

Date: 5/27/26

Subject: Technical Review of “*Techno-Economics of Low-Carbon Freight Rail Transportation in California*”

From: Garrett Anderson

Company: Benchmark Data & Control

To: Mike Swaney

Company: BNSF

The public hearing for the final version of the Barstow International Gateway Environmental Impact Review (BIG EIR) was held May 16, 2026. A paper titled “Techno-Economics of Low-Carbon Freight Rail Transportation in California” by Narayan Gopinathan was submitted as evidence that battery electric locomotives are a feasible alternative to Tier IV diesel locomotives. This paper used a similar analysis to the CARB and Connolly Memos that were included in or referenced by the Earthjustice response to the draft version of the BIG EIR[1]. Gopinathan’s conclusions are based on a a several flawed assumptions that result in incorrect conclusions.

Many of the problems with Gopinathan’s analysis are discussed in “*Analysis of BELs: San Pedro Bay Ports to Barstow*[2].” The three main problems discussed in this memo are in addition to the other problem discussed in the previous report.

- Gopinathan assumed incorrect diesel engine efficiency
 - Doubled estimated diesel consumption
- Gopinathan modeled the wrong train
 - Assumed car was much heavier than expected resulting in a train with the maximum tonnage but lower car count
 - Did not account for train being lighter in the westbound direction
- Gopinathan did not consider hydrogen fuel cell stack efficiency on locomotive
 - Cuts hydrogen consumption in half
 - Compounds with diesel assumption to give hydrogen 4X benefit

Diesel Engine Thermal Efficiency

Gopinathan’s assumed diesel engine efficiency of 22.5%. This estimate was very low for a diesel engine that operates at a moderate load or higher. The data presented in Figure 1 is the efficiency curve for a Caterpillar C175-16 medium speed diesel engine and is about 40 percent [3]. The efficiency curve for the Wabtec Tier IV engine used by BNSF is not public information, but the C175-16 performance data is representative for engines of this class. Although Gopinathan references Popovich, et. al., Popovich estimates an average efficiency of

39% for this class her study[4]. The Popovich efficiency aligns with the C175-16 data. Thus, Gopinathan's assumed efficiency was about half this value which means his analysis doubles fuel consumption without any support.

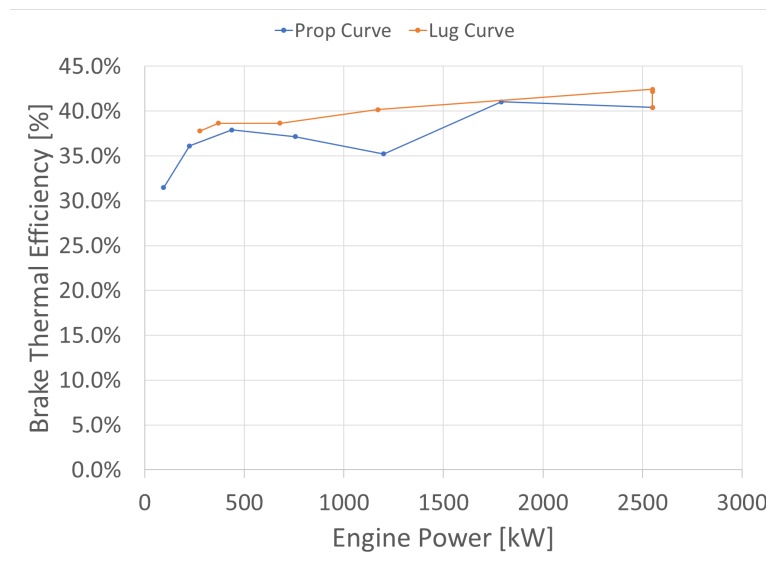


Figure 1. Efficiency curve of Caterpillar C175-16, representative of medium speed diesel engines[3].

The underestimation of diesel engine efficiency invalidates Gopinathan's later financial calculations. This assumption doubles the required amount of diesel fuel. This underestimation results an artificial and unsupported financial advantage for rail electrification and hydrogen.

Train Tonnage and Total Consist Power

Gopinathan assumed an extremely heavy loaded car tonnage of 137.25 short tons. He then assumed train lengths based on the number of cars. These car counts ranged from 90 to 120. He did not estimate train lengths in feet or meters. Gopinathan's train tonnages are annotated in Figures 2 and 3 along with tonnages from the CARB and Connolly memos[1], [2], [5]. It would take 280 cars defined in the CARB Memo to match Gopinathan's 105 car, mid -level train, which roughly matches the BNSF train tonnage and length correlation as shown in Figures 2 and 3. These annotations demonstrate that Gopinathan's trains are not representative of actual BNSF trains.

