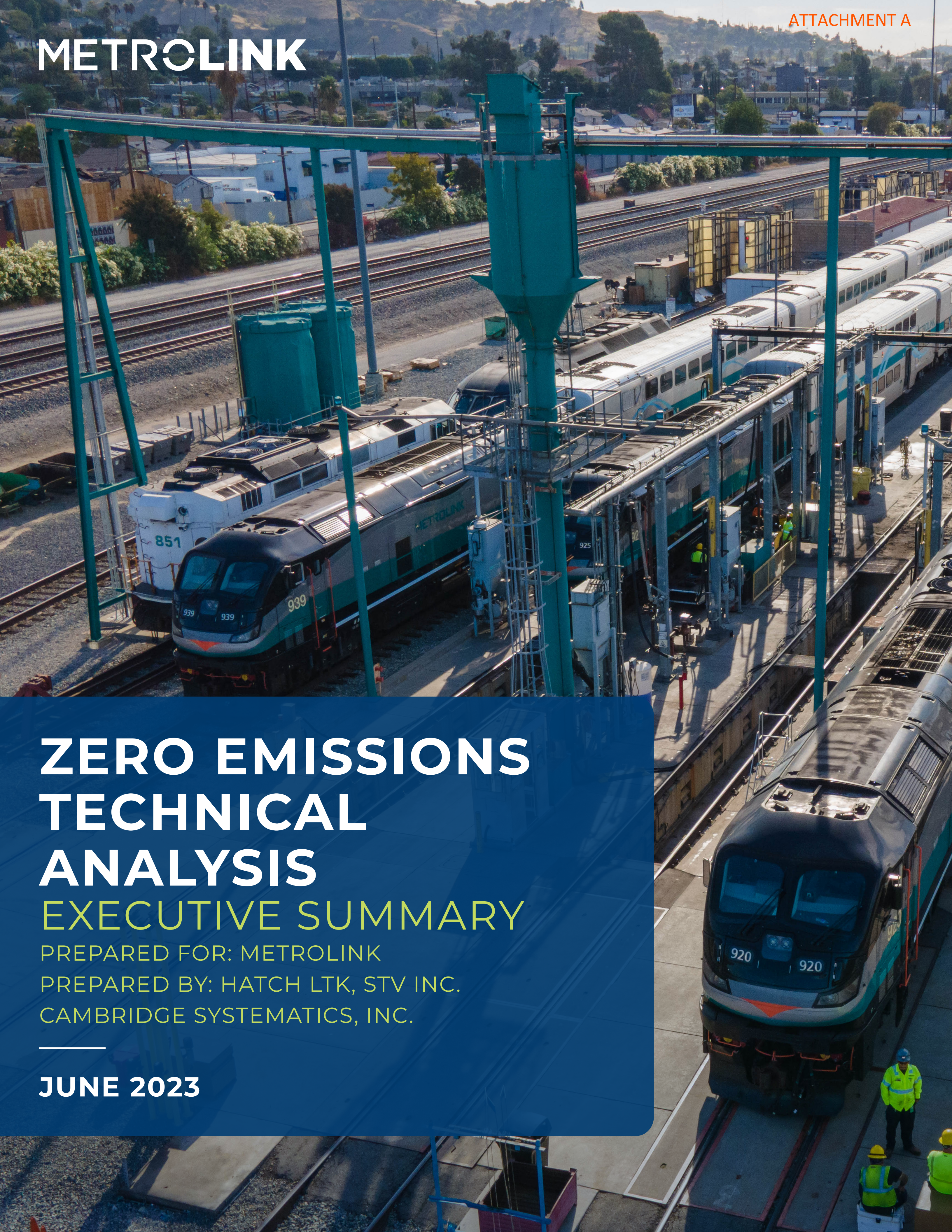
ATTACHMENT A

METROLINK



ZERO EMISSIONS TECHNICAL ANALYSIS

EXECUTIVE SUMMARY

PREPARED FOR: METROLINK
PREPARED BY: HATCH LTK, STV INC.
CAMBRIDGE SYSTEMATICS, INC.

