Task 5.5:

Passenger Rail Technology Options

SLOCOG Coast Corridor Rail Service Study

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1 Introduction

The Passenger Rail Improvement Study (PRIS) will evaluate potential options to introduce regional rail service in the greater San Luis Obispo area. Task 5.5 will define service scenarios that will be analyzed for feasibility and performance in supporting the goals and objectives of the study as defined in Task 5.2. A key element of each service scenario is the rail vehicle technology that would be used. This memo begins with a general overview of existing rail motive power options, then summarizes the vehicle technologies considered for inclusion in the service scenarios.

2 Rail Motive Power Generation and Storage

Trains require significant amounts of energy to move, due to their large mass. The methods of generating and storing energy impact the operational characteristics of trains, including speed/acceleration, range that can be travelled, and emissions produced. The dominant sources of rail power in the United States are diesel combustion and electricity.

2.1 Internal Combustion

Internal combustion engines produce power by burning fuels such as diesel or natural gas that are stored on board the train. Power is then transmitted to electric motors on the wheels of the train to make it move. The combustion of fuel onboard produces emissions of greenhouse gases (GHGs) and criteria pollutants in the area in which a train operates. Using dense fuels provides the capacity to store large amounts of energy on a train, allowing trains to travel long distances without refueling.

The primary combustion fuel used in rail operations is diesel, but alternative fuels can be used, such as biofuels and natural gas. These alternative fuels have different emissions and energy density characteristics but can generally be used in diesel engines with minor modifications. For the purposes of the PRIS, diesel will be the assumed fuel for combustion engine alternatives since alternative combustion fuels will have similar operational implications as diesel in comparison to the non-combustion motive power options described below.

2.2 Conventional Electrification

Electric trains also utilize an electric motor to power their wheels, but generally do not store energy onboard. Electric passenger trains in operation in the United States are provided external power along their route, either via overhead catenary or a third rail aside the rails. Overhead catenary is the primary electrification method used for light rail and is also used for some higher frequency commuter rail operations. Third rail is reserved for fully grade separated corridors such as subways or elevated railroads, due to the safety risks to people crossing the right of way.

The power supplied by conventional electrification can be generated a number of ways, including both renewable sources and combustion of fossil fuels. Emissions impacts depend on the source of power generation but are located at the site of power generation rather than train operations. Conventional electrification is generally limited to high demand, high frequency corridors, due to the high capital cost of constructing the infrastructure to supply power along the route.

2.3 Battery Electric

Battery electric trains are an emerging technology that enables electric operation without fully electrifying a rail corridor by providing onboard storage of electric energy. Like conventional electrification, it allows operation with no GHG or criteria pollutant emissions at the tailpipe. In contrast to combustion fuels, batteries are not energy-dense, requiring orders of magnitude more space and mass to store a given amount of energy. Furthermore, recharging batteries is a slower process than refilling fuel tanks.

Battery technologies are being tested in Europe, but no battery-only electric passenger rail operation currently exists in the United States.

2.4 Hydrogen Fuel Cell

Hydrogen fuel cells utilize chemical reactions between hydrogen and oxygen to produce electricity to power electric motors. Like conventional or battery electrification, fuel cells do not produce GHG or criteria pollutant emissions at the tailpipe, but emissions offsite depend on the source of hydrogen fuel. In terms of storage capacity, hydrogen provides a middle ground between fossil fuels and batteries, enabling lower emission or zero-emission operation over longer ranges, but with more operational limitations than diesel.

Hydrogen power has a short, recent history of use in Europe and will be introduced in the United States with the upcoming Arrow service in Redlands, CA, implemented by the San Bernardino County Transportation Authority (SBCTA) using hydrogen-battery hybrid trains.

2.5 Combinations

Trains can be designed to use a combination of the above power supply methods. For example, a train can use overhead electrification on part of its route and supplement with diesel or battery on non-electrified segments. In the case of the Arrow pilot service, the hydrogen fuel cell provides longer range operation than battery alone, while the battery allows energy from regenerative braking to be stored.

