CALIFORNIA ENERGY COMMISSION

California Energy Commission

Clean Transportation Program

FINAL PROJECT REPORT

Blueprint for Zero-Emission Concrete Logistics

Prepared for: California Energy Commission

Prepared by: Central Concrete Supply Co., Inc.

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program, formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

To be eligible for funding under the Clean Transportation Program, a project must be consistent with the CEC's annual Clean Transportation Program Investment Plan Update. The CEC issued GFO-20-601 to accelerate the deployment of medium-duty and heavy-duty zero-emission vehicles and zero-emission vehicle infrastructure with a holistic and futuristic view of transportation planning. In response to GFO-20-601, the recipient submitted an application that was proposed for funding in the CEC's notice of proposed award on April 8, 2021, and the agreement was executed as ARV-21-021 on October 6, 2021.

ABSTRACT

The Final Project Report for the *Blueprint for Zero-Emissions Concrete Logistics* project focuses on how Central Concrete Supply Co., Inc. can effectively transition its fleet of more than 250 medium-duty and heavy-duty concrete mixer trucks to zero-emission vehicles.

This blueprint plans for a transition of Central Concrete Supply Co., Inc.'s fleet that will phase out diesel vehicles and fueling stations while phasing in hydrogen fuel cell electric vehicles, wet-hose fueling stations, and storage infrastructure.

By the year 2040, wet-hose fueling stations and storage requirements will plateau. The carbon emissions and air pollutants associated with the legacy fleet of diesel vehicles and fueling stations will decrease once the hydrogen vehicles are phased in from 2030 onwards.

Industry experts expect fuel cell electric vehicles to have a lower total cost of ownership than business-as-usual diesel trucks, with a cost breakeven point between 2036 and 2040. In most lifecycle cost analyses, fuel cell electric vehicles offer greater fuel efficiency and reduced maintenance costs than conventional vehicles, which outweighs the additional upfront vehicle costs. Transitioning the Central Concrete Supply Co., Inc. fleet from fossil fuel-based diesel to zero-emission would annually remove over 2,200 tons of carbon dioxide, 8,700 pounds of oxides of nitrogen, 2,500 pounds of reactive organic gases, and 200 pounds of particulate matter smaller than 10 microns in diameter, with up to 22 percent of these emissions reductions occurring in disadvantaged communities.

Keywords: concrete logistics, fuel cell electric vehicles, zero-emission vehicles, medium-duty and heavy-duty vehicles, concrete mixer fleet, ZEV transition

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EXECUTIVE SUMMARY

The California Energy Commission awarded Central Concrete Supply Co., Inc., a subsidiary of Vulcan Materials Company, a $200,000 grant to complete a planning blueprint for transitioning Central Concrete Supply Co., Inc.'s fleet of concrete mixer trucks to zero-emission vehicles. In the completed blueprint, *Blueprint for Zero-Emission Concrete Logistics*, Central Concrete Supply Co., Inc. compares diesel, battery-electric, and hydrogen fuel cell options for Central Concrete Supply Co., Inc.'s zero-emission vehicle transition and determines that hydrogen is the most realistic and cost-effective way to transition this fleet. Battery-electric trucks are not feasible when payloads are heavy and mileage or use duration is long between refueling opportunities, as with concrete trucks; therefore, hydrogen fuel cell electric vehicles become the only choice. The main goal of the blueprint was to assess Central Concrete Supply Co., Inc.'s options for zero-emission vehicle technologies, infrastructure, funding, workforce development, and community outreach, as well as providing next steps for the implementation of these options. The blueprint plans for a transition of Central Concrete Supply Co., Inc.'s fleet of concrete mixer trucks to hydrogen fuel cell electric vehicles. Over the next 20 years, the transition will phase out diesel vehicles and fueling stations while phasing in hydrogen fuel cell electric vehicles, hydrogen dispensing stations, storage infrastructure, and wet-hose refueling trucks.

Central Concrete Supply Co., Inc. worked with partners Arup US, Inc. and Build Momentum, Inc. to achieve all measurable project objectives, including:

- Engaged a stakeholder network to develop an approach to rapidly deploy medium-duty and heavy-duty zero-emission vehicle infrastructure.
- Defined and prioritized vehicle and equipment types most suited for early transition to zero-emission vehicle technologies.
- Defined critical performance specifications that are important for each medium-duty and heavy-duty zero-emission vehicle duty cycle.
- Identified workforce education and training resources to prepare drivers and maintenance technicians for medium-duty and heavy-duty zero-emission vehicles and charging and refueling infrastructure at Central Concrete's facilities.
- Prepared a facility site design for Central Concrete Supply Co., Inc.'s San Francisco plant at Pier 92, vetted the infrastructure design process, and identified real-world operability considerations given existing uses.
- Developed a phased approach to infrastructure deployment that maintains flexibility to react to changes to a nascent market with rapidly evolving technology.
- Developed two improved total cost of ownership models to help medium-duty and heavy-duty fleet and facility operators better understand the capital expenses, operational expenses, and rates of return on investment associated with both vehicles and infrastructure for hydrogen-fueled and battery-electric vehicles.
- Developed an ecosystem of strategic partners and business model innovations to support zero-emission vehicle market adoption.