JUNE 2023

OVERVIEW

The Zero Emission Technical Analysis (Analysis) evaluates and rates the available zero emission propulsion systems (battery electric and hydrogen fuel cell battery hybrid), vehicle types (newly designed locomotive, reconfigured existing locomotive, and rail multiple unit), operational and infrastructure impacts, project cost, safety and regulatory considerations. The Analysis commenced in the late fall of 2021 and includes the findings based on the research, analysis, interviews with original equipment manufacturers, peer agencies and others in the industry conducted between the late 2021 and summer 2022. Developments in zero emissions rail are ongoing and constantly evolving with frequent new partnerships and project announcements. This Analysis captures the best and most accurate information available during the study period.

As part of the 2020 Transit and Intercity Rail Capital Program (TIRCP) funded Metrolink Antelope Valley Line (AVL) Capital and Service Improvements Project, Network Integration funds totaling $10 million were awarded to assess the feasibility of a rail multiple unit (RMU) and zero-emission propulsion service through a pilot project on the Metrolink AVL. This analysis will allow Metrolink to begin the transition to zero emissions with a financially and operationally sustainable pilot demonstration on the Antelope Valley Line that meets passenger needs and Metrolink's strategic goals.

The AVL connects riders along a 76-mile corridor from Lancaster in North Los Angeles County to Los Angeles Union Station in Downtown Los Angeles as shown in Figure I. It crosses rural, suburban, and urban regions of the county and offers opportunities for land use and transportation to support sustainable communities. The terrain of the AVL is challenging. This is especially true for zero emission equipment with an elevation gain of nearly 3000 feet requiring significant energy draw.

FIGURE I: ANTELOPE VALLEY LINE ROUTE

This Analysis will guide Metrolink's initial exploration of zero emissions technology and the implementation of a pilot. Although neither battery electric nor fuel cell battery hybrid propulsion technologies are mature enough to replace the current diesel fleet today, their present technical readiness justifies further evaluation through a pilot project. Broadening Metrolink's understanding of zero emissions technology benefits will help the agency prepare for a complete transition to zero emissions. Additionally, participation in a pilot will explore unknowns and address risks of emergent propulsion technology and will help to further zero emissions knowledge in the passenger rail industry.

This Analysis recommends that Metrolink continue to explore partnership opportunities with Caltrans on a comprehensive research and development program and use the funding from the TIRCP to support additional study and zero emissions pilot vehicle testing. This approach may involve Metrolink field testing a Caltrans-procured vehicle. This approach would allow Metrolink to test at least one zero emissions vehicle without bearing the risk of purchasing untested technology. This approach is consistent with this Analysis's technical findings on compatibility, financial effectiveness, and strategic alignment with the Metrolink program and mission.

Any testing arrangement would need to meet Metrolink's operational, financial, safety and regulatory requirements Subject to the vehicle type selected by Caltrans, the required funding for the testing and infrastructure upgrades may exceed the $10 million available from the Transit and Intercity Rail Capital Program (TIRCP) funded Metrolink Antelope Valley Line (AVL) Capital and Service Improvements Project and additional grant funds would need to be identified to support the test.

These efforts, along with the projects initiated by SBCTA and other passenger rail agencies, will help advance the eventual transition of Metrolink's core fleet to zero emissions.

- This Analysis concludes that testing battery electric technology will be less costly and technologically complex compared to fuel cell battery hybrid technology. Battery electric propulsion has great potential because of the intensive research and development (R&D) efforts of the light-duty vehicle industry and the variety of promising battery chemistries. **If Caltrans as part of their Zero Emission Research and Development Program (Caltrans ZE R&D Program), pursues hydrogen fuel cell technology, then Metrolink could pursue a battery electric vehicle on its own or in partnership with other agencies.**
    - Fuel cell technology has a greater level of technical complexity in comparison with batteries and has not been service proven to the same extent. Maintenance facilities would need to be modified for hydrogen gas leak detection and enhanced ventilation systems as well as possible rail tunnel ventilation improvement costs may be required.
    - The combination of hydrogen fuel cells and battery have a range advantage over battery electric propulsion.
    - San Bernardino County Transit Authority (SBCTA), Metrolink's member agency, is already procuring a fuel cell battery hybrid multiple unit with delivery to the United States expected in 2023, which will be the first of its kind operating in the United States. It is expected that some of the unknowns and risks associated with fuel cell propulsion will be addressed during the deployment. Metrolink can take advantage of lessons learned.[1]

