Evaluating the Feasibility of Electrified Rail at the Port of LA/LB

Final Report

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Disclaimer

Abstract

Electrifying rail at the Ports of Los Angeles and Long Beach has the potential to both replace the congestion and pollution of drayage trucks, and the pollution of rail. The electrification process was analyzed in light of costs, utility, and safety. The length of rail considered for replacing drayage trucks is about 12 miles at the Ports of LA and LB to connect terminal clusters to the UP ICTF, and an additional 20 miles of a single line along the Alameda corridor to the BNSF Hobart yard; assuming the SCIG is not built. Cost of retrofitting conventional rail with at-ground third rail is from $1.42M to $1.5M per mile verses $.825M to $1.5M per mile for overhead caternary; *excluding* the costs of new or retrofit locomotives—from $2M to $5M each, and additional electric power distribution requirements for more tractive power. Operational decisions by the class one rails regarding "switch out" to Diesel power for transcontinental runs will determine the number of new or modified locomotives required; and the length (weight) of shuttle trains will determine the power distribution costs. Neither at-grade third rail nor overhead caternary are conducive to train formation involving loading, unloading, and numerous short switched sidings. However, operational requirements such a switching and power requirements favor overhead caternary, making it the better approach for hauling train sections or shuttle trains from the port to Diesel pulled transcontinental train Intermodal. Safety requirements also infer overhead lines are the better way for retrofit electrification.

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Disclosure

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Evaluating the Feasibility of Electrified Rail at the Port of LA/LB

1 Introduction

Goods movement through the Ports of San Pedro has bogged down in recent years due to truck congestion caused by the rapid increase in container traffic and the local communities' understandable reluctance to accept added pollution that accompanies port growth. The immediate solution for truck congestion is near-dock rail. The solution to the air and noise pollution caused by increased rail movement is rail electrification. The objective of this project was to analyze the cost and feasibility of available, standardized equipment for rail electrification retrofit in the LA basin, and to better define issues involved in electrified "shuttle-trains" for both commercial and military goods movement.

This project was to determine the utility of block switched, third rail electrification of existing and planned near-dock rail at the Port of LA/LB using comparisons with existing and proposed rail electrification projects in other locals. Determination of feasibility was based on consideration of three general issues involved in the transition from conventional to electrified rail: (1) order of magnitude capital and operational cost projections, (2) projected operational utility for near-dock and short haul, and (3) projected operational safety. Initially, the proposed study, sidestepped overhead caternary electrification in favor of on-ground third rail due to the apparent awkwardness of overhead lines at port complexes; however, recent developments in Europe where the caternary can be powered down and swung clear of the track have mitigated this concern. However, even with the added consideration of overhead caternary, we conclude, that neither electrification approach is practical for near-dock rail retrofit; but due to economy and safety, overhead electrification is the more practical of the two approaches to retrofit freight rail away from and beyond the port complex.

The approach to this project for determining the cost and utility of electrification for existing and planned near-dock rail at the Port of LA/LB consisted of three tasks: (1) determining the length of rail to be considered for electrification; (2) the material cost of electrification including rail retrofit, locomotive modification, and power distribution; and (3) the operational considerations of retrofit electrification.

Task 1: The length of rail subject to possible electrification for Diesel pollution mitigation was quantified. Near-dock rail was assumed to consist of rail sidings at major terminals in both ports as well as rail on property managed by the Ports and used by the class-one rails to access the terminals. To respond to Diesel pollution produced by moving cargo out of ports, the rail lines to the UP ICTF and the proposed BNSF SCIG were included as candidates for electrification. Since the BNSF SCIG is only proposed, the length of a single line of the Alameda Corridor to the downtown Hobart yards was also included.

Task 2: The "per-mile" cost estimate of electrifying rail involved the material and retrofit costs and the added installation costs of electrical distribution systems including a possible integrated train control (ITC) network. The third-rail approach to electrification as described here consists of the configuration of the third rail and the system of switched power distribution to the third rail to add safety to a system best applied to those with no pedestrian or vehicle access. The overhead caternary approach was included in the cost estimate since its utility and safety were deemed competitive if not superior to at-ground third rail.

Major manufacturers of Diesel-electric locomotives have built engines configured with "shoe" or pantograph collectors to switch electric motor drive from the on-board Diesel generator to electric utility; a second cost factor, the costs of modifying locomotives was also considered. If the locomotives are intended to switch from electric grid power to on-board Diesel power for long haul, then many locomotives in the fleet must be expensive, "dual-use" electrification and Diesel. If electric driven locomotives are used locally at the Ports and then switched out with Diesel locomotives for long-haul transcontinental runs, then a smaller number of electric driven locomotives—either third-rail or caternary—are needed. Also, depending on rail system operating plans, the third cost factor of electrical distribution depends on how much power is required. Train lengths used presently will require extensive and robust electrical distribution where as shorter, "shuttle trains" will require less infrastructure.

Task 3: The many pros and cons of the applicability of rail electrification at the Port involve not only the construction costs, but also operational considerations and possible costs of disruption of operations during construction. Minor shifts in rail operations, added safety issues, and added electrical generation all need to be considered, along with the expected benefits of reduction of pollution and congestion.

The likely near-dock siding lengths, terminals to intermodal rail distances, and Alameda Corridor to Hobart distances were all determined as described **Section 2** with supporting data detailed in **Appendix A**. Basic third rail and caternary retrofit technologies such as power distribution, locomotive power pickup, grounding approaches, as well as current and voltage waveforms and levels are broadly described in **Section 3**. Characteristics of the two electrification approaches and their application to port and urban freight movement compared with conventional Diesel-pulled trains are discussed in **Section 4**. **Section 5** presents the costs per mile of the at-ground, third rail that were based on extrapolation of electrification costs for proposed and recently constructed, transit systems using third rails. While these referenced systems were designed for passengers and not freight; tractive power of these systems is appropriate for moving short train sections in switching operations. Overhead caternary costs were based on proposed and actual rail retrofits of Diesel-pulled light rail systems **(Appendix B)**; reduced concern of arcing in these systems provides for sufficient tractive power to move shuttle and longer trains. Cost per mile estimates and electric locomotive estimates are supported with details from **Appendices B and C**. Tractive power distribution costs and locomotive retrofit costs for both electrification approaches are similar under similar operating conditions. Finally, **Section 6** provides conclusions as to the feasibility of rail retrofit at the Ports and considers the drawbacks to the third rail system compared to the overhead caternary as well as "strawman" estimate for a shuttle train from a number of clustered port terminals to the ICTF to replace truck drayage.

2 Quantify Existing and Planned Rail Lengths at the Ports of San Pedro Bay

An initial step to evaluating the feasibility of electrification of rail at the Port is to estimate the number of miles of track that should be considered. Considerable port rail is in the terminals and ideally used to form Diesel-pulled transcontinental container trains out of the LA basin and is not a candidate for electrification. A large volume of containers requires truck drayage to intermodal rail yards for loading on transcontinental trains. Electrified rail to replace these drayage trucks is mainly on Port property, providing a proposed BNSF intermodal yard can be built near the Port. If not, rail may need to be electrified to downtown LA to where a large intermodal facility presently operates. The total length of rail finally being considered is around 32 miles.

2.1 Cumulative Length of Switched Siding Rail at Major Terminals

The Ports of Los Angeles and Long Beach have no, true on-dock rail in that shipping containers are not loaded directly on a railcar from the ship, but rather "hustled" from the overhead drop to temporary storage or terminal facilities for transfer to a truck or a railcar. The transfer to a railcar is made at terminal operated rail spurs where containers with a common destination are loaded on short sections of trains. The sections might stay on terminal property for several days while the sections are filled before they are moved to areas of the port with where rail length is sufficient to form full trains for transport along the Alameda corridor and unto the continental US (CONUS). Lack of sufficient rail at the terminals and ports make forming full length trains awkward thus requiring containers to be drayed by truck to rail yards such as the UP's ICTF or the BNSF's Hobart yard where they are loaded on railcars to form full trains for CONUS. As shown in Appendix A, the accumulated track at the major terminals in both ports is about 32 miles. Due to terminal congestion this at-dock rail is likely not a cost effective candidate for electrification. However, shuttle trains using electrified rail from localized clusters of terminals to the aforementioned intermodals could replace drayage trucks.

2.2 Length of Existing Rail to Replace Drayage Trucks to the UP ICTF and Proposed BNSF SGIG

Presently, thousands of drayage trucks carry containers that cannot be loaded on rail in the terminals either to the UP's Intermodal Container Transfer Facility (ICTF) close to the Port or to the BNSF's Hobart Yard (and others) in downtown LA. Replacing those drayage trucks with short shuttle trains requires connecting the previously described terminal rail clusters to these intermodal facilities. The distance to the downtown railyards has prompted the proposal of a new intermodal near the Port; the Southern California International Gateway (SCIG). The distance of electrification of rail from terminals to both the existing and proposed port intermodals is approximately 12 miles.

2.3 Length of Rail to Hobart Yard from Proposed BNSF SGIG Location to Downtown Hobart Yard

If the SCIG is not constructed, the container shuttle trains replacing the drayage trucks would be forming transcontinental trains at the downtown yards. The additional length of electrification retrofit could be at least two of the three rail lines in the Alameda corridor which is a length of about 20 miles for a total electrification retrofit length of about 32 miles of typically double tracked electrification.

3 Electrification Technologies

There are two common approaches to retrofitting existing rail systems. One is the “third rail” method where an at-ground, power-carrying rail is placed between or just outside of the two guiding rails; the locomotive connects to the third rail through physical contact with the third rail by a “shoe” at ground level. The other approach uses a power carrying overhead caternary that the locomotive makes electrical contact through a pantograph on top of the locomotive. Most electrification systems use overhead wires so that the electric power is relatively far from the intrinsic ground return of the rails to prevent arcing and hence deliver more electrical power; so at-ground third rail is an option up to only about 1.2 kV . Section 3.1 describes the third rail technology approach to electrification while Section 3.2 addresses the overhead caternary technology.

The “Diesel” locomotives, operating in the Los Angeles basin and throughout the country in freight and passenger service carry their own electrical power supply, and so are free of the requirement for a “shoe” contacting a powered third-rail, or a pantograph contacting power lines overhead. This freedom from the necessity to connect to an additional electrical distribution source has caused the almost total elimination of electric rail in favor of this less cumbersome “electrification” source for freight applications. Section 3.3 describes the technology of retrofitting “Diesel” locomotives to use the electric grid. Finally Section 3.4 describes a standard power distribution structure common to both third rail and overhead caternary electric rail systems.