- Developed and shared a replicability strategy for deploying zero-emission vehicles and zero-emission vehicle infrastructure throughout the concrete supply chain.

Transitioning the Central Concrete Supply Co., Inc. fleet from fossil fuel-based diesel to zero-emission would remove over 2,200 tons of carbon dioxide, 8,700 pounds of oxides of nitrogen, 2,500 pounds of reactive organic gases, and 200 pounds of particulate matter smaller than 10 microns in diameter annually, with up to 22 percent of these emissions reductions occurring in disadvantaged communities.

CHAPTER 1: Background

1.1 Introduction

1.1.1 Problem Statement

Emissions from petroleum transportation fuels contribute to global climate change and transitioning to zero-emission vehicles (ZEV) is critical to California's statewide plan to address climate change; however, many of California's fleet owners do not have experience with alternative fuels for medium-duty and heavy-duty (MDHD) vehicles. One solution is to draft publicly-shared, detailed transportation planning documents for MDHD zero-emission vehicles and ZEV infrastructure for individual use cases.

Central Concrete Supply Co., Inc. (Central Concrete), a subsidiary of Vulcan Materials Company, applied for and received a $200,000 planning grant from the California Energy Commission to complete a blueprint for transitioning their fleet of concrete mixer trucks to zero-emission vehicles. Central Concrete developed and published the planning document *Blueprint for Zero-Emission Concrete Logistics* (blueprint)[1] to address this gap in education and information by using Central Concrete's unique position as a sustainability leader in the concrete industry to showcase and demonstrate the value of ZEVs to decarbonizing the concrete industry.

California's concrete industry is one of California's most important economic drivers, directly employing thousands of people across the state, bringing in billions of dollars in revenue, and operating in every community in the state. This industry contains fleets consisting of thousands of MDHD vehicles, including ready-mix concrete delivery trucks, as well as fleets for hauling the cement, sand, and gravel from which concrete is made, and consists of a highly diverse and disassociated set of companies, making education about ZEV and ZEV infrastructure options challenging.

1.1.2 Objectives of the Blueprint

The objectives of the blueprint were to:

- Engage a broad stakeholder network to develop a comprehensive, economic, and equitable approach to rapidly deploy MDHD ZEV infrastructure.
- Define and prioritize vehicle and equipment types most suited for early transition to ZEV technologies, such as battery-electric vehicles (BEV) or fuel cell electric vehicles (FCEV).
- Define critical performance specifications that are important for each MDHD ZEV for each duty cycle.

[1] Blueprint for Zero-Emission Concrete Logistics (https://files.vulcanmaterials.com/central-concrete/Blueprint-ZEV-Concrete-Logistics.pdf)

- Identify workforce education and training resources to prepare drivers and maintenance technicians for MDHD ZEVs on the road, as well as charging and refueling infrastructure at Central Concrete's facilities.
- Prepare a facility site design for a representative facility at Central Concrete's San Francisco plant at Pier 92 to vet the infrastructure design process and identify real-world operability considerations given existing uses.
- Develop a phased approach to infrastructure deployment that maintains flexibility to react to changes in a nascent market with rapidly evolving technology.
- Develop two improved total cost of ownership (TCO) models to help MDHD fleet and facility operators better understand the capital expenses (CapEx), operational expenses (OpEx), and rates of return on investment associated with both vehicles and infrastructure for hydrogen fueled and battery electric vehicles.
- Map the ecosystem of strategic partners and business model innovations supported by ZEV market adoption.
- Develop and share a replicable strategy for deploying ZEVs and ZEV infrastructure throughout the concrete supply chain.

1.1.3 Recipient Background

Central Concrete has been serving the San Francisco Bay Area for more than 70 years as a business focused on successful and sustainable projects. It was among the first concrete companies in the nation to formalize a commitment to sustainable construction. Central Concrete constantly strives to improve practices that advance environmental responsibility, including leadership in low carbon dioxide (CO_2) concrete mix design. For instance:

- Central Concrete is a founding member of the Carbon Leadership Forum[2] and is the first ready mix supplier in North America to publish an Environmental Product Declaration for concrete, which was recognized by the United States Green Building Council's Leadership in Energy and Environmental Design (commonly known as LEED) for environmental impact transparency.
- Central Concrete team members participated in the development of Marin County's first low carbon concrete code.
- Since 2015, Central Concrete's entire fleet has run on 33 percent renewable diesel[3], reducing greenhouse gas emissions by 25 percent to 75 percent when compared to conventional diesel.[4]

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[2] Carbon Leadership Forum website (https://carbonleadershipforum.org/)

[3] Renewable diesel is a fuel made from fats and oils, such as soybean oil or canola oil, and is processed to be chemically the same as petroleum diesel. United States Department of Energy Alternative Fuels Data Center (https://afdc.energy.gov/fuels/renewable_diesel.html)

[4] GHG Reduction Calculator (https://www.neste.us/neste-my-renewable-diesel/product-information/greenhouse-gas-calculator)

- Many of Central Concrete’s facilities are recognized for continual improvement of environmental best management practices, earning the National Ready Mixed Concrete Association’s Environmental Excellence Award.