- This Analysis also concludes that testing a locomotive is less capital intensive and complex in implementation. Piloting rail multiple units (RMU)in Metrolink's system will introduce additional requirements, which are highlighted below. **As part of the TIRCP grant, it is recommended that funding be set aside to develop a plan to delve more deeply into the costs and activities required to operate multiple units on the AVL.**
    - Significant capital costs to mitigate the signal system shunting issues are anticipated with a smaller, lighter rail vehicle. A loss of shunt could result in delay or no activation of crossing gates or a loss of track occupancy detection in dispatch. Increased operational costs are also expected for mitigation measures such as frequent track brushing.
    - Rail multiple units typically have a lower seating capacity on an equivalent length basis (approximately half that of a comparable length bi-level consist). If the RMU pilot necessitates passenger capacity equivalent to a 4-car Metrolink train, then the rolling stock cost will increase considerably.
    - A locomotive could utilize existing coach cars, avoiding potential ADA compliance issues with station platforms. Any new car (locomotive-hauled or multiple unit) would

[1] At InnoTrans in September 2022, CalSTA and Caltrans signed an MOU with Stadler, a vehicle manufacturer, for four zero emissions FLIRT trains to be deployed in California. These vehicles will be a longer version of the vehicle that SBCTA is procuring and there are purchase options expected.

need to be compatible with existing platforms. This is currently understood to involve steps and the use of mini-highs for ADA purposes, but changes in ADA regulation or enforcement may require different solutions. If platforms need to be modified, this would represent a significant expense as well as a likely lengthening of a pilot project timeline.

- Additional maintenance facility upgrades would be required, primarily due to the need for synchronized lifting jacks to perform maintenance such as truck replacements.

- Greater impact on space constraints at Central Maintenance Facility (which is already at capacity), due to the longer length of an RMU compared to a locomotive.

The zero emission technologies are new in the rail industry and there are many unknowns for both propulsion types as listed in Table I. The Analysis focuses on promising, but not proven, battery electric and fuel cell propulsion technologies that present the potential to lead Metrolink to a zero emission fleet and operations. Both technologies are promising and both may play a role in Metrolink's long term transition strategy.

Expected Findings from Pilot Program	
Battery Electric	**Fuel Cell Battery Hybrid**
• Battery capacity on the target vehicle • Range on the target routes • Battery charging methods • Infrastructure limitations • Reliability of the propulsion and charger systems • Battery aging • Electricity cost • Maintenance practices and cost • Performance under varying weather conditions	• Fuel cell power on the target vehicle • On-board hydrogen and battery capacity on the target vehicle • Range on the target routes • Facility and infrastructure limitations • Hydrogen delivery and production issues and operating costs • Reliability of the propulsion, fueling, and hydrogen production systems • Maintenance practices and cost • Performance under varying weather conditions

TABLE I: EXPECTED FINDINGS FROM PILOT PROGRAM

Developing the Analysis for the Antelope Valley Line Test Site

The Technical Analysis (Analysis) provides a thorough analysis of technologies but the market research and analyses, such as vehicle simulation, only provide limited information. Both battery and hydrogen fuel cell have considerable performance and economic uncertainties relating to supply and availability of supporting infrastructure. The technology needs to be operationally tested to determine real world performance under various weather conditions and in varied operating environments.

Caltrans, in partnership with California State Transportation Agency (CalSTA), is planning and funding $100 million in zero emission research and development vehicle procurements to advance key intercity rail and bus, and passenger rail pilots. Staff are exploring opportunities to test at least one of the vehicles Caltrans plans to procure as part of this effort. Other key efforts which are also underway.

