JOINT INFORMATIONAL HEARING – ASSEMBLY TRANSPORTATION COMMITTEE AND ASSEMBLY NATURAL RESOURCES COMMITTEE

# What is the Role of Hydrogen in California's Zero-Emission Transportation Future?

California's climate goals include reducing greenhouse gas (GHG) emissions by 40 percent below 1990 levels by 2030 and by 80 percent below 1990 levels by 2050. The Governor has also established longer-term targets for economy-wide carbon neutrality by 2045. Technology will play a large part in meeting our state's climate goals. As vehicle technology transitions, it is important to think critically and proceed with caution to ensure that the cleanest and most cost-effective technologies available at the time are being utilized. This paper focuses on the potential and limitations of hydrogen fuel to meet the state's climate goals.

## The Transportation Sector Continues to be a Large Source of Greenhouse Gas Emissions

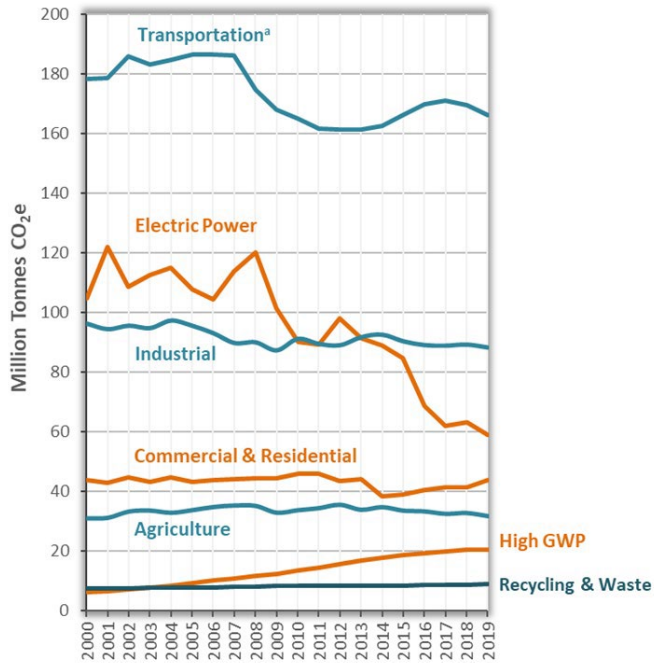
The transportation sector remains the largest source of GHG emissions in the state. Direct emissions from vehicle tailpipes, off-road transportation sources, intrastate aviation, etc., accounted for almost 40 percent of statewide emissions in 2019. When emissions from extracting, refining and moving transportation fuels in California are included, transportation was responsible for over 50 percent of statewide emissions in 2019.[1]

Mobile sources and the fossil fuels that power them also contribute the majority of NOx emissions, a significant precursor to smog and particulate matter.[2]

Not only is the transportation sector the largest source of GHGs, it is proving to be difficult to achieve GHG reductions in this sector for a variety of reasons, such as lack of coordination between housing, land-use, and transportation policies and manufacturer trends towards producing and marketing larger less fuel efficient vehicles. In contrast, the electricity sector has achieved significant GHG emissions reductions since 2000 and has accounted for most of the reductions in the state as shown in the figure below from the California Air Resources Board (CARB) in the 2021 Edition of GHG Emissions Trends and Indicators Report. In contrast, transportation emissions began to decline in 2007, but have since plateaued.

[1] CARB. 2021. California Greenhouse Gas 2000 to 2019 Emission Trends and Indicators Report
[2] CARB. 2021. Mobile Source Strategy.

**Changes in Emissions by Sector between 2009 and 2019**




<u>Zero-emission Vehicles As a Way to Reduce GHG Emissions in the Transportation Sector</u>

The state has implemented various programs intended to reduce GHG emissions in the transportation sector. One approach relates to shifting vehicle fleets to zero-emission vehicles. The Administration has established the goal that, where feasible, all new passenger cars and trucks, as well as all drayage/cargo trucks and off-road vehicles and equipment, sold in California, will be zero-emission by 2035. Similarly, the Administration established the goal that all medium and heavy-duty vehicles will be zero-emission by 2045 where feasible. These goals will be implemented by CARB through regulations currently under development.[3] CARB also provides funding to incentivize consumers to adopt zero-emission technologies and to help offset the additional up-front transition cost for businesses.

