The Potential of Electric Freight Rail in Southern California

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Hector Rail intermodal freight train in Germany, pulled by Bombardier TRAXX electric locomotive
(Photo: pxhere.com, Creative Commons CC0)

1. Introduction

The only proven zero-emissions freight movement technology is a fully electric railroad. Electric trains are the most energy efficient way to move freight on land, moving a ton with typically one-tenth the energy used by diesel-powered road trucks. The electrification of freight rail in California would reduce the public health impacts to local communities affected by diesel-powered locomotives, and reduce the greenhouse gas emissions of freight movement. Electric locomotives also improve the speed of travel with better acceleration, quieter operation, and twice as energy efficient as diesel locomotives. . Used successfully all over the world for over a century, electric freight locomotives have many advantages. In particular, electric locomotives are:

- Zero-emissions at point of use.
- More energy efficient than diesel-electric locomotives, and consume almost no power when idling.
- Capable of using regenerative breaking when going downhill to recover energy that can be stored on-board, used by other trains nearby, or returned as power to the grid.
- Capable of faster acceleration and greater pulling power than diesel-electric locomotives.
- Quieter and lower maintenance than diesel locomotives.
- Capable of being powered by renewably-generated electricity, further enhancing emissions benefits and reducing dependence on fossil fuels. Electrified rail corridors can also serve as electric transmission line routes, potentially accessing many renewable energy generation sites.

The most established way to run trains on electricity is by overhead catenary wires above railroad tracks, also called an overhead contact system (OCS), which power to the moving train's pantograph. While the up-front capital costs may be substantial, all-electric freight rail with overhead catenary is a tried-and-true technology that would pay for itself with significant reductions in emissions and operating costs.

Electrification with overhead catenary wire has been used for over a century for freight rail, and is used today on about one quarter of the world's railroad tracks. Outside of North America, electric freight trains are very common. Globally, electricity's share of moving trains is increasing, about 10% of all track miles electrified in 1975 to over 30% in 2012[1]. Nations from India to South Africa, China to those of Europe, are expanding electrification of heavy freight and passenger lines. A large pool of manufacturers and engineering expertise exists around the world for this technology.

Electrification would build upon ongoing and proposed railroad capacity and safety improvement projects in California, including grade separations, additional main line and siding tracks, improved signal systems and Positive Train Control. The electrification of existing heavy rail lines is coming to California thanks to Caltrain's Peninsula Corridor Electrification Project, which is electrifying the line between San Francisco and San Jose for passenger service. The electrification of Southern California railroads needs to be explored, and can benefit from the experience of the Caltrain electrification.

[1]International Energy Agency, *Railway Handbook 2015*, pg. 24 (Fig. 10) and 27 (Fig. 16): https://uic.org/IMG/pdf/iea-uic_2015-2.pdf

Due to the unfamiliarity in the U.S. with electric freight rail, this technology is too often overlooked as a solution to many of the country's transportation needs, despite its proven track record of success in the rest of the world. Southern California should be a national leader in freight rail electrification due to its need to reduce air pollution, and strong longtime local political support for clean transportation technologies. The region once had an extensive electric rail network of passenger street cars and interurban trains during the first half of the 20th century, and today has a rapidly growing network of all-electric subway and light rail lines. In the past three decades, a number of studies have been commissioned by state and local government agencies on low- and zero-emissions freight rail in Southern California. These publicly-funded efforts were primarily motivated by an interest in reducing air pollution in the region, particularly for those living and working near the tracks. The most recent were two reports evaluating clean freight rail technology released by the California Air Resources Board in the spring of 2016. The last time that a regional, comprehensive rail electrification task force existed was for the 1992 Southern California Accelerated Rail Electrification Program study. Such a regional task force should be created again, with committees for planning, engineering, analysis, operations & maintenance, environmental analysis, funding, legislative and regulatory issues.

Fig. 1. Bombardier IORE electric locomotive set hauling an iron ore train between Sweden and Norway
(Photo: David Gubler, 22.3.2011, http://bahnbilder.ch/picture/7743?title=iore)

2. Electrification of Freight Rail

An electric locomotive can be designed to match or exceed the performance specifications required by U.S. line-haul interstate freight trains, the largest of which weigh around 10,000 tons. In fact, the world's most powerful locomotives are all-electric. In China, a single HXD1 two-section all-electric locomotive set, similar to that shown below in Fig. 2, pulls entire 20,000-ton coal trains under a 25 kilovolt (kV) [2] catenary. The HXD1 has over 19,000 horsepower and 260,000 pounds of starting tractive effort[3]. The largest diesel locomotives currently being manufactured in the U.S. have at most 5,000 horsepower and 200,000 pounds of starting tractive effort. Transnet Freight Rail of South Africa uses a 50 kV catenary system for hauling iron ore trains in excess of 40,000 tons, shown below in Fig. 3. Several times the weight of an average U.S. line-haul freight train, these trains are pulled by up to nine all-electric Mitsui Class 15E locomotives in distributed configuration. Russia's Trans-Siberian has been 100% electric between Moscow and Vladivostok since 2002. At 5,772 miles the longest rail line in the world, this line carries freight train weights similar to U.S. line-haul trains. An extensive network of electrified on-dock and near-dock rail serves Rotterdam, a port similar in size to the San Pedro Bay complex.

Fig. 2. China Railways HXD1 series freight locomotive set, under 25 kV overhead catenary wire
(Photo: https://commons.wikimedia.org/wiki/File:HXD10004.jpg)

[2] 1 kilovolt (kV) = 1,000 Volts.

[3] http://documents.epfl.ch/users/a/al/allenbac/www/HXD1.htm

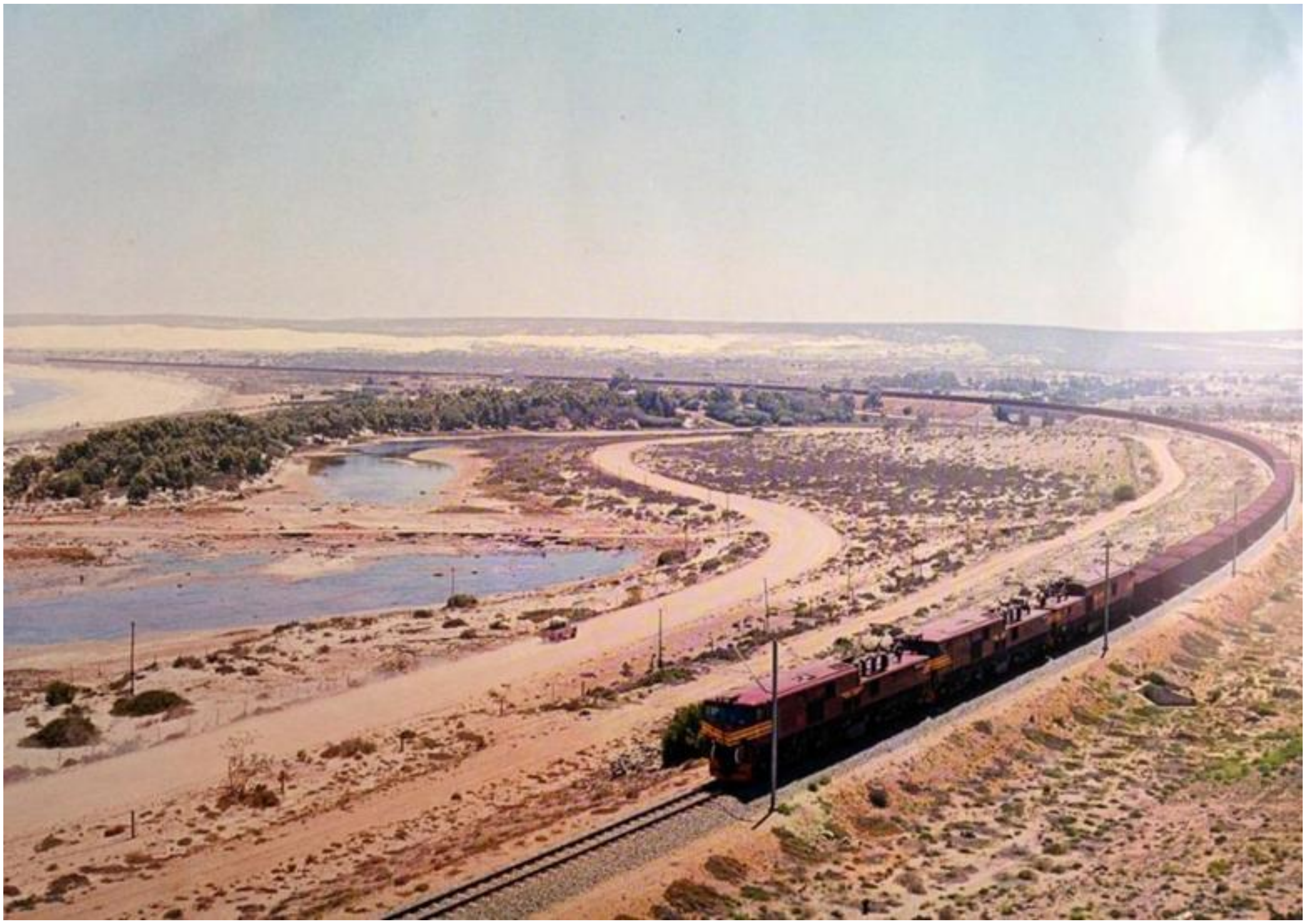

Fig. 3. Long-haul iron ore train on Sishen–Saldanha Orex line in South Africa, pulled by electric locomotives under 50 kV catenary.
(Photo: Peter Ball collection, http://www.theheritageportal.co.za/article/south-africas-world-record-breaking-train)

Overhead catenary wire has been used to power heavy electric freight trains for more than a century, and is tried-and-true technology. A voltage of 25 kV is the world standard for heavy freight and high-speed passenger rail AC catenary electrification. In California, a 25 kV AC catenary system is being installed for Caltrain and California High Speed Rail passenger rail service. 50 kV catenary, used on several heavy freight railroads around the world, offers the advantage of higher power capacity, and requires a smaller number of substations along the route. In Southern California, the steep grade of Cajon Pass would be better suited for 50 kV catenary due to the high power requirements and heavy freight traffic, as well as for long-distance sections. Fortunately, it is possible for electric locomotives to transition between 25 kV and 50 kV catenary at speed. Electrification of an initial pilot rail line, such as the Alameda Corridor, must be compatible with electrification standards that the rest of the North American rail system would follow.

Most urban rail systems in the U.S. run on electricity, but electrification is sparse in the nation's intercity rail network. Amtrak runs electrified passenger service along the 457-mile Northeast corridor from Boston to Washington, and the Keystone Corridor from Philadelphia to Harrisburg, Pennsylvania. While electricity is now a major source of motive power for freight railroads in most advanced economies, the percentage of U.S. rail freight hauled using electricity is close to zero. Three U.S. electric freight lines, with a combined tracking length of about 130 miles, carry coal from mines to power plants in Arizona, Utah and New Mexico, while the Iowa Traction Railway runs 18 miles of electric line from Mason City to Clear Lake.