The Analysis analyzed both propulsion technology and vehicle type with technical, financial, and strategic analyses:

- The first step evaluated the most financially and operationally sustainable propulsion technology for a pilot. From the analyses and studies contained in the report, battery electric propulsion system is easier to integrate into Metrolink's current fleet for a one vehicle pilot. A summary of the reasons is listed in Table II.

Technical	Financial	Strategic
• Higher system efficiency • Less greenhouse emissions • Less hardware and software complexity • Higher potential for technical progress • Dual mode implementation with overhead catenary systems (OCS)	• Lower unit and life cycle costs • Li-Ion battery cost reduction trends in the light-duty vehicle industry	• Leverage the results from SBCTA's fuel cell pilot project • Simultaneously, explore battery electric propulsion and its synergy with OCS • Leverage the infrastructure investments in California High Speed Rail Project

TABLE II: BATTERY ELECTRIC PROPULSION SYSTEM BENEFITS

- In the second step, the most financially and operationally sustainable vehicle type for a pilot was evaluated. From the analyses and studies contained in the report, a new locomotive would be the easiest to integrate into Metrolink's fleet for a one vehicle demonstration. A summary of the reasons is listed in Table III.

Technical	Financial	Strategic
• No need to make yard and platform changes • No change to the existing vehicle maintenance practices • Less potential for shunting related issues • Retain existing legacy coach hauled operations and seating capacities of fleet - Compatibility with any consist	• Locomotive acquisition costs are lower • Additional funds are required if RMU is selected: - Shunting issue - Potential platform height and length issues - Yard upgrades - Central Maintenance Facility upgrades	• Potential locomotive builders may prefer to build the zero-emission propulsion technology on a new platforms to leverage R&D investments and design flexibility.

TABLE III: REASONS FOR SELECTION OF NEW LOCOMOTIVE IN THE PILOT PROJECT

THE ZERO EMISSIONS TECHNICAL ANALYSIS APPROACH

As part of the Transit and Intercity Rail Capital Program (TIRCP) funded Metrolink Antelope Valley Line (AVL) Capital and Service Improvements Project, Network Integration grant funds totaling $10 million are available to advance a zero emissions multiple unit as a pilot on the AVL. Metrolink's Strategic Business Plan (SBP) envisions further reductions of greenhouse gases (GHG), with accelerated efforts to deploy alternative zero-emissions vehicles to be in alignment with its Climate Action Plan (CAP) and the Governor's Executive Order N-79-20 requiring a transition to zero emissions by 2035. Advancing a zero emissions pilot is consistent with Metrolink's strategic direction and planning efforts to date. On April 23, 2021, Metrolink's Board of Directors approved the Rail Fleet Management Plan Update (RFMP). The purpose of the RFMP was to chart a course for future service and investment decisions related to vehicle fleet and facilities in alignment with strategic goals outlined in the SBP and CAP. Additionally, this pilot is consistent with California Air Resources Board (CARB) regulatory efforts as part of the Proposed In-Use Locomotive Regulation. The proposed regulation restricts the purchase and remanufacture of Tier 4 diesel equipment after 2030, subject to a technology assessment to be published in 2027. After 2030, any new equipment purchases, or re-manufacture, must be zero emissions.

Technical Analysis Goals

The objective of the Analysis is to evaluate emerging zero emission propulsion technologies.
The Analysis takes a holistic approach by considering:

- Performance
- Reliability
- Maintainability
- Facilities and Wayside Impact
- Capital Costs
- Lifecycle Costs

The knowledge base gained at the end of the pilot will be used to develop the master plan for a zero emissions fleet and attain the end goal of having a zero-emission fleet as shown in Figure III.

