MOBILITY NEWSLETTER

Research & reporting from California, the U.S., and around the world

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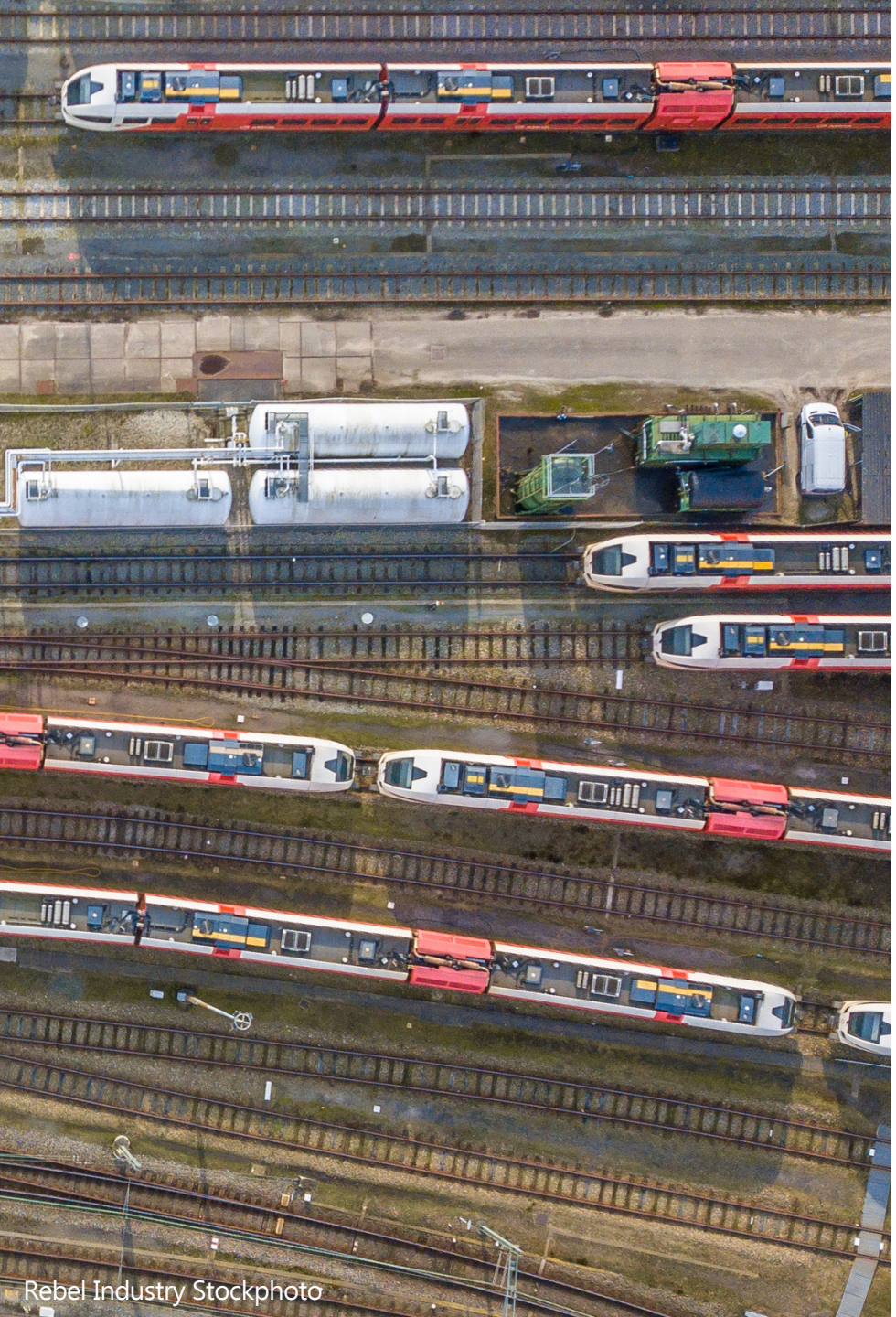


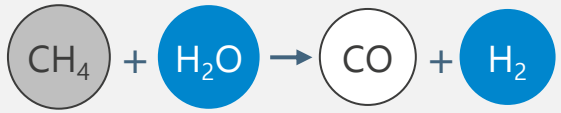
Hydrogen Trains:

The future of low-carbon rail transportation in California?