Outside of North America, electric trains are very common for both passenger and freight, as shown below in Table 1. Almost every industrialized country, including nearly all of Europe and Japan, has an extensive network of electrified freight rail. Switzerland is all electric, except for one tourist line that has steam engines. Over one quarter of India's railways are electrified, and its first two freight-only electric rail lines are under construction in northern India, to carry double-stacked container under the wires. Nations from Chile to South Africa are investing in expanding or building new electrified rail lines, while China is in the middle of electrifying 20,000 km of existing track. As described by the *Solutionary Rail* book:[4]

> AROUND A QUARTER OF THE WORLD'S RAIL LINES ARE ELECTRIFIED, 186,000 miles out of a total of 808,000. Western Europe leads with 53% of lines propelled by electricity, while North America trails with 1%. The global electrification market "continues to grow dynamically," particularly in Western Europe, Africa and the Middle East, SGI/Verkehr reports. Electricity's share in fueling rail is growing, up from 17% in 1990 to 36% in 2012, while oil has held steady at 58% and coal decreased from 25% to 6%....
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> However, these figures understate the significance of electrification. Typically it is the more heavily used lines that are electrified. For example, though France is only 52% electrified, 85% of freight and 90% of passengers run on electrified lines.
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> In Russia the Trans-Siberian, at nearly 6,000 miles the longest continuous rail line in the world, was fully electrified by the end of 2002. This is notable because it runs in one of the world's harshest environments and because reliable operation is critical to Russia's strategic control of its eastern regions. The rail line carries 30% of Russian exports. Overall, electric lines carry 70% of Russian freight, the equivalent in ton-miles of 80% of US rail freight... China's rail electrification has expanded rapidly. Concerted efforts have grown the percentage from only 5% in 1975 to over 40% today.
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> Smaller economic powerhouse nations have largely electrified rail systems. Sweden grew electrification from 61% in in 1970 to 77% of its system in 2005. The Netherlands has increased its electrified network from 52% in 1970 to 73% in 2005. Switzerland is a global standout with a 100% electrification rate. That nation is in the midst of a major rail line improvement program, a central goal of which to move freight from trucks to electric rail. In 17 European nations the rail network is at least 40% electrified.
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> Great Britain, which has lagged other European nations with only 33% of its rail network electrified, in 2007 announced a £1.1 billion effort to expand electrification. The Great Western Line linking London with Wales is slated for full electrification by 2017. Liverpool-Manchester, one of the world's oldest rail lines, was electrified in 2015.
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> Nations around the world that have recently expanded electrified rail or are engaged in significant efforts to do so include Chile, Taiwan, Malaysia, Iran, Israel, Saudi Arabia, Kazakhstan, Uzbekistan, Ethiopia, South Africa, Denmark, Norway, and New Zealand. Electrified rail is working around the world. It can work in the US again.

[4] Bill Moyer, Patrick Mazza and the Solutionary Rail team (http://www.solutionaryrail.org/). *Solutionary Rail: A people-powered campaign to electrify America's railroads and open corridors for a clean energy future,* October 2016, pp.15-17.

Table 1: Railroad electrification around the world (both passenger and freight combined, as of 2016)[5]

Country	Miles Electrified (approx.)	Percentage Electrified
Ethiopia/Djibouti	470	100%
Switzerland	3,200	99%
Belgium	1,900	85%
Sweden	7,600	76%
Japan	12,500	75%
Netherlands	1,400	72%
South Korea	1,600	70%
China	50,000	65%
Italy	8,200	65%
Spain	6,300	64%
Poland	7,400	62%
Austria	2,200	61%
Morocco	800	61%
Germany	12,400	60%
Finland	2,000	55%
France	9,400	52%
Russia	27,000	50%
South Africa	5,900	45%
India	14,700	35%
United Kingdom	3,300	33%

[5] References on rail electrification statistics by country:

https://www.cia.gov/library/publications/the-world-factbook/fields/2121.html

http://uic.org/IMG/pdf/synopsis_2015_print_5_.pdf

http://statbel.fgov.be/fr/statistiques/chiffres/circulation_et_transport/transport/ferroviaire/

The 2018 California State Rail Plan calls for the state government to aid the advancement of zero and near-zero emissions technologies for freight railroads, stating that “priority should be given to rail projects that support the deployment of technologies that produce zero or near-zero air emissions… the State’s role in advancing the adoption of this technology is central, from both a regulatory and financial perspective, because it can help advance development of the prerequisite technology; and by providing financial incentives, support its commercialization”[6].

Conventional electrification with overhead catenary wire is most cost-effective at high train frequencies; and Southern California has some of the busiest railroad corridors in the U.S. For example, the BNSF San Bernardino Subdivision between Los Angeles and Fullerton sees about 50 passenger trains and 60 freight trains per day, and 60 daily freight and 40 passenger trains between West Riverside and Colton. The BNSF Cajon Subdivision, over Cajon Pass, sees nearly 100 freight trains daily. Both passenger and freight rail traffic are expected to increase in the years ahead, making the zero-emissions benefits of electric trains even more important for trackside communities.

Battery-electric locomotives-

Freight car switching on either end of electrified track segments can be performed by zero emissions battery-electric switcher locomotives, which would not require overhead catenary. Locomotives with both batteries and a retractable overhead pantograph for receiving power from overhead catenary could utilize catenary wire where it exists, and also run on battery where there is no catenary. Therefore, with the added flexibility of battery locomotives, even an ‘incomplete electrification’ of the region’s rail network could still be very useful in the transition to a zero-emissions railroad system. Some versions of Alstom’s Prima H3 and Prima H4 electric switcher locomotives have batteries as well as a pantograph, and have entered commercial service in Germany.

Along with limited battery range, a primary operational challenge with successfully introducing a battery locomotive into service is incorporating efficient plug-in charging infrastructure and procedures into daily operations. This is especially true with locomotives that must be taken out of service or “blue flagged” in order to plug in to trackside electricity cables. This is a time-consuming process, and could cause costly delays to rail operations. An overhead catenary wire can charge the locomotive’s batteries while simultaneously powering the train’s motion, providing a significant operational improvement over all- battery locomotive adoption.

The 2018 California State Rail Plan called for a “battery assist switcher demonstration” in rail yards, and a need to “reduce yard and terminal emissions through implementation of zero emissions technologies (cargo handling and switching)..”[7]. In late 2017, the California Air Resources Board awarded funding to a demonstration project at the Port of Los Angeles, in partnership with Pacific Harbor Lines, of a battery-electric/natural gas hybrid locomotive developed by VeRail Technologies[8].

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[6]California State Department of Transportation, *2018 California State Rail Plan*, Public Release Draft, November 2017, section 5.2.7 (Advancement of Zero and Near-Zero Emissions Technologies), Pg. 168:

http://www.dot.ca.gov/californiarail/docs/CSRP_PublicReleaseDraft_10112017.pdf

[7]Ibid., pg. 167:
http://www.dot.ca.gov/californiarail/docs/CSRP_PublicReleaseDraft_10112017.pdf

[8]https://www.portoflosangeles.org/Board/2018/May%202018/05_17_18_Agenda_Item_11.pdf

Emissions benefits-

Even with conventional diesel locomotives, emissions per ton are several times less by rail when compared to on-road trucks. With electrification, the emissions directly emitted by locomotives drops to zero. Given the choice, rail is always a cleaner way to move freight than by truck. For example, Southern California's busiest truck corridor (Interstate 710) produces ten times more emissions than the region's busiest rail corridor. Diesel trucks are the single greatest source of smog-forming nitrogen oxide (NOx) emissions in Southern California. In 2012 the average nitrogen oxide (NOx) emissions from heavy-duty diesel trucks was 143 tons per day within the South Coast Air Quality Management District's jurisdiction of Los Angeles, Orange, San Bernardino and Riverside counties. By contrast, cars produced an average of 42 tons of NOx per day, light-duty trucks 37 tons, and medium-duty trucks 27 tons. Locomotives produced an average of 20 tons of NOx per day[9].

Historically, efforts to advance electrification and other clean transportation technologies in the region have been driven primarily by a desire to reduce local air pollution. Many populated areas in Southern California regularly do not meet federal air quality standards, especially those near freight movement sites such as ports, rail yards and warehouses. The huge amount of freight movement activity in the South Coast Air Basin (SCAB) results in a massive amount of emissions from diesel-powered trucks and trains. Diesel exhaust around the San Pedro Bay ports and the region's railroad yards and freight facilities has been linked to cancer, asthma and many other ailments, as well as contributing to premature deaths in nearby communities. Emissions from goods movement, including levels of NOx, SOx and diesel particulate matter (PM), have declined significantly in the past decade due to stricter regulation and the introduction of cleaner diesel engines. However, the public health impacts in the region caused by both port-related and domestic goods movement still contribute to thousands of premature deaths and billions of dollars in health care costs each year[10]. The area around the San Pedro Bay ports has even been dubbed the "diesel death zone"[11]. In the Inland Empire, a hub of port-related goods movement and warehousing, residents also suffer from some of the highest particulate and ozone pollution levels in the U.S.

Switching from a freight rail system that relies on diesel power to one that relies on electric power will substantially reduce air pollution in Southern California. In addition to reducing emissions of pollution with local public health impacts, electrifying freight rail will also help meet the state's goals for reducing greenhouse gas (GHG) emissions. If more freight and passenger traffic is shifted from road to rail in the future, the emissions benefits of electric rail would be more significant. According to the 2016 RailTEC report, if all line-haul freight rail locomotives in the SCAB were all-

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[9] Tony Barboza, "Southern California regulators have a chance to rein in freight pollution. Will they take it?", *Los Angeles Times*, April 5, 2018:
http://www.latimes.com/local/lanow/la-me-freight-air-quality-20180405-story.html

[10] Port of Long Beach & Port of Los Angeles, *San Pedro Bay Ports Clean Air Action Plan 2017, Draft Final Clean Air Action Plan Update*, July 2017, pgs. 16-20:
http://www.cleanairactionplan.org/documents/clean-air-action-plan-2017-draft-document-final.pdf

[11] Marla Cone, "U.S. Neighborhoods Struggle with Health Threats from Traffic Pollution", *Scientific American*, October 11, 2001:
https://www.scientificamerican.com/article/us-neighborhoods-struggle-with-health-threats-from-traffic-pollution/

electric (and all electricity used from zero-emissions sources), compared to using a fleet of 100% Tier 2 diesel locomotives, the annual emissions reductions possible would be as follows[12]:

- 372,000 tons CO_2
- 3,750 tons NOx
- 1,000 tons CO
- 200 tons hydrocarbons (HC)
- 140 tons particulate matter (PM)

The above figures do not include the region's freight yard/switcher or passenger locomotives. However, over 80% of locomotive emissions in the South Coast Air Basin are from line-haul freight trains. It is worth noting how the emissions reductions of fully electric locomotives are superior to other low emissions technologies. The 2016 RailTEC report also concluded that Tier 4 diesel freight locomotives with after-treatment (the report's preferred alternative), would not reduce CO_2 or CO emissions in the region. Also, diesel-LNG locomotives would decrease CO_2 emissions, but increase CO emissions.[13]

Energy savings benefits-

On a per-ton basis, a double-stack container rail car pulled by a conventional diesel-electric locomotive moves freight three to five times more fuel-efficiently than a truck[14]. The overall energy efficiency of diesel-electric locomotive, or the proportion of energy diesel fuel converted to useful motive power, is typically less than 40%. In fact, U.S. freight railroads have substantially improved their overall energy efficiency in the past several decades. According the Association of American Railroads, U.S. freight railroads moved one ton of freight an average of 468 miles per gallon of diesel fuel, up from 235 miles in 1980[15]. However, there is limited room for further improvement of the fuel efficiency of diesel engines. According to a 2014 Federal Railroad Administration report, the diesel locomotive fleet efficiency is expected to improve 15% to 20% by 2030, although this could be increased slightly with more efficient operating pratices such as optimized distributed power, train management software, and improved maintenance practices[16]. Diesel engines in general up are expected to have up to 15% improvement in fuel efficiency over the next decade or so[17].