CHAPTER 2: Community and Stakeholder Engagement

2.1 Summary and Outcomes of Engagement

The purpose of community and stakeholder engagement was to gather the perspectives, opinions, and input of community members and stakeholder groups for use in the development of the final blueprint. A flexible, adaptable outreach approach fostered a two-way dialogue to share perspectives on challenges, risks, concerns, and opportunities.

Outreach efforts began in February 2022 following approval of the "Community and Stakeholder Engagement Plan" in late January. The team developed the outreach plan by first identifying a list of stakeholder types and what the project team hoped to learn from them. The project team went on to identify specific outreach targets within the stakeholder groups and set out from there to engage with specific targets. Given the range of diversity among stakeholder groups, the team employed a tailored approach to each group. The team first reached out to each stakeholder, and after describing the project and goals, asked them how much they wanted to be engaged in the community and stakeholder engagement process, and then engaged with them in those ways.

In many cases, stakeholders explained they were unable to participate in any engagement due to their own organization's bandwidth constraints. This significantly impacted the team's engagement efforts, and some stakeholders simply directed the project team to their websites. In other instances, when stakeholders agreed to meet, they did not have the capacity to follow up. Oftentimes, stakeholders cited COVID-19 pandemic-related staffing shortages. Because of these constraints, outreach efforts began in February and lasted seven months, though initially they had been planned to begin in January and last four months.

The project team held its first meetings with target audiences in March 2022, with substantial progress made at the Advanced Clean Transportation Exposition in May 2022. The team made many contacts there, which laid the groundwork for follow-up meetings that cold calling might otherwise not have. The project team learned that there were no zero-emission concrete trucks available in the United States, and likely will not be for several years. Importantly, because of the outreach required for this project, the grant recipient's parent company, Vulcan Materials Company, established a relationship and began working with a concrete truck manufacturer that is developing a zero-emission concrete truck for use in California.

Generally, private stakeholders seemed most motivated to engage with the project team, with the original equipment manufacturers (OEM) being willing to meet as often as necessary in order to paint a complete picture of the ZEV landscape. Many of them shared information about existing and anticipated government policies and regulations to support early adoption of ZEVs, which guided their zero-emission strategies. Many manufacturers of heavy-duty vehicles shared that the development of specialty ZEVs, such as concrete mixer trucks, would follow a wider-scale deployment and commercialization of MDHD ZEVs, such as Class 8 trucks, given the relative distribution of vehicles on the road. In contrast, community-based organizations and local government agencies showed some signs of outreach fatigue in their lack of enthusiasm to meet. Many directly stated they were overburdened by outreach requests, or did not respond to requests. This, combined with the previously mentioned bandwidth constraints, left the team struggling to gather meaningful community-level perspectives. Therefore, the blueprint focuses more on successful outreach, such as engagement with internal stakeholders, external stakeholders, and OEMs. Central Concrete remains committed to community-level engagement throughout blueprint implementation.

CHAPTER 3: Blueprint Development

3.1 ZEV Technology and Infrastructure Assessment Summary

3.1.1 Technology

Zero-emission MDHD vehicles are still emerging. Neither battery-electric nor fuel cell electric concrete mixers are commercially available in the United States.

Central Concrete Fleet Inventory and Usage

The project team reviewed vehicle trip logs and fuel consumption records for concrete mixing trucks from three Central Concrete sites to identify average and peak trip lengths, as well as average and peak fuel consumption, in order to create typical vehicle usage profiles for the two cases studied for this project: BEVs and FCEVs. At the three representative sites – San Francisco, San Jose, and Pleasanton – early-stage analysis of vehicle usage patterns showed the three sites represent different geographies in which Central Concrete operates: Pier 92 in San Francisco offers a high urban density, where vehicle mileage is typically smaller and average speeds lower, and San Jose and Pleasanton, which offer increasingly less dense locations, where trips are typically over longer distances and at higher average speeds. The San Jose plant offers a less dense urban location than San Francisco, and suburban Pleasanton provides the least dense site of the three.

Vehicle site logs, including concrete mixer truck daily mileage, number of concrete loads, total amount of concrete carried, as well as total shift duration, were analyzed for these three sites. Data summaries for tracking site average and peak values informed infrastructure planning decisions. In all scenarios, project partner Arup US, Inc. (Arup) took the largest mileage and energy demand for multiple years of data to give a conservative estimate. This data is provided in Table 1.

