. Air pollutants have an immediate impact on health and local communities. By narrowly focusing only on the reduction of greenhouse gases, policymakers will miss the opportunity for achieving air pollutant reductions from the displacement of combustion-based generation and transportation.

Photo: Doosan Fuel Cell System,
Courtesy of Doosan Group, www.doosan.com

2 IDENTIFY PROGRAMS THAT CREATE SHORT- AND LONG-TERM IMPACT AND SUPPORT

The retirement of diesel generators should be accelerated. Beyond the existing waiver of permitting requirements for fuel cell systems, California should accelerate the replacement of diesel backup generators with resilient, grid independent fuel cells. While new permitting of diesel generators for primary generation should be limited, the adoption of fuel cell systems, for both primary and backup power should be encouraged.

A self-contained sustainable energy and transportation system at ports should be developed. This would resolve the requirement of additional electric generation capacity and emissions reduction at ports and their surrounding communities, and provide support for the fueling of hydrogen fuel cell electric and plug-in electric vehicles.

3 STIMULATE INVESTMENT IN ZERO NET-CARBON FUEL PRODUCTION AND INFRASTRUCTURE

Recommendations for the development and use of zero net-carbon fuel should be included in short-term state plans for distributed energy, decarbonization and integrated resource planning.

Resulting policies and incentives should be adopted to significantly increase sustainable production and use of renewable fuels for electricity generation by non-combustion resources such as fuel cells.

The Short-Lived Climate Pollutant Reduction Strategy, the Low Carbon Fuel Standard policies, as well as the CPUC biomethane and building decarbonization proceedings should embrace a holistic view of the energy system that will advance the development of in-state renewable gas resources, and include provisions for credits for renewable electricity and hydrogen.

Policies that enable zero-emission fuel production and infrastructure development from over-generation of renewable wind and solar power should be developed and maintained to capture and store, rather than curtail, these valuable energy resources.

Agencies should proactively explore and assess the role of hydrogen not only as a storage medium, but also as a resource to decarbonize the natural gas system, and as a renewable fuel for electricity generation in support of the of the grid evolution.

Agencies should proactively explore and assess the role of hydrogen by research, development and demonstration projects for hydrogen use in difficult to electrify end-uses such as heavy-duty transportation, aviation, rail, shipping, fertilizer, and other industrial applications.

STATIONARY FUEL CELL ROADMAP

YEAR
2025

SHORT-TERM

Fuel cells deliver GHG-reduction with natural gas and biogas

Fuel cells improve community air quality by replacing local primary and backup combustion power generation

Distributed resource planning and tariffs support the use of fuel cell systems

YEAR
2035

MID-TERM

Utility planning and procurement of fuel cell systems supports renewable power generation

Fuel cells accelerate deployment of microgrids

Tri-generation of power, heat and hydrogen is prevalent

YEAR
2050

LONG-TERM

Fuel cells facilitate renewable, resilient and balanced grids

Production of renewable hydrogen from electrolysis enables massive and seasonal storage for a zero-carbon economy

Fuel cells and electrolyzers enable significant improvements in air quality with local and utility generation

KEY POWER AND FUEL CELL DEFINITIONS

Behind-the-Meter Generation: An energy resource on the customer side of the meter with loads and an interconnection point to the host utility.

Combined Heat and Power (CHP): Concurrent production of electricity and useful heat (thermal energy) from a single source of energy, such as a fuel cell.

Combined Cooling, Heating and Power (CCHP): Concurrent production of electricity and heat, and conversion of heat to produce chilled water for cooling or air conditioning.

Distributed Energy Resources (DER): Resources, including generation, storage, and controllable loads, that are connected to the distribution system and close to the loads they serve.

Electrical Efficiency: The ratio of total electric energy produced to the total energy input in the form of fuel.

Electrochemical Conversion: The non-combustive process used in fuel cells to convert fuel and air into electricity and water.

Electrolysis: The process of using electricity to split water into hydrogen and oxygen.

Firm Power: Constant (24/7), controllable, and load-following generation of high quality power.

Grid Independence and Resiliency: The ability of an on-site system, such as a fuel cell, to operate as a facility or microgrid primary power source in concert with the grid, and to continue operating during grid outages.

Grid Services and Renewable Intermittency Support: Ancillary services, such as ramping up and down, providing local capacity, voltage, and frequency support needs of the grid due to the high use of diurnal varying and intermittent renewables.

Hybrid Fuel Cell Systems: Integration of a fuel cell with another energy conversion device such as a turbine or energy storage, where the combination has benefits for efficiency, pollutant and GHG reduction, load-following, and grid services.

Load-Following: The ability of fuel cell systems to rapidly adjust the power output of a system to match changes in load.

Microgrid: A collection of distributed energy resources like fuel cells that includes generation and loads that act as a single controllable entity and that can operate in both grid-connected and islanded mode.

Photo: University of California San Diego
Fuel Cell Installation, Courtesy of FuelCell Energy,
www.fuelcellenergy.com

Non-Combustion: Fuel cell systems produce power through electrochemical reactions which produce zero pollutants in sharp contrast to combustion generation.

Renewable Hydrogen: Hydrogen created through electrolysis of water powered by renewable electricity from otherwise curtailed solar or wind that can be stored, distributed and used to generate electricity and heat or power fuel cell vehicles.

Reversible Fuel Cell: An electrochemical cell that produces dispatchable clean electricity and heat in fuel cell mode, or produces pure hydrogen and oxygen from water and electricity in electrolysis mode.

System Efficiency: The ratio of total useful electricity, thermal energy, and fuel produced to the total energy input to the system. The ability to configure systems to serve both electrical and thermal loads enables total system efficiencies that exceed 90% with fuel cell systems. Typical system efficiencies exceed 80%.

TIGER Stations: Transmission Integrated Grid Energy Resources (TIGER) are large-scale fuel cell systems deployed on the utility side of the meter for grid support where transmission and land use are constrained and increased reliability and low emissions are required. Examples range from a 15 MW system in Connecticut, to a 30 MW system in Delaware, to a 59 MW system in Korea.

Tri-Generation or Poly-Generation: A stationary fuel cell designed to produce hydrogen as well as electricity and heat. The hydrogen can be used in fuel cell vehicles or other applications.

Photo: University of California Irvine Medical Center Fuel Cell Installation, Courtesy of FuelCell Energy, www.fuelcellenergy.com

For more information, check out the video at **nfcrc.uci.edu/RoadmapVid**

NFCRC

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Founded in February 1998, the NFCRC facilitates and accelerates the development and deployment of fuel cell technology and fuel cell systems; promotes strategic alliances to address the market challenges associated with the installation and integration of fuel cell systems; and educates and develops resources for the various stakeholders in the fuel cell community. The NFCRC was established at the University of California, Irvine by the U.S. Department of Energy and the California Energy Commission with the goal of both developing and transitioning to a form of power generation that is energy efficient, resilient and environmentally sensitive.