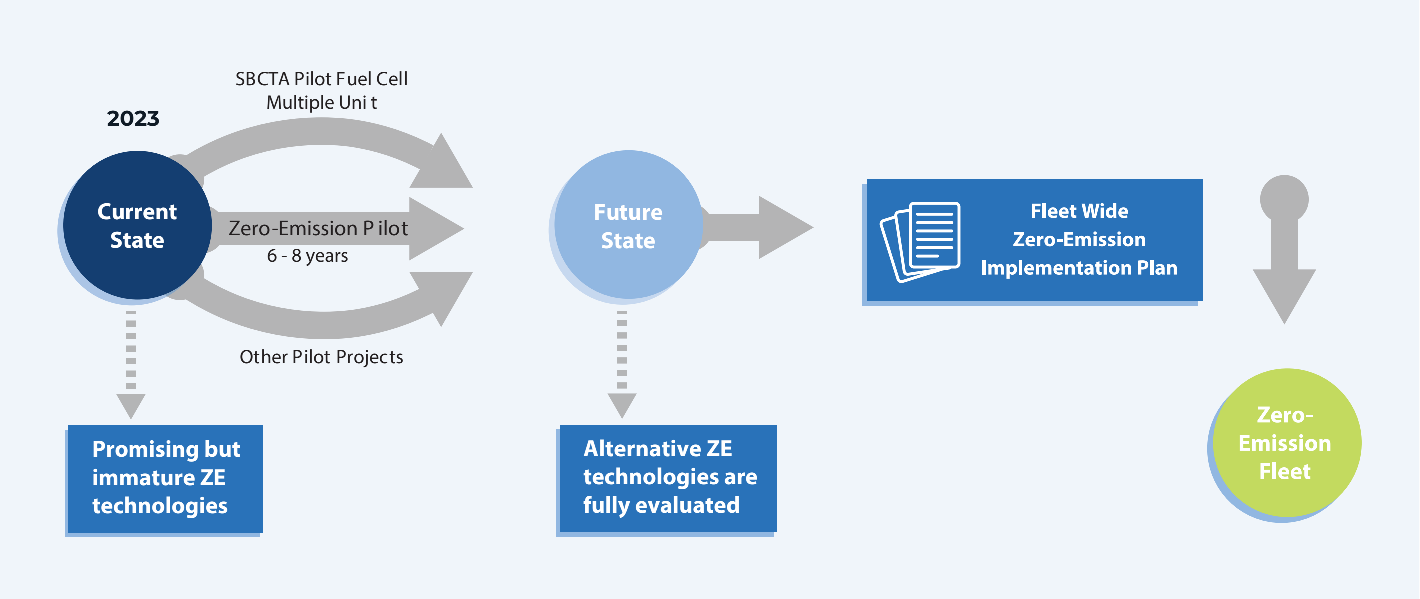


FIGURE III: OBJECTIVE OF ZERO EMISSION TECHNICAL ANALYSIS

Technical Analysis Options

The Analysis evaluates two feasible propulsion technologies that lead to zero emissions operations, and which the rail industry is actively researching and investing resources in. As a result of this and previous studies, there are two propulsion technologies and three vehicle types to consider:

Propulsion technology:

- Battery Electric
- Fuel Cell - Battery Hybrid

Vehicle type:

- Rebuilt Locomotive (Conversion)
- New Locomotive
- Rail Multiple Unit (RMU)

As a result, the Analysis benchmarks all the combinations of the propulsion technologies and vehicles types and recommends one of the options shown in Table IV.

Vehicle Type / Propulsion Type	New Locomotive	Rebuilt Locomotive	Rail Multiple Unit
Battery Electric	Option 1	Option 2	Option 3
Fuel Cell Battery Hybrid	Option 4	Option 5	Option 6

TABLE IV: OPTIONS FOR PIP

Technical Analysis Methodology

The methodology shown in Figure IV is developed to evaluate analytically all the available options and prepare the PIP.

