California Energy Commission

CONSULTANT REPORT

South Coast Air Basin Medium- and Heavy-Duty Zero-Emission Vehicle Blueprint Metrics Summary

Prepared for: **California Energy Commission**
Prepared by: **University of California, Irvine**

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ABSTRACT

The goals of the project, "A Replicable Zero-Emission Blueprint for Medium-and Heavy-Duty Fleets in the South Coast Air Basin" are to (1) develop a replicable blueprint for medium- and heavy-duty charging and hydrogen infrastructure within the South Coast Air Basin with a focus on transit, drayage, and long-haul trucking, (2) consider stakeholder input, and 3) ensure that the blueprint is available to the public, and to industry and community stakeholders. This report is the first step in developing a South Coast Air Basin regional blueprint for medium- and heavy-duty vehicle charging and fueling infrastructure. The goal of the blueprint is to outline a replicable framework for the build-out of medium- and heavy-duty zero-emission vehicle infrastructure that can result in a cost-effective, reliable, and resilient charging and fueling network with consideration to disadvantaged communities. To that end, this report establishes the technical, economic, and environmental metrics that will be used to develop the blueprint and evaluate its impact on the South Coast Air Basin within the context of existing policies related to reducing transportation-related greenhouse gas emissions and criteria air pollutants. The technical metrics are vehicle demand met in terms of vehicle miles traveled, and vehicle fuel consumption, station capacity, and general station siting within the region. The economic metrics are fuel cost and station cost. The environmental metrics are reduction in GHG emissions, reduction in criteria air pollutant emissions, change in regional air quality, and change in local air quality associated with disadvantaged communities.

Keywords: Blueprint; metrics; medium-and heavy-duty vehicles; charging and fueling infrastructure; air quality; disadvantaged communities

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EXECUTIVE SUMMARY

Medium- and heavy-duty zero-emission vehicles offer compliance with established greenhouse gas emissions reduction targets and offer an opportunity to tackle degraded regional air quality. Without sufficient models of successful infrastructure for medium- and heavy-duty use, it may be challenging for fleets to navigate the processes of planning, construction, and operation. Fleets need to be confident that they have a plan that minimizes risk and will ultimately meet their operational needs. The project is designed to help overcome medium- and heavy-duty operators' resistance to adoption of zero-emission vehicle technology by increasing transparency of the infrastructure requirements and reducing uncertainty surrounding cost and reliability. Creating a regional blueprint for charging/fueling infrastructure will facilitate a coordinated build-out of medium- and heavy-duty zero-emission vehicle infrastructure, resulting in a cost-effective, reliable, and resilient charging and fueling network.

In addition to capturing the regional perspective of medium- and heavy-duty zero-emission vehicle infrastructure deployment, this project will highlight relevant vocation-specific requirements for transit, drayage, and long-haul. Transit applications have proven as an early success for zero-emission vehicle adoption. Drayage trucks are another early vocation for zero-emission vehicle adoption due to their relatively short travel distances and impact on disadvantaged communities within the South Coast Air Basin. Lastly, long haul trucks may be more challenging to transition to zero-emission vehicles due to their significantly longer routes compared to other vocations and less frequent tendency to return to a "home base" location. Identifying long-haul requirements and potential barriers to zero-emission vehicle infrastructure deployment for this vocation can facilitate broader adoption within the MHDV sector.

In Task 2, relevant Federal, State, and local goals and plans are summarized. Major greenhouse gas emissions reduction goals include reaching 1990 levels by 2020, 40% below 1990 levels by 2030, and carbon neutrality by 2045. Key MHDV regulations include the Innovative Clean Transit regulation and the Advanced Clean Truck regulation. Current medium- and heavy-duty zero-emission vehicle and infrastructure funding opportunities are diverse, including federal, state, and regional programs. Leading programs include the Low Carbon Fuel Standard, the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, and the newly announced EnergIIZE Commercial Vehicles. While funding can significantly reduce the capital costs of deploying medium- and heavy-duty zero-emission vehicle, rollout is also constrained by medium- and heavy-duty zero-emission vehicle availability, lead times, and infrastructure permitting and construction times, which are currently impacted by supply chain issues.

Qualitative and quantitative metrics were identified to evaluate the impacts of the blueprint. The three areas of evaluation are technical, economic, and environmental: vehicle demand met, station siting nearness to demand, station capacity, station costs, fuel cost, greenhouse gas and criteria air pollutant emission reductions, and coincidence of air quality changes and disadvantaged communities. Map based estimates of future conditions will be core to "A Replicable Zero-Emission Blueprint for Medium-and Heavy-Duty Fleets in the South Coast Air Basin" Project report.

CHAPTER 1:
EXISTING POLICIES AND PLANS

The South Coast Air Basin (SoCAB) encompasses Orange County, and portions of Los Angeles, San Bernardino, and Riverside Counties (Figure 1). Historically, this air basin has been impacted by degraded air quality, stemming from a combination of heavy economic activities, such as goods movements to and from the Los Angeles and San Pedro ports, and geographic and meteorological conditions that build and concentrate air pollutants within the region.

Figure 1: South Coast Air Basin

Basemap from arcGIS. *Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community*

There are several policies at the federal, state, and local levels targeting greenhouse gas emissions, criteria air pollutant emissions, zero-emission vehicle and infrastructure deployments, and equity relevant to the development of a SoCAB MHD-ZEV infrastructure Blueprint. At the federal level, President Biden's Executive Order (E.O.) 14057 directs the United States to reduce its scope 1 and 2 greenhouse gas emissions by 65% below 2008 levels by 2030 and achieve a 100% zero-emission vehicle acquisitions by 2035, with the ultimate goal of a net-zero emissions economy by 2050 [1]. Under E.O. 14008, the President established the Justice40 Initiative, which directs federal agencies to ensure that at least 40% of benefits achieved through the climate and clean energy investments be realized within disadvantaged communities [2].

At the state level, California is committed to combatting climate change and in doing so, also addressing inequity related to its current energy system [3]. To that end, it has adopted several emissions reduction goals. In 2006, the State passed Assembly Bill (AB) 32, which committed to reduce statewide emissions to 1990 levels by 2020 [4]. In 2016, Senate Bill (SB) 32 expanded on the emissions reduction framework established in AB 32, adding a 2030 target of 40% emissions reduction below 1990 levels [5]. Former Governor Brown's E.O. B-55-18 directs California to achieve carbon neutrality economy-wide by no later than 2045, with a further goal of being net carbon-negative after that date [6].