CARB certifies new passenger cars, light-duty trucks, and medium-duty passenger vehicles as zero-emission vehicles if the vehicles produce zero exhaust emissions of any criteria pollutant (or precursor pollutant) under any and all possible operational modes and conditions.[4]

Two main types of zero-emission vehicles are plug-in battery electric vehicles and fuel cell electric vehicles.

- **Battery electric vehicles** use a battery pack to store the electrical energy that powers the motor. Electric vehicle batteries are charged by plugging the vehicle into an electric power source. Although electricity production may contribute to air pollution, the U.S.

[3] Advanced Clean Cars 2 and Advanced Clean Fleet regulations
[4] Alternative Fuels Data Center https://afdc.energy.gov/laws/4249

Environmental Protection Agency (and CARB) categorizes all-electric vehicles as zero-emission vehicles because they produce no direct exhaust or tailpipe emissions.[5]

- **Fuel cell electric vehicles** are powered by hydrogen. A fuel cell is an electrochemical cell that converts the chemical energy of hydrogen and oxygen into electricity. Fuel cell electric vehicles are more efficient than conventional internal combustion engines and produce only water vapor and warm air at the tailpipe.[6]

Battery electric vehicles are more efficient than fuel cell electric vehicles. For every 10,000 miles of travel, a battery electric vehicle requires 3,000 kilowatt-hours of electricity, while a fuel cell electric vehicle requires 7,300 kilowatt-hours of electricity.[7]

A total cost of ownership study from the National Renewable Energy Laboratory finds that battery electric and fuel cell electric commercial trucks could be economically competitive with conventional diesel trucks by 2025 in some operating scenarios.[8]

CARB's 2020 Mobile Source Strategy makes several specific technology and fuel assumptions in creating a scenario to arrive at 100 percent zero-emission vehicle sales by 2035. These assumptions include the relative ratio of combined battery electric vehicles and fuel cell electric vehicle sales starting at 90/10, respectively, in 2030 and scaling to 75/25 by 2045. The rationale for these assumptions reflects increasing fuel cell electric vehicle adoption as hydrogen fueling infrastructure expands and that a subset of the vehicle market will still require frequent, relatively fast refueling, particularly for larger vehicle classes.[9]

As adoption of vehicles with zero-emissions at the tail-pipe increases, focus will need to shift to upstream emissions (or full life-cycle considerations). This means that the emissions created during the production of the energy powering the vehicle would be taken into account. Fuel life cycle analysis is a technique that allows the quantification of the potential impacts to the environment from all aspects of a fuel's life, including fuel production processing, transport, and use.

Another assumption that CARB's 2020 Mobile Source Strategy makes is that by 2045, approximately 90 percent of all electricity used in the production of hydrogen is from renewable sources, such as wind or solar. The Strategy also assumes that 100 percent of electrolytic hydrogen (made by splitting water with electricity) will use renewable electricity as utilities progress towards more renewable electricity generating portfolios. CARB notes that many of the assumptions contained in the Mobile Source Strategy would require new policy actions.

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[5] Alternative Fuels Data Center https://afdc.energy.gov/vehicles/electric_basics_ev.html

[6] Alternative Fuels Data Center https://afdc.energy.gov/vehicles/fuel_cell.html

[7] California Energy Commission Legislative Hydrogen Briefing. December 9th 2021.

[8] Hunter et al. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks.

[9] CARB. 2021. Mobile Source Strategy.

What is Hydrogen and How Do Hydrogen Fuel Cell Vehicles Work?

Hydrogen is the most abundant element in the universe. On Earth, hydrogen is found in the greatest quantities in water, but can also be found in fossil fuels, and biomass.

A hydrogen fuel cell generates current from a chemical reaction between hydrogen and oxygen. The oxygen comes from the air. The hydrogen, compressed, is stored in a tank on board the vehicle, and is replenished at a filling station similar to gasoline. Unlike a battery, a fuel cell creates exhaust, but it is simply water—the reaction product of hydrogen and oxygen.