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[12] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016, pg. 52. https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf.

[13] Ibid., pg. xiii. https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf.

[14] Federal Railroad Administration, *Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors*, November 2009, pg. 9: https://www.fra.dot.gov/eLib/details/L04317 .

[15] Association of American Railroads, *The Environmental Benefits of Moving Freight by Rail,* June 2017: https://www.aar.org/BackgroundPapers/Environmental%20Benefits%20of%20Moving%20Freight%20by%20Rail.pdf

[16] Federal Railroad Administration, *Best Practices and Strategies for Improving Rail Energy Efficiency - Final Report*, Office of Research and Development, Washington, D.C., January 2014, pg. 71: https://www.kpesic.com/sites/default/files/DOT-VNTSC-FRA-13-02.pdf

[17] https://www.theicct.org/blogs/staff/ever-improving-efficiency-diesel-engine
https://www.arb.ca.gov/msprog/onroad/caphase2ghg/presentations/2_7_wayne_e_cummins.pdf

The overall per-ton energy efficiency advantage of rail more than doubles with an all-electric locomotive, which converts over 80% of the electric energy captured from the overhead catenary wire into useful motive power[18]. The annual 'at wheel' energy consumption of all line haul freight rail locomotives operating in the SCAB, pulling an average of 130 line-haul freight trains per day, is presently about 435,000 MWh.

Energy consumption of electric rail, utility participation-

Electric utilities must be involved in planning for rail electrification from the outset. It is the electric utilities who will provide the electric energy, build up new substation infrastructure to service electrified track, and construct or upgrade distribution and transmission lines. While there would be a need to construct new electric power infrastructure to serve electrified freight rail lines, electric utilities could see the new loads from freight trains as a business opportunity. In fact, the region's utilities are concerned about losing revenue from more and more customers, particularly large industrial and institutional ones, investing in distributed self-generation projects such as rooftop solar. Utilities also would benefit from being able to transmit or distribute power via rail rights-of-way. Existing transmission and distribution grid infrastructure needed to service electrified track in the Los Angeles area tends to be in industrial areas and alongside rail lines. The power for electric locomotives can come from zero-emissions sources, including hydroelectric, geothermal, solar and wind power, providing a larger market for these resources.

Table 2: Typical Electric Power Equivalent of Railroad Trains[19]

Light Rail or Subway	1 MW or less
Commuter Trains	3 to 4 MW
High Speed, Intercity Passenger Trains	4 to 8 MW
Very High Speed Passenger Trains	8 to 20 MW
Long-Haul U.S. Freight Trains	18 to 24 MW

As shown in Table 2 above, a single large line-haul freight train can consume the equivalent of over 20 MW of electric power. The 2016 CARB RailTEC report estimated that UP and BNSF locomotives operating in the South Coast Air Basin, about 130 line-haul freight trains per day, currently consume the equivalent of 435,000 MWh/year, or about 50 MW average load[20]. The 2016 CARB studies estimated that powering all line-haul freight locomotives with electricity would require just over 400,000 MWh of electricity per year (45 MW average load) at present rail traffic levels, and 1,000,000 MWh/year by 2050 (114 MW average load). This amount of electric energy is well under 1% of the present-day annual consumption of the combined Southern California Edison (SCE) & Los Angeles Department of Water and Power (LADWP) service areas.

Both LADWP and SCE have goals of meeting 33% of total electric energy demand from renewables by 2020, and 50% by 2030, reflecting the state of California's goal as a whole. LADWP has pledged to completely phase out coal-generated electricity by 2025. In 2016, about 20 TWh of solar electricity was generated in California (not including roof-top solar

[18] RailTEC, Spring 2016, pg. 49. https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf.

[19] B. Bhargava, *Railway Electrification Systems and Configurations*, SoCal Edison, Institute of Electrical and Electronics Engineers (IEEE), 1999.

[20] RailTEC, Spring 2016, pg. 48: https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf.

projects on homes and small businesses), while wind generated about 13.5 TWh and geothermal contributed about 12 TWh[21].

As a comparison, the total solar, wind and geothermal share of the electricity generated in 2016 within California, approximately 46 TWh, is *forty six times* the 2050 projected freight rail electric energy consumption for the South Coast Air Basin described by the 2016 CARB studies. The share of renewable energy in the state's electricity mix is growing rapidly. California leads the nation in utility-scale solar energy development, with an installed generating capacity of about 10,000 MW in 2016[22]. At least 15,000 MW of solar energy capacity is in various stages of development in the state[23]. A typical solar power plant has an overall capacity factor of 20%. In theory, this would indicate that about 570 MW of solar power generation capacity would be needed to produce 1 TWh of annual electric energy.

Energy storage, as well as SCE and LADWP's self-generation incentive programs, are also changing their utility business model. In the SCE planning area, the peak output of customer self-generation by solar photovoltaic (PV) sources is projected to increase to as much as 2,500 MW by 2026, and as much as 1,300 MW for non-PV source[24]. In the LADWP planning area, the peak output of customer self-generation by PV sources is projected to increase to as much as 340 MW by 2026, and as much as 240 MW for non-PV sources[25]. California's largest utilities are also now required to procure progressively larger amounts of energy storage capacity in the years ahead. Energy storage connected to electric rail catenary, and trackside charging systems for locomotives with batteries, could be located at passenger train stations and along freight railroads. A sufficient level of energy storage along a rail line could provide backup power in case of a local or regional power outage.

These rail energy storage systems could provide a new business opportunity for electric utilities. Under utility control, these distributed energy storage systems could be charged at off-peak hours, provide power to the local distribution grid during periods of peak demand, and provide ancillary services such as voltage and frequency support, reactive power, or aid integration of distributed solar energy systems. California utilities should consult the experience of other countries with both extensive electric rail and high percentage of renewable energy generation, such as Germany and Spain. Both of these nations have populations greater than California's, meet more than one-third of their overall electricity needs from renewable sources (excluding large-scale hydroelectric), and have a rail system electrification rate of at least 60%.

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21 California Energy Commission, California Electrical Energy Generation statistics page: http://www.energy.ca.gov/almanac/electricity_data/electricity_generation.html

22 http://www.energy.ca.gov/renewables/tracking_progress/documents/installed_capacity.pdf

23 https://www.seia.org/research-resources/major-solar-projects-list

24 *California Energy Demand 2016-2026 Revised Electricity Demand Forecast, Volume 2: Electricity Demand by Utility Planning Area*, California Energy Commission, January 2016, pg. 43: http://docketpublic.energy.ca.gov/PublicDocuments/15IEPR03/TN207438_20160115T152222_California_Energy_Demand_20162026_Revised_Electricity_Demand_Fo.pdf

25 Ibid., pg. 108.

3. Electric Freight Rail in Southern California

With its deep-water ports and extensive network of railways and highways, Southern California has long been one of the country's most important hubs for freight movement. Moving freight efficiently is vital to the region's economy. The freight movement sector directly involves the transportation, warehousing, trade, manufacturing, construction, agriculture, mining and utilities industries. In Southern California, the industries of freight transportation and warehousing directly contribute over 300,000 jobs and about $25 billion of gross regional product. Industries dependent on goods movement directly or indirectly represent nearly $300 billion in gross regional product, and support about 3 million jobs[26]. Warehousing, distribution and logistics centers in Southern California boast about 1.2 billion square feet of storage space, representing 15% of the entire U.S. market, and 40% of the West coast market. Despite the status of Los Angeles as a global entertainment and media center, the regional economic importance of these industries is exceeded by those related to freight movement.

The adjacent ports of Los Angeles and Long Beach, which share San Pedro Bay, are in combination the busiest container port in North America, and responsible for the majority of the region's rail freight. In overall tonnage, San Pedro Bay ranks as the third largest on the continent behind the ports of Houston and South Louisiana. Arguably the most important single international trade gateway on the continent, the Ports of Los Angeles and Long Beach together handle about 40% of all containerized U.S. imports. In 2017, nearly 17 million twenty-foot-equivalent units (TEUs) of intermodal container traffic moved through the San Pedro Bay Ports. Over $300 billion worth of goods moved in these containers. The majority of this freight is shipped by trucks and trains through the Los Angeles Basin to destinations outside of Southern California.

The vast majority of California's rail freight traffic is carried by the two Class I railroads serving the state: Burlington Northern Santa Fe (BNSF) and Union Pacific (UP), which together operate about 130 line-haul freight trains each day in the SCAB[27]. Trains originating or terminating in the South Coast Air Basin transport nearly 100 million tons of freight annually. A map of the region's major freight rail corridors, prepared for State of California Air Resources Board's 2016 zero-emissions rail report, is shown in Fig. 4 below.

Rail cargo at the San Pedro Bay ports is about half intermodal containers, and half carload traffic. In California, intermodal container traffic is growing faster than carload traffic[28]. However, carload rail traffic of bulk commodities remains vital for California's agriculture, automobile, manufacturing, chemical and petroleum industries. In 2016, 28% of containerized import cargo moving through the San Pedro Bay ports left the docks by rail, and 72% by truck. In 2012, the San Pedro Bay Ports were responsible for approximately 55,000 direct daily regional truck trips, many of which are for moving containers. The trends of intermodal freight growth, such as ever-larger container ships, are leading to not only

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[26] Southern California Association of Governments, *2016-2040 Regional Transportation Plan/Sustainable Communities Strategy, Goods Movement Appendix*, April 2016, pg. 5: http://www.freightworks.org/DocumentLibrary/2016RTPSCS_GoodsMovement.pdf

[27] RailTEC, Spring 2016 , pg. 24: https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

[28] California State Department of Transportation, *2018 California State Rail Plan, Public Release Draft*, November 2017, section 1.3.4 (Freight Demand and Growth Trends), Pg. 17: http://www.dot.ca.gov/californiarail/docs/CSRP_PublicReleaseDraft_10112017.pdf

congestion of port facilities but also highways and railways. The San Pedro Bay Ports anticipate annual intermodal cargo volumes to increase about 3% per year, and to over 36 million TEUs annually by 2040.