California has also made strong commitments to improve air quality. The 2017 Update to the Scoping Plan emphasizes the opportunity of climate actions to reduce concurrently criteria air pollutant (CAP) emissions attributed to poor air quality [7]. Disadvantaged communities (DACs), as defined under the guidance of SB 535 [8], are historically disproportionately impacted by degraded air quality and therefore, actions towards maximizing air quality co-benefits can provide significant health benefits to local communities [9]. In 2016, AB 1550 was passed, expanding funding to DACs by requiring that at least 25% of Cap-and-Trade revenues (the Greenhouse Gas Reduction Fund) go towards projects with DACs [10].

To achieve its climate and air quality goals, California has adopted aggressive zero-emission vehicle adoption goals for on-road vehicles, as well as interim requirements for internal combustion vehicles. Several policies target the medium- and heavy-duty sector, including the Low NOx Heavy-duty Omnibus Regulation, which requires a 75% reduction in NOx emissions below current standards for all new heavy-duty ICV models starting in 2024 and an 90% reduction in NOx emissions in 2027 [11]; SB 350 enabled electric grid infrastructure planning for transportation electrification [12]; AB 8 which provides funding to hydrogen refueling stations until 100 stations are available [13]; Innovative Clean Transit regulation which mandates 100 percent zero-emission public bus fleets by 2040 [14]; the Advanced Clean Trucks regulation which mandates increasing sales of zero-emission medium- and heavy-duty vehicles (MHDVs) thru 2035 [15]; and Governor Newsom's EO N-79-20 which directs that all drayage trucks be zero-emission by 2035, and all other MHDVs be zero-emission by 2045, where feasible [16]. The California Air Resources Board is also drafting an Advanced Clean Truck Fleets regulation to target high priority fleets in support the goals of E.O. N-79-20 [17].

AB 2127 commissioned biennial electric vehicle charging infrastructure assessments to evaluate market trends and identify charging needs [18]. While the assessment focuses on the 2030 interim targets, the governor has directed consideration of the end target of 2045, 100% ZEVs [19]. The 2021 AB 2127 assessment found that at least 157,000 chargers are needed to support medium- and heavy-duty zero-emission vehicle (MHD-ZEV) deployments by 2030. Furthermore, it recommended a standardized, network-based approach to increase charger reliability and reduce consumer uncertainty [20].

Within the South Coast Air Basin (SoCAB) region, the South Coast Air Quality Management District (SCAQMD) has a number of initiatives to improve regional air quality. For example, South Coast AQMD Clean Port Initiative outlines steps that the SCAQMD in partnership with other agencies can take to reduce local port pollution, including emissions associated with drayage trucks. Additionally, the two ports in SoCAB—the Port of Los Angeles and the Port of Long Beach—have agreed to the San Pedro Clean Air Action Plan which targets NOx and PM emissions reductions and sets the goal of 100% zero-emission operations by 2035 [21].

Funding Programs Relevant to Medium- and Heavy-Duty Zero-Emission Vehicles and Infrastructure

Investing in zero-emission vehicles, whether battery electric or fuel cell electric, costs considerably more than internal combustion vehicles. Direct government funding for MD/HD-ZEVs helps offset the higher capital costs of alternative fueled vehicles, making price less of a consideration for early adopters. Subsidized purchases increase demand. Increased sales of a new product such as a ZET might establish increased supply. Subsequent loss of subsidy with government supply policy can drive the market towards parity with conventional technologies. There are several federal, state, and regional funding programs that provide funding for MD/HD ZEVs as well as their required fueling infrastructure. Available programs vary in terms of funding structure and include point-of-sale vouchers, grants, and rebates. Some programs allow for "stacking" –combining multiple program funds to support a single project and/or procurement for equipment.

- **National Electric Vehicle Infrastructure Formula Program**: created under the Bipartisan Infrastructure Bill and administered by the Federal Highway Administration, the goal of this program is to fund State electric vehicle charging infrastructure projects to support a broader, more reliable, and interconnected charging network [22].
- **Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)**: Funded by the California Climate Investments, this program provides point-of-sale vouchers for eligible vehicles from approved vendors. Eligible vehicles include medium-duty vans, medium- and heavy-duty trucks (including refuse), buses (including school buses), refuse trucks, and electric power take-off [23].
- **Carl Moyer Memorial Air Quality Standards Attainment Program**: Voucher incentive program to purchase on-road, low carbon vehicles or convert

polluting vehicles (greater than 14,000 lbs.) to lower carbon power trains for small fleets (10 or fewer vehicles) [24].

- **Volkswagen Diesel Emissions Environmental Mitigation Trust**: Administered by Air Quality Management/Control Districts, the trust funds both zero-emission vehicle and infrastructure deployments, spanning light-duty to heavy-duty applications [25].
- **Energy Infrastructure Incentives for Zero- Emission Commercial Vehicles (EnergIIZE Commercial Vehicles):** Newly launched program to partially fund fueling equipment for medium- and heavy-duty battery electric and hydrogen fuel cell electric vehicles. The program will offer four "funding lanes," including a fast-track lane for fleets that already have purchased a vehicle [26].
- **Low Carbon Fuel Standard**: Tradeable credits program with the goal of reducing the carbon intensity of transportation fuels, including electricity and hydrogen. Eligible fuel providers receive credits based on volume and the calculated carbon intensity of the certified fuel pathway [27].
- **Discretionary Grant Program for Charging and Fueling Infrastructure:** Established under the Bipartisan Infrastructure Bill, this program focuses on deploying zero-emission vehicle fueling infrastructure along identified corridors. At least 50 percent of the benefits (are earmarked for low- and moderate-income communities [22].
- **Zero and Near Zero-Emission Freight Facilities:** provides funding for "pre-commercial" deployments that demonstrate emerging, zero- and near-zero emission technologies [28].
- **Sustainable Transportation Equity Project (STEP):** Program funded under the California Climate Investments, focuses on community-level investment in sustainable transportation, encompassing public transit and other clean mobility initiatives [29].
- **Zero-Emission Truck and Bus Pilot Projects:** subprogram under the California Climate Investments, administered by the California Air Resources Board, that funds pilots [28].
- **Targeted Airshed Grants program:** program by U.S. Environmental Protection Agency to address degraded air quality within communities [30].