3 Rail Technology Options

The analysis of comparable systems performed in Task 5.1 identified three vehicle technologies in use, or planned to be used, on similar corridors as the Santa Maria-Paso Robles study corridor. Technologies currently in use are Locomotive Hauled Coaches (LHC) and Diesel Multiple Units (DMU). The Arrow service in Redlands will initiate service with DMU trains in 2022 but will introduce service using Hybrid Hydrogen Fuel Cell Multiple Units (Hybrid FCMU) in 2024. These technology options are briefly summarized below.

3.1 Locomotive Hauled Coaches (LHC)

LHC trains consist of unpowered passenger cars (coaches) pushed or pulled by one or more engine vehicles (locomotives). This is the vehicle type currently used on the Coast Corridor by Amtrak's Pacific Surfliner and Coast Starlight, as well as large commuter railroads in California, including Metrolink, Caltrain, and COASTER. A typical commuter rail train consists of one locomotive and four to six two-level coaches. Locomotives can be powered by the variety of sources described above, but all comparable systems reviewed utilize diesel-fueled locomotives. On some high frequency routes in large metro areas, electric locomotives drawing power from overhead catenary are also used. As discussed in Section 4.2, conventional electrification has been excluded for the PRIS, so only diesel powered LHC will be considered for the PRIS.

3.2 Rail Multiple Units

In contrast to LHC (where separate vehicles provide motive power and carry passengers), each car of a Multiple Unit is self-propelled, containing both space for passengers and the engine to move the train. Compared to LHC, Multiple Units provide superior acceleration and deceleration, which is advantageous on routes with frequent stops or steep grades.

Multiple Units trains typically consist of two to four single level cars, and thus have lower capital and operating costs than LHC. Since each car powers itself, cars can be added to meet demand without sacrificing performance. This makes Multiple Unit service well suited to situations where the higher seating capacity of long LHC trains is not needed.

Like LHC, Multiple Units can use a variety of power sources. The review of comparable systems identified diesel as the primary power source for most operators and hydrogen fuel cells as a pilot technology on the upcoming Arrow service in Redlands. In addition, battery electric technology is in the early stage of use on European railroads.

Multiple Units face restrictions in operating on corridors shared with heavier trains. First, vehicles must comply with Federal Railroad Administration (FRA) safety regulations discussed in Section 4.1. Second, they must be approved for use by the owner of the railroad. Although various Multiple Unit models are currently operating in revenue service in the United States, none are operating on Union Pacific Railroad (UPRR) lines, which is the preferred route for much of the proposed service. UPRR currently prohibits Multiple Unit operations, due in part to their concerns about safely operating lightweight passenger vehicles alongside heavy freight trains. As multiple unit trainsets gain wider acceptance in the United States and establish a solid record of safe operation, UPRR may, at some point, reevaluate their position.

3.2.1 Diesel Multiple Units (DMU)

DMU are a well-established vehicle type used to implement urban transit service without the capital investment and impacts on shared operations of conventional electrification. While DMU are a cost-effective option for smaller commuter rail operations, LHC provide economies of scale when longer trains are needed, since power from one locomotive may be more efficient than multiple power sources on long DMU trains. As shown in Table 5-1, capital and operating costs of LHC are approximately double those of DMU, but a 4-coach train can seat more than four times as many passengers as a typical 2-car DMU.

3.2.2 Battery Electric Multiple Units (BEMU)

Electric trains are an option for operating rail service with no emissions. Battery power is used by electric trains in Europe and Japan, primarily to bridge short gaps on otherwise electrified railroads. Battery-only operations are possible but limited to short corridors by vehicle range. For example, Stadler's Flirt Akku vehicles are estimated to have a range of 94 miles under optimal conditions, which is insufficient to complete a round trip on the mountainous, approximately 60-mile corridor between Santa Maria and Paso Robles.[1] Travelling longer distances requires en-route charging. This can be done at stations, but may require longer dwell times, thus increasing overall travel times and reducing operational flexibility. The use of batteries to store energy has the advantage of allowing regenerative braking to recapture energy as trains decelerate. In addition, eliminating the diesel engine reduces a significant amount of the noise produced by rail operations.

Battery-only electric trains remain an unproven technology, with no existing operations in the United States. As a result, it is unlikely that SLOCOG could procure an existing model "off the shelf," and would probably need to fund design to ensure that vehicles are FRA compliant. Furthermore, Buy America requirements for federally assisted projects pose an additional challenge for technologies not yet manufactured in the United States.

