# Propulsion Technologies for Passenger and Freight Rail: Scenario Updates

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## RESEARCH QUESTIONS

*Both passenger and freight train volumes are increasing. As this continues to occur, and as the automotive sector shifts over to cleaner fuels, how can trains do their part to help achieve sustainability/climate goals?*

*Are any such changes economically viable? How effective are they in reducing GHG emissions? Are there any major logistical challenges?*

## FUELS BACKGROUND

**Diesel-Electric:** Currently powers approximately 87% of all domestic rail service (US DOE, 2013), and the vast majority of freight rail operations.

**Electricity (via Catenary) –** Approx. 2-3% of track over which passenger rail operates in the United States is electrified (Amtrak); however, due to the density of passenger rail traffic in the 'Northeast Corridor,' passenger rail operational energy is currently split at 47% diesel, 53% electric. (US DOE, 2014). Exact $CO_2$ emissions varies by region, depending on the fuel mix of electricity generation at the producing power plants.

**Biodiesel –** Biodiesel is a renewable biofuel that is blendable with diesel fuel in a range of applications and specifications. "Renewable diesel," typically produced using hydro-treating to upgrade oils, and which can be produced from a wide range of feedstocks, is one variant that is capable of 100% operation in any diesel engine (NREL, 2006).

- Drop-in diesel fuels made via gasification technologies are a potential future technology. These methods, which currently remain expensive and non-commercial, allow any biomass to be converted to long-chain hydrocarbons, via processes such as Fischer-Tropsch (F-T).
- In part due to the range of possible feedstocks and pathways, biodiesel and renewable diesel fuel emissions amounts are hard to pinpoint. Additionally, the $CO_2$ and other GHG emissions released during feedstock conversion and fuel production can be significant, as might be land use and soil carbon changes.

**Natural Gas -** At least one freight firm, as well as one passenger rail agency, is considering CNG as a potential rail fuel. While requiring a simpler system than LNG, CNG stores less energy per unit volume.

- Several freight firms are experimenting with LNG. Challenges include the low temperature at which it must be kept (roughly - 260 F), and that liquefaction is energy intensive and causes a loss in overall system efficiency compared to CNG. "Boil-off" is likely during refueling and on-board storage.
- With natural gas' lower energy density than diesel, tender cars will be required in most freight applications. Amount of methane leakage within the fuel supply change is under investigation, but likely has significant emissions implications.

**Hydrogen/Fuel Cell -** Fuel cells produce zero pollutant or GHG emissions at the "tail pipe," and are more efficient than ICEs. This reduces the fuel requirement and, potentially, the cost - though hydrogen, where available, is currently not an inexpensive fuel.

- HDV applications of fuel cells have been demonstrated in U.S. bus systems. In Europe, Alstom has partnered with Hydrogenics, and plans to have 40 passenger trains operating in Germany by 2020.
- With a large enough distribution demand, H2 movement by dedicated pipeline is likely optimal (UC Davis, 2014); a pipeline could serve both rail facilities and other sources of demand, e.g. buses and trucks.
- Even in liquid form, hydrogen's per gallon energy density is much lower than diesel fuel. Fuel cell stack lifetime is another area of concern; however, one AC Transit (SF Bay Area) bus has a stack in operation that has required no major overhauls despite nearly 21,000 hours of operation.

## ANALYSIS ASSUMPTIONS

Using one actual (passenger) rail corridor and one devised (freight) corridor, our analysis aims to estimate refueling infrastructure costs in a "real world" context. All LCA GHG low-high emissions values are based on Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET), 2014, values. Efficiency assumptions also come from GREET, except for LNG HPDI (High Pressure Direct Injection), whose efficiency is assumed as same as diesel. Locomotive maintenance was estimated, based on consultant input, at $1.20/mile for Diesel, Biodiesel, LNG, and Hydrogen; $0.72/mile for Electricity (electric adjustment based on literature) for passenger; for freight, at $1.00/mile for Diesel, Biodiesel, LNG; and Hydrogen; $.60/mile for electricity. All other cost information was estimated based on input from a variety of sources, spanning both public and private firms/agencies.