Funding for pilots and other "pre-commercial" deployments is important for proof-of-concept designs that will inform broader deployment of zero-emission vehicle infrastructure to meet State goals. For example, the current ZANZEFF projects at the Ports are creating a test bed for the development of the next generation of heavy-duty fuel cell electric trucks and hydrogen refueling stations [31], [32].

The major California investor-owned utilities have also implemented charging infrastructure funding programs. In the SoCAB region, Southern California Edison's Charge Ready Transport program, which helps fleets design, install, and maintain charging infrastructure, including transformer upgrades, as well as covers some of the costs [33].

In addition to technology funding, the California Energy Commission recently awarded funding to support workforce development, under GFO-21-602 IDEAL ZEV Workforce Pilot, to multiple recipients within the SoCAB region [34].

Medium- and Heavy-Duty Zero-Emission Vehicle Availability

Depending on the model, vehicle lead times can be over a year due to the in-development status of many as well as supply chain challenges that are compounded by COVID-19 delivery delays. Table 1-Table 3 provide a list of announced and available MHD-ZEVs for the U.S. market.

Table 1: Announced ZEVs

Make	Model	Class	Fuel Type	Expected Delivery Date
BusTech	City Bus	8	Electric	N/A
	School Bus	8	Electric	N/A
	Double Decker Bus	8	Electric	N/A
	Articulated Bus	8	Electric	N/A
	Electric Rapid Transit Bus	8	Electric	N/A
Vanhool	Exqui.City 18m Electric Rapid Transit Bus	8	Electric	N/A
	Exqui.City 24m Electric Rapid Transit Bus	8	Electric	N/A
Volta	Zero - Delivery Truck	8	Electric	2023
Nikola	Two FCEV Long Haul Truck	8	H2	2024
	Tre FCEV Long Haul Truck	8	H2	2023
Kenworth	T680 FCEV Long Haul Truck	8	H2	Used in Pilot Programs
Geely	Homtruck – Semi Truck	8	Electric	2024

N/A = Not Available

Table 2: Commercially Available MHD-FCEVs

Make	Model	Class	Tank Capacity (kg)	Tank Rated Pressure (Bar)
Hyundai	Xcient Fuel Cell Truck	Class 8	32	350
Van Hool	A330 Fuel Cell Bus	Bus	N/A	N/A
ENC	Axess-FC 35 ft. Bus	Bus	50	N/A
	Axess-FC 40 ft. Bus	Bus	50	N/A
New Flyer	Xcelsior CHARGE H2 40 ft Bus	Bus	37.5	350
	Xcelsior CHARGE H2 60 ft Bus	Bus	60	350

N/A = Not Available

Table 3: Commercially Available MHD-BEVs

Make	Model	Class	Battery Size (kWh)	Make	Model	Class	Battery Size (kWh)
BYD	8TT Tandem Axle Truck	8	422, 563	Kenworth	T680E Truck	8	396
	8R Refuse Truck	8	281, 403		K270E Truck	6	141-282
	8Y Terminal Tractor	8	217		K370E Truck	7	141-282
	6R Refuse Truck	6	281	Freightliner	eActros	8	336, 448
	6F Cab and Chassis	6	211		eCascadia Truck	8	475
	Transit Buses	7	215, 313		eM2 Truck	6-7	315
	K8M Transit Bus	8	391	FUSO	eCanter Truck	4	81
	K9M and K9MD Transit Buses	8	313, 446	Workhorse	C1000 Truck	4	70, 105
	K11M Transit Bus	8	578	Arrival	Van	3-5	44-133
	C6M Coach Bus	6	141		Bus	8	N/A
	C8M and C8MS Coach Buses	8	313	Nikola	Tre BEV	8	753
	C9M Coach Bus	8	446	Van Hool	CX45E	8	676
	Coach Buses	8	446	Bustech	ZDI	8	450
	Type D School Bus	8	274, 300	Thomas	Saf-T-Liner C2 Jouley	8	226
	Various Forklifts	2-4	N/A	Proterra	ZX5 - 35 ft Bus	8	225, 450
Ford	E-Transit	2-4	68		ZX5 - 40 ft Bus	8	225, 450, 675
Volvo	VNR Electric Truck	7-8	375, 565	New Flyer	Excelsior - Bus 60 ft	8	N/A
	FM Electric Truck	8	180-540		Excelsior - Bus 40 ft	8	N/A
	FMX Electric Truck	8	180-540	ENC	Axess – 32 ft.	8	444, 518
	FE Electric Truck	7	200-265		Axess – 35 ft.	8	444, 518
	FL Truck	5	200-395		Axess – 40 ft. BEB	8	444, 518
	FH Truck	8	180-540	Tesla	Semi	6-8	N/A
	BZL Bus	6	470	Hyundai	Transit Bus	6	128, 256
	7900 Bus	6-8	198, 264, 330, 396	Rivian	Prime Van	2-4	N/A

N/A = Not Available

Existing Zero-Emission Charging and Fueling Infrastructure and Future Plans

Many of the charging stations for MHD-BEVs are for early markets, including delivery vehicles, school buses, and transit buses. Most relevant for this study, several transit agencies with the SoCAB region have already begun to transition to zero-emission buses, including OCTA, LA Metro, and Foothill Transit, see Table 4. CARB hosts the existing ZEB rollout plans on its ICT website [35]. The listed agencies with existing plans are planning to rely mostly on depot-based charging/fueling.