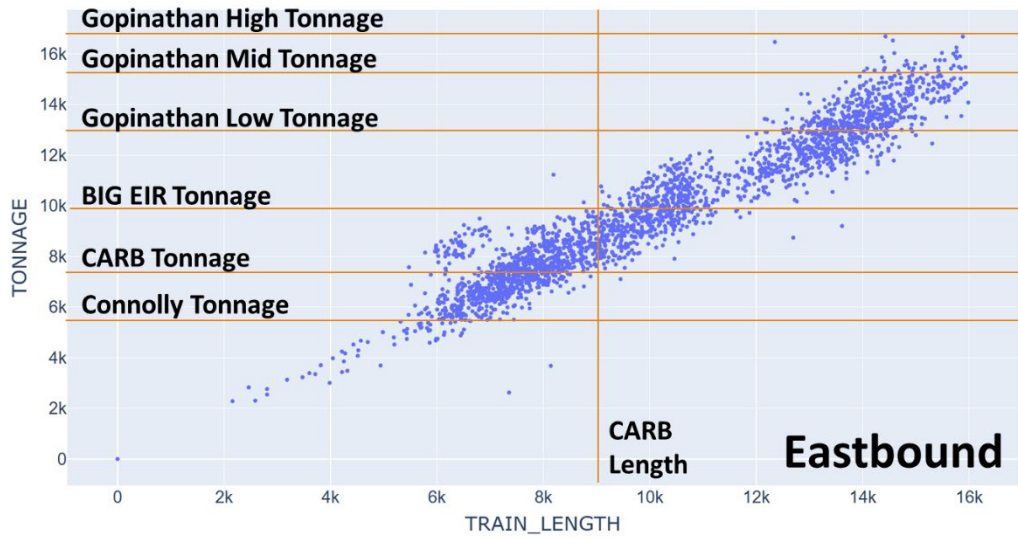


Figure 2. Scatter plot of train tonnage and length for trains operating between the POLA and Barstow, CA with gross tonnages for Gopinathan, CARB, and Connolly denoted[1], [2], [5].



Figure 3. Scatter plot of train tonnage and length for train operating between Barstow, CA and the POLA with gross tonnages for Gopinathan and Connolly denoted[1], [2], [5].

These discrepancies in train definition are important because heavier cars require lower car counts to reach a specified tonnage. A train with fewer cars will have less rolling resistance and reduced aerodynamic drag when compared to trains with more cars and equivalent tonnage. Incorrectly estimating these loads results in an inaccurate energy requirement used for Gopinathan financial estimates.

Assumed Hydrogen Fuel Cell Efficiency of 100%

Gopinathan incorrectly assumes a fuel cell stack efficiency of 100% through his modeling approach. Fuel cells convert hydrogen to electricity. Gopinathan equated the hydrogen demand to the estimated electricity demand. He did not account for the efficiency of the hydrogen fuel cell which is about 50%[6]. Omission of the hydrogen fuel cell efficiency cut the hydrogen requirement in half.

A gallon of diesel contains equivalent energy of about 1.1 kg of hydrogen. Therefore, this omission estimated one gallon of diesel being equivalent to 0.55 kg of hydrogen. Combining this omission with the incorrect diesel engine efficiency produced a model that demonstrates that one gallon of diesel is equivalent to 0.275 kg of hydrogen.

Conclusions

Correctly modeling these systems with appropriate efficiencies and costs is paramount when estimating the economics of technology adoption. Gopinathan's errors in estimation undermines these potential rail technologies because predicted performance will not match actual performance.

References

- [1] C.-T. K. Gupta, “Feasibility Analysis: Zero Emission Train from the Port of Los Angeles to Barstow (Aug. 2024),” California Air Resources Board, Aug. 2024. [Online]. Available: <https://ww2.arb.ca.gov/sites/default/files/2024-08/Feasibility%20Analysis%20Zero%20Emission%20Train%20from%20the%20Port%20of%20Los%20Angeles%20to%20Barstow%20Updated.pdf>
- [2] G. Anderson, “Analysis of BELs: San Pedro Bay Ports to Barstow,” Benchmark Data & Control. [Online]. Available: <https://www.barstowca.org/home/showpublisheddocument/15791/639137950279470000>
- [3] “Caterpillar Marine C175-16 Specification Sheet.” Caterpillar Inc. Accessed: May 18, 2026. [Online]. Available: https://www.teknoxgroup.com/fileadmin/user_upload/C175_3003_3256_3420.pdf
- [4] N. D. Popovich, D. Rajagopal, E. Tasar, and A. Phadke, “Economic, environmental and grid-resilience benefits of converting diesel trains to battery-electric,” *Nat. Energy*, vol. 6, no. 11, pp. 1017–1025, Nov. 2021, doi: 10.1038/s41560-021-00915-5.
- [5] Y. Morena, “Connolly Memo Attached to Comments on City of Barstow General Plan and BNSF Barstow International Gateway (BIG) Draft EIR (SCH No. 2024020501),” Jan. 12, 2026. [Online]. Available: <https://www.barstowca.org/departments/community-development-department/planning/barstowgeneralplanupdate-com/documents-for-public-review-download-ver1>
- [6] USDOE Office of Energy Efficiency and Renewable Energy (EERE), Sustainable Transportation Office. Vehicle Technologies Office. Batteries for Advanced Transportation Technologies (BATT) Program *et al.*, “All Composite Data Products: National FCEV Learning Demonstration With Updates Through January 18, 2012,” NREL/TP--5500-54021, 1036040, Jan. 2012. doi: 10.2172/1036040.