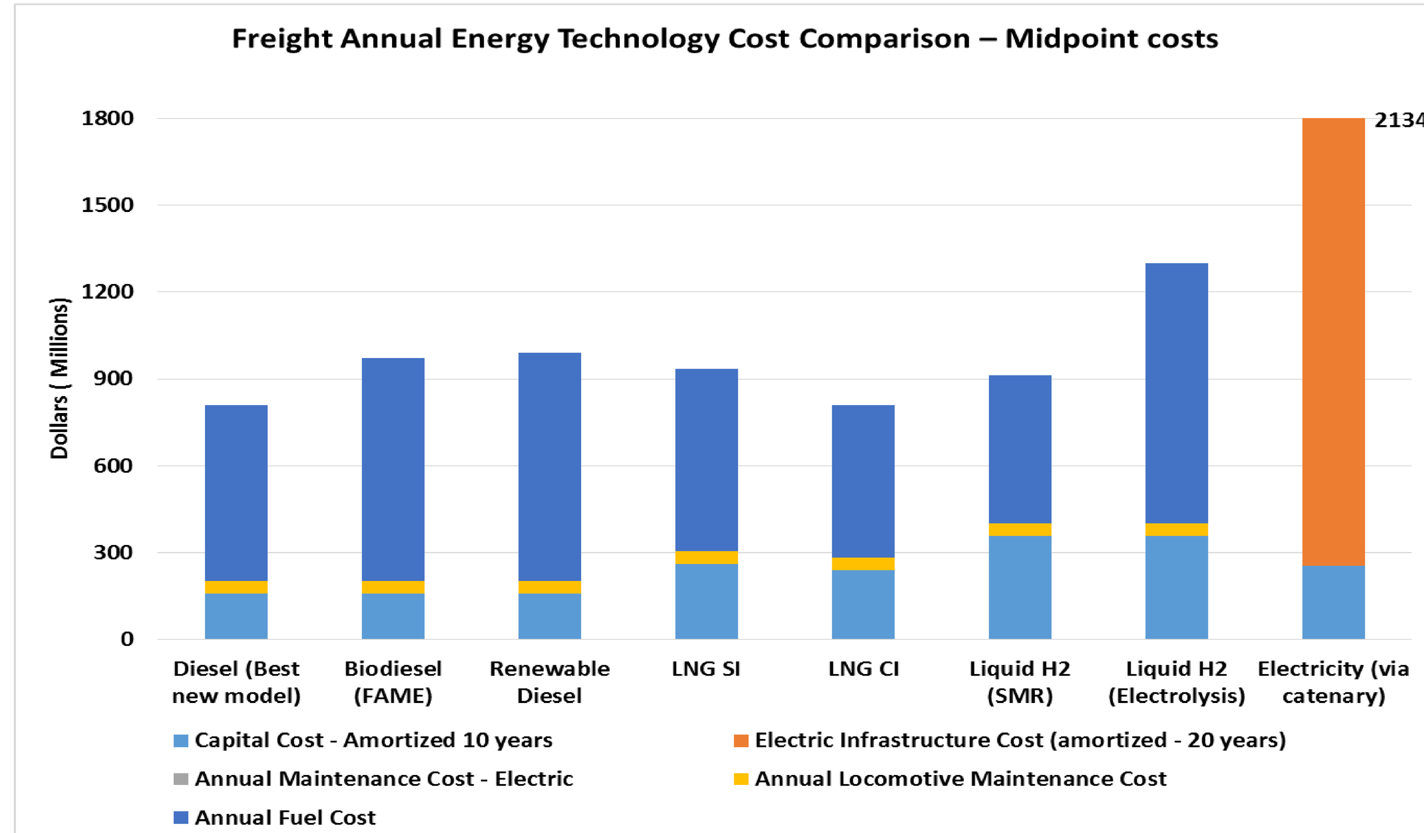
Passenger Rail

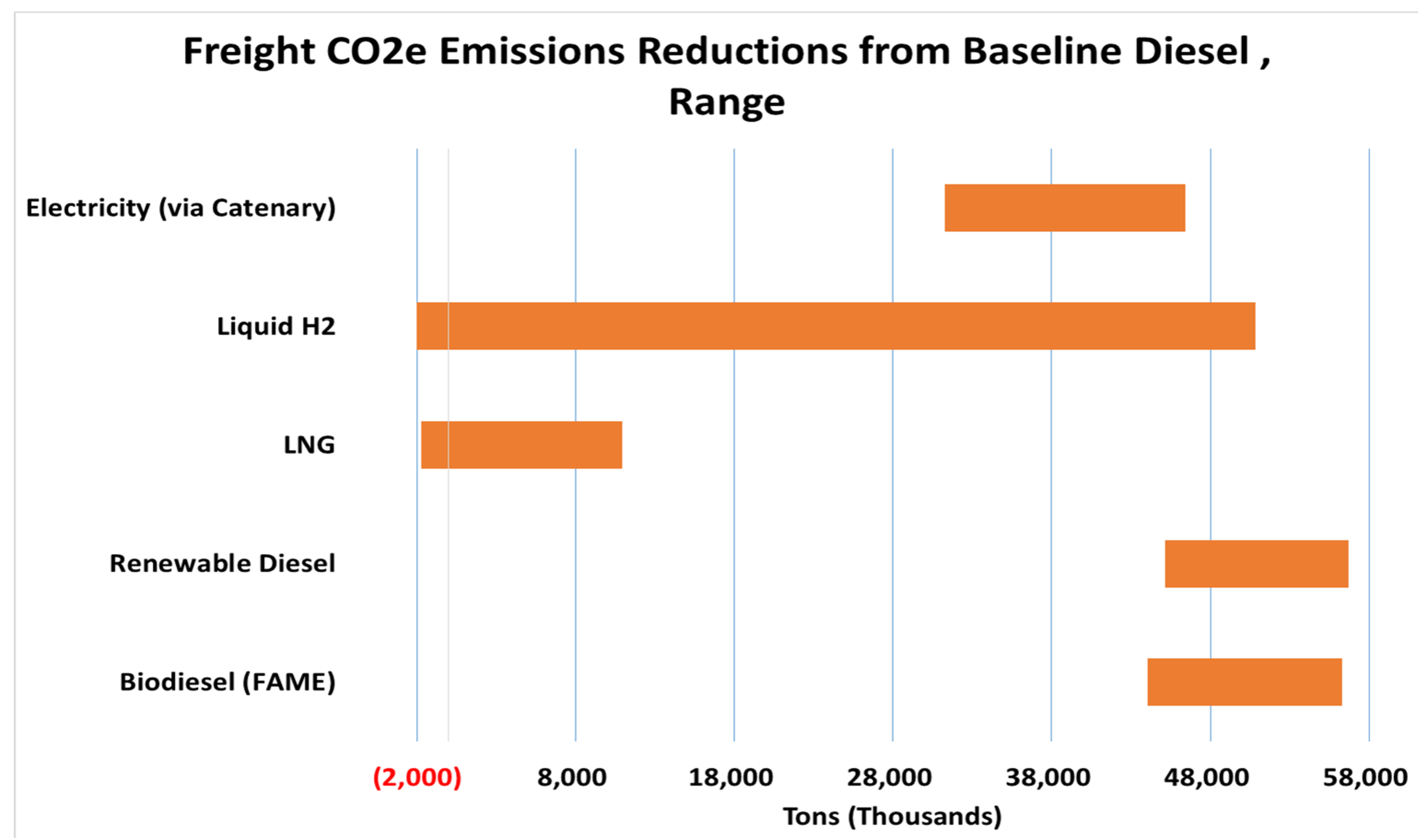
Chart values modeled off of a standard sized Amtrak Capitol Corridor (CA) train, with actual FY 2013 annual mileage adjusted to a potential future schedule. Diesel fuel consumption based on a slight improvement over current Capitol Corridor fuel consumption, based on latest available engine technology (based on EPA certification data).