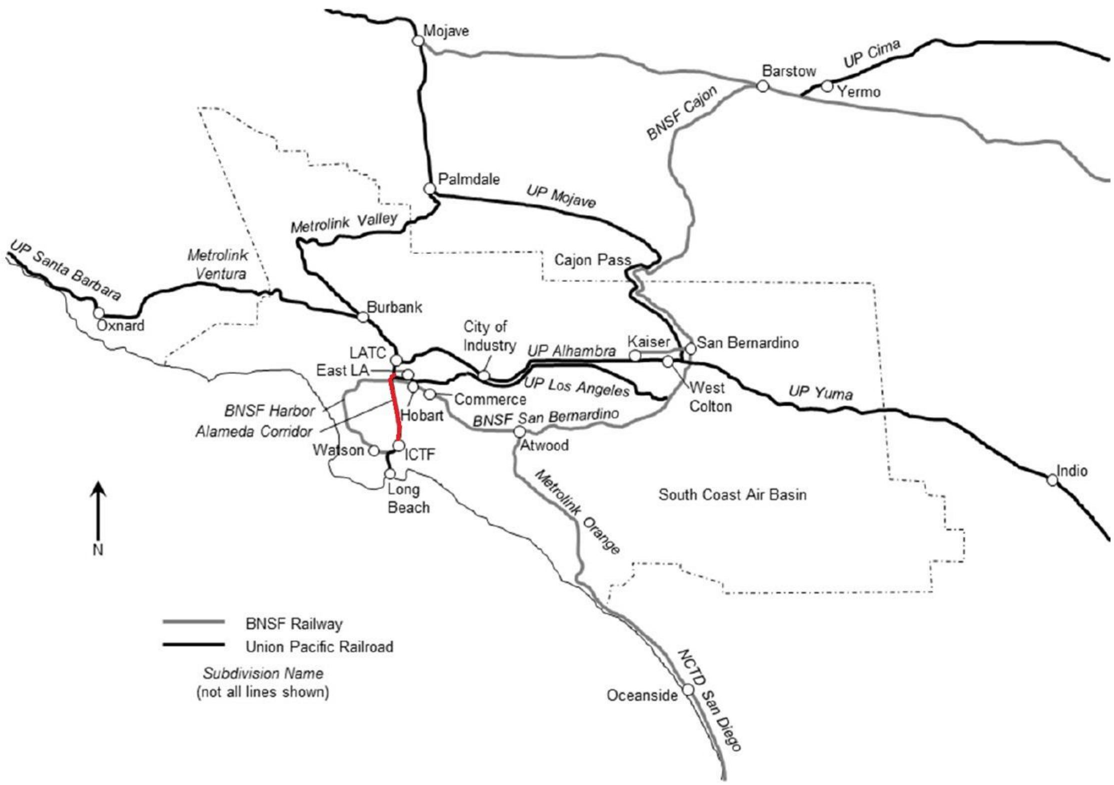

Fig. 4. Map of line-haul freight rail network in the South Coast Air Basin (SCAB) of Southern California, highlighted to show the Alameda Corridor.

Source: Figure 3-2 from *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California: Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016.

On-dock railyards offer the greatest opportunity to reduce truck miles per container, yet represent roughly 10% of the San Pedro Bay ports' intermodal freight traffic. The amount of containers transferred to on-dock rail is increasing, and transferring more containers on-dock from ship to rail is a goal of both ports. Both ports now have on-dock rail infrastructure at nearly all container terminals. The past decade has seen more than $2 billion worth of port-area on-dock rail capacity improvements, and there is $1 billion of proposed investment in near-dock rail infrastructure[29]. In May 2018, the Los Angeles County Metropolitan Transportation Authority, in partnership with the Port of Los Angeles, Port of Long Beach, and Alameda Corridor-East Construction Authority, received nearly $138 million of state SB1 funding from the California Transportation Commission's 2018 Trade Corridor Enhancement Program

[29] Southern California Association of Governments, *2016-2040 Regional Transportation Plan/Sustainable Communities Strategy, Goods Movement Appendix*, April 2016, pp. 32-34: http://www.freightworks.org/DocumentLibrary/2016RTPSCS_GoodsMovement.pdf

(TCEP) as part of the Southern California Rail Project. This rail infrastructure project includes eight directly connected component projects, and represents an investment totaling just over $1 billion, leveraging funding from multiple sources (private, state, and local). The eight component projects include five on- or near-dock rail projects at the ports and three rail-highway grade separations on the Alameda Corridor-East – UP Los Angeles and Los Angeles–San Diego–San Luis Obispo Rail (LOSSAN) –BNSF San Bernardino Subdivisions main lines[30].

Off-dock railyards, including near-dock facilities that are 5 miles or less away from the port, handle about 30% of the San Pedro Bay ports' intermodal freight traffic. UP's proposed expansion of the Intermodal Container Transfer Facility (ICTF) in Long Beach, and BNSF's proposed new near-dock Southern California International Gateway (SCIG) project nearby in the Wilmington neighborhood of Los Angeles, have met significant community opposition largely due to air pollution concerns. Further inland, the off-dock intermodal facilities include BNSF's San Bernardino and Hobart (the busiest in the country) yards, and UP's LA Transportation Center (LATC) and City of Industry yards, shown on the map in Fig. 4 below. Also important for freight movement in the region are transloading or transshipment facilities, where goods are typically taken out of 40' international containers arriving from the port, sorted, repackaged or placed in storage, then moved to a 53' container for domestic shipping to the rest of the U.S. In May 2018, the governing board of the South Coast Air Quality Management District voted to craft rules to reduce vehicle emissions at warehouses, distribution centers and rail yards[31]. This action by the region's chief air quality regulating authority could put pressure on the freight railroads to consider electrification. The Port of Long Beach and the Port of Los Angeles have long been leaders in reducing emissions from port operations. Electrification of rail lines around the ports would reduce emissions further and build upon, and add value to, the large infrastructure investments that the ports and region are making to shift more freight from truck to rail.

Alameda Corridor-

The Alameda Corridor and the Pacific Harbor Line system around the ports (shown on the map in Fig. 5 below) could serve as a pioneering example of freight rail electrification. The 20-mile, triple-tracked and grade-separated Alameda Corridor line, between the ports and the main freight yards east of downtown LA, was built with enough vertical clearance (25' minimum) for an overhead catenary wire over a double-container stacked train, along with other features such as spaces for substations, which could be used for future electrification. Completed in 2002, it is publicly-owned by the Alameda Corridor Transportation Authority (APTA), a joint-action agency of the cities of Los Angeles and Long Beach. However, the Alameda Corridor Operating Agreement presently states that the ACTA cannot require the private railroads to use electric locomotives. Currently used by about 40 trains per day, the Alameda Corridor has the capacity for about 150, making the corridor an underutilized resource. However, the corridor is still credited with reducing truck traffic congestion on the I-710 and other freeways. The Alameda Corridor's Mid-Corridor Trench, shown in the photo in Fig. 6 below, is a 33' deep, 10 mile-long, below-ground segment that is that allows the rail line to avoid more than 200 street-level railroad crossings.

[30] http://www.catc.ca.gov/programs/sb1/tcep/docs/TCEP_Applications_Final/SoCal-Rail-Project.pdf

[31] http://www.latimes.com/local/lanow/la-me-freight-pollution-20180504-story.html

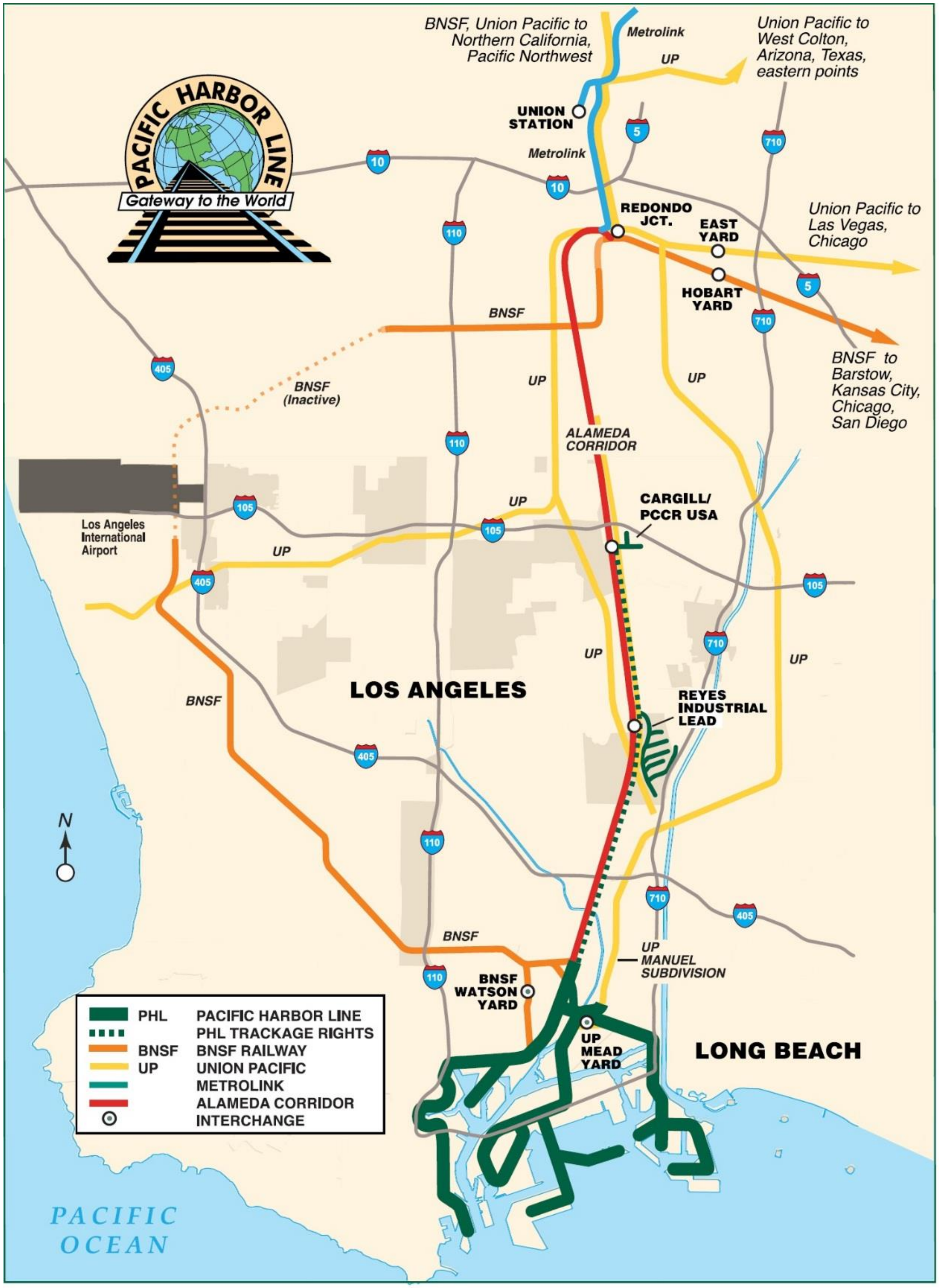

Fig. 5. Map of the Alameda Corridor, Pacific Harbor Line, and connecting freight rail lines.
(Map: Anacostia Rail Holdings, http://www.anacostia.com/sites/www.anacostia.com/files/assets/PHL-LA-LBTml-Map081414.pdf)

Fig. 6. A section of the Alameda Corridor's mid-corridor trench in the city of Compton.
(Photo by Brian Yanity)

Electrification of the Alameda Corridor, combined with other infrastructure projects and policies which encourage shifting of port freight movement from truck to rail, is a superior environmental and socially-acceptable alternative to adding more lanes to the I-710 freeway.

Freight car switching on either end of electrified track segments could be performed by zero emissions battery-electric switcher locomotives, which would not require overhead catenary. Electrification of the Pacific Harbor Line could be implemented with battery-electric switcher locomotives to complement an overhead catenary system, a scenario shown on the map below in Fig. 7.