Table 1: Vehicle Usage Patterns by Site

SITE	AVERAGE MILEAGE	PEAK MILEAGE
URBAN	43	80
SUBURBAN	78	155
EX-URBAN	92	150
AVERAGE:	**70**	**120**

Source: Arup US, Inc.

Vehicle usage patterns vary widely across sites and the regions they service, with an average mileage difference of more than 113 percent between the dense, urban sites and the low-density, exurban sites. The average vehicle duty shift is more than nine hours, leaving an average of 14 hours for electric charging for the BEV case (although the worst case is a more significant constraint, as some workdays span as long as 20 hours). The peak daily truck mileage occurs at suburban and ex-urban sites, averaging about 150 miles to 155 miles per day. Both average and peak mileage are important for infrastructure assessment. Average mileage is used for overall infrastructure sizing (i.e., electrical grid infrastructure or hydrogen storage capacity), and peak mileage is used for sizing vehicle charger capacity (i.e., vehicle charge range or hydrogen on-board range). Not all vehicles will need to charge or fuel at the maximum rate, nor at the same time; however, maximum charging or fueling rate is essential to maintaining the rapid turnaround times between trips within one workday.

Charging and Refueling Technologies

The hydrogen-as-a-fuel market is still in its infancy, and there is a large measure of uncertainty about the future of hydrogen infrastructure. Hydrogen is a zero-emissions fuel when measured at the exhaust pipe of a vehicle, but as it is produced from other energy sources, typically fossil fuels, it only has zero lifecycle emissions if it is produced from zero-emissions energy sources, such as wind or solar electricity, instead of fossil fuels.

There are several benefits and drawbacks to hydrogen fuel usage. For example, one possible benefit is that no investment needs to be made into hydrogen infrastructure for on-site storage or dispensing if an organization is operating the wet-hose refueling practice using a third-party mobile fueling source. Wet-hose diesel refueling means refueling is done through a hose that is dipped in a diesel fuel source, usually a tank truck, and pumped into the vehicle. In this method, there is no need to invest in hydrogen infrastructure, like storage or dispensing systems, as a third-party mobile fueling source provides the fuel, making it more convenient and cost-effective for organizations. Another benefit is that hydrogen fueling is useful for sites that lack the space for diesel fuel storage and dispensing equipment as hydrogen fueling requires less space. However, the blueprint also discusses the drawback that hydrogen is not as straightforward as fossil fuels because hydrogen for vehicles is often compressed to a higher pressure for storage.

The blueprint considers the following hydrogen fueling technologies:

- Mobile fueling
- On-site gaseous and liquid hydrogen storage and dispensing
- On-site hydrogen production via electrolysis.

Summary of Technology Findings

The zero-emission concrete mixer truck market is still in early development, and there will not be any commercially available zero-emission concrete mixer vehicles on the market until at least 2024. Due to the reduced range and carrying capacity of battery electric concrete trucks, compared to a typical internal combustion engine (ICE) mixer truck, there will need to be a breakthrough in battery energy density or vehicle efficiency to make BEVs a viable zero-emissions replacement to the ICE for concrete mixer trucks.

Alternatively, hydrogen FCEVs provide a much smaller weight penalty compared to ICE vehicles and can easily be manufactured with increased range with larger hydrogen storage tanks. Hydrogen storage infrastructure is currently available in the form of gaseous or liquid storage and can even be produced on-site. The project team expects mobile fueling and lower costs for on-site storage infrastructure in the future. As a result, hydrogen is the leading zero-emission alternative for concrete mixer trucks.

3.1.2 Infrastructure

Site considerations and ZEV Feasibility Assessment

The feasibility assessment focused on the required infrastructure at the site for the adoption of zero-emission transportation, including both BEV and FCEV alternatives. Arup conducted the feasibility assessment across Central Concrete's sites (in the course of work, the project team opted to not conduct a detailed site design because the initial study proved sufficient to establish feasibility and complete the task requirements).

The blueprint considers the on-site benefits of hydrogen fueling. The current fueling strategy for the diesel truck fleet is a combination of mobile refueling and onsite diesel storage. Based on outreach with Central Concrete's fleet manager and plant managers, this strategy provides the optimal balance between operational costs and logistics. Third-party mobile refueling of the fleet overnight allows for every truck to start the day with a full tank and minimal space required for on-site logistics or additional time for Central Concrete employees.

The placement of hydrogen infrastructure takes into consideration the applicable codes and standards and the various site constraints gathered during site visits. These considerations span usability, operation efficiency, and health and safety, including the following:

- Site traffic flow and right of way and blocking active working areas.
- Worker health and safety including tripping hazards.
- Required hydrogen safety setbacks and separation distances as per the National Fire Protection Association Standard 2 (NFPA 2).[5]
- Availability of electrical power for hydrogen dispenser.
- Infrastructure protective equipment from collision or damage (i.e., bollards).