3.1 Third-Rail Approach to Electrification

Third rail current collection comes in a variety of designs. The simplest is what is called "top contact" because that’s the part of the rail upon which the pick-up shoe slides. Being the simplest and oldest third rail approach, its drawbacks are well documented. First and foremost is the safety risk of the exposed electric conductor. The second obvious issue is the collecting of ice and leaves during bad weather render top contact third rail systems almost unworkable unless expensive remedies are carried out as shown in Figure 1. Bottom contact is best - you can cover effectively most of the rail and it is protected from the worst elements of the environment. Bottom contact shoes are spring loaded to provide the necessary contact force. An example of a bottom contact shoe as used on a German metro line is shown in the photo of Figure 2. Mechanical or pneumatic systems have been devised to make it possible to disconnect shoes from the third rail remotely from the cab.

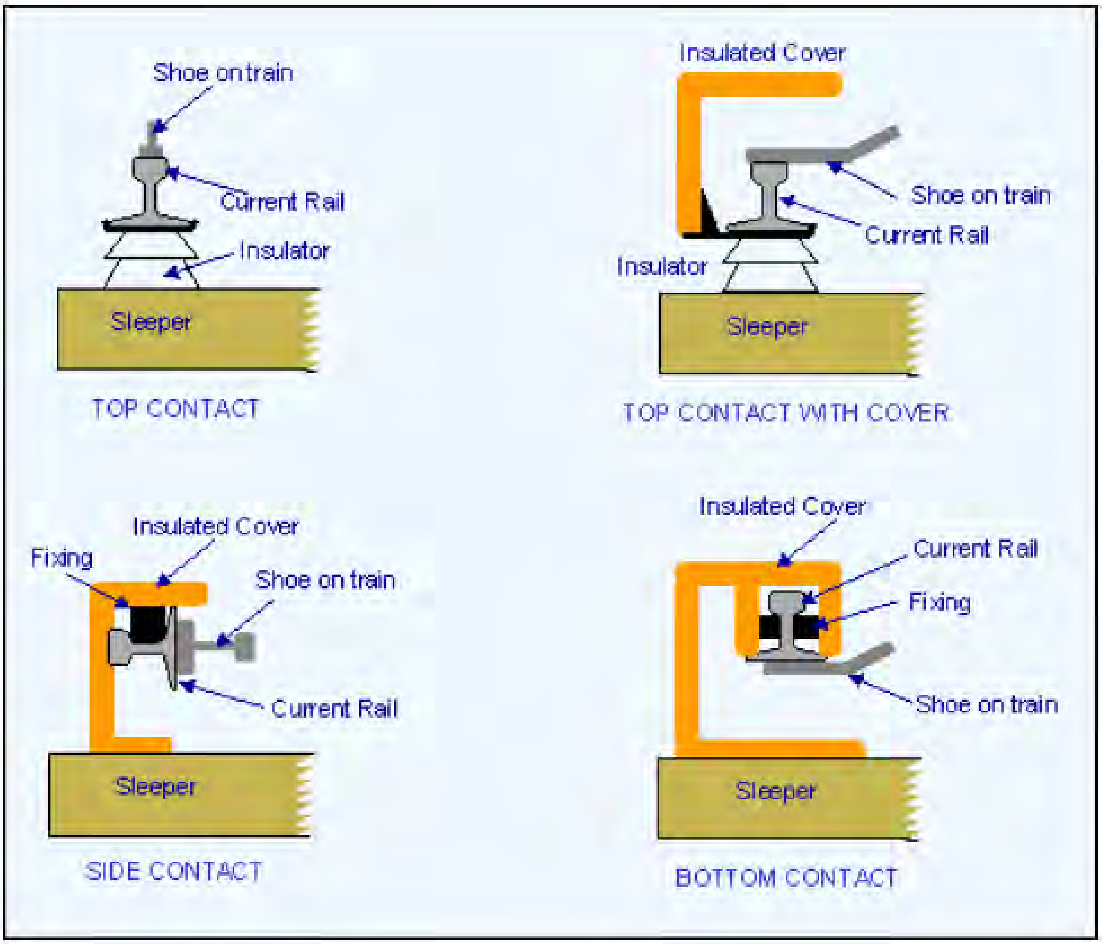

Figure 1- Several Forms of Third Rail – Shoe Contact in Order of Safety and Expense (least to most safe and expensive)

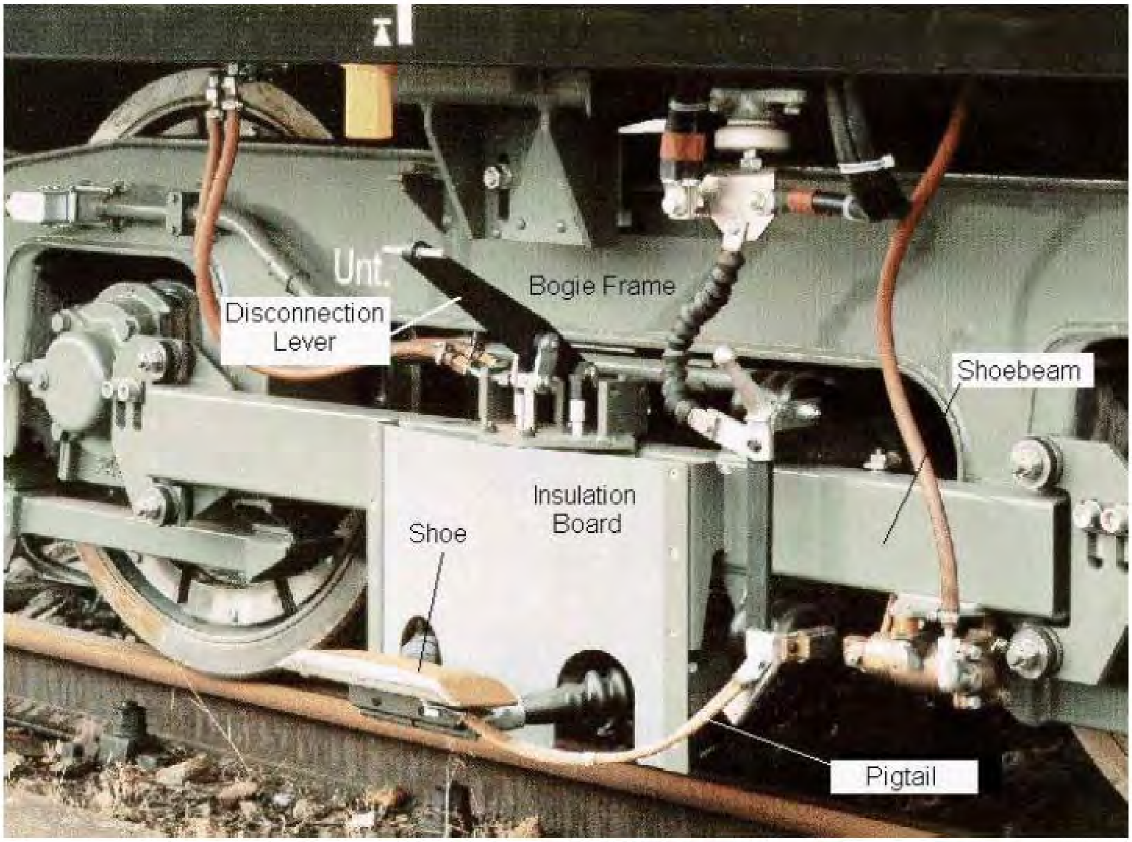

Figure 2- Example of a Bottom Contact Shoe

Note that like other commercial electric transmission systems electric rail systems typically have a single conductor power feed (third rail—shoe in this case) and a "ground" return. For an electrified rail system the return is typically the wheel to rail connection, and since the track is not necessarily contiguous, the natural contact of rail to earth likely forms the final return path. When such a convenient return circuit could produce unsafe potential gradients, a "fourth rail" is added as the return as done in several systems. The London Underground and Vancouver's Sky Train are both third and fourth rail systems using two rails: one for power distribution and one for return.

Most distributed commercial electric power is AC rather than the more difficult to distribute (until recently) DC power. While use of a third rail does not require the use of DC, in practice all third-rail systems use DC because it can carry 41% more power than an AC system operating at the same peak voltage. Maximizing the power for the arc-limited third rail geometry has kept DC as the dominate power distribution waveform.

3.2 Overhead Caternary Retrofit Material and Installation Costs Conventional

Third rail systems requiring at-ground foundation and substantial metallic conductors seemingly cost more for materials and installation than simply stringing overhead wires between distant poles for a catenary rail electrification system. The difference in cost however is not that great; due to the fact that contact between the overhead wire and the pantograph on the locomotive is not a simple arrangement. The mechanical contact between the spring loaded pantograph and the hanging power wire is difficult to maintain due to physical waves set up in the wire. Multiple pantographs per train mitigate intermittent contacts. Maintaining a level power wire requires significant tension which for simple systems limits the spacing of the caternary supports. In order to space the supports further apart and hence improve economy, modern electrified rail uses a true caternary as a support for the power wire much like a suspension bridge supports a roadway. “Droppers” and “stitches” support the power line from the caternary as shown in the photo of the Acela, Boston to Washington train in Figure 3.

Figure 3- Pantograph on the Acela Contacting Power Wire Supported from Overhead Caternary (“Messenger Wire”) by “Droppers”

Early overhead caternary systems used DC transmission and DC traction motors similar to third rail systems; however, ease of transmission and the aforementioned higher voltage capacity has caused AC to become the prevalent form of electrification for overhead caternary rail electrification.

In addition, modern 3-phase AC motors have proven more efficient and as easy to control as DC motors. Thus 3-phase AC motors are prevalent in modern overhead caternary rail systems. However, like 3-phase electric grid power transmission, three separate wires are required to drive these AC motors and this implies three overhead wires and three pantographs; a situation that presents insurmountable difficulties in practice. Thus single phase transmission is the lone caternary power supply as shown in Figure 3.1, and the single phase is converted to 3-phase on board for the 3-phase motors as shown in inset to Figure 4. Even two separate caternary wires—one power, one return—are not used in practice due to the difficulty of maintaining contact in a two wire, two pantograph geometry.