3.2.3 Hybrid Fuel Cell Multiple Units (Hybrid FCMU)

Hydrogen fuel cell vehicles are an emerging technology that has no operational GHG or criteria pollutant emissions but does not require electrification of the rail corridor. The use of hydrogen as fuel provides denser energy storage than batteries, with similar operating range as diesel. For example, Alstom's Coradia iLINT has a range of approximately 625 miles, an order of magnitude above the 75-mile range of the battery-electric Coradia Continental.[2]While hydrogen fuel cells offer the possibility to significantly

[1] Source - https://www.stadlerrail.com/en/media/article/stadler-supplies-55-battery-operated-flirt-trains-for-theschleswig-holstein-local-transport-association/522/
[2] Sources - https://www.railwayage.com/passenger/commuterregional/alstom-coradia-ilint-passes-tests/, https://www.alstom.com/press-releases-news/2020/2/alstom-signs-first-contract-battery-electric-regional-trains-germany

reduce emissions, they remain an emerging technology and have the associated challenges. The first implementation of hybrid FCMU for passenger service began in Germany in September 2018. The first use in the United States will be the Arrow, with hybrid FCMU planned to enter service in 2024. SBCTA selected vehicles that will be powered by a combination of battery storage and electricity generated by a hydrogen fuel cell. The inclusion of a battery allows regenerative braking to improve fuel efficiency.

SBCTA's existing relationship with Stadler gives FCMU an advantage over BEMU in regulatory compliance. First, the vehicles are being designed to be FRA compliant for shared operation with freight and intercity rail. Second, Stadler is opening a new manufacturing facility in Utah to comply with Buy America provisions. The primary challenge is the provision of hydrogen fuel, which must be delivered or produced on site. Unlike Southern California, the San Luis Obispo area does not have an existing network of hydrogen fueling stations for automobiles to which hydrogen is delivered. Like battery electric operation, the GHG reductions associated with use of hydrogen fuel vary based on the method of generating the hydrogen fuel used.

Since the study area is not in a federal nonattainment area for any criteria pollutants, the air quality benefits of zero-emission train operations may not contribute to grant competitiveness as much as in other parts of the state.

4 Options Excluded from Consideration

Additional rail technologies are common in the United States but excluded from consideration. The study corridor is an active freight and intercity line owned primarily by UPRR. As a result, two types of technology options were excluded from consideration: technologies that do not meet FRA safety regulations, and technologies that require conventional electrification.

4.1 FRA Non-Compliant Technologies

Light rail vehicles used in urban transit do not meet safety standards set by the FRA for shared operation on railroads with heavier locomotive hauled trains in service. Since the Coast Rail Corridor is an active freight and intercity rail line, any technology implemented must comply with these regulations.

An exception to these safety requirements can be made via temporal separation, where non-compliant vehicles are allowed to operate over the same tracks as heavier vehicles if they exclusively operate at different times of day. For example, the North County Transit District's SPRINTER service in northern San Diego County utilizes non-compliant DMU passenger vehicles during the day and restricts freight operations to nighttime. Given that both freight and intercity passenger rail operations on the Coast Corridor occur during the day, this would not be a feasible option for service in San Luis Obispo.

4.2 Conventional Electrification

The use of electric trains, both locomotives and multiple units, is a well-established, proven technology, but power must be delivered along the rail route. This can be done by overhead catenary or third rail. Third rail is not safe for rail corridors that are not fully grade separated, such as the Coast Corridor. It is assumed that overhead catenary along the UPRR Coast Corridor would not be feasible due to cost and required institutional agreements and may not be preferred due to potential visual impacts of construction. Therefore, no alternatives using conventional electrification were considered.

5 Comparison of Technology Options

Table 5-1 provides a comparison of the operating characteristics, advantages, and disadvantages of LHCs, DMUs, FCMUs, and BEMUs.