Hydrogen is Produced from Various Sources.

The source of the hydrogen and the source of the energy used to split hydrogen from its source plays a significant role in determining the lifecycle emissions associated with hydrogen vehicles. Today, there are several means of hydrogen production and it is likely that these will evolve as technology advances. The types of hydrogen produced today are discussed in more detail below, beginning with the cleanest type of hydrogen fuel. The figure on the next page provides an overview of different hydrogen production methods, or the "colors" of hydrogen.

Green hydrogen results in almost no GHG emissions. Produced by electrolysing water, green hydrogen is made using 100 percent renewable electricity to split hydrogen from water molecules. Less than 0.1 percent of hydrogen production globally comes from water electrolysis. In the future, policymakers should approach the "green" hydrogen label with caution, as new definitions for green hydrogen are developed, and may not always include electrolytic production with no carbon release.

Ninety six percent of the hydrogen today is considered to be gray hydrogen. Gray hydrogen is produced by heating natural gas, or methane, with steam to form syngas (a mixture of hydrogen and carbon monoxide and carbon dioxide).[10] The syngas is separated to produce hydrogen. This process results in a relatively high release of GHGs.

Blue hydrogen attempts to mitigate some of the GHG emission release during the production of gray hydrogen by pairing production with carbon capture and storage. However, not all of carbon dioxide emissions can be captured, and some carbon dioxide is emitted during the production of blue hydrogen.[11] Carbon capture increases the cost and inefficiency of the production of blue hydrogen.

Renewable hydrogen is produced mainly by steam methane reformation of biomethane (renewable feedstock) from North American landfills.[12] Renewable hydrogen is part of the policy discussions in California. Senate Bill 1505 (Lowenthal, Chapter 877, Statutes of 2006) requires 33 percent of the hydrogen produced for fueling stations that receive state funds be made from eligible renewable energy resources, including biomass, digester gas, landfill gas,

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[10] World Energy Council. 2019.

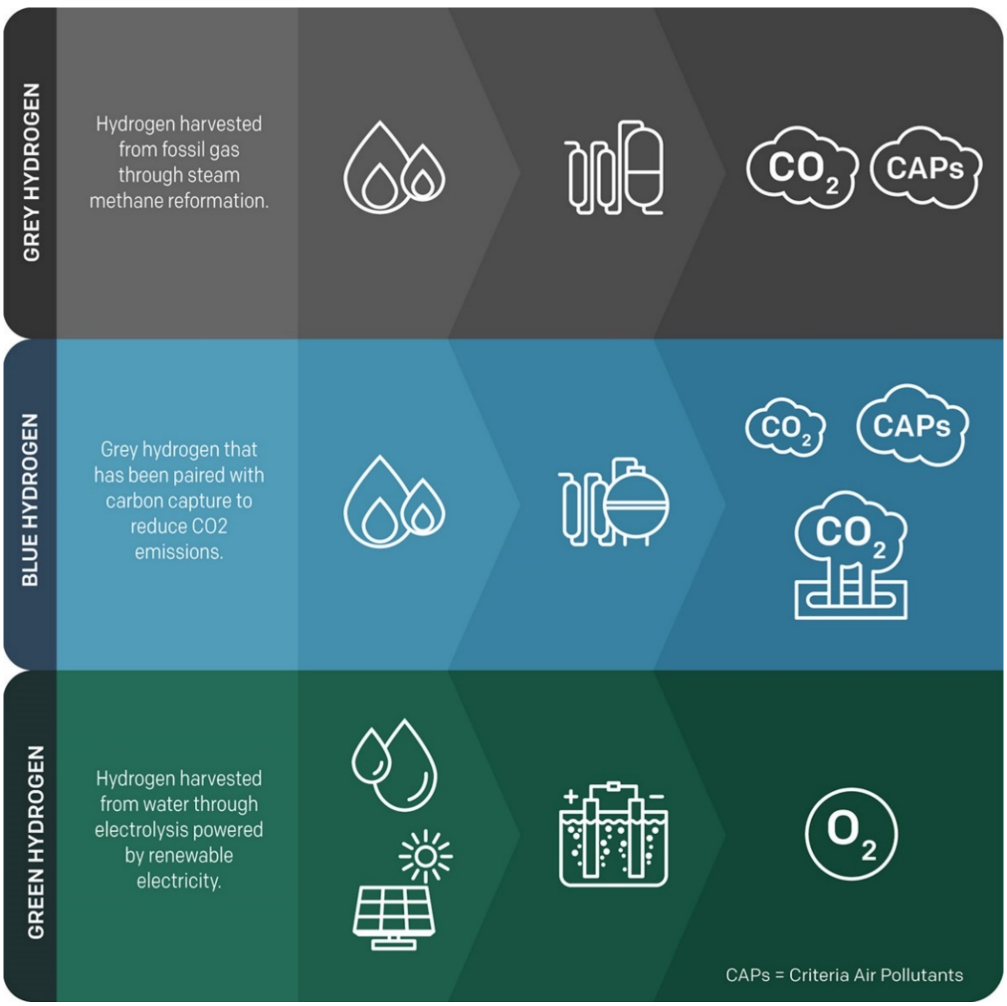
[11] Bartlett J, Krupnick A. Decarbonized Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions. Report 20-25. Resources for the Future; 2020. https://media.rff.org/documents/RFF_Report_20-25_Decarbonized_Hydrogen.pdf.