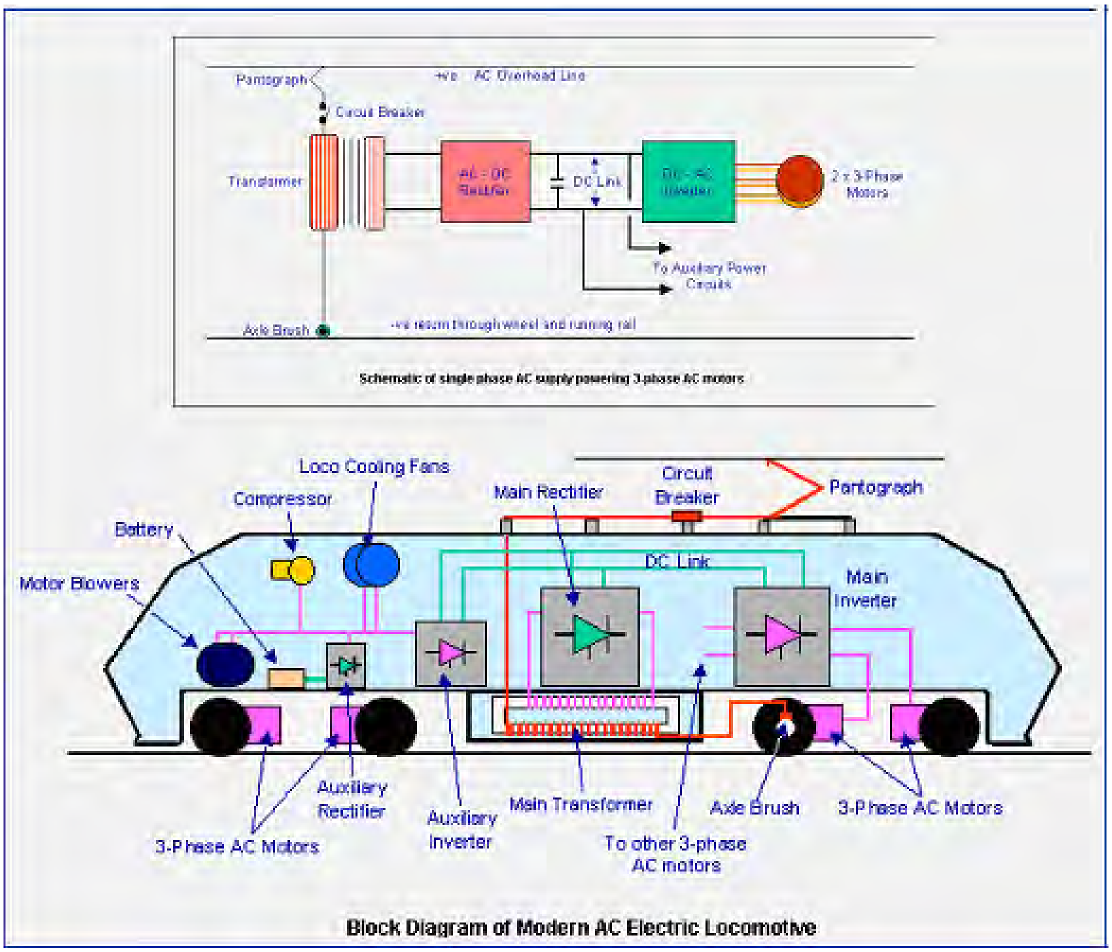

Figure 4- Modern Singe Phase AC Locomotive with Single Phase AC Caternary Power Converted to 3-Phase Power For the Motors (Inset)

Unlike third rail where each track has its own power rail, multiple tracks can share the same caternary support structure, hence slightly reducing cost if multiple, parallel rail lines are retrofit. Some approaches of electrifying multiple tracks are noted in the Figures 5 and 6.

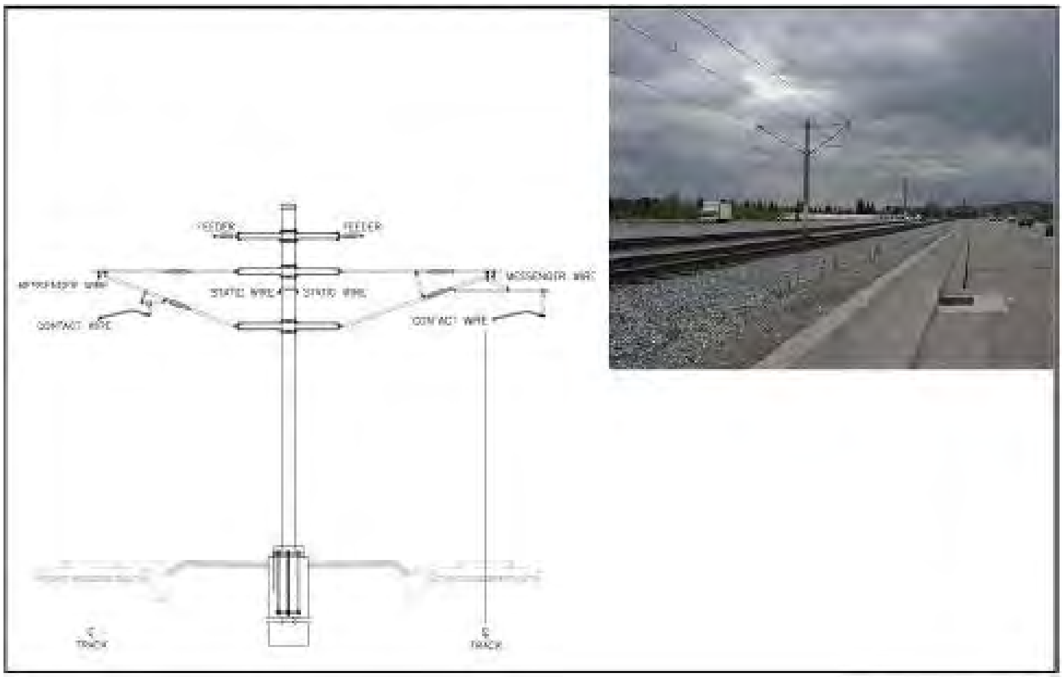

Figure 5- Overhead Contact System Two Track Arrangement with Center Pole Construction

Figure 6- Overhead Contact System Typical Portal Arrangement

3.3 Third-Rail and Overhead Caternary Approach to "Diesel" Locomotive Retrofit

The so-called "Diesel" locomotives, operating in the Los Angeles basin and throughout the country in freight and passenger service, are not like Diesel trucks, in that the Diesel engine is the power source but not the motive force. If a Diesel locomotive operated like a truck does, a massive (and inefficient) mechanical transmission would be required to couple the engine's power to the wheels. Instead, a locomotive's Diesel engine drives an electric generator which in turn powers electric motors directly coupled to the wheels as shown in Figure 7.

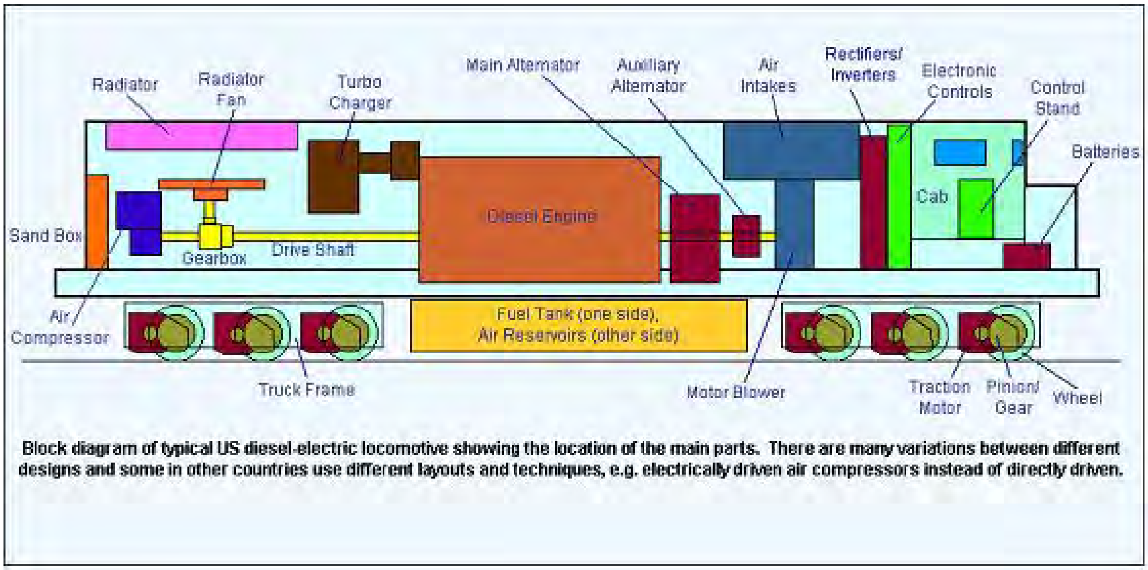

Figure 7- Typical "Diesel Electric" Locomotive Prevalent on US Freight and Passenger Rail

The electric motors in these *Diesel-electric* locomotives transmit power to the wheels, as well as add weight to the locomotive for more traction. These locomotives carry their own electrical power supply, and so are free of the requirement for a "shoe" contacting a powered third-rail, or a pantograph contacting power lines overhead. This freedom from the necessity to connect to an additional electrical distribution source has caused the almost total elimination of electric rail in favor of this less cumbersome "electrification" source for freight applications.

However, some applications exist that require hybrid "electro-Diesel" systems. Freight and passenger rail systems near New York City utilize Diesel generators on two-rail tracks through Long Island and Connecticut, but when entering the rail tunnels in the vicinity of the city, the locomotives drop a hydraulic "shoe" onto a powered third-rail and discontinue generating electric power with Diesel engines to conform to ordinances prohibiting locomotives from emitting smoke within the tunnels. Such "electro-Diesel" locomotives have been manufactured by both General Electric and General Motors (see Figure 8).

A " dual-mode" **P32AC-DM** locomotive was developed by General Electric to run its electric motors on power from the onboard Diesel engine or from a third rail carrying 750 volts of direct current and seamlessly transition between the two modes while underway. The P32AC-DM is unique not only because of third-rail capability, but also because it is equipped with AC (alternating current) traction motors.

The **EMD FL9** (New Haven Class EDER-5) was a dual-power electro-Diesel locomotive, capable of self-powered Diesel-electric operation and of operation as an electric locomotive powered from a third rail. A total of 60 units were built between October 1956 and November 1960 by General Motors Electro-Motive Division as a custom order for the New York, New Haven and Hartford Railroad Railed Crane

Figure 8- Examples of Hybrid Locomotives for Use on Electrified Rail

While operation in tunnels created the need for hybrid locomotives, the growing demand for zero-emission freight and passenger transport requires "all-electric" forms of propulsion. While these forms of propulsion in urban and industrial areas may be provided by third rail or catenaries, the exposed electric power lines will likely introduce numerous safety issues.

3.4 Power Distribution

Power distribution to electrified rail systems is similar to electric grid distribution for any major power customer. Sub-transmission stations connected to main transmission lines, typically carrying around 230 kV AC, step down the voltage to anywhere from 11 kV to 56 kV AC depending upon the customer. The power from the sub-transmission stations is then transmitted to substations along the electrified rail route.