Freight Rail

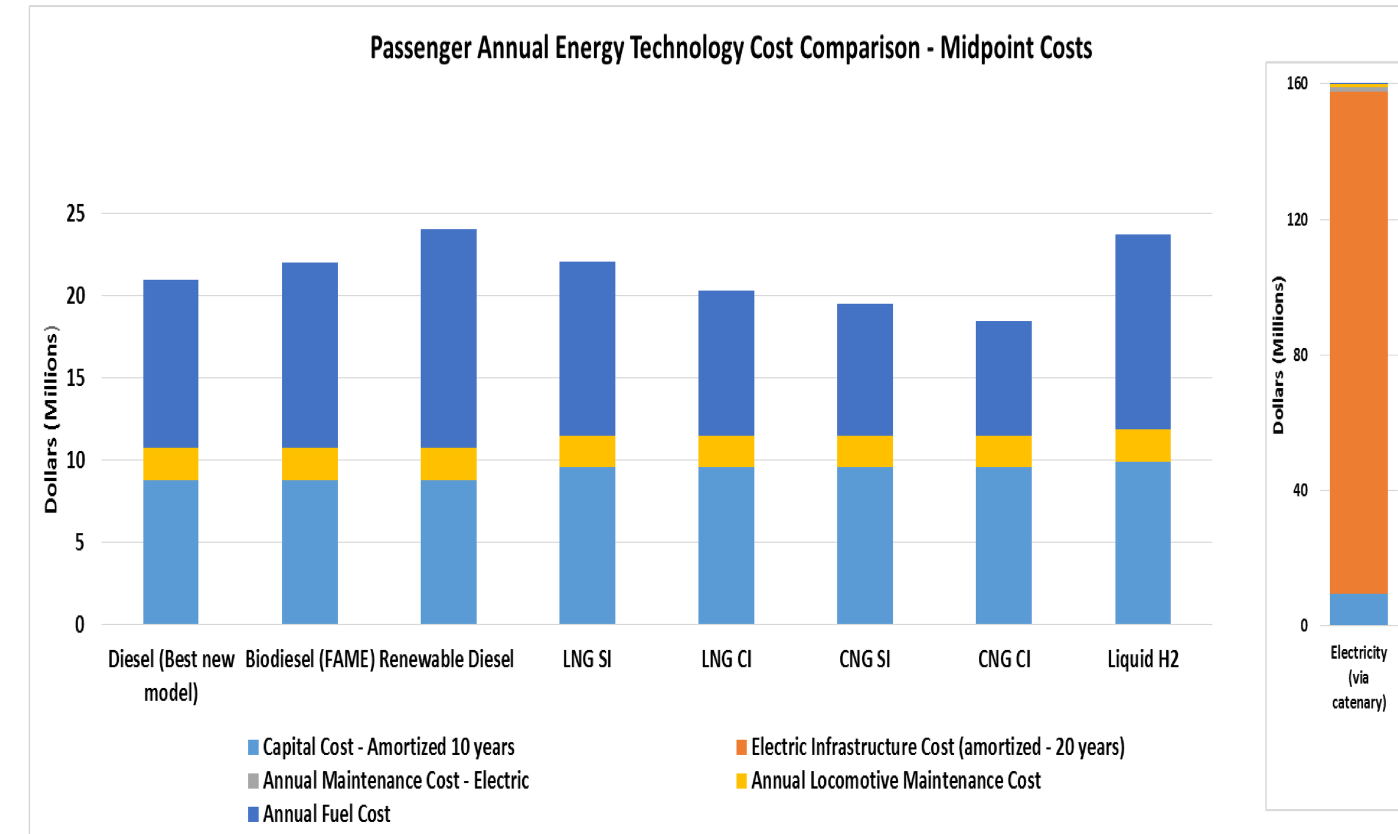
Ten trains per day were assumed to leave origin en route to a 2,000-mile journey, to later return the same distance back to the origin. Round-trip time is 6 days. Total period covered is one year. 3 new locomotives purchased for each of the 60 trips (i.e. 10 different vehicles departing origin on each day of six-day set). Diesel fuel consumption modeled off of a combination of national consumption data from the Association of American Railroads combined with data on typical train weight for intermodal trains provided by a Class I firm. Locomotive fuel tank size information was also provided by this Class I firm. Tender requirements for LNG and hydrogen assume no additional refueling required (i.e. other than origin) along 2,000-mile one-way trip route.