Summary of Infrastructure Findings

Each Central Concrete site was individually analyzed in consultation with Central Concrete's fleet manager. The project team did not consider BEV charging to be feasible for concrete mixer truck operations, so only FCEVs were studied in the blueprint. This assessment focused on selecting either mobile wet-hose fueling or on-site infrastructure. Table 2 shows the considerations and their implications for fueling infrastructure choices.

Table 2: List of Additional Sites for Infrastructure Assessment

Site Considerations	Decision Making Implications (On-site infrastructure vs. mobile wet-hose refueling)
Site logistics (including location of overnight vehicle parking)	Work sites with overnight parking locations, or other site logistics not favorable to on-site infrastructure, favor deployment of wet-hose refueling methods.
Site area (land available for EVSE or hydrogen fueling infrastructure)	A general lack of available area for on-site infrastructure makes mobile wet-hose fueling more ideal.

[5] Hydrogen Technologies Code, NFPA, 2020 (https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=2)

Quantity (number of Class 8 concrete mixer trucks on site)	Larger quantities of concrete being produced on site would favor on-site infrastructure due to economies of scale.
Mileage (average and peak daily truck mileage and duration of shift)	Facilities where cement trucks are dispatched more frequently, or have longer average mileage, will require more frequent refueling, justifying the investment into on-site infrastructure.
Existing fueling strategy (mobile refueling via diesel wet-hose or on-site storage tank)	The existing fuel method in place for each site will likely be the optimal strategy for hydrogen at the same site, and onsite diesel storage volume informs the quantity of on-site volume available for hydrogen.
Proximity to a public right-of-way and nearby buildings for required safety standoffs	If the site lacks the minimum safety standoff distance for on-site hydrogen infrastructure, wet-hose refueling is a better strategy.
Grid (local grid infrastructure capacity)	Lack of grid capacity recommends wet-hose, since on-site infrastructure likely requires additional capacity.
Ownership (structure of the site)	If the work site is a satellite or shared property, mobile wet-hose refueling will avoid risky investments of onsite infrastructure.
Waste & Stormwater (site area devoted to wastewater retention of floodway)	If the site is dedicated to wastewater retention or is a floodway, this would reduce the area available for on-site infrastructure.

Source: Arup US, Inc.

3.2 ZEV Financial Assessment Summary

Arup conducted a market readiness study largely through interactions with vendors of vehicles, charging equipment, and zero-emission fuels (electric utilities and hydrogen gas suppliers). The financial analysis includes TCO models for both BEV and FCEV and their respective infrastructure and is narrowly focused on the financial costs and benefits to Central Concrete as a business.

3.2.1 Life Cycle Cost Analysis

This blueprint section compared the TCO for Central Concrete's mixer trucks over the course of a vehicle's life cycle between ICE concrete mixer trucks and FCEV to help better understand how a ZEV transition could impact Central Concrete's fleet expenses. The life-cycle cost analysis took into consideration CapEx, OpEx, and the replacement expenses (RepEx) associated with both vehicles and infrastructure for hydrogen-fueled vehicles in comparison to a theoretical business-as-usual scenario with existing diesel trucks.

Project partner, Arup, developed a life-cycle cost analysis model to compare the TCO for a business-as-usual ICE fleet in comparison to a low-emissions alternative hydrogen fleet. Capital costs and life cycle costs, including OpEx and RepEx costs were developed for each option. The assumptions for the cost estimate represent Arup's best estimates for current and future conditions; however, there is considerable uncertainty around the cost of diesel and hydrogen over the next two to three decades due to increasing changes in vehicle technologies and funding opportunities.

Key inputs to the life-cycle cost model included:

Capital Expenditures

- Mixer Trucks: diesel or hydrogen fuel cell electric trucks.
- Infrastructure: on-site hydrogen fueling infrastructure (liquid storage and high-speed dispensing).
- Projected cost reductions of hydrogen-related equipment.

Operational Expenditures

- Maintenance cost of vehicles and infrastructure, including routine maintenance.
- Fuel costs of hydrogen and diesel.
- Low Carbon Fuel Standard credit revenue.
- Projected future cost reduction of hydrogen-related equipment maintenance.

Replacement Expenditures

- Cost of replacing trucks when they reach their useful life of 12 years.
- Cost of infrastructure after end-of-life.
    - Hydrogen infrastructure useful life of 30 years.