The substations supply sufficient electric power to trains on the route. If the route's electric transmission system (third-rail or catenary) is not capable of delivering significant power, than the substations need to be spaced closer together in order to reduce the number of trains operating between substations. This is the particularly true for third-rail (Figure 9) since the at-ground arcing condition limits the transmission voltage—hence increasing current and "i squared R" losses. In addition, the third-rail systems being exclusively DC, their substations also require AC to DC converters making them more expensive than for AC electrification at the same voltage levels.

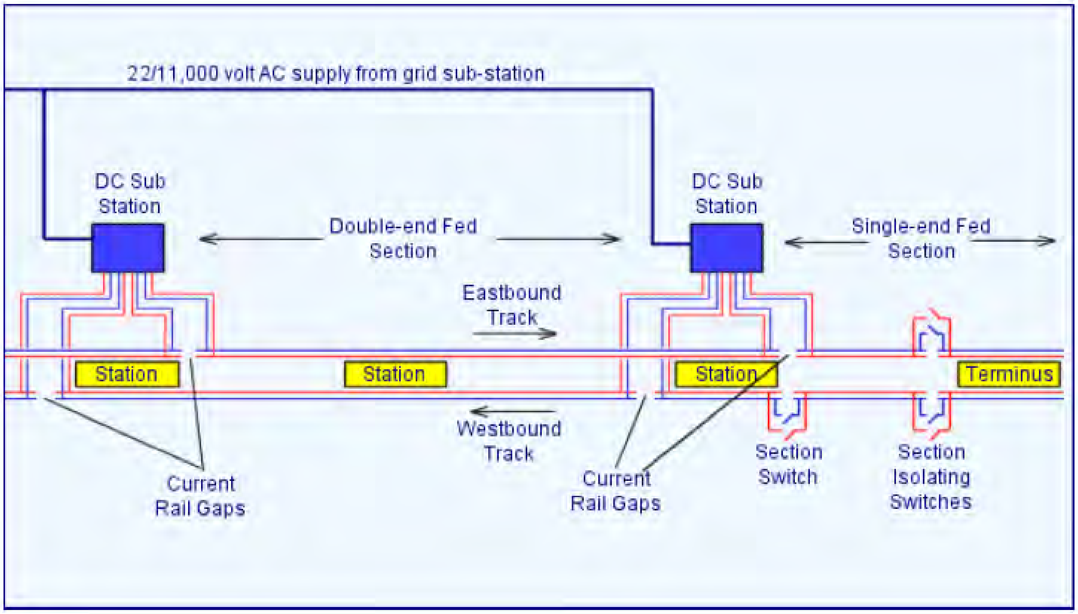

Figure 9- Typical Layout of a Third Rail Power Distribution System

Modern overhead caternary takes full advantage of its non-arching situation and uses up to 25 kV transmission for power; thus requiring fewer substations which can be spaced further apart. A schematic layout of a modern AC electrification subsystem is shown in figure 10. While these high voltage AC substations have no AC to DC conversion, the size and complexity of their required electrical components makes them somewhat more costly.

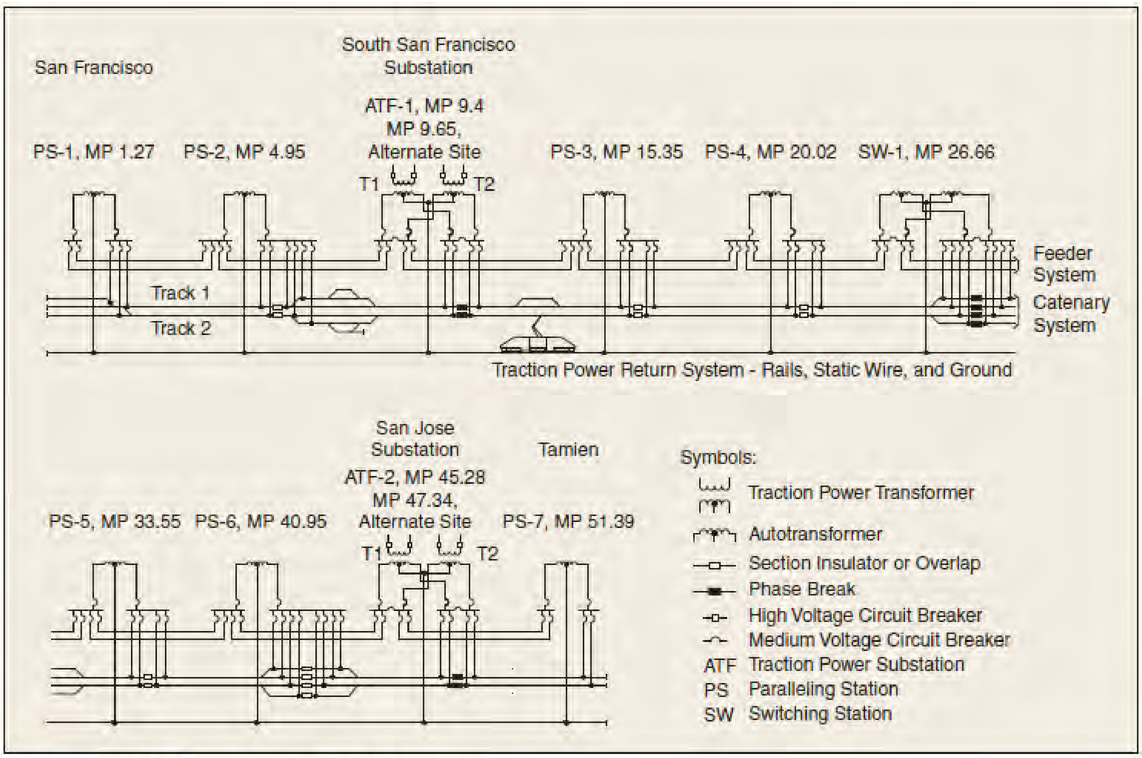

FIGURE 1 Caltrain 2 × 25 kV proposed electrification system.

Figure 10- Detailed Schematic of Proposed 25 kV Overhead Caternary Electrification

4 Operational Considerations and Comparisons of Diesel Driven Freight to Both Third Rail and Overhead Caternary Retrofit Freight Electrification

There are numerous projects worldwide where conventional Diesel driven rail—both passenger and freight—is being retrofit for electrification. The reasons are numerous: (1) Pollution from power generation is located at a single source, enhancing the efficiency of pollution control devices compared to having control devices on each engine. It is much easier to reduce CO_2 emissions at a stationary source than in a mobile source. CO_2 emissions are a world wide concern and all major developed countries are seeking methods of reducing their emissions, such as recently proposed underground storage. There is no way to incorporate this type of emission control in a Diesel locomotive. Also electric motors are considerably more efficient than Diesel engines. (2) Nationally the trucking industry carries about 75% of the freight and railways only 10%. Switching to railways should increase efficiency considerably. A well designed electric motor can have efficiency greater than 95%. An ideal Diesel engine (truck or locomotive) cannot have efficiency greater than its theoretical maximum efficiency of 56%. (3) No idling is required when the electric train is stopped. All Diesels required a warm-up period before they are loaded. (4) Reduced dependence on oil can occur since electrical power can be generated by many methods that are not dependent on oil. (5) Reduced dependence on truck usage and the resultant reduction of truck traffic on highways. The availability of inexpensive Diesel fuel and many highways led to the proliferation of the trucking industry without regards to their environmental impact on pollution, traffic congestion, and accelerated wear of highways.

4.1 Operational Characteristics of Third Rail Systems and Their Applicability to Freight Handling

While electrification has the aforementioned operational benefits over Diesel driven freight, the specific advantages and disadvantages of third rail electrification are listed as follows:

Advantages:

- Little if any visual intrusion on the environment.
- Third-rail systems are cheaper to install than overhead wire systems,
- Requires no vertical clearance, such as tunnels and bridges; thus reducing construction costs of tunnels and underground railways.
- More robust than overhead line systems.
- Relatively cheap to install, compared to overhead wire contact systems, as no structures for carrying the overhead contact wires are required,
- Within easy reach, instead of many feet up in the air, a third rail system allows easy maintenance

Disadvantages:

- A limitation on speed due to the mechanical impact of the shoe; 160 km/h (100 mph) is considered the upper limit of practical third-rail operation.
- Unguarded electrified rail is a safety hazard, and people have been killed by touching the rail or by stepping on it while attempting to cross the tracks.
- Limited capacity due to the low voltage necessary in a third-rail system—otherwise, electricity would arc from the rail to the ground or the running rails—resulting higher current
- High currents produce more voltage drop per mile causing sub-stations to be set up at frequent intervals along the line, increasing operating costs.
- The low voltage also means that the system is prone to overload, which makes such systems unsuitable for freight or high-speed trains demanding high amounts of power. These limitations of third-rail systems have largely restricted their use to mass transit systems.
- Under certain circumstances it is possible for a train to become "gapped" - stalled with none of its shoes in contact with the live rail.

4.2 Operational Characteristics of Overhead Caternary Systems and Their Applicability to Freight Handling

Overhead caternary, while the retrofit system of choice for most projects, also has its own, unique advantages and disadvantages:

Advantages:

- Does not require a high degree of segregation from the public; similar to power line distribution.
- Handles higher voltages allowing larger separation distances between power distribution stations; thus reducing costs
- Not as prone to faults from debris falling on top of conductor.
- Not obstructive to ground vehicle traffic.

Disadvantages:

- Possibility that pantograph can become tangled with wire and destroy that section of the system, thereby stopping service to the whole line. Prone to effects of high winds.
- Requires costly and complex constant tensioning of wire due to temperature fluctuations changing the wires length.
- Requires poles and caternary wires to support the contact wire that provides the power to the train.
- Requires methods to mitigate the traveling standing waves produced when the pantograph moves across the conducting wire. This was the limiting factor in the rail speed record set by the French.
- Danger to persons touching the necessarily exposed wire and being electrocuted and a safety hazard to bystanders if live wire breaks and comes in contact with the train.
- Visible obstructive and considered to be non-aesthetic in most urban areas; a legislative issue in Washington.
- The height of overhead wiring can create hazards at level crossings, where it may be struck by road vehicles.

5 Cost Estimate Summary for Third-Rail and Overhead Caternary Retrofit to Conventional Rail Infrastructure

To estimate the cost of retrofit electrification, both the material costs and operational costs should be considered. The material costs consist of (1) the cost per mile of retrofitting existing rail with either third-rail or overhead caternary, (2) the cost for converting Diesel electric locomotives to "hybrid" locomotives retrofit with a third rail shoe system or an overhead pantograph system; or the cost of an entirely new electric locomotive, and (3) the cost of dedicated electric power substations and substation distribution structure. Knowing the length of electrified rail and the number and length of trains using the system, a reasonable estimate of the system cost can be made.