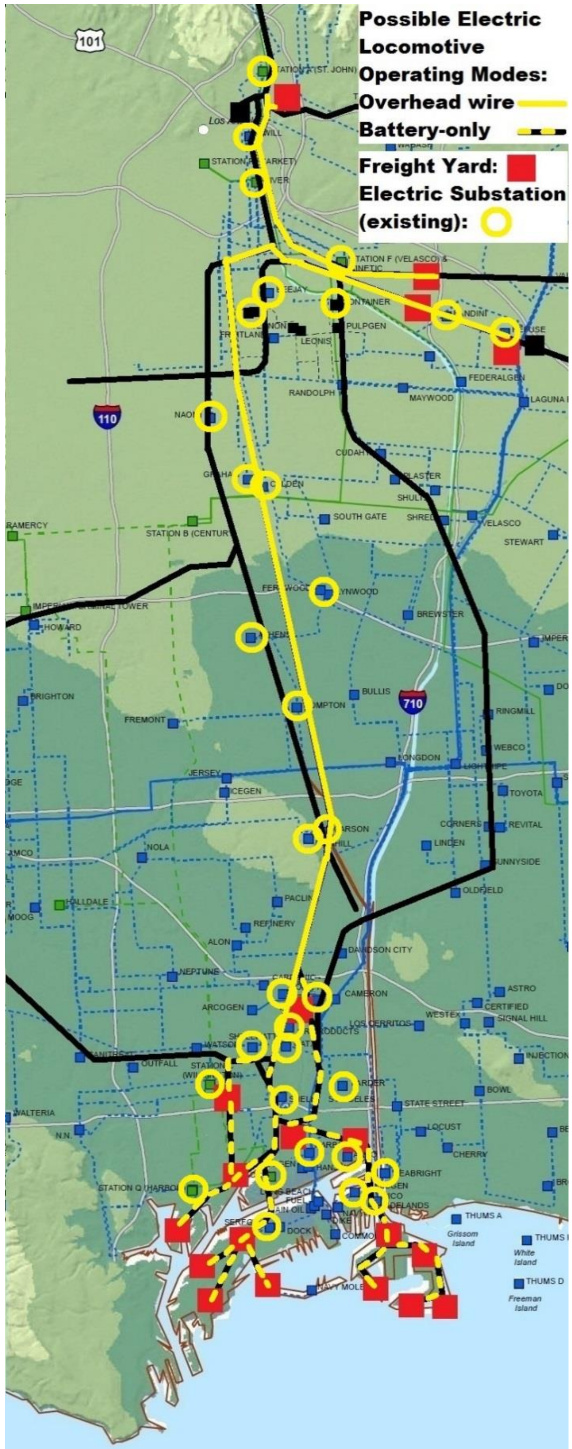

Fig. 7. Possible operating scenario of Alameda Corridor electrification using catenary/battery hybrid locomotives, overlaid on map of existing electric utility transmission lines and substations

(Background map: California Energy Commission)

Electrification of short-haul freight rail from the Ports of Long Beach and Los Angeles to the Inland Empire-

The 'Inland Empire' region, consisting of San Bernardino and Riverside counties, has emerged as a major warehousing, distribution, logistical and transshipment center, due to available land and its strategic location along major rail and highway networks. The majority of freight passing through the San Pedro Bay ports also travels through the Inland Empire. About a third of all containerized imports that move through the San Pedro Bay ports go by truck to warehouses and distribution centers in San Bernardino and Riverside counties. A map of over 1000 distribution centers in the greater Los Angeles area is shown below in Fig. 8; and Fig. 9 shows the estimated one-way trip times for a truck travelling from the San Pedro Bay ports under congested conditions. Short-haul rail could also be used by the Class I railroads to assemble a long-haul train at railyards in the Inland Empire, by combining several short 'shuttle' trains from the ports.

Exhibit 15: Regional Distribution Centers

Fig. 8. Locations of over 1000 regional distribution centers

(Exhibit 15 from *Inland Port Feasibility Study, Project No. 06-023 Final Report*, Prepared by the Tioga Group Inc., Railroad Industries, Inc. and Iteris for the Southern California Association of Governments, August 2008, pg. 22: http://tiogagroup.com/docs/Tioga_Grp_SCAGInlandPortReport.pdf)

Exhibit 16: Port to DC Congested Travel Times

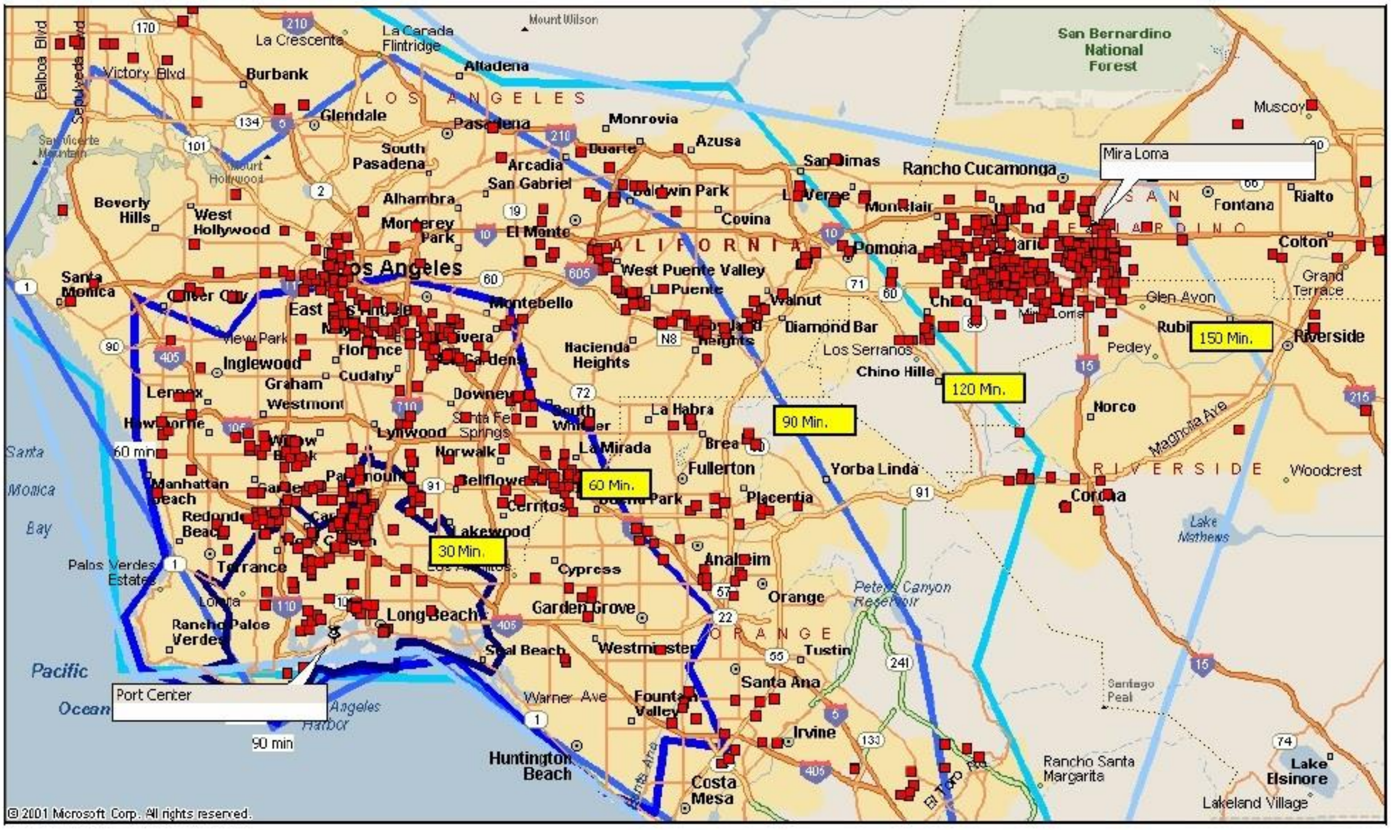

Fig. 9. Estimated port truck drayage times under congested highway conditions (30 mph on highways and 20 mph on surface streets). Under those conditions, the approx. 60-mile drayage times to the large concentrations of distribution centers (DCs) in the Ontario Airport/Mira Loma area are 120-150 minutes.
(Exhibit 16 from *Inland Port Feasibility Study, Project No. 06-023 Final Report*, Prepared by the Tioga Group Inc., Railroad Industries, Inc. and Iteris for the Southern California Association of Governments, August 2008, pg. 23: http://tiogagroup.com/docs/Tioga_Grp_SCAGInlandPortReport.pdf)

According to the 2008 *Inland Port Feasibility Study* for the Southern California Association of Governments (SCAG), there were at the time about 3,500 daily truck trips between the Ports and Riverside and San Bernardino countries combined. This 2008 study concluded that two daily round trip intermodal trains could divert up to about 35% of these trips. Regional truck vehicle miles travelled (VMT) was predicted to decline with the introduction of a short-haul rail service. However, there was predicted to be a localized increase in truck traffic in the immediate vicinity of the inland port terminal[32]. Existing freight railyards in the region are operating at capacity and have very limited surrounding land

[32] *Inland Port Feasibility Study, Project No. 06-023 Final Report*, Prepared by the Tioga Group Inc., Railroad Industries, Inc. and Iteris for the Southern California Association of Governments, August 2008, pg. 1: http://tiogagroup.com/docs/Tioga_Grp_SCAGInlandPortReport.pdf

available for expansion, so sites for new rail-truck intermodal facilities were studied. The new inland terminal locations studied included Mira Loma, Ontario and Victorville.

From the ports, many shippers have historically found that trucking containers to the Inland Empire for transloading from 40' international containers to 53' domestic containers to be cheaper than paying the fee to use the Alameda Corridor. However, in recent years drayage trucking costs have increased due to highway congestion, tightened port security, higher driver wages and other factors. Increased road congestion and trucking costs, particularly near the Ports of Los Angeles and Long Beach, have renewed interest in short-haul freight rail service to the Inland Empire, which previous studies had concluded to be operationally feasible yet not economically viable. The most recent such study was completed in 2008. Conditions have changed in the past decade, and benefits which may have been undervalued in past studies include reduced diesel emissions from trucks resulting in less public health impacts, decreased port and road congestion, reduced wear on road infrastructure, and increased port capacity and efficiency. A 2017 analysis by the American Transportation Research Institute estimated that road congestion in the Los Angeles area costs the trucking industry greater than $1 billion per year in added operational costs, the most of any metropolitan area in the nation[33]. The ports' Clean Air Action Plan will also increase trucking costs by requiring newer, cleaner trucks and eventually fees for non-zero emissions vehicles[34].

Many major ports around the world, including several in the U.S., have dedicated short-haul rail service from the docks to special intermodal freight railroad yards known as 'inland ports'. In recent decades, the business model of Class I freight railroads such as UP and BNSF has focused on long-haul bulk shipments over 500 miles in length, and not short-haul trains that would compete more directly with truck. However, the decline of bulk commodity shipments of coal and oil in the past several years have made U.S. freight railroads more open to exploring new business opportunities such as short-haul rail.