Table 4: Zero-Emission Bus Transition Status of Major Transit Agencies within the SoCAB Region

Transit Agency	Transition Status	Total Fleet Size	Current BEV Fleet	Current FCEV Fleet
Antelope Valley Transit Authority	100% fixed-route ZEB	At least 65	All BEB	0
City of LA DOT	100% by 2028	503	29, 30 more planned	0
Culver CityBus	100% by 2028	54	4, 6 more ordered	0
Foothill Transit	100% by 2030	At least 350	33	20 planned
GTrans (Gardena MBL)	100% by 2035	At least 65	2	0
Glendale Beeline	100% by 2040	About 80	0	0
LA Metro	100% by 2030	About 2,300	At least 40	
Long Beach Transit	100% by 2030	About 250	10, 20 more planned	0
Montebello Bus	100% by 2040	66	0	0
Orange County TA	100% by 2040	508	10	10
Santa Clarita Transit	100% by 2040	56 local, 28 commuter, 1 trolley, 21 Dial-A-Ride, 8 ASI	0	0
Santa Monica Bus	100% by 2030	195	At least 18	0
Omnitrans	100% by 2040	269	4	0
Riverside TA	100% by 2040	334	0	0

Sources: https://ww2.arb.ca.gov/our-work/programs/innovative-clean-transit/ict-rollout-plans; https://www.avta.com/avta-passes-a-new-electric-milestone-seven-million-miles-of-zero-emission-bus-operations; https://ladot.lacity.org/dotnews/los-angeles-department-transportation-install-solar-and-storage-microgrid-and-ev-charging; https://ww2.arb.ca.gov/sites/default/files/2020-12/LADOT_ROP_Reso_ADA12172020.pdf; https://content.govdelivery.com/accounts/CACULVER/bulletins/2f358c3; https://ww2.arb.ca.gov/sites/default/files/2020-09/Foothill_ROP_Cover%20LetterADA09092020.pdf; https://luskin.ucla.edu/wp-content/uploads/2021/06/1GTransBusesRevised_RA.pdf; https://www.latimes.com/socal/glendale-news-press/news/story/2020-01-30/glendale-buys-new-buses-environmental-debate; https://www.metro.net/about/l-a-metro-now-running-all-zero-emission-electric-buses-on-the-g-orange-line-in-the-san-fernando-valley/; https://ridelbt.com/pr-new-bebs/;

There are existing charging and hydrogen fueling infrastructure deployed across the State and specifically in the SoCAB region. Statewide, there are currently over 40 hydrogen refueling stations and over 9,000 DC fast chargers deployed [36], most of these stations were built for light-duty vehicles. Generally, the ability of MHDVs to use light-duty-based infrastructure is limited, given 1) significantly larger fuel demand, in which a couple MHDVs could consume the total of an LDV station’s daily capacity,

2) MHD-ZEVs may have different fueling/charging protocols [37], [38], and/or 3) they may not be able to navigate the station due to station design (location, spacing).

There are a few hydrogen stations within the SoCAB region that are specifically designed to meet MHD-FCEV demands. A recent renewable hydrogen production solicitation at the CEC, GFO-20-609, showed CapEx from $12M - $144M for 1 – 12 tons/day [41]. So far, these hydrogen stations have been designed to meet specific fleet needs. These stations include: POLB hydrogen refueling station dispensing hydrogen sourced exclusively from biogas using tri-generation to produce electricity, heat, and hydrogen fuel to support the use of FCEV Class 8 drayage trucks [39] and two hydrogen fueling stations along drayage routes servicing drayage trucks from POLA [32], and a hydrogen refueling station at the Orange County Transit Authority [40].

CHAPTER 2: METRICS FOR DEVELOPING AND EVALUATING A REPLICABLE BLUEPRINT FOR MEDIUM- AND HEAVY-DUTY VEHICLE INFRASTRUCTURE DEPLOYMENT

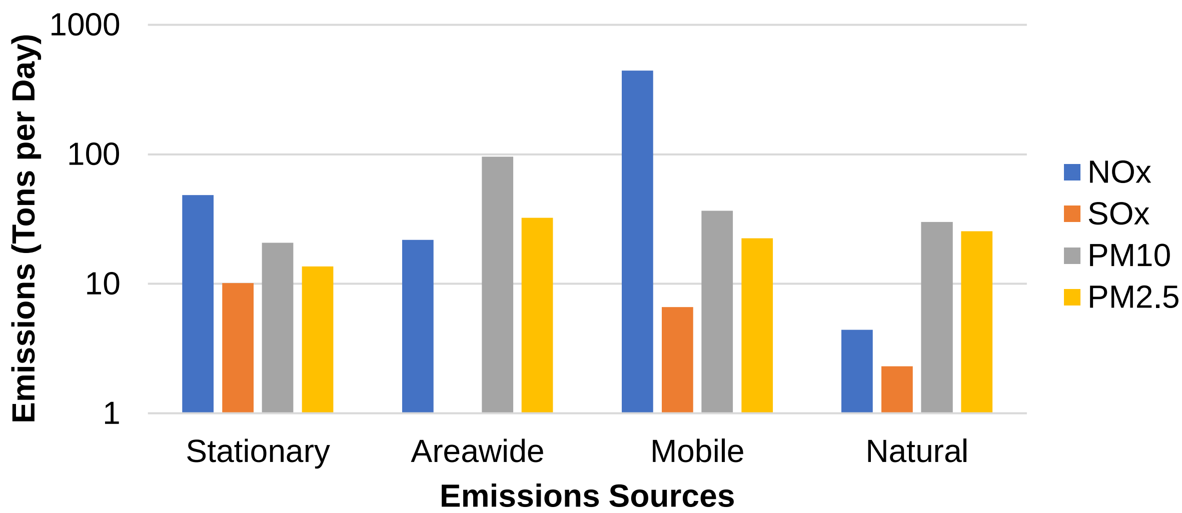
The blueprint will be evaluated based on three general categories: technical performance, cost, and environmental impacts. The following sections describe the specific metrics in more detail.

Technical Metrics

Technical performance will be evaluated based on the percentage of MHD-ZEV demand that can be met with the Blueprint. This percentage will be based on the projected MHD-ZEV demand to meet 2045 targets, with an additional focus on the year 2035 for the three target vehicle categories: transit, drayage, and long-haul.

The proposed approach for the blueprint infrastructure is to site charging and hydrogen stations based on projected MHD-ZEV demands to meet the 2045 State goals. Siting will require the spatial and quantitative data on target vehicle fleets as well as assumptions on vehicle and station performance and capacity. Baseline data on regional emissions are available through CARB, see Figure 2 [42]. As the figure shows, mobile sources contribute the greatest amount of NOx emissions within the SoCAB region.