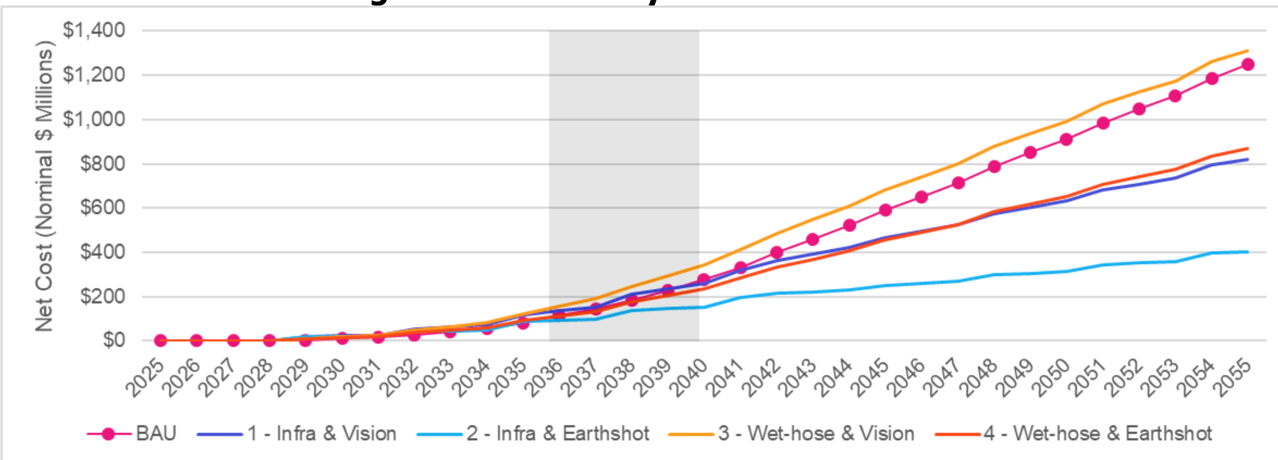
The analysis shows that the TCO in three out of the four hydrogen scenarios is lower than the business-as-usual scenario. The initial cost of purchasing the fleet and related infrastructure is significantly higher for the hydrogen scenarios, but the operating expenses are significantly lower.

Figure 1 shows the total costs for the four fuel cell scenarios versus the total cost of diesel trucks. Discounted cash flow indicates that three of the four fuel cell scenarios are better options compared to diesel trucks when total cumulative costs are accounted for over 30 years. VISION projections stem from Argonne National Laboratory VISION model which provides estimates of the potential energy use, oil use, and carbon emission impacts of advanced light- and heavy-duty vehicle technologies and alternative fuels through the year 2050.[6] Earthshot projections stem from the United States Department of Energy's Energy

[6] Argonne National Laboratory VISION Model (https://www.anl.gov/esia/vision-model)

Earthshot project, which seeks to reduce the cost of clean hydrogen to $1.00 per kilogram by 2031.[7]

Figure 1: Cost Analyses for Each Scenario



Credit: Arup US, Inc.

The most probable scenario is an average of all four scenarios, with a combination of on-site infrastructure and wet-hose fueling and hydrogen costs reductions somewhere between the VISION projections and the Earthshot projections. Therefore, this scenario has a high probability of having a lower TCO than the current fleet strategy.

3.2.2 Funding and financing

To advance its many environmental and clean energy policies, the State of California has a well-established ecosystem of incentive opportunities, funding programs, and financing mechanisms to offset the capital and operational expenses associated with the deployment of advanced energy and zero-emission transportation technologies. California's cleantech funding ecosystem is unique in that it extends beyond state-level incentives to include many opportunities at the local and regional levels.

The blueprint summarizes how several state and regional governmental agencies interact with the clean transportation ecosystem and with organizations and blueprints. The blueprint also discusses the opportunities and risks associated with private funding.

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[7] United States Department of Energy Earthshots Initiative (https://www.energy.gov/policy/energy-earthshots-initiative)

CHAPTER 4: Blueprint Production

4.1 Summary of Blueprint

4.1.1 Community & Stakeholder Outreach

Given the range of diversity among stakeholder groups, the team employed a tailored approach to each. Outreach success depended on the type of organization the team engaged with. For example, private stakeholders seemed most motivated to engage with the team, with OEMs being very happy to meet as often as necessary to paint a complete picture of the ZEV landscape. In contrast, community-based organizations and local government agencies showed some signs of outreach fatigue in their lack of enthusiasm to meet. In many cases, bandwidth constraints significantly impacted the level at which stakeholders were able to engage, and some stakeholders simply directed the team to their websites.

Attending the Advanced Clean Transportation Exposition in May 2022 provided a route to successful engagement and outreach. The team made many contacts there which laid the groundwork for future collaboration or engagement.

4.1.2 Community Benefits and Employment Opportunities

The ZEV transition of Central Concrete's mixer truck fleet would remove over 2,200 tons of CO_2 annually. In addition, other harmful emissions are avoided via reduced diesel combustion including over 8,700 pounds (lbs.) of NOx, 2,500 lbs. of reactive organic gases[8], and 200 lbs. of particulate matter smaller than 10 microns in diameter (PM10) per year. Up to 22 percent of these emissions reductions would occur in disadvantaged communities[9] with the largest impact in Alameda County, where the majority of annual truck miles are driven. If extrapolated to concrete mixer trucks statewide, the transition could remove around 38,000 tons of CO_2 per year, in addition to other harmful pollutants.