[12] CARB. 2018. CA-GREET 3.0 Lookup Table Pathways Technical Support Documentation.

solar, and wind. California's network has recently been dispensing up to 90 percent renewable hydrogen, and CARB projects that the future network will maintain a minimum 40 percent renewable content through 2027.[13] The remaining non-renewable hydrogen production is made with fossil fuels.

Supplying hydrogen to industrial users is a major business around the world. Demand for hydrogen, which has grown more than threefold since 1975, continues to rise – almost entirely supplied from fossil fuels, with 6 percent of global natural gas and 2 percent of global coal going towards hydrogen production. As a consequence, production of hydrogen is responsible for emissions of around 830 million tonnes of carbon dioxide per year, equivalent to the $CO_2$ emissions of the United Kingdom and Indonesia combined, or more than double California's 2018 $CO_2$ emissions across all sectors.[14]

**Key Differences between Grey, Blue, and Green Hydrogen**




[13] CARB. 2020. Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development.

[14] IEA. 2019. The Future of Hydrogen, IEA, Paris https://www.iea.org/reports/the-future-of-hydrogen

Where Does the Use of Hydrogen Make the Most Sense?

Using hydrogen that has the lowest GHG emissions during its production is critical to help the state and world achieve their climate goals. However, green hydrogen is currently relatively expensive when compared to other zero-emission technologies and the vast majority of the hydrogen available for use today is not green. Green hydrogen is more expensive to produce than gray hydrogen, but as the cost of renewable energy is decreasing rapidly and electrolyzers are becoming more efficient, the cost of producing green hydrogen is dropping. In addition, infrastructure barriers currently limit the supply of green hydrogen. Both production costs and infrastructure limitations may persist for the next several decades.[15] Therefore policy makers may wish to consider prioritizing the use of hydrogen where it results in the greatest net GHG reduction at a reasonable cost, with the understanding that this prioritization may change over time.

For example, for transportation purposes in the short term, replacing an internal combustion engine of a heavy duty truck with a fuel-cell electric vehicle will reduce GHG emissions and improve air quality overall, regardless of the method of hydrogen production. However, in the long-term, the full life cycle of hydrogen production will grow increasingly important to achieving the state's climate goals, and other technologies such as battery electric vehicles may be a cleaner choice for the replacement of internal combustion engines for certain duty cycles.

An environmental law organization, Earthjustice, recently released a report identifying promising applications for green hydrogen and ranks its use by least-regrets uses, sectors to explore with caution, and sectors where hydrogen is not a solution. The report categorizes maritime shipping, aviation, and long-haul trucks and trains as "sectors to explore with caution." The least-regrets uses for green hydrogen are displacing fossil hydrogen in current uses as an industrial feedstock. Sectors where hydrogen is not a solution according to Earthjustice, are combustion in fossil gas power plants, gas-burning appliances in homes and commercial buildings, and cars, buses, and regional trucks.[16]

Other environmental groups have weighed in on the appropriate uses of hydrogen. For example, the Natural Resources Defense Council has raised concerns about heating homes with hydrogen and finds that heating is one of the least-efficient and most costly options available.