Figure 2: SoCAB 2012 Annual Average Emissions by Source



Data from California Air Resources Board

Vehicle Demand

Vehicle emissions can be further resolved using CARB's EMFAC tool, which provides vehicle population, vehicle miles traveled, fuel consumption, and emissions data by sub-region or statewide. For example, EMFAC shows that while heavy-duty vehicles represent less than one percent of on-road vehicles in the region, they contribute about 32% of on-road NOx emissions [43]. Table 5 presents the vehicle categories within EMFAC and how they map to other vehicle categorization systems.

Table 5. Vehicle Classifications

<table>
<tr><th rowspan="2">Gross Vehicle Weight Rating (lbs.)</th><th colspan="4">Vehicle Classifications</th></tr>
<tr><th>Class</th><th colspan="2">California ARB (EMFAC 2021) [43]</th><th>U.S. FHWA [44]</th></tr>
<tr><td>0-6,000</td><td>1</td><td>Light-Duty Cars and Trucks (LDA, LDT1, LDT2)</td><td rowspan="2"></td><td rowspan="2">Light Truck</td></tr>
<tr><td>6,001 – 8,500</td><td>2A</td><td>Medium-Duty Cars And Trucks (MDV)</td></tr>
<tr><td>8,501-10,000</td><td>2B</td><td>Light-Heavy Duty Trucks (LHD1)</td><td rowspan="8">Buses (SBUS, Motor Coach, UBUS, OBUS, All Other Buses)</td><td>Light/Medium Duty Truck</td></tr>
<tr><td>10,001 – 14,000</td><td>3</td><td>Light-Heavy Duty Trucks (LHD2)</td><td rowspan="4">Medium Duty Truck</td></tr>
<tr><td>14,001 – 16,000</td><td>4</td><td>(T6 Class 4) Public, Instate Delivery, Instate Other, CAIRP, OOS</td></tr>
<tr><td>16,001 – 19,500</td><td>5</td><td>(T6 Class 5) Public, Instate Delivery, Instate Other, CAIRP, OOS</td></tr>
<tr><td>19,501 – 26,000</td><td>6</td><td>(T6 Class 6) Public, Instate Delivery, Instate Other, CAIRP, OOS</td></tr>
<tr><td>26,001 – 33,000</td><td>7</td><td>(T6 Class 7) Public, Instate Delivery, Instate Other, CAIRP, OOS</td><td rowspan="3">Heavy Duty Truck</td></tr>
<tr><td>33,001 – 60,000</td><td>8A</td><td rowspan="2">(T7 Class 8) Public, CAIRP, Utility, NNOOS, NOOS, POAK, POLA, Other Port, Single Concrete/Transit Mix Truck, Single Dump, Single Other, Tractor, SWCV, T7IS, PTO</td></tr>
<tr><td>>60,000</td><td>8B</td></tr>
</table>

Data from EMFAC2021

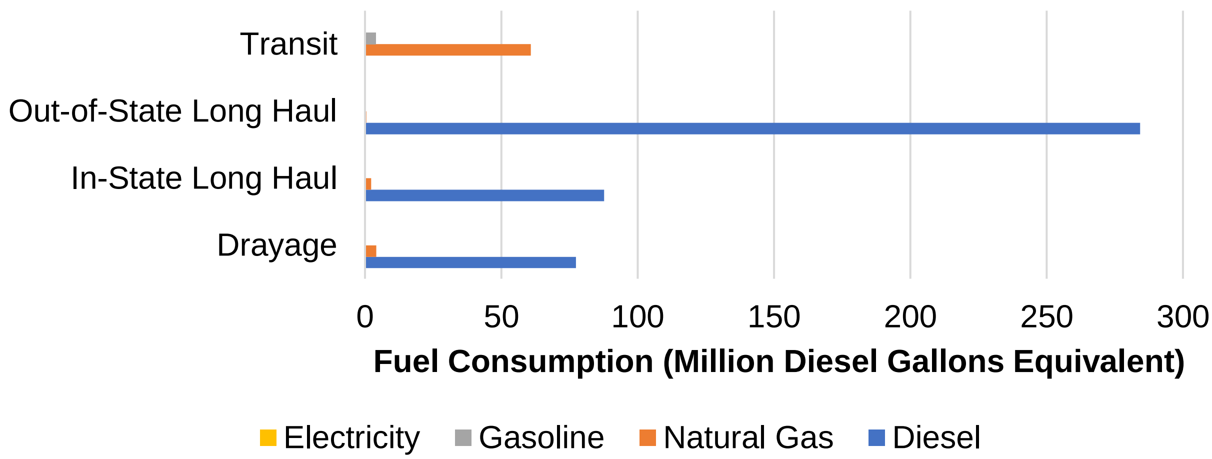
This study focuses on three MHDV categories: transit, drayage, and long haul. Long haul is further divided into "instate" and "out-of-state" vehicles. This distinction is important, as it is less clear how regulations will be enforced on out-of-state vehicles, and it is less likely that out-of-state vehicles will be able to fuel with fleet "home base" stations and instead will more likely require the use of public charging/fueling stations. Table 6 shows how the vehicle categories for the current study map to the EMFAC classifications. Figure 3 shows the baseline fuel consumption for the target vehicle categories as estimated in EMFAC.

Table 6. Target Vehicle Categories mapped to EMFAC

Vehicle Category for Study	EMFAC Classification(s)
Instate long haul	T7 Class 8 Tractor
Out-of-State Long Haul	T7 Class 8 CAIRP, T7 Class 8 NNOOS, T7 NOOS
Drayage	T7 Class 8 POLA, T7 Class 8 POAK *
Transit Buses	UBUS

**For the year 2019 in EMFAC2021, there is one POAK drayage truck that operates within the SoCAB region. According to the model, no 'Other Port' trucks operate within SoCAB for the timespan examined.*