In addition to investing in more on-dock rail access, the Ports of Long Beach and Los Angeles announced in late 2015 that they were launching a joint feasibility study of short-haul rail service to move containers from the ports to a cluster of new intermodal distribution facilities located in the Inland Empire[35]. The study is motivated by the need to reduce truck congestion at the ports and on highways by shifting of more freight from truck to rail[36]:

> The concept has been studied periodically over the past two decades, but the economics always fell short and the logistical challenges could not be overcome. However, growing port congestion the past two years, increased drayage costs and a desire by beneficial cargo owners in Southern California's Inland Empire to avoid sending their truckers to the harbor offer financial encouragement. Shippers in the Inland Empire will have the advantage of sending their trucks only a short distance to the new rail hub rather than all the way to the harbor and back.

[33] http://atri-online.org/2017/05/16/cost-of-congestion-to-the-trucking-industry-2017-update/

[34] Port of Long Beach & Port of Los Angeles, *San Pedro Bay Ports Clean Air Action Plan 2017, Draft Final Clean Air Action Plan Update*, July 2017, pg. 62: http://www.cleanairactionplan.org/documents/clean-air-action-plan-2017-draft-document-final.pdf

[35] "LA-LB ports revisit short-haul rail to beat congestion", *Journal of Commerce*, December 22, 2015: http://www.joc.com/port-news/us-ports/port-los-angeles/la-lb-ports-revisit-short-haul-rail-beat-congestion_20151222.html

[36] "Shippers await short-haul rail option to LA-LB ports", *Journal of Commerce*, April 27, 2016: http://www.joc.com/rail-intermodal/shippers-await-short-haul-rail-option-la-lb-ports_20160427.html

> The key to success may be held by the importers that operate warehouses in the sprawling Inland Empire east of Los Angeles who would ultimately pay for the service through their freight rates. [economist John] Husing has been talking to the shippers, and he said they are "quite enthused." Warehouses in the Inland Empire would significantly reduce the distance trucks would have to travel if a short-haul service was established there from the ports. Also, there are a number of shippers with operations in Phoenix and Las Vegas that would be much happier sending their trucks to the Inland Empire rather than to the harbor, Husing said.
>
> …developing short-haul rail in Southern California will require support from the UP and BNSF railroads, which own the tracks and much of the rolling stock and equipment in the region. The railroads could work out an agreement with Pacific Harbor Line, which performs switching in the harbor on behalf of the railroads, to pull the trains to the Inland Empire, but that would be a new venture for PHL in its relationship with UP and BNSF.
>
> UP spokesperson Justin Jacobs said the railroad is in early discussions with the various parties about opportunities that exist for on-dock and short-haul rail at the ports, but any project that moves forward must "make sense from a commercial and business perspective." BNSF spokesperson Lena Kent noted that historically there has not been a compelling business case for a short-haul rail service to the Inland Empire. Therefore, BNSF has concentrated its efforts on attempting to secure environmental clearance for construction of its proposed near-dock Southern California International Gateway five miles from the harbor, which would provide sufficient staging acreage for trains that cannot be built on dock. However, a California court recently found the SCIG environmental impact report to be inadequate, so the future of the near-dock facility is uncertain.

The Ports' 2017 Clean Air Action Plan update stated that the Ports are continuing to pursue a detailed review of the short-haul freight shuttle concept, and that further study is necessary to ensure that potential impacts are not just being shifted to a new location[37]. The 2018 California State Rail Plan also described the potential benefits of short-haul freight shuttle trains[38]:

> Short-haul rail shuttles connecting ports with inland regions hosting substantial international trade-related distribution activity offer the opportunity to improve the velocity of the flow of goods into and out of the densely populated regions of Southern California and San Francisco Bay Area. With sufficiently high volumes, short-haul rail shuttles transfer the volume of freight truck traffic away from the already congested highways, particularly in and around the major ports. The capital investment in short-haul rail shuttle improvement can be made using the Traffic Congestion Relief Program funds, given a clear analysis of how the rail shuttle can help relieve congestion on roadways. The feasibility of short-haul rail shuttles is highly sensitive to the differential in costs between rail and highway transportation, and would require efficient operation to maximize their viability, and to capture a better rate of return on the investment of public funds.

The 2008 SCAG study identified some necessary implementing steps for an inland port/rail shuttle system, each with significant barriers to overcome[39]:

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[37] Port of Long Beach & Port of Los Angeles, *San Pedro Bay Ports Clean Air Action Plan 2017, Draft Final Clean Air Action Plan Update*, July 2017, pg. 62:
http://www.cleanairactionplan.org/documents/clean-air-action-plan-2017-draft-document-final.pdf

[38]California State Department of Transportation, *2018 California State Rail Plan*, Public Release Draft, November 2017, section 5.2.6 Short-Haul Rail Improvements), pg. 168:
http://www.dot.ca.gov/californiarail/docs/CSRP_PublicReleaseDraft_10112017.pdf

[39] *Inland Port Feasibility Study, Project No. 06-023 Final Report*, Prepared by the Tioga Group Inc., Railroad Industries, Inc. and Iteris for the Southern California Association of Governments, August 2008, pg. 2:
http://tiogagroup.com/docs/Tioga_Grp_SCAGInlandPortReport.pdf

Target Markets- The primary near-term market identified in the 2008 study was an area in the Inland Empire centered on Mira Loma, due the large number of existing distribution and transshipment facilities in that area which receive cargo trucked from the Ports. The Barstow and Victorville markets are developing and would likely be candidates for future logistics parks served by inland ports.

Choose and Secure Terminal Sites- The study identified a small number of candidate sites for Inland Empire terminals serving Mira Loma, as well as the Southern California Logistics Airport in Victorville and an open area [Lenwood] west of the BNSF yard in Barstow. Locating new intermodal facilities in populated areas have proven to be extremely difficult for freight railroads, due to local community opposition over pollution, traffic and noise concerns.

Provide Port-Area Rail Capacity- Substantial improvements to the port-area rail network would be required.

Rail Service Agreement- The railroad(s) would agree to operate a fixed schedule of rail shuttle trains, or allow a contractor to do so, in return for operating payments and capacity funding. This arrangement would be similar to existing agreements with Amtrak and Metrolink passenger rail in the region.

Substantial improvements to the region's main line rail network would also be necessary, including the ongoing and planned rail capacity improvements funded by government agencies and Class I railroads. Adding more trains on an already-congested freight rail system in Southern California, which shares capacity with passenger rail, is only possible with additional track capacity. Class I railroads will not accept short-haul trains if they interfere with to their primary business of long-haul trains.

A conventional U.S. intermodal terminal typically requires at least 300 acres of land alongside a rail line. It is therefore very unlikely that a new intermodal railyard of this size could be built in the central Inland Empire, where the vast majority of land has already been developed. New types of rail freight service must be explored for the region, which do not depend on slow freight trains or large intermodal facilities conventionally found in the U.S., which take hours to load or unload. There are a number of European innovations in intermodal rail freight which could serve as an example for California, discussed below. These include fast electric freight trains, carrying between 10 to 50 containers or truck trailers, designed to be competitive with highway trucking for distances less than 500 miles. Such trains use innovative intermodal terminals with short loading and unloading times, which do not require large amounts of land.

The economic feasibility of Port-to-Inland Empire short haul freight rail service is beyond the scope of this paper, but if such a service proves to be economically viable it would be a logical first phase for freight rail electrification. Electrified freight shuttles could also utilize the same overhead catenary infrastructure used by electric Metrolink, Amtrak or high-speed rail passenger trains. All-electric locomotives dedicated to the short-haul service could go back and forth along the less-than-100 mile electrified track between San Pedro Bay and the Inland Empire, while conventional non-electric line-haul freight trains could continue to use the same tracks. The 2012 SCAG freight rail electrification report proposed three options, which could also be broken out into construction phases, of freight rail electrification in the region that would cover distances required by short-haul service. These three options are shown on the map in Fig. 10 below, annotated to show potential future intermodal facility/inland port sites which have been discussed in recent studies[40]:

[40] *Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region (Final Technical Memorandum)*, prepared by Cambridge Systematics, Inc. for Southern California Association of Governments, April 2012, pgs. 3-1 to 3-6. http://www.freightworks.org/DocumentLibrary/CRGMSAIS%20-%20Analysis%20of%20Freight%20Rail%20Electrification%20in%20the%20SCAG%20Region.pdf

- Option I: Alameda Corridor, electrification from the ICTF (UP) yard, located just north of the port, to LATC (UP) and Hobart (BNSF) yards east of downtown LA [51 track miles].
- Option II: LATC to West Colton yard (UP), Hobart to San Bernardino (BNSF), sharing catenary with electric passenger trains [422 track miles].
- Option III: Ports to Barstow/Yermo/Indio/Chatsworth/San Fernando [863 track miles].

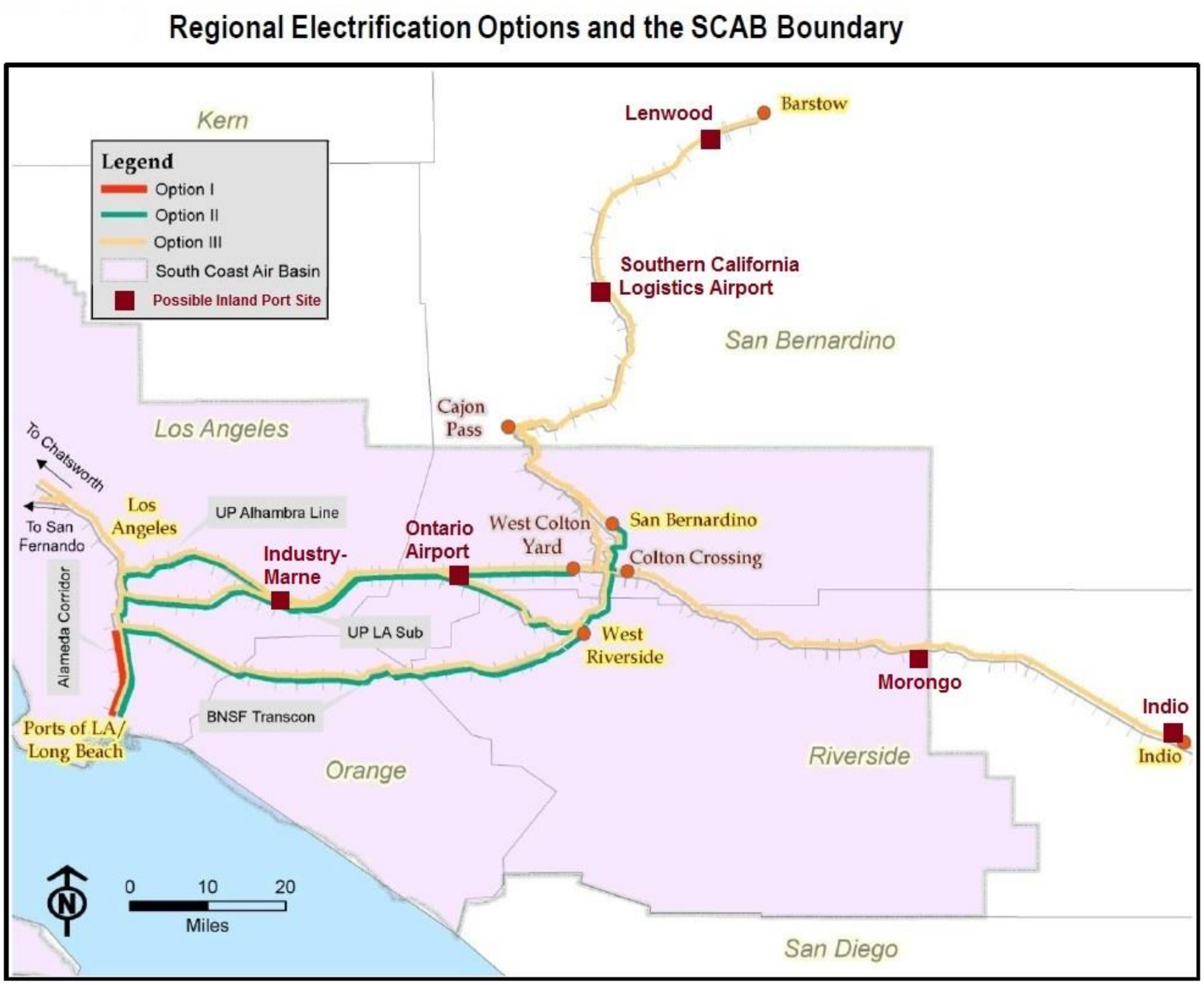

Fig. 10. Freight rail electrification scenarios in the South Coast Air Basin, as proposed by 2012 SCAG report, and annotated to show possible intermodal facility sites for electrified short-haul rail service.
(Background map: *Task 8.3: Analysis of Freight Rail Electrification in the SCAG Region (Final Technical Memorandum)*, prepared by Cambridge Systematics, Inc. for Southern California Association of Governments, April 2012, pg. 4-24)