State and Federal Funding Are Available to Advance Hydrogen Production

The 2022-2023 Governor's Budget proposes $100 million General Fund to the California Energy Commission to demonstrate scaling green hydrogen production in 10 to 15 commercial scale projects with a focus on the following areas:

- Grants to support the production of lower cost green electrolytic hydrogen for delivery/use in California. Approximately two-thirds of this funding will focus on cost reduction and efficiency improvements for electrolyzers.

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[15] Howarth and Jacobson. 2021. *Energy Science and Engineering.* How Green is Blue Hydrogen?

[16] Earthjustice. 2021. Reclaiming Hydrogen for a Renewable Future.

- Grants to support the transportation, storage, and conversion of green hydrogen to the site where needed. Alternative configurations will be demonstrated and evaluated:
  - One demonstration option will be to generate the hydrogen and transport it for storage at a local storage facility on or near the same conversion site.
  - A second demonstration option will be to generate the hydrogen, centrally store it, and then transport it longer distances to various site locations. This hub and spoke design may prove more cost-effective.

The Federal Bipartisan Infrastructure Bill, also known as the Investment and Infrastructure Jobs Act or IIJA, enacted in November 2021 provides $9.5 billion nationwide for clean hydrogen research, development, and demonstration programs to be managed by the Secretary of Energy.[17] The bulk of this funding—$8 billion—is authorized to the newly created Office of Clean Energy Demonstrations for the development of four regional clean hydrogen hubs to be located in different geographic regions across the U.S. with the goal of demonstration projects and end-use diversity, which are likely to be led by companies. The largest amount will go into carbon capture and developing hydrogen-based power systems.

## Funding for Hydrogen Vehicles

The state does not have dedicated funding for fuel cell electric vehicles, and programs for zero-emission vehicles remain technology neutral. The state both regulates the manufacturing of, and offers incentives for zero-emission passenger vehicles and medium- and heavy-duty trucks. This year's Governor's Budget includes $6.1 billion to support more affordable clean cars, trucks, and buses and expand access to zero-emission vehicles and zero-emission vehicle infrastructure in low-income communities. In this case, zero-emission is a mix of both battery electric and fuel-cell electric vehicles and infrastructure. The Clean Transportation Program is the largest source of state money for funding zero-emission vehicle infrastructure, including battery electric vehicle chargers and hydrogen refueling stations.

## Defining Clean and Green Hydrogen

For the first time, U.S. law will define "clean hydrogen". The current definition explicitly includes hydrogen produced from renewables, fossil fuels with carbon capture, utilization and sequestration technologies, nuclear, and other eligible sources. The IIJA requires the Secretary of Energy in consultation with the Environmental Protection Agency (EPA), to develop an initial standard for the carbon intensity of clean hydrogen production. It initially defines "clean hydrogen" to mean hydrogen "produced with a carbon intensity equal to or less than 2 kilograms of carbon-dioxide equivalent produced at the site of production per kilogram of hydrogen produced." However, the IIJA provides that the Secretary of Energy may adjust that standard after its consultation with the EPA.

[17] H.R. 3684 https://www.congress.gov/bill/117th-congress/house-bill/3684/text

Discussions regarding the definition of green hydrogen for the Governor's budget proposal are currently ongoing. Otherwise, state law is not explicit, in terms of production, when referencing hydrogen to be used as an energy source or a transportation fuel. Current state statute (Public Utilities Code 400.2) defines "green electrolytic hydrogen" as hydrogen gas produced through electrolysis and does NOT include hydrogen gas manufactured using steam reforming or any other conversion technology that produces hydrogen from a fossil fuel feedstock. Existing law (PUC 400.3) requires the Public Utilities Commission, CARB, and the Energy Commission to consider green electrolytic hydrogen an eligible form of energy storage, and to consider other potential uses of green electrolytic hydrogen.