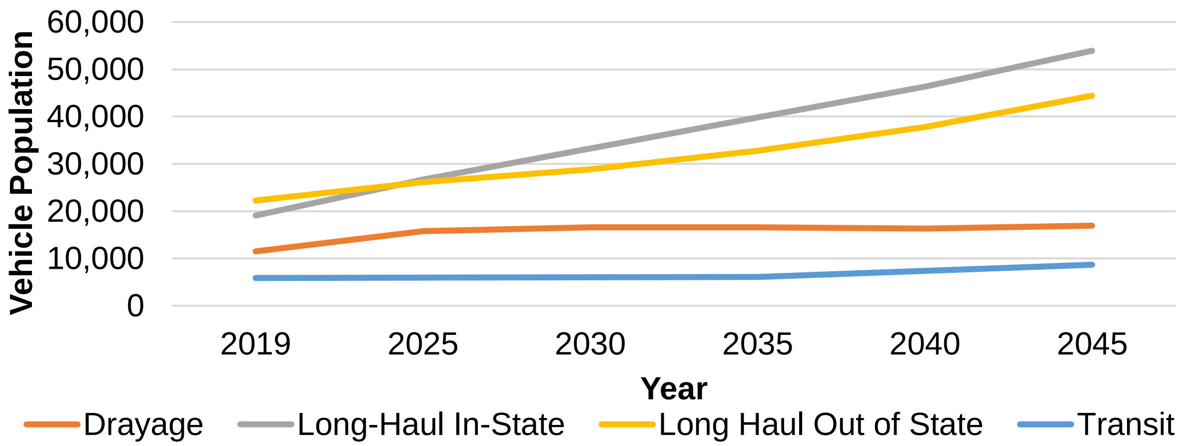
Figure 3: Fuel Consumption by Vehicle Category and Fuel Type, Year 2019



Data from EMFAC 2021

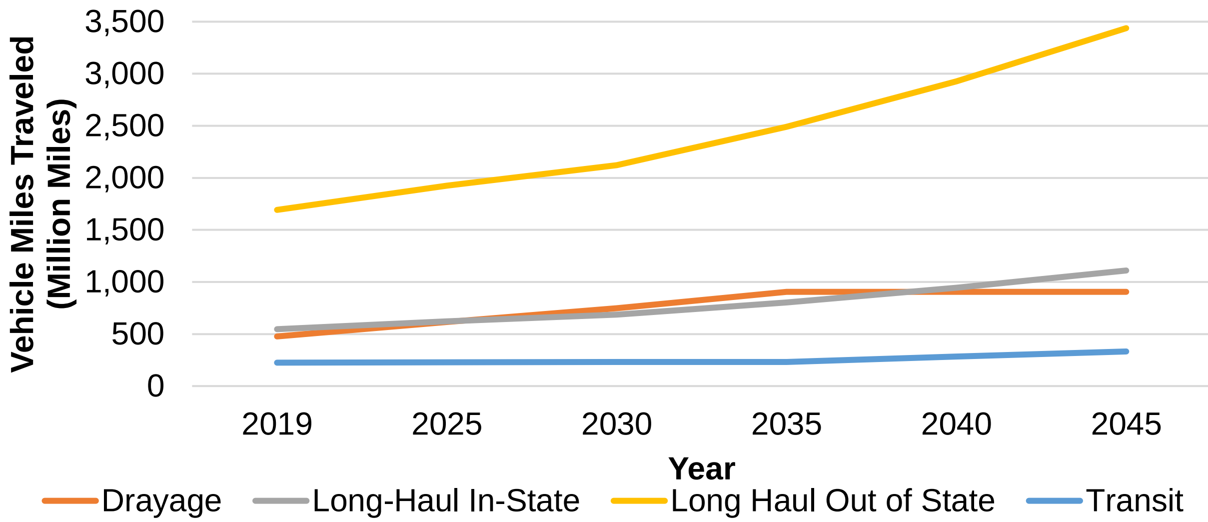
The EMFAC vehicle projections for the SoCAB region will be used as a base case for the current study against which the blueprint-enabled MHD-ZEV adoption will be evaluated, see Figure 4 and Figure 5. MHD-ZEV adoption requirements stipulated for the blueprint will follow the State mandated sales requirements and will align with previous work conducted for the California Environmental Protection Agency [45].

Figure 4: Projected SoCAB Population of Target Categories, Years 2019 - 2045



Data from EMFAC 2021

Figure 5: Projected SoCAB Vehicle Miles Traveled of Target Categories, Years 2019-2045



Data from EMFAC 2021

Under their "Low Carbon" scenario, Brown et al (2021) calculated the statewide rollout of MHD-ZEVs needed to meet 2045 State goals [45]. These projections, paired with EMFAC regional and existing fleet transition plans will be used to inform the rollout of MHD-ZEVs required to meet 2045 goals within the SoCAB region.

Station Design and Spatial Considerations

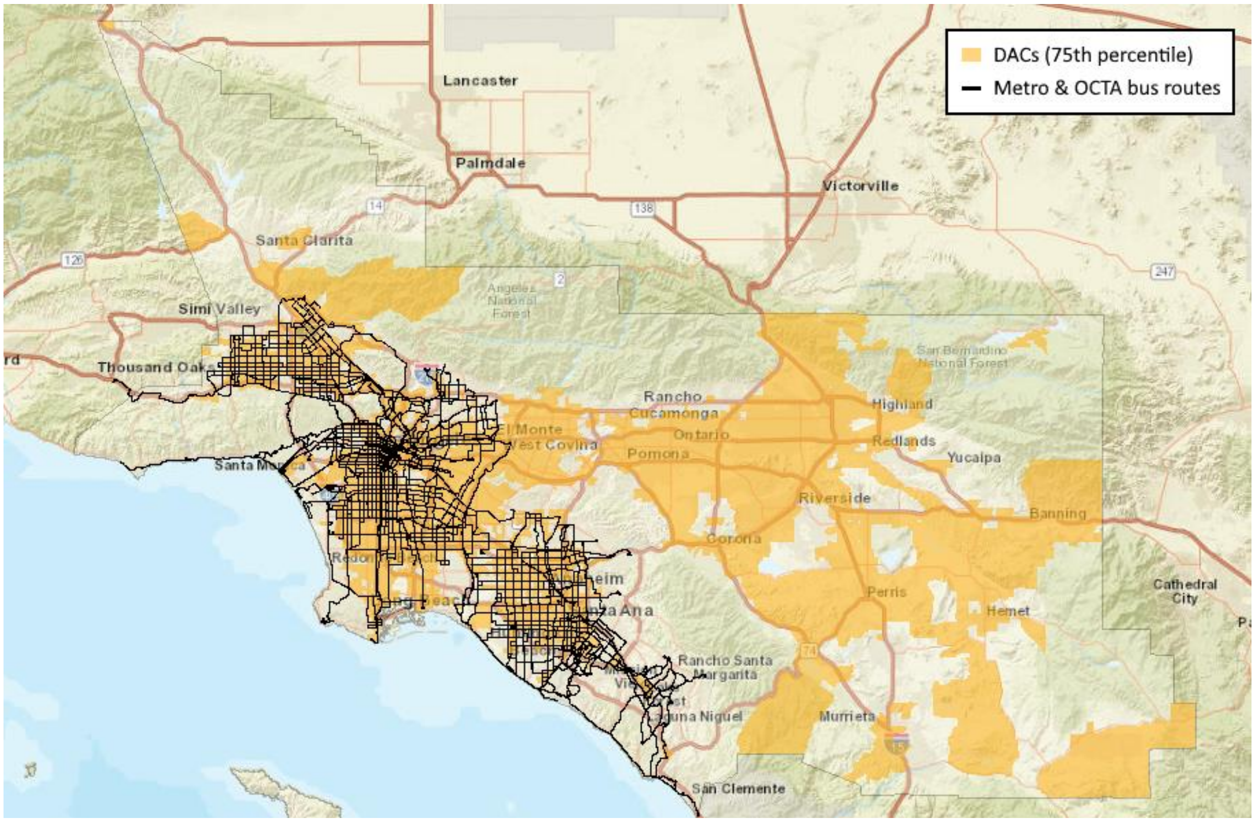
There are four general categories of stations:

1. Private station that provides fuel to a single fleet
2. Private station that provides fuel to multiple fleets under a shared-use agreement
3. Public station that is restricted to a specific class of vehicles (e.g., LDV versus MHDV)
4. Public station that provides fuel for all on-road vehicle types

Early MHD-ZEV station deployments have shown a preference for infrastructure co-located with fleet depots and along fleet routes. Spatial siting of stations will differ between bus and truck categories. For transit fleets, the focus will be on depot-based stations for specific fleets that are informed by publicly available data on depots and bus transfer stations. For drayage and long-haul trucks, the focus will be on charging and hydrogen fueling stations along truck routes. Where sufficient data are available to identify depot locations, fleet-specific stations will be considered.

Spatial resolution of vehicle travel patterns are available through a combination of references including CARB, the Federal Highway Administration, as well as other models such as the Heavy-Duty Truck Model developed by the Southern California Association of Governments [46] and the anticipated MHD-ZEV infrastructure model HEVI-LOAD (previously HEVI-Pro) [47]. Transit routes are publicly available, and at least two of the major transit agencies, LA Metro and OCTA have arcGIS files of routes that can be utilized for the spatial siting analysis and DAC impact assessment, see Figure 6.

Figure 6: LA Metro and OCTA Bus Routes in the SoCAB Region



Basemap from arcGIS. *Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community*

Data Sources: CalEnviroScreen 4.0; LA Metro; OCTA

In summary, three technical metrics will be used to evaluate the impact of the MHD-ZEV Infrastructure blueprint: 1) vehicle demand met in terms of vehicle miles traveled and fuel consumption (hydrogen, electricity), 2) required capacity of fueling/charging stations, and 3) spatial distribution of stations within the region.

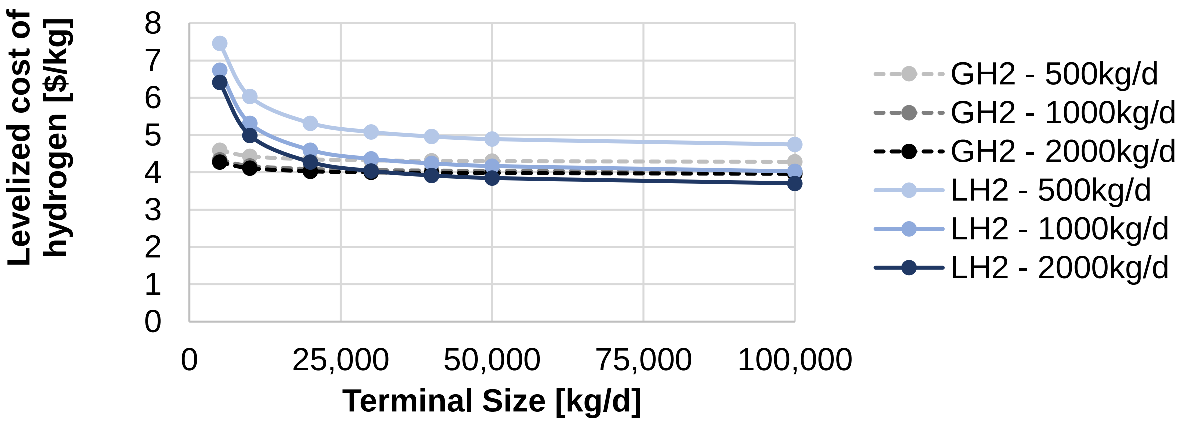
Economic Metrics

Two economic metrics will be used to evaluate the impact of the MHD-ZEV Infrastructure blueprint: 1) fuel cost and 2) station cost. These costs will be quantified for both hydrogen refueling stations and BEV charging stations.

Hydrogen Station Costs

Hydrogen station costs will be based on the combined cost of hydrogen distribution and dispensing is sourced from the U.S. Department of Energy's H2A Delivery Analysis model [48], with results displayed in Figure 7. These costs include transport to a terminal from the production site, compressing or liquifying as appropriate, transport to the dispensing station, and the dispensing station itself. Note both terminal size and state (gaseous "GH2" or liquid "LH2") have an impact on cost. Present work assumes liquid hydrogen will be dominant with higher capacity stations supporting widespread hydrogen adoption for MD/HD FCEVs.