Table 5-1: Comparison of Vehicle Types

	Locomotive Hauled Coach (LHC)	Diesel Multiple Unit (DMU)	Hydrogen Fuel Cell Multiple Unit (FCMU)	Battery Electric Multiple Unit (BEMU)
Typical Characteristics of Each Technology				
Local Example(s)	Amtrak, Metrolink	SMART, Arrow	Arrow	N/A
FRA Compliant	Yes	Yes	Yes	Likely Possible
Typical Consist	1 locomotive, 4-6 passenger coaches	2-3 cars	2 cars plus power pack	2-3 cars
Seated Capacity	500 (4 coach set)	118 (2-car Stadler Flirt DMU)	108 (2-car Stadler Flirt H2)	124 (2-car Stadler Flirt Akku)
Capital Cost	$21 million (4 coach set) [3]	$10.3 million (2-car Stadler Flirt DMU)[4]	$12 million (2-car Stadler Flirt H2)[5]	Similar to other multiple units[6]
Operating Cost[7]	$87 per revenue train mile $2,560.53 per revenue train hour	$45.25 per revenue train mile $1,023.26 per revenue train hour	Similar to DMU[8]	Similar to DMU[8]
Advantages	• Flexibility in types of passenger cars (ex. bike car, quiet car) • Staff and facility needs would be similar to existing Amtrak service in the area • Equipment could be shared with other Amtrak services • Lower capital cost if high seating capacity is needed • Existing market of older vehicles • Approved for operation on UPRR	• Higher acceleration improves travel time, particularly on routes with frequent stops and curves or steep grades • Scalability – each car can propel itself, so train length can be modified based on demand • Existing market of older vehicles	• No tailpipe emissions (except water) • Battery enables regenerative braking to reduce energy consumption • Higher acceleration improves travel time, particularly on routes with frequent stops and curves or steep grades • Scalability – each car can propel itself, so train length can be modified based on demand • Operates with very little noise • Can travel farther than battery vehicles without refueling	• No tailpipe emissions • Battery enables regenerative braking to reduce energy consumption • Higher acceleration improves travel time, particularly on routes with frequent stops and curves or steep grades • Scalability – each car can propel itself, so train length can be modified based on demand • Operates with very little noise • Does not require hydrogen delivery or conventional electrification
Disadvantages	• Produces tailpipe emissions • Not fuel efficient if only short trainset is needed • High capital costs if large seating capacity is not needed	• Produces tailpipe emissions • Higher capital cost and worse fuel-efficiency than LHC for long trainsets where high seating capacity is needed • Not currently approved for operation on UPRR	• Hydrogen fuel must be delivered or produced on-site • New technology carries more uncertainty • There are no used vehicles available for purchase • High capital cost if high seating capacity is needed • Not currently approved for operation on UPRR	• Limited range and charging time limit operational flexibility • Unproven technology • There are no used vehicles available for purchase • High capital cost if high seating capacity is needed • Not currently approved for operation on UPRR
Typical service pattern	• Limited service focused on peak hours • Stations 2.5-10 miles apart	• Moderate frequency across the day • Stations 1.5-5 miles apart	• Limited use in similar patterns as DMU	• Limited use in similar patterns as DMU and on partially electrified railroads

[3] Based on SCRRA procurement of 40 EMD F-125 locomotives beginning in 2013 and MBTA procurement of 80 Hyundai-Rotem bi-level coaches in 2019
[4] Based on SBCTA procurement of 3 DMUs for $31M in 2018
[5] Based on SBCTA procurement of 1 2-car Stadler Flirt H2 in December 2019
[6] While there are no recent US procurements of BEMU, SBCTA's ZEMU Concept Feasibility Study estimated cost of $10.2 million for BEMU, compared to $11.2 million for FCMU (lower than the final procurement at $12 million). Battery-only technology would generally be slightly cheaper than combining battery and hydrogen energy systems, but a similar order of magnitude, likely between DMU and FCMU.
[7] For LHC and DMU, median costs from FTA's 2019 National Transit Database for all commuter or hybrid rail operations using exclusively the respective vehicle.
[8] SBCTA's ZEMU Concept Feasibility Study estimated annual fuel related costs for FCMU of $540,000 to $1,154,000 and a range of $690,000 to $769,000 for BEMU, in comparison to $750,000 for DMU. Costs not related to fuel would be similar for all multiple units, regardless of motive power.