Deep Inland Ports-

If "deep inland" undeveloped desert areas near Victorville, Morongo, Barstow, Indio or even further-inland sites such as Needles or Yuma turn out to be the only available Inland Port sites, this could justify an initial rail electrification effort encompassing all three electrification phases listed above in the 2012 SCAG study. These inland facilities could also serve as locomotive exchange points for long-distance freight trains.

The Cajon Pass between San Bernardino and Victorville represents a particularly important opportunity for energy and emissions savings through freight rail electrification. The steep grade between San Bernardino (1,053‘elevation) to Cajon Pass (3,777’ elevation) climbs over a track length of less than 30 miles. Such a grade is well-suited to an electric locomotive's many advantages in mountainous terrain, including better adhesion, greater power at low speeds, and regenerative braking. The two rail subdivisions through the Cajon Pass, UP Mojave and BNSF Cajon, together represent 256,000 MWh annually of ‘at-wheel' locomotive energy, or about 60% of all energy consumed by freight locomotives in Southern California[41]. An average of about 100 freight trains per day traverse Cajon Pass, making it the rail section in California which would have greatest emissions and energy-use reductions with electrification. In addition, routing new electric transmission lines along railroad corridors to the desert, such as Cajon Pass, would provide more transmission corridors between solar energy development areas and the Los Angeles Basin.

Electric trucks and electric trains, both serving an ‘all-electric' intermodal facility or Inland Port-

Electrification is possible for all land movements of a shipping container, from unloading off a ship with an electric crane, drayed by an electric truck to a nearby transshipment facility or intermodal yard, moved around at that facility with an electric forklift, and carried away on an electric train. A new intermodal facility, such as BNSF's proposed Southern California International Gateway (SCIG) project, or a proposed Inland Port served by short haul rail, could be designed from the ground up as all-electric, utilizing both electric trucks and electric trains along with electric freight movement equipment. The local community and environmental opposition to the SCIG or Inland Port site could be mitigated if the facility would be required to utilize a significant fraction, or even entirely, all-electric trucks and all-electric shuttle and long-haul freight trains. Perhaps a solution to the current SCIG impasse could be found in the form of a 21st century intermodal facility based entirely on electrified modes of transport- both trains and trucks. The several miles between the port docks and the proposed SCIG site in Wilmington would be easily managed by battery-powered electric container drayage trucks that exist today. BNSF has already started testing electric trucks at its Southern California intermodal facilities.

Electrification of intrastate line-haul freight lines operating within California-

Intrastate freight rail, trips typically less than 500 mile between regions within California, has been largely ignored by Class I railroads in the U.S. along with other types short-haul and medium-haul rail. Of the more than 1 billion freight tons moved entirely within California in 2012 (not including pipelines), 94% was by truck and 1% was by rail[42]. Increasing the amount of intrastate freight shipped by rail would reduce air pollution, fuel consumption and reduce North-South truck traffic on Interstate 5 and State Route 99 in the Central Valley. A 2017 article by Michael Setty in *California Rail News* proposed electrifying a new freight rail line over Tejon Pass, paralleling Interstate 5[43]. In order to be competitive

[41] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016, pg. 48:
https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf

[42] California State Transportation Agency, California Freight Mobility Plan, December 2014, pg. 145:
http://www.dot.ca.gov/hq/tpp/offices/ogm/CFMP/Dec2014/CFMP_010815.pdf

[43] Michael Setty, "'Electric fast freight' in California? Moving short-distance truck freight to rail", *California Rail News*, May-September 2017: http://www.calrailnews.org/wp-content/uploads/2017/06/crn0617h-web.pdf

with truck for distances less than 500 miles, intrastate trains would be have to be much faster than a conventional U.S. line-haul freight train. Electric intrastate freight trains can be faster than truck over mountain grades such as Tejon Pass, due to the higher tractive effort of electric locomotives. Light, fast and relatively short (10 to 50 car) trains carrying intermodal container or roll on/off trailers, similar to those in Europe described below, could share electrified passenger tracks.

Roll-on/roll-off "rolling highway" intermodal truck-rail freight service-

A 'rolling highway' or 'rolling road' train enables complete tractor-trailer trucks to drive on or off train cars quickly, without the need for heavy machinery to load or unload the train. The practice is similar to how a truck would drive on or off a ferry boat as part of a longer journey. Rolling road trains can carry the tractor and trailers together, with the drivers riding in a passenger car, or as trailers alone like conventional 'piggyback' intermodal rail cars.

Austria and Switzerland have long had policies which encourage trucks ride through the Alps via electric 'rolling highway' train, to reduce pollution, congestion and accidents on mountain highways. Swiss company RAlpin (http://www.ralpin.ch/), operator of the all-electric Rolling Highway trans-mountain train shown below in Fig. 11, is one of several freight rail operators which carry trucks travelling between France, Germany and Italy. These trains typically have a set schedule, similar to a ferry or passenger rail service.

Fig. 11. RAlpin 'rolling road' electric train carrying trucks in Switzerland
(Photo: RAlpin AG, http://www.ralpin.ch/media/)

European companies such as Modalohr (http://lohr.fr/lohr-railway-system) and Flexiwaggon (http://www.flexiwaggon.se) provide special freight rail cars which allow trucks to quickly drive on or off a train. As described by German freight transport expert Dr. Christoph Seidelmann[44]:

> In the early 1970s a European wagon manufacturer created a revolutionary new freight wagon for combined road-rail transport: the “rolling motorway” wagon. The principle was similar to that of combined road-rail transport in the USA: each wagon had a loading surface that was low and completely flat so that the entire loading area of the rake of wagons could be driven on. The first HGV [tractor-trailer combination] would drive up an end-loading ramp at the rear of the train and continue over the coupled wagons until it had reached the head of the train, where it would be maintained in place (generally with its own handbrake), and the driver would disembark.
>
> In the meantime the next HGV would board the train, followed by the others, until the entire train was laden. A normal European rolling motorway train can carry 20 to 27 trailer trains or semi-trailer trucks and can be loaded in under 30 minutes. The transhipment equipment is also simple and inexpensive: all that is needed is a track which the entire train length and an end-loading ramp.

Modalohr operates trains through the Alps between its roll on/roll off facilities in France and Italy, as well as between Luxembourg and the France/Spain border. The Modalohr intermodal facility in Aiton, France is shown below in Fig. 12 and Fig. 13.

Fig. 12. Modalohr intermodal facility in Aiton, France
(Photo: http://lohr.fr/lohr-railway-system/)

[44]Christoph Seidelmann, *40 years of Road-Rail Combined Transport in Europe, From piggyback traffic to the Intermodal transport system*, International Union of Roal-Rail Transport Companies (UIRR scrl), Brussels, 2010, pg. 25.

European-style electric 'rolling highway' train concepts are being studied for applications in the U.S., most notably the state of Nevada's Land Ferry proposal for the I-80 corridor[45]. The feasibility of zero-emissions rolling-highway intermodal freight service, using a combination of both electric trains and electric trucks, needs to be explored for Southern California. Rolling road trains using electric locomotives could carry trucks between the San Pedro Bay ports and inland locations such as the Inland Empire, Barstow and Indio, from where they could continue their journey. Also possible would be rapid-loading rolling road trains to carry trucks or trailers from Southern California to Nevada and Arizona.

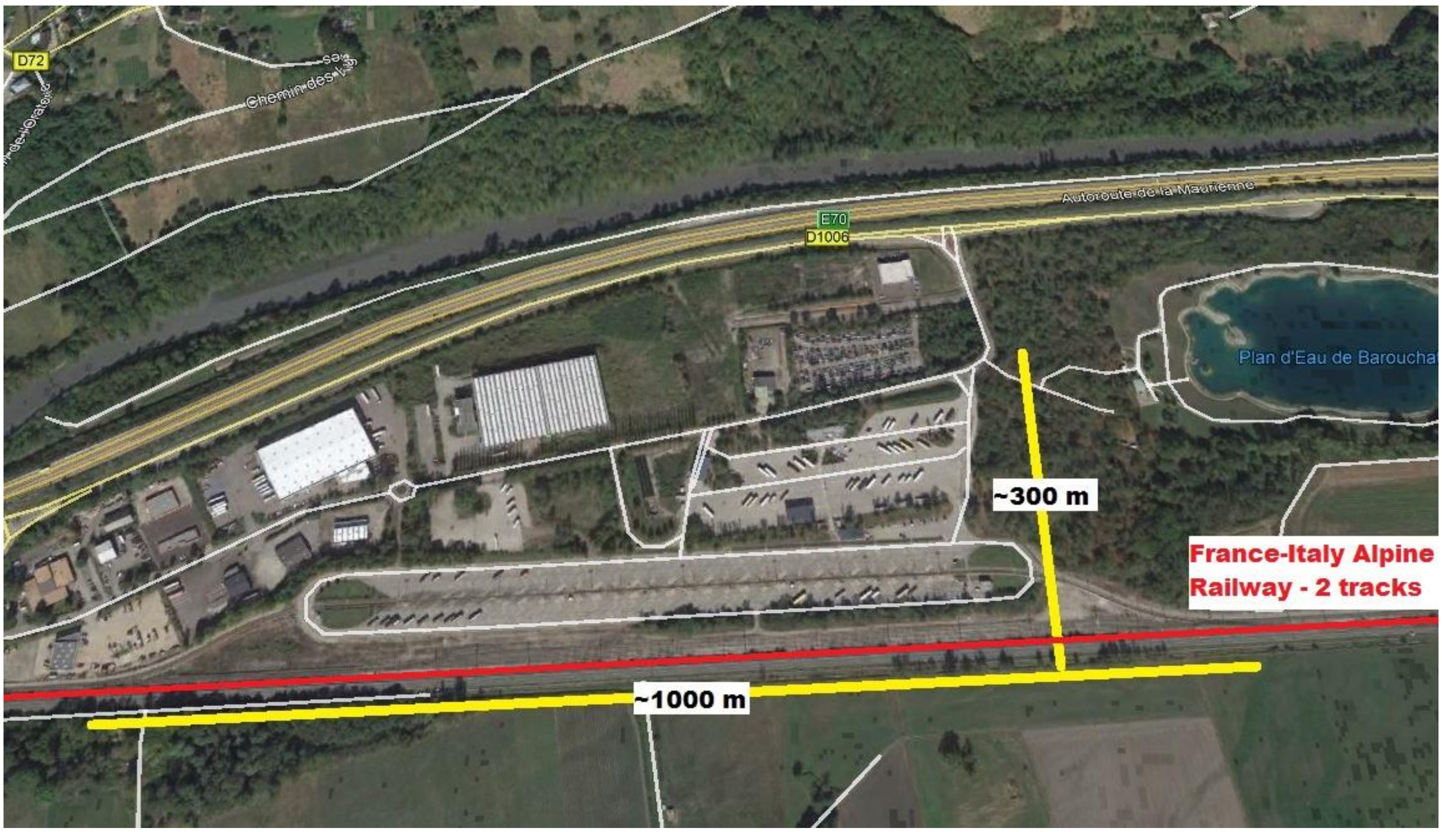

Fig. 13. Modalohr intermodal facility in Aiton, France, with dimensions
(Background aerial photo: Google Earth)