However, operational costs involved in switching out locomotives or optimizing lengths of shuttle trains or train sections cannot be estimated without specifically defining an operating scenario. Once the operating requirements of a system are defined, the number of tracks, locomotives, and substations will determine overall system costs. So the most immediate cost estimation involves the per-mile costs of double track (bi-directional for heavy use) track electrification, the per-locomotive cost, and the substation cost-per mile. The proper combination of these costs can produce a reasonable system cost estimate—excluding operational interface considerations—once a system's requirement is defined. Note also that operational scenarios requiring "seamless compatibility" with existing rail processes involving long trains and long distances, without allowances for the benefits of electrification, will almost certainly be an expensive retrofit to existing rail and possibly infer economic infeasibility.

5.1 Estimate of Third-Rail Retrofit per Mile

Due to the inherent danger and low tractive power of third rail systems they are used primarily in limited access passenger systems such as subways. The cost of subway projects has skyrocketed making relavant cost data scarce as well as difficult to extrapolate to freight movement. The extension of the Bay Area Rapid Transit (BART) and the retrofit of third rail to the planned electrification of CalTrain through San Jose are two recent California above ground third-rail projects that are applicable. Both are passenger systems so the main correction to third rail freight electrification esimates involves the additional power of distribution and substations, and operating requirements of locomotives.

A number of third rail passenger systems that have been built in the United States were summarized in Table 1. Since the civil infrastructure for retrofit electrification of freight rail already exists within the Port; such costs as land, guideway, stations, etc. can be excluded from a cost estimate. Also, vehicles and power distribution for these rail retrofit costs are considered in a later section or the report and were not considered in the costs of electrification rail retrofit. As is typical of these existing and planned passenger systems as well as urban freight systems, all per mile costs consider two tracks for simultaneous bi-directional travel.

Using the "trackwork" percentage of table 1, BART electrification was 3% of the system cost or about $750k/mile ($900k/mile in 2008 dollars).

Breakdown of metro capital costs by subsystem for five US metros.

Subsystem	San Francisco BART (%)	Atlanta MARTA Phase A (%)	Baltimore MTA Phase I (%)	Chicago CTA O'Hare (%)	Boston MBTA Red Line South (%)
	3rd rail	3rd rail	OCS	3rd rail	3rd rail
Land	7	9	2	0	11
Guideway	37	33	25	20	15
Stations	19	20	30	28	33
Trackwork	3	2	2	7	7
Power	2	1	2	5	6
Control	4	2	4	8	7
Facilities	2	3	2	4	0
Eng./Mgt./Test	14	23	24	8	6
Vehicles	12	7	9	20	15
Total	100	100	100	100	100
Source: Federal Transit Authority 1992.					
cost in millions	$ 1,510	$ 2,270	$ 1,289		
% for trackwork + power	5	3	4	12	13
Mileage	60.5	26.8	7.6		
Cost/mile mi	1.2	2.54	6.8		

Cost is in 2002 dollars,

Table 1- Capital Cost Breakdown of the BART Third Rail System

A third rail system estimate that w as an act ual poposed retrofit to a " Diesel-pull" passenger s ystem is the C alTrain system which r uns f rom t he S an J ose a rea t o S an Fansisco. The fourth column of Table 2 from that proposal sites the cost of electrification as $600k/mile ($920k/mile in 2008 dollars).

BUDGETARY DIRECT COST COMPARISON OF STANDARD ELECTRIFICATION SYSTEMS FOR TYPICAL 50 MILES OF 2-TRACK ROUTE

Standard System Configuration	25kV AC Overhead	1500 VDC Overhead	600 VDC Overhead	600 VDC Ground Level
Distribution System	Lightweight Conductors	Heavy Conductors	Heavy Conductors	Third Rail
Current Capacity (typical)	600A	1500A	1800A	1800A
Substations (S/S) Size (typical)	20 MVA	1 MW	1 MW	1 MW
Primary Supply Spacing (typical)	115 kV	34.5 kV	34.5 kV	34.5 kV
Spacing (typical)	20 miles	3 miles	1 mile	1 mile
Qty S/S in 50 miles of route	3	16	50	50
S/S Cost Each	$2.2M	$0.8M	$0.5M	$0.5M
S/S Cost Total (a)	$6.6M	$12.8M	$25M	$25M
STM in 50 miles of route	105	105	105	-
Cost of OCS per mile	$400k	$450k	$500k	-
Cost of OCS Total (b)	$42M	$47.2M	$52.5M	-
STM in 50 miles of route	-	-	-	105
Cost of Third Rail per mile	-	-	-	$600k
Cost of Third Rail Total (b)	-	-	-	$63M
Total cost for 50m of route (a+b)	$48.6M	$60M	$77.5M	$88M
Civil Modifications Allowance	$10M +∅	$10M +∅	$10M +∅	$10M *∅
Electrical Installation Direct Cost(a+b+c)	$58.6M∅∅	$70 ∅∅	$87.5M	88M$
Cost Ratio	1.0 (base)	1.2	1.5	1.5

Legend:

STM	Single track miles, including crossovers and sidings
*	Essential fencing allowance for public safety. Actual costs may be much more.
∅	Excludes tunnel work to accommodate double stack freight
+	Overhead clearance attainment for catenary, and provision of safety barriers on bridges.
∅∅	Excluding motive power, signalling, communications and maintenance facility, design, construction protection, construction management, inflation, contingency and financing, and all owner costs.

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Table 2-Third Rail Electrification Estimate for CalTrain

5.2 Estimate of Overhead Caternary Retrofit per Mile

Safety concerns impose limited access requirments on third rail systems and has limited their use to subways and single use guideway systems more than retrofits to conventinal rail. More recent rail electrification retrofits involve overhead caternary, single phase, high votage A C transmission for onboard, electronic control of 3 -phase A C traction motors. The earlier referenced CalTrain retrofit of Table 2 not only considered third rail electrification but also overhead caternary. The first column of Table 2, delinenating the cost of high votage overhead caternary, sites the cost of electrification as $400k/mile ($614k/mile in 2008 dollars).

A more recent and far more deatailed overhead caternary estimate for rail retrofit comes from the Lakeshore Corridor commuter rail line in Toronto Canada. The line has operated for several years as a "Deisel-pulled" passenger system. For both economic and environmental reasons, it is presently being retrofit to an electric rail line that uses electric locomotives. The cost estimates refered to as Rough Order of Magnetude Estimates (ROMEs) were based on exceptionally detailed cost data, as exemplified in Appendix B, in that this project is going forward with the retrofit. Table 3 summerizes those detailed estimates of overhead caternary distribution cost for 556 Single Track Kilometers (STK) or 173 double track miles, to allow comparison with previous data. The conversion of the 2008 Canadian dollar (CD) to US dollar (USD) involves the exchange rate of .9426 USD to one CD at that time. Thus the overhead caternary costs of $149M CD (second row of Table 3) for 556 STK converts to $812k/mile in 2008 USD.

Captial Cost Estimate

ROME Estimate - Capital Costs	Cumulative Total at 2015	Total Between 2016 & 2031	Total Between 2032 & 2043	Totals
SYSTEMS - POWER SUPPLY AND DISTRIBUTION				
Traction power supply: substations	$76,029,525	$50,847,280	$0	$126,876,805
Traction power distribution: Overhead Catenary	$98,156,064	$51,077,283	$0	$149,233,347
Subtotal—SYSTEMS - POWER SUPPLY AND DISTRIBUTION	$174,185,589	$101,924,563	$0	$276,110,152

Table 3- Rough Order of Magnitude (ROME) Cost of Caternary Installation (Second Row) and Substation (First Row) Analysis of a 173 Double Track Mile Section of the Toronto Lakeshore Line Electrification Retrofit

5.3 Estimate of Single Diesel-Electric Locomotive Conversion to Hybrid Electric Locomotive for Third-Rail and/or Overhead Caternary Operation

The previously described "electro-Diesel" locomotives have been manufactured by both General Electric and General Motors engines, costing about $2M each. A small number of these could have direct application for electrified rail movement at the Port and in the Los Angeles basin as shuttle train engines. The class one rails, however, rather than using these proven hybrid locomotives for shuttle trains to move containers and form long haul trains outside of urban areas might be "hiding behind the need for absolute perfection" to both avoid major operational shifts and inflate electric locomotive costs. While the safety and geometric complexities of using electric locomotives for train formation at the Port complex prohibits electrification; short distances from terminals to the ICTF and SCIG, as well as the Alameda Corridor are reasonable candidates for electrification. These candidate routes considered here presently carry full-length trains intended to leave the Ports and the LA basin for transcontinental travel. To avoid economically and spatially costly exchange of electric for Diesel locomotives for these long, heavy trains at the terminus of electrified rail, the Class I rails are requiring hybrid electro-Diesel locomotives capable of pulling transcontinental trains as described in Appendix C. To avoid "switch out" of selected hybrid electro-Diesel locomotives, the rail companies are further suggesting replacing their extensive fleet (on the order of 12,000 to 16,000 Diesel locomotives) with the hybrids as a cost of electrification.

Use of the already designed and manufactured, but less powerful hybrids for electric shuttle train operation is not being considered due to its shift in operational efficiency and cost. Product managers at General Electric state they are looking at a major redesign and will not use the existing plans for the dual-mode electro-Diesel passenger locomotives previously described in this report, nor are they considering retrofitting conventional Diesel locomotives. The new electric locomotive design will cost $5M each, almost twice the cost of conventional Diesel and be required wherever a conventional locomotive is used now. Using the Class I rails operating scenario, electrification of even a modest length of a pollution saturated route might trigger a multi-billion dollar expense.

Whether an electrified retrofit shuttle train operating scenario, using a handful of conventional hybrid locomotives at $2.5M each, or the conversion of present operating rail practices to partial electrification at the cost of billions of dollars is a subject for further analysis and discussion.

5.4 Estimate of Electric Grid Substation and Block Electric Distribution

Again the estimates for substation and block electrification can be estimated from proposed and existing systems for both third rail and overhead caternary. A difficulty arises when the length of the electrification retrofit is unknown. For relatively short systems of a mile or two, at least one substation and block feeder system is required. If the spacing between required substations and feeders is close, then the cost of that short system increases significantly with increased length. However, systems requiring fewer substations and feeders over a distance will see a slower rise of cost as system length increases compared to a short system. Since the purpose of this report is to generalize the relative costs of various freight electrification approaches, system length will be assumed sufficiently long to account for more than one substations and multiple block feeds.