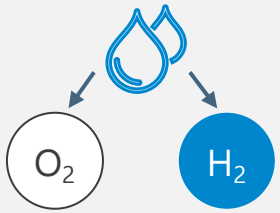
Hydrogen is a sustainable alternative to diesel and is better-suited to the U.S. rail context than electrification.

Hydrogen trains are powered by a hydrogen internal combustion engine or using Hydrogen fuel cells (HFC), which is more common.[1] The use of hydrogen as fuel emits **only water and no other pollutants**.

Hydrogen can be **manufactured for fuel** by splitting methane (CH_4) using a process called pyrolysis,[2] or by splitting water (H_2O) in a process called electrolysis:[3]



Pyrolysis process



Electrolysis process

To **generate useful electricity**, hydrogen fuel cells work like batteries; the hydrogen undergoes a chemical reaction with oxygen inside the cell, creating electricity, water vapor and a small amount of heat, without any polluting emissions.

Hydrogen to electricity process

Because hydrogen fuel is portable and emission-free, hydrogen trains are an especially attractive option for rail applications.

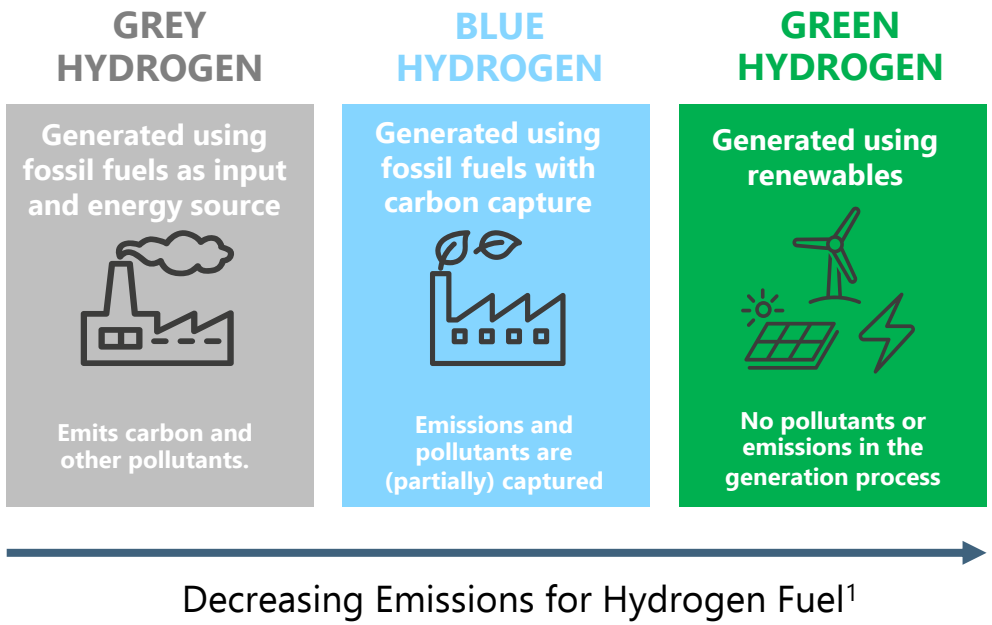
Versatility: Current HFC trains offer versatility and flexibility,[4] and have a comparable range and refueling time to diesel trains.[5] As a result, HFC trains are a good fit in many areas like the U.S. where few railroads are electrified (which is very costly) but low-carbon transportation is a priority.