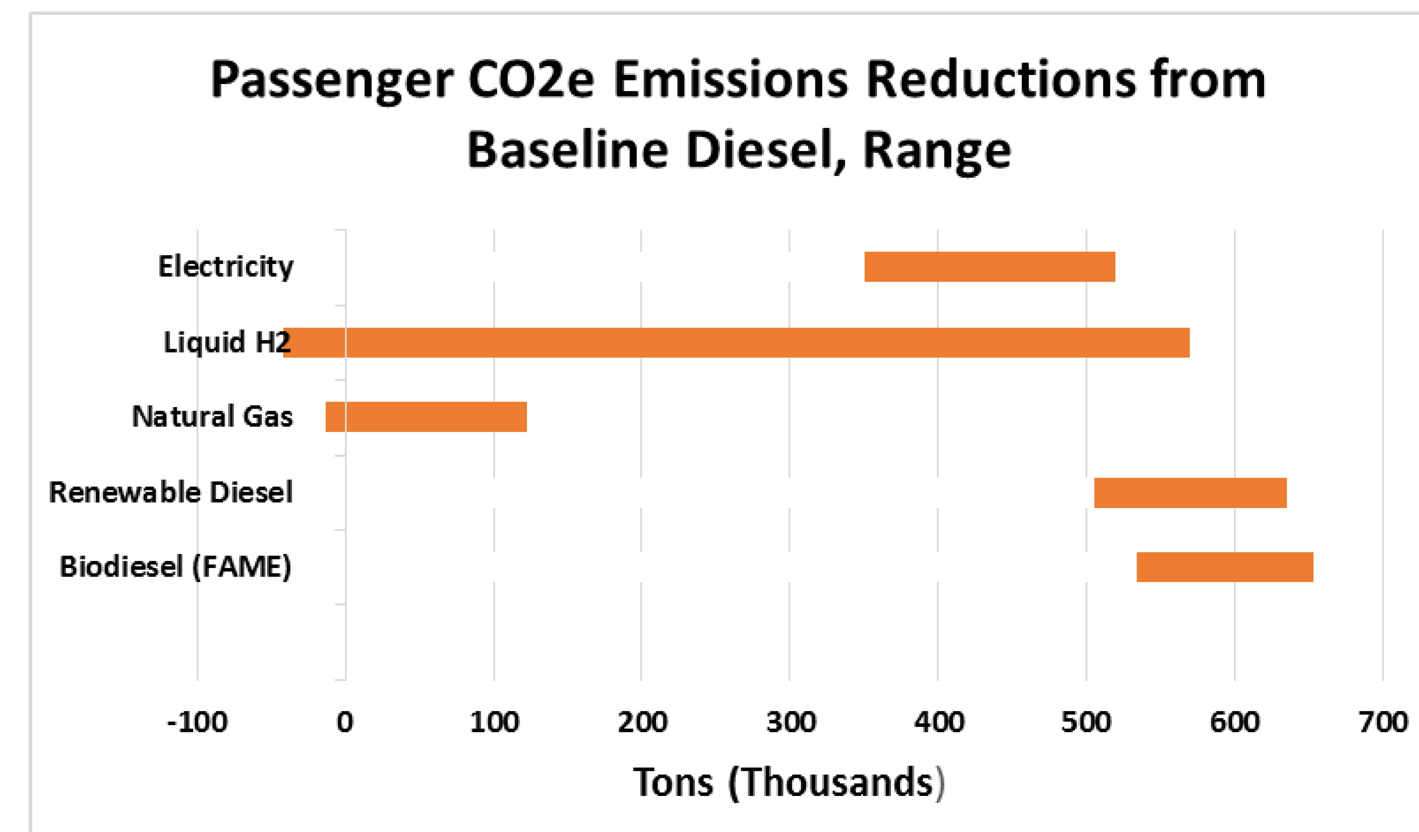
## FREIGHT RESULTS



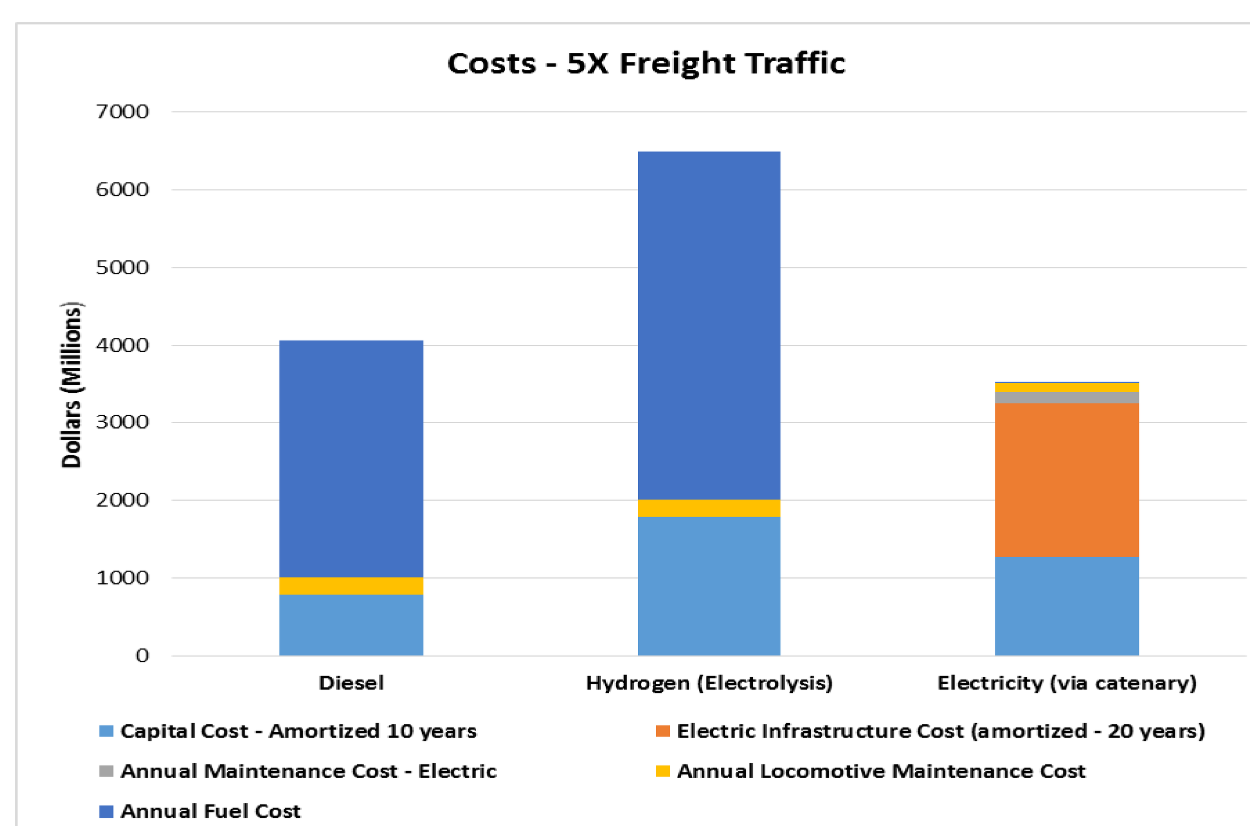

## PASSENGER RESULTS




## HIGH FREIGHT VOLUME

In areas with heavy freight traffic in both directions (50 trains per day, in this example), electricity becomes advantageous vis-a-vis all other options (with diesel and H2 via electrolysis demonstrated here)*




* This chart assumes that there remains two tracks, only, along this route, as was the assumption for ten trains per day scenario

## FINDINGS OF NOTE

- The options that would keep costs relatively stable or even offer savings, in the near-term, are not necessarily the ones that will offer significant CO2 benefits. Beyond the near-term, future research and development are likely to lower some of the higher cost options (especially hydrogen).
- Beyond cost uncertainty, fuel supply and storage characteristics of alternatives to diesel technology would likely pose the most significant impacts of any transition to these fuels.
- Electric catenary installation costs are very high, > $1 million/track mile. High levels of traffic on a given route can mitigate the high cost of this fixed infrastructure.

## RESEARCH NEXT STEPS

- Add hybridized powertrains into analysis, and use rail simulation software to simulate duty cycles so as to increase analysis precision (e.g. exact powertrain requirements) for diesel, hydrogen, and battery hybrids of one or both of these.
- Incorporate more details on diesel-electric efficiency improvement potential, incorporate weight aspects across fuels
- Develop a spatial analysis of fuel supply (e.g. LNG, H2) over a widespread rail network

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