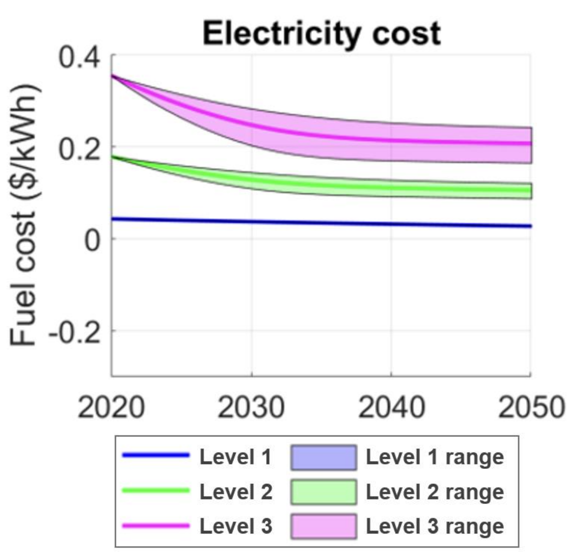
Figure 7: Levelized Cost of Hydrogen Distribution and Dispensing



Electric Charging Station Costs

Electric charging station cost is dependent on the level (or power) of charging. A per-unit cost of charging station is developed from work by Lane et al. [49] which calculated Level 2 dispensing infrastructure costs for LDVs in California and normalizing by quantity dispensed. An assumption here is made that these charging costs are applicable for MHDVs, which is argued valid as charging power is the primary differentiation between charging different classes of vehicles. For DC fast charging (Level 3), the same methodology is used though component costs are increased in alignment with the increase in charging power [50].

Figure 8: Projected Electricity Cost ($/kWh) for MD/HD BEV Charging



Costs will be used to compare different deployment scenarios. Cost comparisons will be made across different technology selections and station configurations. Total costs will be weighed against the percent of MHDV demand met.

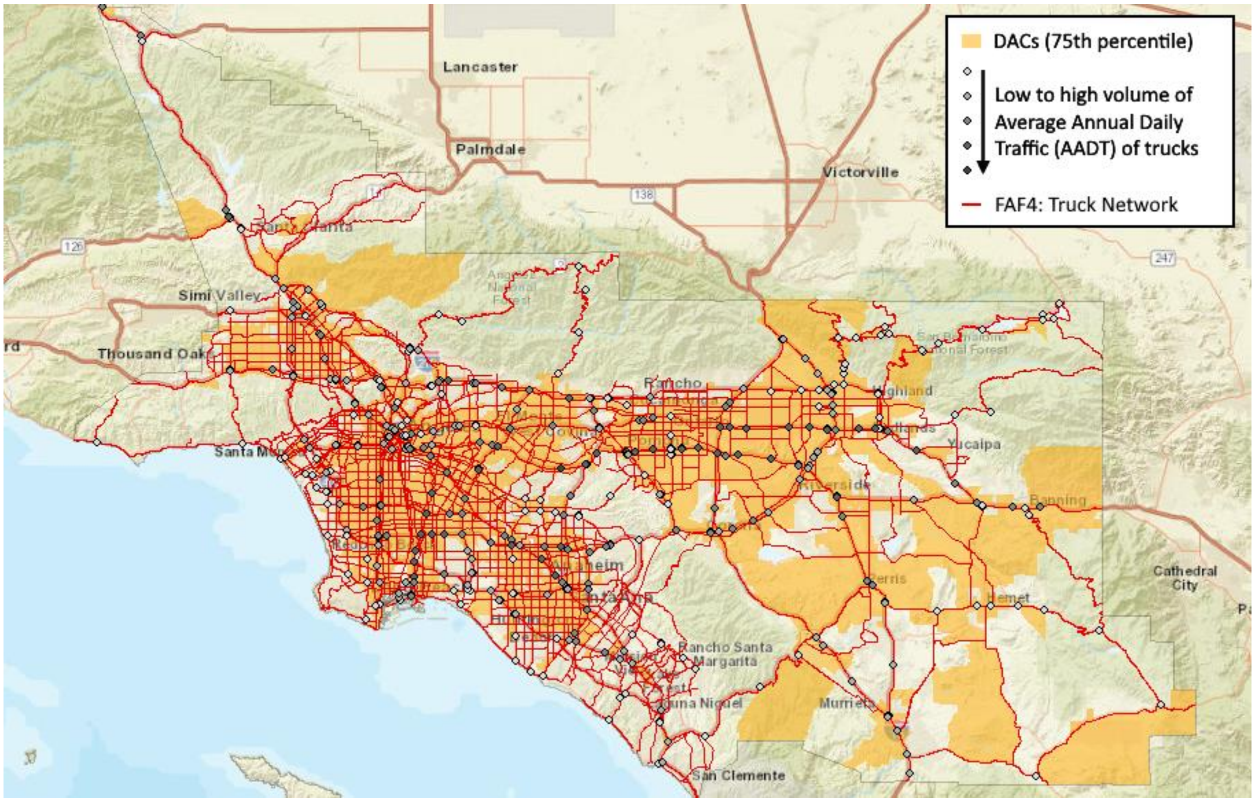
Environmental Metrics

Three environmental metrics will be used to evaluate the impact of the MHD-ZEV Infrastructure blueprint: 1) GHG emissions reduction, 2) criteria air pollutant emissions reduction, and 3) change in regional air quality – with a focus on disadvantaged communities.

GHG emissions reductions will be evaluated at the basin level, using CARB EMFAC data on baseline emissions and the reduction potential of the technologies modeled. Criteria air pollutant emissions reductions will be calculated both at the basin level and at a more refined resolution that will be used as in input to the air quality modeling.

The air quality modeling will be conducted by resolving the change in vehicle emissions within the Sparse Matrix Operator Kernel Emissions (SMOKE) tool, which spatially and temporal assigns emissions within a matrix format for easy utilization within an air quality model [51]. The outputs from SMOKE will then be translated to Community Multiscale Air Quality Modeling System (CMAQ) to determine the change in atmospheric pollution levels, specifically for this study, PM2.5 and ozone [52]. The coincidence of air quality changes with DACs will be spatially assessed using spatial mapping tools.

Figure 9: Coincidence of Heavy-Duty Vehicle Miles Traveled and Disadvantaged Communities with the SoCAB Region



Basemap from arcGIS. *Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community*

Data Sources: CalEnviroScreen 4.0; Caltrans AADT Data; Bureau of Transportation Statistics FAF4 Truck Network

In conclusion, by defining the metrics within each category, and accumulating the defined goals for these metrics, we will be able to clearly measure and easily choose activities to mitigate climate change in the highly populated South Coast Air Basin in California.

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