Sustainability: While traditional diesel locomotives emit many pollutants, HFC locomotives do not emit any pollutants from tank-to-wheel during operation.[6]

Sources: 1: Fuel Cells | Department of Energy 2: What is Pyrolysis? | USDA ARS 3: Hydrogen Production: Electrolysis | Department of Energy
4: Fuel cell & hydrogen trains | Roland Berger 5: FLIRT H_2 Locomotive: Stadler Rail 6: 2021 Hydrogen Fact Sheet, | California Energy Commission

The overall impact of hydrogen fuel on the environment depends on manufacturing inputs and energy sources.

Though *using* hydrogen fuel is always pollution-free, the overall emissions profile of the fuel depends on how it is *manufactured*. Three main energy sources can be used to manufacture hydrogen fuel, and hydrogen is categorized into "colors" that indicate how sustainable it is.



Green hydrogen is the most sustainable and desirable, but categorizing and tracking how hydrogen is produced is still a challenge, and guidelines are vague across the world. While blue hydrogen is less polluting than grey hydrogen (which also uses natural gas as the source of methane for production through pyrolysis), **recent studies have shown the decrease in emissions due to carbon capture during the manufacturing process of blue hydrogen is marginal**.[2] Clarifying these distinctions is needed to fully understand our environmental impact, and standardization is essential for further development of hydrogen infrastructure and application for transport uses.[3]

In the first quarter of 2023, the European Union enacted the **Renewable Energy Directive II** to create clear regulations regarding renewable hydrogen for transport uses. The certifications apply to all hydrogen destined for the EU market.[4]

In the U.S. no such regulation has been introduced. However, California has made numerous investments in sustainable hydrogen development since 2008.[1]

Sources: 1: 2021 Hydrogen Fact Sheet | California Energy Commission 2: How Green is Blue Hydrogen? | Energy Science & Engineering
3: Hydrogen: Paving the way for new European standards | European Commission 4:Rules for Renewable Hydrogen, European Commission

Hydrogen train technology is still new, and comes with the associated costs and risks…

The first commercial passenger hydrogen train was only introduced five years ago in Lower Saxony (Germany), where it was implemented as an alternative to diesel locomotives in 2018.[1]

Technological maturity:
Hydrogen is still quite new as a technology and, compared to tried-and-true solutions like diesel, is generally riskier. Innovation in hydrogen technology is accelerating, which means current technology may become obsolete quickly. Additionally, hydrogen production capacity is still low and is less reliable nationwide compared to electricity or diesel.

Infrastructure:
HFC trains require a lot of supporting infrastructure, which must be funded through investments by governments or third parties outside the rail operators.[2] Besides hydrogen production capacity, distribution, storage, and refueling infrastructure need to be strategically located for cheap, efficient operations using HFC.

Cost:
HFC trains are more expensive compared to diesel trains, but how much depends on context. In Lower Saxony, the HFC trains were 30% more expensive than traditional alternatives,[1] but in California, they may be as much as double the price.[3] Over their lifetimes, HFC trains are expensive to operate, though with plentiful, cheap renewable energy (and thus cheap hydrogen production) they can reach cost parity, as they have in parts of Scandinavia.[4]