Third rail costs for electric power distribution is determined from Bart electrification using the "power" percentage of 2% (Table 1) of the system cost or about $500k/mile ($600k/mile in 2008 dollars). The third rail approach to CalTrain electrification power cost are derived from Table 2 where the cost per substation is $500k and one is required every mile for a cost of $500k/mile ($770k/mile in 2008 dollars).

CalTrain cost of power distribution for overhead caternary electriciation power distribution cost are derived from Table 2 where the cost per substation is $2.2M and three are required for 50 miles for a cost of $132k/mile ($203k/mile in 2008 dollars).

Table 3 summerizes those detailed estimates of overhead caternary distribution cost for 556 Single track Kilometers (STK) or 173 double track miles, to allow comparison with previous data. The cost of $127M CD for 556 STK converts to $692k/mile in 2008 USD.

6 Conclusions and Recommendations

Information from Sections 5.1, 5.2, and 5.4 indicate the cost of double track retrofit electrification of rail ranges from $1.42M to $1.5M per mile for third rail and $.825M to $1.5M per mile for overhead caternary. These are only the capital costs for providing power to a locomotive on existing right-of-way. Since these costs were derived from passenger systems, use of longer and heavier freight trains at the Port will likely require more power for more tractive effort, and hence the distribution costs of these estimates could be somewhat higher.

Neither at-grade third rail nor overhead caternary are conducive to train formation involving loading, unloading, and numerous short switched sidings. However, operational requirements such as switching and power requirements favor overhead caternary, making it the better approach for hauling train sections or shuttle trains from the port to Diesel pulled transcontinental train intermodals. Even with block switching of at-ground third rail–applying power only to segments used by the locomotive, this approach for rail retrofit electrification is deemed too dangerous. Thus, overhead caternary seems the more operationally realistic and safest approach to retrofit rail electrification for moving trains from terminals to ICTF, SCIG, or along the Alameda Corridor.

An important issue concerning feasibility, however, is the intended operating process of the electrified rail. With the cost of modern hybrid locomotives capable of operating on electrified tracks running from $2.5M to $5M each (Appendix D) (on the order of worst case cost of retrofit electrification per mile), the number and cost of the locomotives for a operating scenario will be the major factor in electrification cost for short haul distances.

The Alameda Corridor is a dedicated freight rail corridor running 22 mi directly between the Ports of Los Angeles and Long Beach and the Redondo Junction, near the major rail yards just east of downtown Los Angeles. The corridor currently carries more than 50 trains per day. If overhead caternary retrofit is possible or third rail retrofit required for vertical clearance issues, a very rough estimate of retrofit electrification to the three track corridor might be $45M. At this juncture an estimate requires an assumption as to the power and number of required locomotives. Shuttle trains would be more numerous than long transcontinental trains and locomotives dedicated to operating on the corridor could make multiple round trips per day; limiting the number of existing dual-mode electro-Diesel locomotives engines to an optimistic number of 150 (50 pull teams of 3 engines (Figure 8), each making 3 round trips per day and moving the equivalent of 50 transcontinental trains) for a cost of $300M. The total infrastructure investment for electrifying the Alameda Corridor would be $345M providing a shuttle train scenario was realistic. This is in line with a prior SCAG study (1992) with adjusted cost estimate of

$233M. If the present operating Scenario for the Corridor is continued with the addition of electrification, the 50 transcontinental trains per day, each requiring about 10 days for the pull team of 4 modern hybrid engines to return; around 2000 such engines (<10% of Class I rail inventory) would be required at a cost of $10B, a prohibitive amount in the present economic climate.

So, while electrification of existing freight rail at the Ports of San Pedro is economically and operationally feasible, the particular operating scenario involving the required type and number of electric locomotives will be the deciding factor in determining overall practicality.

A yet to be defined third approach to rail electrification that overcomes both the power and safety limitations of at-ground third rail and the inherent climbing limitation of friction propulsion of a caternary system could allow for not only less complex near-dock operation, but also a more agile urban freight rail system. Such a system should also provide for minimum intrusion into port operations during its installation.

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Appendix A

Justification of Mileage Estimate for Port Rail Electrification Retrofit

APPENDIX A

Justification of Mileage Estimate for Port Rail Electrification Retrofit

Table A.1

track in Miles	track in Km	terminal	feet of spur
		Port of Los Angeles	
		WEST BASIN CONTAINER TERMINAL	berth 100
		WEST BASIN CONTAINER TERMINAL	* berth 121-131
0	0	TRANS PACIFIC CONTAINER SERVICE CORP. (TraPac)	no rail berth 135-139
0	0	PORT OF LOS ANGELES CONTAINER TERMINAL	no rail berth 206-209
0	0	Yusen Terminals Inc.	no rail berth 212-225
		Seaside Transportation Services, LLC	* berth 226-236
		APL TERMINAL/GLOBAL GATEWAY SOUTH	* berth 302-305
		APM TERMINALS/PIER 400	* berth 401-406
		west basin	
4.69	7.54	Three loading railtracks, each approximately 3000 feet (914 meters) long, and capable of handling a total of 27 five-platform doublestack railcars	
		Three adjacent storage railtracks, each approximately 3000 feet (914 meters) long, and capable of handling a total of 27 five-platform doublestack railcars	
		Dedicated departure railtrack with a 27 five-platform railcar capacity	
		i.e. five platform doublestack cars =250 Feet	
		PORT OF LOS ANGELES CONTAINER TERMINAL	
		no useable rail, nothing is hooked to the main line	
5.34	8.60	**seaside**	
		working tracks (1) 7500 ft + (4)*2300 + (5)*2300 storage tracks	
8.18	13.17	**APL**	
		Eight loading railtracks, each approximately 2700 feet (823 meters) long, and capable of handling a total of 64 five-platform doublestack railcars	
		Eight adjacent storage railtracks, each approximately 2700 feet (823 meters) long, and capable of handling a total of 64 five-platform doublestack railcars	
12.95	20.85	**apm/ Maersk**	
		12 loading tracks, each approximately 2500 feet (762 meters) long	
		Each track has the capability of handling eight 305-foot-long (93-meter-long) doublestack railcars, for a total capacity of 96 railcars	
		each capable of handling 21 305-foot-long (93-meter-long) doublestack railcars for a total capacity of 126 railcars	
31.16	**50.15**	**Total track available for electrification at the Port of Los Angeles**	

APPENDIX A

Justification of Mileage Estimate for Port Rail Electrification Retrofit

Table A.2

Miles	Kilometers				
		terminal	feet of spur		
		California United Terminals	none	pier E	
0.53	0.85	TTI hanjin(storage and usable track)	28000'	pier T	
1.23	1.98	Its	6505	pier G	
1.52	2.44	LB container terminal	8000	pier F	
4.77	7.68	Pacific Container	12*2100	pierJ	
3.03	4.88	SSA	2* 8000'	pier A	
		SSA	none	pier C	
		* Pacific Container has two rails one is 50 and the other is 25 each measured in stacked car lengths, one stacked car length is from 266 -300 ft			
11.08	**17.83**	**Total track available for electrification at the Port of Long Beach**			
		ICTF			
17.04	27.42	Six loading/unloading tracks and one running track which will hold 243 conventional cars and 84 double-stack cars.			1962 Ft
		Ten additional storage tracks in the Dolores Support Yard, which will hold 169 double-stack cars.			89570 Ft
2.19	3.22	**Trackage from Ports of San Pedro to ICTF**			
		Terminal Island Container Transfer Facility (TICTF)/			
6.57	10.58	Four loading railtracks, each approximately 2300 feet (701 meters) long, and capable of handling a total of 28 five-platform doublestack railcars			
		Five adjacent storage railtracks, each approximately 2300 feet (701 meters) long, and capable of handling a total of 35 five-platform doublestack railcars			
		Dedicated arrival railtrack with a 28 five-platform railcar capacity			
		Dedicated departure railtrack with a 28 five-platform railcar capacity			
20.00	32.18	**Alameda Corridor**	3 tracks at 20 miles each only one track candidate for electrification		
88.05	141.38	**totals without Hobart or East LA yards**			
31.16	50.15	Total track available for electrification at the Port of Los Angeles			
11.08	17.83	Total track available for electrification at the Port of Long Beach			
42.25	**67.99**	**Total track available for electrification at the Ports of San Pedro**			
42.25	67.99	Total track available for electrification at the Ports of San Pedro			
2.19	3.22	Trackage from Ports of San Pedro to ICTF			
44.4	**71.2**	**Rail length candidate for electrification not including the Alameda corridor**			

As seen in the bold entry on Table A.1 the total rail miles for the Ports of San Pedro deemed feasible for electrification connecting major terminals at the Ports to the ICTF is 44.4 miles. Adding one rail of the Alameda Corridor as shown in table A.2 adds another 20 miles. Thus the total rail miles that is candidates for electrification are 64.4 miles."

Appendix B

Excerpt GO Lakeshore Corridor Electrification

Excerpt GO Lakeshore Corridor Electrification

APPENDIX M

GO - LAKESHORE ELECTRIFICATION - ROME ESTIMATE

Date: October 17, 2008
Version: ROM D02

Assumptions:
2008-2015

1. Existing Legacy Signal Plant will be upgraded from relay logic to a Processor Based Control system (eg GEO).
2. All Tracks will likely be Electrified - 25KVA AC Propulsion
3. All DC and electronic coded Track Circuits will likely be converted to to PSO type circuits, to accommodate 25KVA electrical propulsion.
4. FOTS - SCADA communications system previously installed which can be built on or expanded.
5. Signal locations and spacing will remain as is on existing tracks.
6. Mixed mode operation on all tracks.

2016-2031

1. New tracks will be added and allow mixed mode operations.
2. All new tracks will likely be electrified - 25KVA Propulsion.
3. Cab Signalling will be overlayed on all tracks. Non-equipped trains will comply with CROR.
4. Cost to upgrade FOTS - SCADA to support cab signalling solution are included in the estimate.
5. Cost to equip Go trains for Cab Signalling are included in the estimate.
6. New tracks shall have signals spaced similar to existing tracks to allow existing users unrestricted access.
7. Unfitted trains operating on new tracks shall operate under CROR rules as per existing operation.

Estimating:

1. Signal Bridges - assumed 25% of existing bridges to be replaced where new adjacent signals required.
2. For storage siding assumed 1 new power switch per track.
3. For maintainance facility assumed 2 new power switches per track.
4. Assumed 50% of radio transmitters can be mounted on existing structures.
5. Existing control of Lakeshore corridor is by CTC. This estimate includes the cost for intermin alterations to this method of control and also for eventual replacement by a new dedicated corridor control center.
6. Many different CAB signalling systems are available that can achieve similar objectives however the implementations vary as does the system components and price. This estimate tries to consider this fact and how engineering development could influenence system components.
7. Nature of some signalling alterations determined by engineering development therefore estimate reflects this status.
8. Some specific contengencies included where technological issues are to be overcome or new technology developed.
9. No general contingencies have been considered.