In total, when implemented by 2050, the ZEV transition in the concrete industry could produce $4 million to $9 million in monetized annual health savings by eliminating emissions that can have negative health consequences for people in the surrounding environment. Given that 22 percent of vehicle miles traveled occur in disadvantaged communities, $1.0 million to $2.0 million of annual health benefits would be expected to accrue to residents of disadvantaged communities as well. It is important to note that there are more than 76,000 Class 7 and Class

[8] Reactive organic gases are any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions. California Air Resources Board Abbreviations and Acronyms (https://ww2.arb.ca.gov/abbreviations-and-acronyms-carb-speciation)

[9] Disadvantaged communities refers to the areas throughout California which most suffer from a combination of economic, health, and environmental burdens. California Public Utilities Commission (https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/disadvantaged-communities)

8 vehicles in California[10], which offers a significant opportunity to expand this transition beyond concrete mixer trucks to produce even more impactful results. The ZEV transition for the concrete industry would be a major benefit to California's disadvantaged communities, contributing to improved economic productivity, reduced strain on the health care system, and improved overall quality of life.

To summarize the workforce impact and needs of Central Concrete's ZEV transition (and MDHD vehicle transition more generally), businesses need to enhance their workforce competencies in battery technologies and electrical and charging equipment as well as general electrical and ZEV knowledge. The three job categories with the most workforce development potential associated with the MDHD ZEV transition are equipment vending, operations and maintenance, and infrastructure installation. Education and training for MDHD ZEV jobs is available through automotive technology training programs or through working as an electrician; however, there are only two community colleges in the state that offer MDHD ZEV training programs, both in Southern California. To mitigate the potential initial lack of maintenance personnel with MDHD ZEV training, vendors propose to bear a portion of the workforce risk associated with new technology adoption by offering warranties and operations and maintenance contracts. Representatives from the trade union International Brotherhood of Electrical Workers located in Central Concrete's service area are confident that they have enough trained members to fulfill workforce needs.

4.1.3 ZEV Technology and Infrastructure Assessment

For the ZEV Technology Assessment Summary, Arup considered Central Concrete's fleet inventory, typical fleet usage, and potential charging/refueling technologies. The blueprint compares battery-electric concrete mixer trucks with hydrogen fueled trucks. Hydrogen FCEVs provide a much smaller weight penalty compared to battery-electric vehicles and can easily increase their range with larger hydrogen storage tanks. Hydrogen storage infrastructure is currently available in the form of gaseous or liquid storage or even on-site hydrogen production. The project team expects mobile fueling and lower costs for on-site storage infrastructure in the future. As a result, hydrogen is the leading zero-emission alternative for concrete mixer trucks.

For this blueprint, the project team individually analyzed each Central Concrete site in consultation with Central Concrete's fleet manager. EV charging was not considered feasible for concrete mixer truck operations so only FCEV was studied. This assessment focused on the selecting either mobile wet-hose fueling or on-site infrastructure. Table 2 shows the considerations and their implications for fueling infrastructure choices.

4.1.4 Financial Considerations

The life cycle cost analysis compared the TCO for Central Concrete's mixer trucks over a vehicle's life cycle between ICE concrete mixer trucks and hydrogen FCEVs to help better understand how a ZEV transition could impact Central Concrete's fleet expenses.

The analysis shows that the TCO in three out of the four analyzed hydrogen scenarios is lower than the ICE scenario. The initial cost of purchasing the fleet and related infrastructure is

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[10] Large Entity Fleet Reporting, CARB, 2022 (https://ww2.arb.ca.gov/sites/default/files/2022-02/Large_Entity_Reporting_Aggregated_Data_ADA.pdf)

significantly higher for the hydrogen scenarios, but the operating expenses are significantly lower. The blueprint also discusses public (state and local governmental agencies) and private funding opportunities that could support the ZEV transition.

4.2 Outcomes and Key Findings

This was a successful planning project. The project team did not consider BEV charging to be feasible for concrete mixer truck operations, so only FCEVs were studied in the blueprint. The participants were greatly influenced by the analysis. The goals and objectives were achieved. The transition to zero-emission vehicles is both timely and necessary to reach California's goal of carbon neutrality by 2045. Transportation is currently the largest source of greenhouse gas emissions in California, and decarbonizing this sector is critical. The transition to zero-emissions is not a one-size-fits-all scenario; many niche and bespoke solutions are required for various vehicle types and uses. While the transition will come with financial costs for many businesses owning and operating MDHD fleets, there are many funding channels in both the private and public domains offering opportunities for cost savings.