Propulsion Technology Analysis

Among the zero emission propulsion technologies, full overhead catenary for electric propulsion is excluded as cost prohibitive for a pilot, but electrification synergies with California High Speed Rail are explored. A technical benchmark summarized in Table V was established for comparison of battery electric and fuel cell battery hybrid technologies based on the following criteria:

System efficiency	Greenhouse gas emissions	Range
Recharging or refueling time	Required infrastructure complexity and cost	Hardware and software complexity
Technical maturity and future potential	Meeting Metrolink's operational requirements	Potential of hybrid implementation with other propulsion technologies

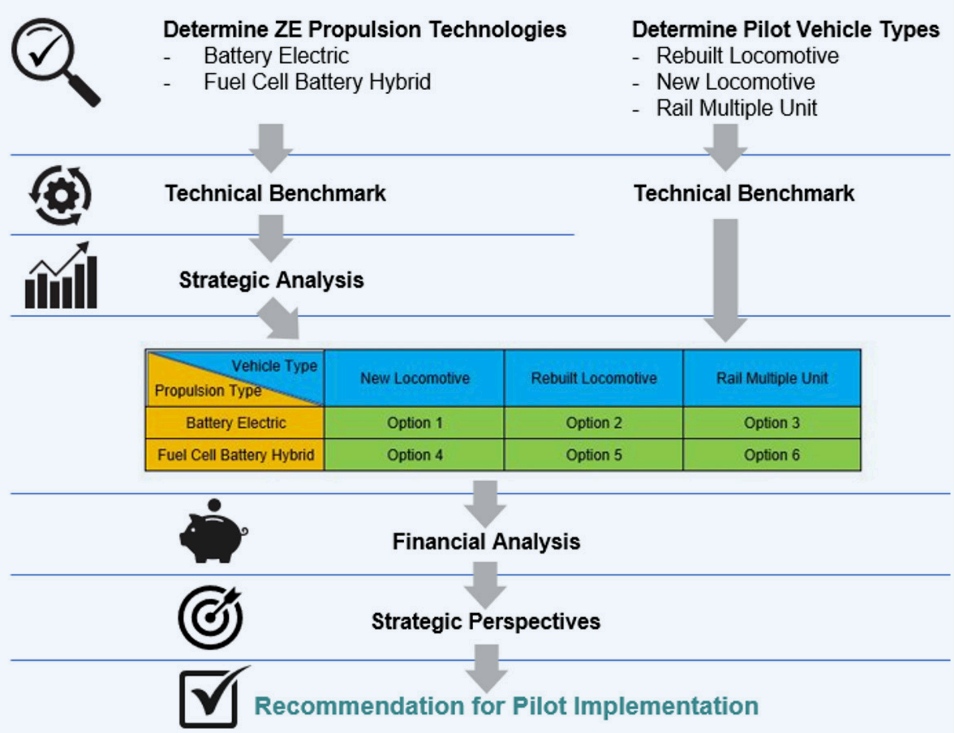


FIGURE IV:
TECHNICAL ANALYSIS DEVELOPMENT METHODOLOGY

Based on the above criteria, the battery electric propulsion system emerges as the leading solution when compared to hydrogen fuel cell, with the recognition that neither technology currently matches the overall performance of a diesel-powered locomotive, particularly for range and operating/life cycle costs.

	BATTERY ELECTRIC	FUEL CELL BATTERY HYBRID
System Efficiency	VERY GOOD	GOOD
Greenhouse Gas Emissions (Well-to-Wheels)	VERY GOOD	GOOD
Range	DEFICIENT	UNSATISFACTORY
Charge/Refuel Time	DEFICIENT	UNSATISFACTORY
Required Infrastructure	UNSATISFACTORY	DEFICIENT
Hardware/Software Complexity	GOOD	UNSATISFACTORY
Technology Maturity	UNSATISFACTORY	DEFICIENT
Technology Cost	UNSATISFACTORY	DEFICIENT
Meeting Metrolink's Operational Requirements	DEFICIENT	UNSATISFACTORY
Hybrid Operations with Other ZE Technologies	GOOD	UNSATISFACTORY

TABLE V: SUMMARY OF TECHNICAL BENCHMARK RESULTS

All zero emission propulsion technologies have some disadvantages and challenges that need to be evaluated and ultimately resolved in the field. None of these alternatives are definitively superior. Deployment of new technology will benefit from collaboration with vehicle builders and peer operators to uncover and address as many unknowns as possible about each potential technology.