Excerpt GO Lakeshore Corridor Electrification

GO - LAKESHORE ELECTRIFICATION - ROME ESTIMATE

Date: October 17, 2008
Version: ROM.D02

Conventional Signals	
Materials and Equipment Costs	$51,137,076
Labour Total @ 75%	$38,352,807
Sub Total	$89,489,883
Engineering @ 15%	$13,423,482.46
Stageworks	$136,000,000
Industry	$31,500,000
Connections	$40,000,000
Total =	**$310,413,366**

CAB Signalling	
Materials and Equipment Costs	$44,869,230
Labour Total @ 75%	$33,651,923
Sub Total	$78,521,153
Engineering and Development @ 35%	$27,482,403
Engineering Application Design @ 100%	$44,869,230
Total =	**$150,872,786**

Legacy Upgrades - Existing Track	
Materials and Equipment Costs	$3,351,777
Labour Total @ 75%	$2,513,833
Sub Total	$5,865,610
Engineering @ 15%	$879,841
Total =	**$6,745,451**

AC Immunisation - Existing Track	
Materials and Equipment Costs	18104526.96
Labour Total @ 75%	13578395.22
Sub Total	31682922.18
Engineering @ 15%	4752438.327
Engineering Predictor Development	1347754.05
Total =	**$37,783,115**

AC Immunisation New Track	
Materials and Equipment Costs	$4,888,634
Labour Total @ 75%	$3,666,476
Sub Total	$8,555,110
Engineering @ 15%	$1,283,267
Total =	**$9,838,377**

Overall Total	**$515,653,095**

Excerpt GO Lakeshore Corridor Electrification

Equipment Case (Per Case)			
Description	**Qty**	**Price**	**Total**
Case, high double	1	$ 3,380.00	$ 3,380.00
Foundation assembly kit	1	$ 380.00	$ 380.00
Power service	0.75	$ 5,000.00	$ 3,750.00
Power Cable (TECK) - 3C#6 /m (Power & SCD)	10	$ 6.87	$ 68.70
Electrical panel - Square D 30	1	$ 330.00	$ 330.00
Battery charger, electronic 12/20 (NRS)	1	$ 307.80	$ 307.80
Saft SPL165 165 A-Hr	9	$ 119.85	$ 1,078.65
Battery Lug assy Kit 20 mm post consisting of:	8	$ 20.00	$ 160.00
SP20-4A surge protection	1	$ 200.00	$ 200.00
	2	$ 19.13	$ 38.26
Equalizer	1	$ 12.48	$ 12.48
Fuse (10A)	1	$ 15.00	$ 15.00
	1	$ 50.00	$ 50.00
Ground rods (2) and copper wire	1	$ 20.00	$ 20.00
Case Wire, Eyes, Terminals, test links, log book, Etc	1	$ 150.00	$ 150.00
Total			$ 9,940.89

Grounding of Structures			
Description	**Qty**	**Price**	**Total**
Grounding mat - PSM4644C2/0	1	$ 707.00	$ 707.00
CadWeld molds - approx. $100.00 each	6	$ 100.00	$ 600.00
CadWeld kit - approx. $460.00	2	$ 460.00	$ 920.00
CadWeld One Shots	1	$ 2.50	$ 2.50
2/0 copper cable	10	$ 18.00	$ 180.00
Total			$ 2,409.50

Impedance Bonds			
Description	**Qty**	**Price**	**Total**
Impedance bond - AC MINI, 300 AMPS, Normal Overload	1	$ 5,160.00	$ 5,160.00
M16 22mm Rail Power Bond, SS Stud, copper bush	2	$ 38.30	$ 76.60
Single 5/8" Hole Heavy Duty Copper Lug for 1325/24	2	$ 23.40	$ 46.80
Ground (Every 3rd Joint)	0.3	$ 2,409.50	$ 722.85
535MCM, Hi-Flex DLO, $12.73/ft	10	$ 12.73	$ 127.30
Total			$ 6,133.55

Double Rail Track Bonding			
Description	**Qty**	**Price**	**Total**
M16 22mm Rail Power Bond, SS Stud, copper bush	12	$ 38.30	$ 459.60
Single 5/8" Hole Heavy Duty Copper Lug for 1325/24	12	$ 23.40	$ 280.80
535MCM, Hi-Flex DLO, $12.73/ft	32	$ 12.73	$ 407.36
Total			$ 1,147.76

Touch Potential for Masts/Bridges			
Description	**Qty**	**Price**	**Total**
Touch protection cages for masts/bridges etc. ($1,000 average)	1	$ 1,000.00	$ 1,000.00
Total			$ 1,000.00

FOTS Communication Channel per Track Mile			
Description	**Qty**	**Price**	**Total**
8 Strand SM Fiber - Outdoor Cable Track /Ft (@5280 Ft/Corridor Mile /2.51)	2107	$ 1.44	$ 3,034.08
Messenger Wire #6 ACSR /Ft (@5280 Ft/Corridor Mile /2.51)	2107	$ 0.95	$ 2,001.65
Cable Attachments & Termination (@$1630 per Corridor Mile /2.51)	1	$ 650.46	$ 650.46
Fiber Modems (@$500 per Corridor Mile /2.51)	1	$ 199.54	$ 199.54
Total			$ 5,885.73

Comms Cost/Mile			
Description	**Qty**	**Price**	**Total**

[redacted]

Excerpt GO Lakeshore Corridor Electrification

APPENDIX J-1

	Component	Qty	Unit	Rate	Material	Installation	Total
Typical Cantilever Assembly							
1	Steel Mast	1	no.	1,282.05	1,282	641	1,923
2	Rod Insulator	2	no.	73.33	147	73	220
3	Eye clamp for 55 tube	1	no.	12.58	13	6	19
4	Eye clamp for 70 tube	4	no.	13.46	54	27	81
5	Catenary wire support	1	no.	62.33	62	31	93
6	Cantilever brace (dia = 42mm)	1.5	m	6.50	10	5	15
7	Clevis end fitting for 42 tube	2	no.	19.23	38	19	58
8	Strut tube (dia = 70mm)	4.5	m	15.76	71	35	106
9	Clevis end fitting for 70 tube	1	no.	25.64	26	13	38
10	Steady Arm L = 1050mm	1	no.	63.99	64	32	96
11	Eye clamp for tube 70	1	no.	11.62	12	6	17
12	Drop bracket	1	no.	38.86	39	19	58
13	Steady tube 55 (L = 2m)	2	m	13.21	26	13	40
14	Clevis end fitting for 55 tube	1	no.	22.44	22	11	34
15	Standoff Insulator	1	no.	73.33	73	37	110
16	Foundation	1	no.	641.03	641	321	962
					2,580	**1,290**	**3,870**
Typical Portal Assembly (4 Tracks)							
1	Steel Spport Structure	2	no.	3,846.15	7,692	3,846	11,538
2	Steel Head Structure	1	no.	6,410.26	6,410	3,205	9,615
3	Drop Tube Assembly	4	no.	641.03	2,564	1,282	3,846
4	Rod Insulator	16	no.	73.33	1,173	587	1,760
5	Eye clamp for 70 tube	16	no.	13.46	215	108	323
6	Catenary wire support	16	no.	62.31	997	498	1,495
7	Cantilever brace (dia = 42mm)	40	m	6.54	262	131	392
8	Clevis end fitting for 70 tube	16	no.	25.64	410	205	615
9	Steady Arm L = 1050mm	4	no.	63.97	256	128	384
10	Drop bracket	4	no.	38.85	155	78	233
11	Steady tube 55 (L = 2m)	8	m	13.21	106	53	158
12	Clevis end fitting for 55 tube	16	no.	22.44	359	179	538

Excerpt GO Lakeshore Corridor Electrification

13	Standoff Insulator	4	no.	73.33	293	147	440
14	Foundation	2	no.	641.03	1,282	641	1,923
					22,175	**11,088**	**33,263**

Typical Portal Assembly (5 Tracks)

1	Steel Sppport Structure	2	no.	5,128.21	10,256	5,128	15,385
2	Steel Head Structure	1	no.	7,692.31	7,692	3,846	11,538
3	Drop Tube Assembly	5	no.	641.03	3,205	1,603	4,808
4	Rod Insulator	20	no.	73.33	1,467	733	2,200
5	Eye clamp for 70 tube	20	no.	13.46	269	135	404
6	Catenary wire support	20	no.	62.31	1,246	623	1,869
7	Cantilever brace (dia = 42mm)	50	m	6.54	327	163	490
8	Clevis end fitting for 70 tube	20	no.	25.64	513	256	769
9	Steady Arm L = 1050mm	5	no.	63.97	320	160	480
10	Drop bracket	5	no.	38.85	194	97	291
11	Steady tube 55 (L = 2m)	10	m	13.21	132	66	198
12	Clevis end fitting for 55 tube	20	no.	22.44	449	224	673
13	Standoff Insulator	5	no.	73.33	367	183	550
14	Foundation	2	no.	769.23	1,538	769	2,308
					27,976	**13,988**	**41,963**

Typical Portal Assembly (6 Tracks)

1	Steel Sppport Structure	2	no.	6,410.26	12,821	6,410	19,231
2	Steel Head Structure	1	no.	8,974.36	8,974	4,487	13,462
3	Drop Tube Assembly	6	no.	641.03	3,846	1,923	5,769
4	Rod Insulator	24	no.	73.33	1,760	880	2,640
5	Eye clamp for 70 tube	24	no.	13.46	323	162	485
6	Catenary wire support	24	no.	62.31	1,495	748	2,243
7	Cantilever brace (dia = 42mm)	60	m	6.54	392	196	588
8	Clevis end fitting for 70 tube	24	no.	25.64	615	308	923
9	Steady Arm L = 1050mm	6	no.	63.97	384	192	576
10	Drop bracket	6	no.	38.85	233	117	350
11	Steady tube 55 (L = 2m)	12	m	13.21	158	79	238
12	Clevis end fitting for 55 tube	24	no.	22.44	538	269	808
13	Standoff Insulator	6	no.	73.33	440	220	660
14	Foundation	2	no.	897.44	1,795	897	2,692