The key findings of this blueprint are as follows:

- The transition to FCEV concrete trucks is feasible. Central Concrete's leadership and staff support it, and it is much more anticipated than feared.
- Concrete trucks and similar specialty Class 8 heavy-duty vehicles are difficult to transition because of their small market size, tight weight allowance, and very high energy demand. The transition will be considerably delayed compared to heavy-duty vehicles with larger markets. CARB's proposed ZEV transition timeline accounts for this, delaying transition of specialty heavy-duty vehicles to between 2030 and 2042.
- BEV is not feasible when payloads are heavy and mileage or use duration is long between refuelling opportunities, as with concrete trucks; therefore, hydrogen FCEV becomes the only choice.
- Fueling infrastructure for FCEV needs to be looked at on a case-by-case basis to account for the specifics of different vehicle usage patterns, company operations, and site constraints. For Central Concrete, different sites require different solutions (mobile wet-hose at some, hydrogen fueling infrastructure at others).
- A transition is planned from an initial pilot stage to 100 percent conversion over the course of 18 years, which allows for the development and production of the specialty vehicles and minimizes the costs of having to replace diesel vehicles that are currently in use before their typical end of life.
- TCO depends heavily on the projections of future costs for both hydrogen vehicles and hydrogen fuel. Favorable forecasts lead to a positive TCO compared to the business-as-usual diesel fleet scenario.
- Community engagement shows that most of the issues surrounding the transition of concrete mixer trucks to ZEVs center around the need for technology development.
- The ZEV transition would have real, beneficial impacts to air quality, especially in local disadvantaged communities, and the statewide impact of transitioning all concrete trucks would be significant.
- There are two approaches to workforce development for the MDHD ZEV transition: one is through automotive courses and programs at community colleges—there is a specific

need for these in Northern California, and the other is through apprenticeship and on-the-job training; labor unions are key partners for this approach and are managing it successfully so far in Northern California.

GLOSSARY

BATTERY ELECTRIC VEHICLE (BEV)—Also known as an "All-electric" vehicle (AEV), BEVs utilize energy that is stored in rechargeable battery packs. BEVs sustain their power through the batteries and therefore must be plugged into an external electricity source in order to recharge.

"BLUEPRINT FOR ZERO-EMISSION CONCRETE LOGISTICS" (blueprint)—A planning document to educate, inform, showcase and demonstrate the value of ZEVs to decarbonizing the concrete industry.[11]

CALIFORNIA ENERGY COMMISSION (CEC)—The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The Energy Commission's five major areas of responsibilities are:

1. Forecasting future statewide energy needs
2. Licensing power plants sufficient to meet those needs
3. Promoting energy conservation and efficiency measures
4. Developing renewable and alternative energy resources, including providing assistance to develop clean transportation fuels
5. Planning for and directing state response to energy emergencies.

CAPITAL EXPENDITURES (CAPEX) – Funds used by a company for the purchase, improvement, or maintenance of long-term assets or to improve the efficiency or capacity of the company.[12]

CARBON DIOXIDE (CO_2)—A colorless, odorless, nonpoisonous gas that is a normal part of the air. CO_2 is exhaled by humans and animals and is absorbed by green growing things and by the sea. CO_2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO_2 also serves as the reference to compare all other greenhouse gases.

CENTRAL CONCRETE SUPPLY CO., INC. (Central Concrete) - a subsidiary of Vulcan Materials Company, a California Energy Commission grant recipient, and sustainability leader in the concrete industry.

FUEL CELL ELECTRIC VEHICLE (FCEV) - A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.

INTERNAL COMBUSTION ENGINE (ICE) - An engine in which fuel is burned inside the engine. A car's gasoline engine or rotary engine is an example of an internal combustion engine. It differs from engines having an external furnace, such as a steam engine.

[11] Blueprint for Zero-Emission Concrete Logistics (https://files.vulcanmaterials.com/central-concrete/Blueprint-ZEV-Concrete-Logistics.pdf)

[12] Corporate Finance Institute Glossary (https://corporatefinanceinstitute.com/resources/accounting/capital-expenditures)

MEDIUM-DUTY AND HEAVY-DUTY (MDHD) - Vehicles that have a gross vehicle weight rating of more than 10,000 pounds and include vans, buses, and trucks.

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx)—A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion processes and are major contributors to smog formation and acid deposition. NO_2 is a criteria air pollutant and may result in numerous adverse health effects.

OPERATIONS EXPENDITURES (OPEX) - The costs incurred by a business for its operational activities.[13]

PARTICULATE MATTER (PM)—Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines. PM10 describes inhalable particles with diameters that are generally 10 micrometers and smaller.[14]

REACTIVE ORGANIC GASES—Any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions.

REPLACEMENT EXPENDITURES (REPEX) - The prices that it would cost to replace an existing asset with a similar asset at the current market price.[15]

TOTAL COST OF OWNERSHIP (TCO) - A calculation of all the costs involved in buying and using a product over time.[16]

ZERO-EMISSION VEHICLES (ZEV) - Vehicles which produce no emissions from the on-board source of power (e.g., an electric vehicle).

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[13] Corporate Finance Institute Glossary (https://corporatefinanceinstitute.com/resources/accounting/operating-expenses)

[14] United States Environmental Protection Agency Particulate Matter Basics (https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM)

[15] Corporate Finance Institute Glossary (https://corporatefinanceinstitute.com/resources/valuation/replacement-cost-real-estate)

[16] Corporate Finance Institute Glossary (https://dictionary.cambridge.org/us/dictionary/english/total-cost-of-ownership)