According to the latest available plan documents, California High Speed Rail will share some of Metrolink's corridors (Lancaster - Palmdale, Burbank Airport – Los Angeles Union Station, and Los Angeles Union Station to Anaheim). This sharing of infrastructure might lead to the possibility of electrifying some of Metrolink's route segments more cost effectively. The battery and catenary dual operations would be an extension to this target, and hence, a battery electric propulsion pilot would be the first crucial step.

Vehicle Type Analysis

In addition to propulsion technology, the Analysis evaluated the type of vehicle on which the zero-emission propulsion technology will be installed. In this study, the following vehicle types were evaluated for use:

- Rebuilt Locomotive
- New Locomotive
- Rail Multiple Unit (RMU)

First, RMUs are benchmarked against locomotives in terms of technical criteria. Then, financial analyses are conducted for each option listed in Table IV. The vehicle types were evaluated for operational constraints in the following areas:

- Seating capacity and empty vehicle weight per seat
- Shunting related issues
- Platform height and length limitations
- Facilities modifications
- Federal Railroad Administration (FRA) safety considerations

Metrolink's system and facilities are designed for the operations and maintenance of locomotives whereas multiple units require significant capital investment to address the shunting issue and facilities modifications as well as ongoing operating costs for brushing.

Multiple units can operate on the Metrolink system but likely will require a significant commitment of resources to ensure safe operation.

Financial Analysis

Battery electric locomotives are the most cost effective overall considering initial capital investment as well as ongoing operating costs. Unit costs and life cycle costs of all propulsion technology and vehicle type options are calculated for the pilot to assess financial impacts on Metrolink. The operating costs were estimated for the pilot period of two years. Moreover, rebuilt locomotives, new locomotives, and RMUs are financially benchmarked by considering all related cost items for pilot as shown in Table V.

According to this table, rebuilt and new battery locomotives have the lowest overall cost while rebuilt and new fuel cell battery hybrid locomotives have the highest cost. Although battery propulsion has the highest yard and layover cost mainly due to the required grid upgrades for high power charging, it is advantageous in the other cost items. Rebuilt and new battery locomotives also have the lowest life cycle cost. **Fuel cell battery hybrid RMU option is estimated to be less expensive than battery RMU and fuel cell battery hybrid locomotive options due to the European fuel cell battery hybrid MU designs that are already in development.**

In the cost projections, it is assumed that Metrolink would use existing spare trailer and cab cars for the locomotive pilot in a consist with one trailer car and one cab car. If Metrolink cannot accommodate these cars for the pilot due to the full utilization of the existing fleet, it may be required to acquire one trailer car and one cab car by leasing or purchasing them. If the cost of purchasing these cars is included in the cost projections, the total cost of the pilot locomotive options would increase by approximately $8,400,000 and the total cost of rebuilt and new battery locomotive options would be closer to the cost of the fuel cell battery hybrid RMU option. Moreover, in the financial analyses, it was assumed that all non-recurring engineering costs are reflected in the cost of a single pilot vehicle other than for fuel cell battery hybrid RMU which are already in development.