Excerpt GO Lakeshore Corridor Electrification

					33,776	16,888	50,664

Typical Headspan Assembly

1	Steel Mast	2	no.	2,982.05	5,964	2,982	8,946
2	Rod Insulator	6	no.	73.33	440	220	660
3	Eye clamp for 55 tube	12	no.	12.58	151	76	227
4	Eye clamp for 70 tube	12	no.	13.46	162	81	242
5	Catenary wire support	6	no.	62.33	374	187	561
6	Cantilever brace (dia = 42mm)	15	m	6.50	98	49	146
7	Clevis end fitting for 42 tube	12	no.	19.23	231	115	346
8	Strut tube (dia = 70mm)	12	m	15.76	189	95	284
9	Clevis end fitting for 70 tube	6	no.	25.64	154	77	231
10	Steady Arm L = 1050mm	3	no.	63.99	192	96	288
11	Eye clamp for tube 70	6	no.	11.62	70	35	105
12	Drop bracket	3	no.	38.86	117	58	175
13	Steady tube 55 (L = 2m)	10	m	13.21	132	66	198
14	Clevis end fitting for 55 tube	6	no.	22.44	135	67	202
15	Standoff Insulator	3	no.	73.33	220	110	330
16	Foundation	2	no.	641.03	1,282	641	1,923
					9,909	4,954	14,863

Other Material (Option A)

1	Contact Wire	616,325	m	15	9,402,908	4,701,454	14,104,362
2	Messager	616,325	m	10	6,242,267	3,121,133	9,363,400
3	Return Wire	616,325	m	15	9,402,908	4,701,454	14,104,362
4	Ground Wire	616,325	m	4	2,607,529	1,303,765	3,911,294
5	Dropper Assembly	44,023	no.	10	461,905	230,953	692,858
6	Anchor	1,000	no.	769	769,231	384,615	1,153,846
7	Fix Termination	500	no.	769	384,615	192,308	576,923
8	Mid Point	500	no.	3,922	1,960,958	980,479	2,941,437
9	Section Insulator	500	no.	2,593	1,296,410	648,205	1,944,615
10	Phase Break	50	no.	10,256	512,821	256,410	769,231
11	Motorised Switch	100	no.	16,011	1,601,103	800,551	2,401,654
12	Manual Switch	200	no.	11,567	2,313,462	1,156,731	3,470,192
13	Disc Insulator Assembly	5,000	no.	46	228,846	114,423	343,269
14	Flexible Connection	5,000	m	103	512,821	256,410	769,231
15	BWA	500	no.	665	332,574	166,287	498,861
16	Anti-Climbing Device	1,000	no.	962	961,538	480,769	1,442,308
17	High Voltage Danger Sign	10,000	no	5	50,000	25,000	75,000
18	Insulated Overlap	500	no.	3,846	1,923,077	961,538	2,884,615
19	Surge Arrestor	500	no.	740	370,192	185,096	555,288
20	Track Bonding & Grounding	10,000	no.	482	4,816,346	2,408,173	7,224,519
					46,151,511	23,075,755	69,227,266

Other Material (Option B)

1	Contact Wire	629,092	m	15	9,597,691	4,798,845	14,396,536
2	Messager	629,092	m	10	6,371,576	3,185,788	9,557,365
3	Return Wire	629,092	m	15	9,597,691	4,798,845	14,396,536
4	Ground Wire	629,092	m	4	2,661,545	1,330,772	3,992,317
5	Dropper Assembly	44,935	no.	10	471,474	235,737	707,210
6	Anchor	1,000	no.	769	769,231	384,615	1,153,846
7	Fix Termination	500	no.	769	384,615	192,308	576,923
8	Mid Point	500	no.	3,922	1,960,958	980,479	2,941,437
9	Section Insulator	500	no.	2,593	1,296,410	648,205	1,944,615
10	Phase Break	50	no.	10,256	512,821	256,410	769,231
11	Motorised Switch	100	no.	16,011	1,601,103	800,551	2,401,654
12	Manual Switch	200	no.	11,567	2,313,462	1,156,731	3,470,192
13	Disc Insulator Assembly	5,000	no.	46	228,846	114,423	343,269
14	Flexible Connection	5,000	m	103	512,821	256,410	769,231
15	BWA	500	no.	665	332,574	166,287	498,861
16	Anti-Climbing Device	1,000	no.	962	961,538	480,769	1,442,308
17	High Voltage Danger Sign	10,000	no	5	50,000	25,000	75,000
18	Insulated Overlap	500	no.	3,846	1,923,077	961,538	2,884,615
19	Surge Arrestor	500	no.	740	370,192	185,096	555,288
20	Track Bonding & Grounding	10,000	no.	482	4,816,346	2,408,173	7,224,519
					46,733,969	23,366,985	70,100,954

Appendix C

The Journal of Commerce BNSF Eyes Route to Electric Trains

The Journal of Commerce: BNSF Eyes Route to Electric Trains

BNSF Eyes Route To Electric Trains

John D. Boyd | Apr 13, 2009 6:24PM GMT
The Journal of Commerce Online - News Story
Class I Railroads | Rail Suppliers | Technology | Rail + Intermodal | Special Report: Electrifying Freight Rail | United States

Railroad could carry power lines in rail corridors, run locomotives off electricity

> *"It's really going to have to be a federal vision, with some federal funding."*

Converting the freight rail system to electric trains from today's all-diesel operations might seem like a far-off notion, but BNSF Railway's Matthew K. Rose is starting to explore this new frontier.

If his ideas pan out, BNSF's still-early planning efforts could help produce historic change for North American freight railroads.

Rose, BNSF's chairman, president and CEO, told *The Journal of Commerce* his company is in talks with electrical power line builders about stringing or burying transmission lines in some of BNSF's inter-city rail corridors.

With those line-easement leases emerging as a possible new revenue source, BNSF officials are also weighing how to electrify the carrier's mainline track system and asking equipment makers about locomotives that could run both under electric or diesel power.

That puts the nation's second-largest railroad in the midst of a power-line building boom to upgrade the electrical grid, and angling to be ready for the time when proposed federal caps on carbon emissions might turn diesel use into a big financial disadvantage.

"We have had conversations with two, if not three, outside organizations," Rose said, "around using railroad right of way for different opportunities of electrification." He does not see such potential power line projects developing quickly on the railroad, but said BNSF is in "serious" talks with two of them.

He said BNSF could opt to draw electricity from those lines for its own use, in lieu of cash payments. With that, it might also offer power along with freight transportation to a new-era industrial park for various types of factories that burn lots of energy.

BNSF has not asked locomotive makers to prepare any plans, Rose said, but has discussed with them what kind of equipment is already available or could be developed if the railroad begins to integrate electric power with its vast diesel territory.

He said the price tag to electrify all BNSF mainline tracks could be $10 billion, including what the carrier would need in dual-mode locomotives. That's too steep a price for BNSF to justify right now, but the initial power line projects could be a way to start.

"Without a doubt it helps a lot, but it's not like either of these deals that we've looked at on transmission lines are to blanket our 26,000 miles of railroad," Rose said.

Appendix D

The Journal of Commerce a Call for New-Era Engines

The Journal of Commerce: *a Call for New-Era Engines*

A Call for New-Era Engines

John D. Boyd | Apr 13, 2009 4:00AM GMT
The Journal of Commerce Online - News Story
Class I Railroads | Rail Suppliers | Technology | Rail + Intermodal | Special Report: Electrifying Freight Rail | United States

Dual-mode locomotives could take trains in, out of electrified zones

"It's not a technology leap. It's an incremental move."

Builders of the largest inter-city locomotives for North American freight railroads say they can develop "dual-mode" units to run under either diesel or electric power, but they can't do it overnight.

Specialists at **GE Transportation** — one of two major builders of long distance or "line- haul" freight engines on this continent — said it would take several years to integrate technologies that have not yet been paired on freight units, at a cost considerably higher than today's diesel locomotives.

Still, if freight lines opted to run electric trains in parts of the country and transition their fleets with dual-mode locomotives, it is "clearly within the scope" of the equipment industry, said Joseph Dougherty, marketing leader for GE's global locomotive operations.

He said because GE, as well as other suppliers, has built dual-mode units in the past for passenger systems, it understands what it would take even though they have not built them for the heavier physical demands of freight operations.

"It's not a technology leap," said Dougherty. "It's an incremental move to a new generation of dual mode."

Yet it is not as simple as bringing some old plans from when GE last sold dual-mode units to Amtrak and New York's Metro North passenger lines from 1994 through 2001 up to date.

Instead, "you're looking at a major redesign," said product manager Pete Lawson.

That's partly because only a few of those earlier units approached the more powerful horsepower needs of freight service, and because diesel locomotives have undergone many changes in the past decade to meet tougher emission rules.

BNSF Railway Chairman, President and CEO Matthew K. Rose says he might want such locomotives if he moves BNSF toward electrified track systems. Other railroads are also studying this option.

BNSF is in talks with power line firms to build new lines within the railroad right of way, which would allow the carrier to tap that electricity for train operations. But Rose says he would want engines that could move easily from electrified track into non-electric zones without stopping to change out a train's locomotives.

The Journal of Commerce: *a Call for New-Era Engines*

Dual-mode locomotives could take trains in, out of electrified zones

These GE officials said they had not talked with BNSF about the idea, and thought it could take three years to take such a new model from the concept stage to production.

However, Dougherty said if a railroad asked for such equipment, "the time required to electrify the line would exceed the time we would need" to provide the power units.

They said electrified freight rail lines in other parts of the world are using or considering less costly all-electric engines rather than mixing dual-modes into their fleets. And even if such were in use overseas, they said, those engines could not be deployed back here.

"We run the heaviest axle loads in the world," explained Lawson. "There's no one moving the freight like North American railroads are," and so the entire locomotive has to be designed around that world-leading load requirement.

They also said dual-mode units might cost up to twice the price of new diesel units in today's North American line-haul fleets, which can run $2.5 million apiece.

Rose said cost estimates he has heard would also favor all-electric units, but that would limit the company by forcing it either to change out a cross-country train's engines as it goes in and out of electrified territory, or force a railroad to wait until it could electrify large segments all at once rather than shift in stages to a new system.

Other industry sources wonder if there might be an in-between option. Some recent designs are already tapping a locomotive's braking energy, routing it into powerful batteries and drawing on it to augment the diesel-generated power at times of greatest demand.

Those sources speculate such units could be modified to take electricity from a high-voltage trackside power line and convert it to an energy level the engine can use. The result should be much cheaper than a dual-mode unit.

The GE officials said U.S. passenger systems in the Northeast have opted for dual-mode units because limits on diesel exhaust in heavy population areas favored electric engines, but most of the line they used between cities was not electrified.

That emissions constraint could also be a factor for freight railroads, which have come under growing pressure around the country to cut their yard emissions to help curb city smog levels.