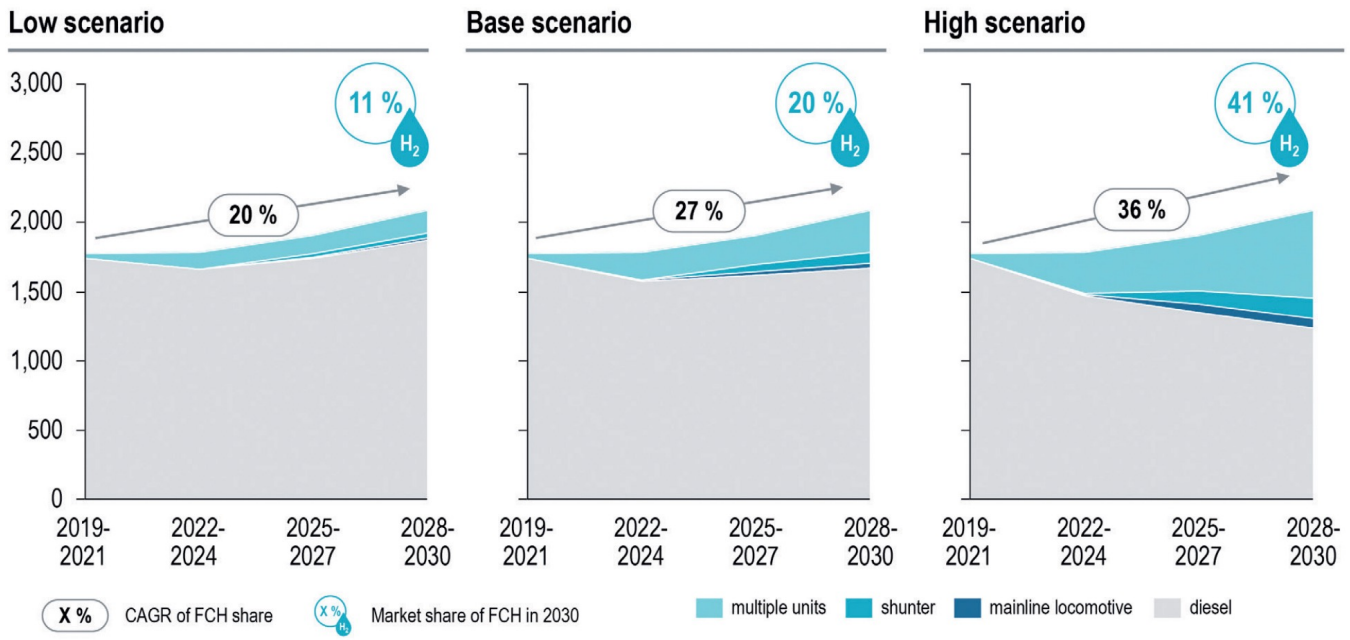
Safety:
Hydrogen must be held under high pressure and is very flammable. Like other fuels, hydrogen must be handled carefully and requires extensive safety measures. Public skepticism also poses a challenge even with effective risk management, as new technology is often faced with safety concerns from the general public.

Sources: 1: Brennstoffzellenfahrzeuge in Niedersachsen | Verkehr und Technik. 2: RFI NO. 21-1002519 Approach to Hydrogen Supply Storage Fueling | SBCTA
3: California State Rail Plan 4: Fuel cell and hydrogen trains | Roland Berger

In Europe, the demand is high for hydrogen trains, and they are poised to gain market share over diesel.

A 2019 study funded by the E.U. indicated that 20% of regional diesel trains in Europe will be replaced by hydrogen-powered locomotives as soon as 2030.[1] In an accelerated adoption scenario, that number could double.

The forecasted growth is driven by environmental concerns, government initiatives, technological advancements, infrastructure development, and industry partnerships.

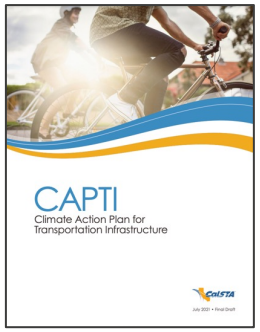


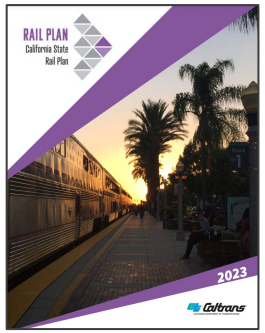
Source: Study on the Use of Fuel Cells and Hydrogen in the Railway Environment | Roland Berger

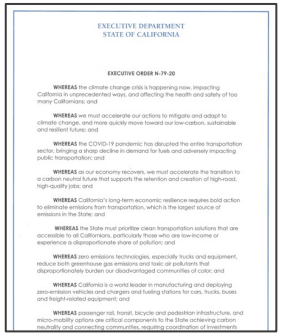
In the U.S., California is an ideal place to start introducing hydrogen trains.