		Battery Electric			Fuel Cell Battery Hybrid		
		Locomotive		RMU	Locomotive		RMU
		Rebuilt	New	New	Rebuilt	New	New
Acquisition	Non-recurring Engineering	$13,050,000	$11,920,000	$17,410,000	$29,800,000	$32,940,000	$16,340,000
	Material + Labor	$6,560,000	$7,670,000	$11,980,000	$6,790,000	$7,900,000	$12,530,000
	Spare Parts	$1,500,000	$1,500,000	$1,500,000	$1,500,000	$1,500,000	$1,500,000
	Contingency	$5,880,000	$5,880,000	$8,820,000	$10,980,000	$12,250,000	$8,660,000
	Metrolink + Consultant Engineering/Testing Labor	$3,920,000	$3,920,000	$5,880,000	$7,320,000	$8,170,000	$5,770,000
	Acquisition Cost Total	**$30,910,000**	**$30,890,000**	**$45,590,000**	**$56,390,000**	**$62,760,000**	**$44,800,000**
Operational	Maintenance during Pilot Testing	$130,000	$130,000	$100,000	$140,000	$140,000	$120,000
	Energy Cost during Pilot Testing	$560,000	$560,000	$450,000	$970,000	$970,000	$850,000
	Additional Rail Brushing during Pilot Testing	$0	$0	$730,000	$0	$0	$730,000
	Operational Cost Total	**$690,000**	**$690,000**	**$1,280,000**	**$1,110,000**	**$1,110,000**	**$1,700,000**
Facilities	Facility - Shop Cost	$16,000	$16,000	$1,860,000	$215,000	$215,000	$2,140,000
	Facility - Yard and Layover Cost	$8,400,000	$8,400,000	$8,400,000	$4,210,000	$4,210,000	$4,210,000
	Facilities Cost Total	**$8,416,000**	**$8,416,000**	**$10,260,000**	**$4,425,000**	**$4,425,000**	**$6,350,000**
Shunting	Testing	$0	$0	$8,270,000	$0	$0	$8,270,000
	Wayside Upgrades	$0	$0	$25,350,000	$0	$0	$25,350,000
	Shunting Cost Total	**$0**	**$0**	**$33,620,000**	**$0**	**$0**	**$33,620,000**
	Total	**$40,016,000**	**$39,996,000**	**$90,750,000**	**$61,925,000**	**$68,295,000**	**$86,470,000**

TABLE VI: FINANCIAL BENCHMARK OF OPTIONS FOR PILOT ANTELOPE VALLEY LINE

Summary of Findings

Table VI summarizes all the findings in a condensed form to compare the available options according to various criteria categorized under Technical, Financial, and Strategic groups. The evaluations are performed according to the color codes. Green, yellow, orange, and red show sequentially the degree of the advantage, green and yellow colors mean superior to the diesel electric propulsion and red and orange colors mean inferior to the diesel electric propulsion.

		BATTERY ELECTRIC				FUEL CELL BATTERY HYBRID			
		Locomotive		RMU		Locomotive		RMU	
		No High Power Charging	High Power Charging	No High Power Charging	High Power Charging	Hydrogen Delivery	Green Hydrogen Production	Hydrogen Delivery	Green Hydrogen Production
TECHNICAL	System Efficiency	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow
	Greenhouse Gas Emissions	Green	Green	Green	Green	Yellow	Yellow	Yellow	Yellow
	Range	Red	Red	Red	Red	Orange	Orange	Orange	Orange
	Charge/Refuel Time	Red	Red	Red	Red	Orange	Orange	Orange	Orange
	Hardware/Software Complexity	Orange	Orange	Orange	Orange	Red	Red	Red	Red
	Technology Maturity	Orange	Orange	Orange	Orange	Red	Red	Red	Red
	Meeting Metrolink's Operational Requirements	Red	Red	Red	Red	Orange	Orange	Orange	Orange
	Synergy with Overhead Catenary System	Green	Green	Green	Green	Red	Red	Red	Red
	Seating Capacity	Green	Green	Orange	Orange	Green	Green	Orange	Orange
	Platform Height and Length Issues	Green	Green	Red	Red	Green	Green	Red	Red
	Shunting Issue	Green	Green	Red	Red	Green	Green	Red	Red
	Facility Modifications	Orange	Red	Red	Red	Orange	Red	Red	Red
FINANCIAL	Unit Cost	Orange	Orange	Red	Red	Red	Red	Red	Red
	Electricity/Hydrogen Cost	Green	Yellow	Green	Yellow	Red	Red	Red	Red
	Life Cycle Cost	Orange	Orange	Red	Red	Red	Red	Red	Red
	Infrastructure Cost	Orange	Red	Orange	Red	Orange	Red	Orange	Red
STRATEGIC	Holistic Approach	Red	Green	Red	Green	Red	Green	Red	Green
	Supports Information-based Decision Making	Yellow	Green	Red	Yellow	Red	Orange	Red	Red
	Synergy with California High-Speed Rail Plan	Green	Green	Green	Green	Red	Red	Red	Red
	Complements SBCTA's Pilot Fuel Cell Project	Green	Green	Yellow	Yellow	Orange	Orange	Red	Red

TABLE VII: SUMMARY OF FINDINGS