Societal & Political goals

The state of California has ambitious environmental goals, outlined in documents like the Climate Action Plan for Transportation Infrastructure (CAPTI) and the State Rail Plan (currently being finalized). Executive Order N-79-20 also sets the goal that all off-road vehicles, including trains and other rail vehicles, will run emissions-free by 2035.[1]

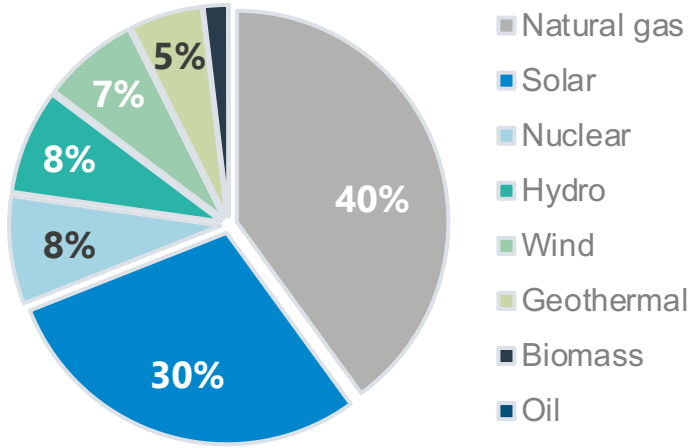






Energy Infrastructure

California is a leader and innovator in renewable energy production; renewable power is abundant, which is beneficial for hydrogen development, and the state has already begun investing in expanding hydrogen infrastructure.



Californian Electricity Production Mix[2]

Current Rail Infrastructure

California has a large high-speed rail and intercity network, but very few of California's railroads are electrified. Though the state has the ambition to electrify the high-speed rail sections, hydrogen locomotives can replace diesel locomotives without requiring the costly electrification of the rail infrastructure.

Sources: 1: California Executive Order N-79-20 2: California Electricity Generation | Energy.Gov

California is already exploring hydrogen for passenger and freight rail, with plans to expand service soon.

The California State Transportation Agency (CalSTA) and **Caltrans** signed a Memorandum of Understanding last September with train producer Stadler for the design and delivery of at least four hydrogen trains to service the Californian Central Valley on the route between Merced and Sacramento. These zero-emission HFC trains can replace the current diesel locomotives that operate on the Amtrak network. The MOU includes options for the purchase of up to 25 additional locomotives.[1]

The trains included in the MOU are based on Stadler's design for **San Bernadino Country** (The FLIRT H_2 pictured above), which will be delivered in 2024 to service a 9-mile route on the Redlands Passenger Rail System.[2,3] The trains will all be manufactured here in the U.S. at Stadler's facility in Utah.[1]

The **Sierra Northern Railway**, located in Central California, is also currently piloting a hydrogen-powered train, supported by a $4M grant from the California Energy Commission awarded in 2021.[4] The pilot is intended to demonstrate the viability and commercial benefits of hydrogen rail, especially on short-line and switching locomotive tracks, which represent a large share of the last-mile rail freight capacity in the state.[5]

Sources: 1: California orders 29 hydrogen trains for inter-city services | International Railway Journal. 2: SBCTA and Stadler unveil 1st ZEMU | SBCTA
3: FLIRT H_2 | Stadler 4: California State Rail Plan 5: California Energy Commission awards... | Sierra Northern Railway

Balancing promise and complexity: prospects and implementation challenges of hydrogen-fueled trains.

- (Green) hydrogen is a sustainable energy source
- Abundance of renewable energy sources in California
- Hydrogen is an enabler for other industries too

Hydrogen shows promise as a decoupled energy source aligning with Caltrans and California's goals, offering local pollutant-free operation. It holds potential for sustainable energy solutions, including application in heavy-duty vehicles alongside trains, utilizing the state's abundant renewable energy sources.

- Hydrogen technology is developing
- Costly compared to more mature technologies
- Need for regulations and clear certification

However, hydrogen faces challenges due to its nascent stage, resulting in issues with production, distribution, and refueling. High costs compared to diesel or electric trains, coupled with regulatory and certification complexities, hinder its widespread adoption in the near term. Transparency and clear certification are also necessary for sustainable use.

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