A possible site for a European-style all-electric roll on/roll off intermodal facility exists just west of Ontario International Airport. The possible site is mostly vacant land at present, alongside UP's main line Los Angeles and Alhambra Subdivisions. This site is strategically located near many warehouses and distribution centers (as shown on the map in Fig. 14 below), and is imediately west of Ontario International Airport, a major air cargo hub. Ontario is the nation's 13th busiest airport for cargo, moving nearly 520,000 tons in 2016[46]. Trailers could be quickly moved with electric trucks from

[45] http://tnmc.faculty.unlv.edu//LandFerry/Index.php

[46] https://www.aci-na.org/content/airport-traffic-reports

trains to airport cargo facilities only one to two miles away. With freight shuttle trains from the port, such a facility adjacent the airport would be a strategic rail-truck-sea-air intermodal hub.

Exhibit 15: Regional Distribution Centers

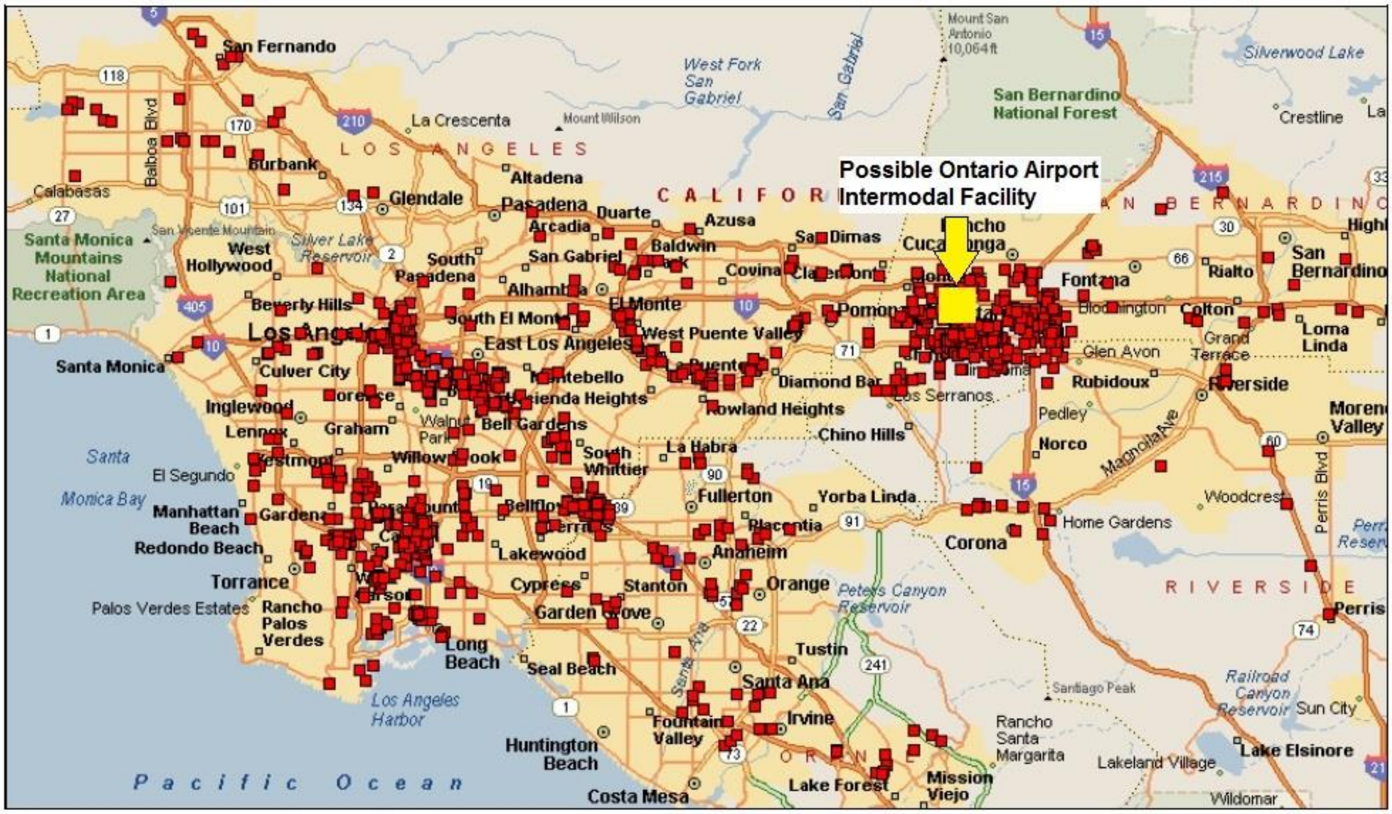

Fig. 14. Location of possible Ontario Airport intermodal facility site, on map of regional distribution centers
(Exhibit 15 from *Inland Port Feasibility Study, Project No. 06-023 Final Report*, Prepared by the Tioga Group Inc., Railroad Industries, Inc. and Iteris for the Southern California Association of Governments, August 2008, pg. 22: http://tiogagroup.com/docs/Tioga_Grp_SCAGInlandPortReport.pdf)

The parcels composing the land of the potential site, shown on the Google Earth image below in Fig. 15, is zoned by the City of Ontario as "Vacant Land", "M1 Limited Industrial" and "M3 General Industrial". The area has enough room between the two double-track rail lines, shown in Fig. 15 below, to accomodate a rapid roll on/roll off intermodal facility similar to those existing in Europe. Intermodal transfer track sections could be built along both the UP LA and Alahambra Subdivision tracks which straddle either side of the site.

Fig 15. Possible "All-Electric Ontario Intermodal Facility" site, with dimensions
(Background aerial photo: Google Earth)

4. Challenges of Freight Rail Electrification

Capital costs and financing-

The main challenge for electric freight rail is the high capital cost of overhead catenary wire, power supply infrastructure, and new electric locomotives. As a complex undertaking, it would certainly cost at least several billion dollars to electrify the main freight lines of Southern California. However, this cost is not known until a comprehensive feasibility study is completed. Also unknown is the full extent of the economic, environmental and public health benefits of electrification until such a study is completed. A proper rail electrification feasibility study would include preliminary design and cost estimates of electric catenary and power distribution infrastructure, specific to particular rail corridors. These cost estimates would also include modifications to existing overhead structures above or along tracks, such as bridges.

The California High Speed Rail Authority has estimated a 25-kV electrification cost of around $8.5 million per route mile for most (~430 miles total) of the Phase 1 route, the majority of which is in the flat, open Central Valley[47]. However, in urban and suburban areas, the cost is much higher. The Caltrain electrification costs between San Francisco and San Jose are about $26 million per route mile, not including the purchase of the new electric multiple unit (EMU) passenger trains[48]. Using the Caltrain construction cost estimates as a basis, the April 2016 CARB freight locomotive report estimated that freight rail electrification capital costs in the South Coast Air Basin would be about $50 million per route mile[49]. However, these costs were rough estimates, and not based on a detailed analysis of existing rail routes. A comprehensive engineering design study and cost estimate of freight rail lines in the South Coast Air Basin needs to be conducted. Overhead catenary system maintenance costs were estimated by the 2016 CARB RailTEC report to be $30,000 per route mile, per year[50]. The higher train frequency for a particular track segment, the more economical electrification will be. Factoring in the social benefits of reduced pollution, electrification for several key Southern California freight and passenger lines was economically favorable according to a cost-benefit analysis done by Paul Druce in 2015[51]:

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[47] Alon Levy, Pedestrian Oberservations blog post May 22, 2018:
https://pedestrianobservations.com/2018/05/22/construction-costs-electrification/
".. with the latest cost overrun, the projected [California High-Speed Rail] electrification cost is $3.7 billion* The length of route to be electrified is unclear: Phase 1, Los Angeles to San Francisco with a short branch up to Merced, is a little more than 700 km, but 80 km of that route is Caltrain, to which the high-speed rail fund is only contributing a partial amount. If the denominator is 700 km then the cost is $5.3 million per km."
*Table 4,-p. 14 of California High Speed Rail Authority, *DRAFT REVISED 2018 Business Plan: Technical Supporting Document- Capital Cost Basis of Estimate Report*, June 1, 2018:
https://www.hsr.ca.gov/docs/about/business_plans/DRAFT_2018_Business_Plan_Basis_of_Estimate_Report.pdf

[48] http://www.caltrain.com/Assets/Caltrain+Modernization+Program/Documents/PCEP+Quarter+4+2016+Report.pdf

[49] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-10 to VIII-11.
https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

[50] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016 (https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf), pg. 20.

[51] Paul Druce, *Reason & Rail* blog, September 5, 2015:

> [with social, environmental and economic benefits] combined, we see that it takes 21-29 bidirectional frequencies for benefits to match the costs of railroad electrification [for passenger rail].
>
> In California, this would indicate that it would be justified to electrify Caltrain between San Jose and San Francisco. With increased service, electrification would also be justified on Metrolink's San Bernardino Line as well as LOSSAN between Burbank and Irvine (Metrolink and Pacific Surfliner) and Oceanside and San Diego (Coaster and Pacific Surfliner).
>
> For freight trains, the decreased fuel costs play a much larger role, and more importantly, the only one that the board of directors actually care about, resulting in break even at fewer frequencies. From the 2014 STB R-1 reports, we see that, for the Class I railroads, there is an average consumption of 6.92 gallons per train-mile; a comparable figure for electric traction would be 86.5 kWh per train-mile. Because of the significantly greater fuel consumption, the pay off is much quicker: Only 9 trains per day are needed in each direction with social benefits included or 15.4 when only considering fuel costs. Of course, private companies aren't going to be using Federal discount rates and will likely be seeking money on the open market. While this will be more expensive, it won't be enormously so. Union Pacific recently sold 40-year bonds at 3.875%; if I've done the math correctly, this would come out to $212,374 per mile of track, pushing the break-even points to 10 and 17.3 frequencies. In Southern California, this would justify the electrification of the Alameda Corridor, Sunset Corridor, and Southern Transcon.

The high upfront capital costs for rail electrification need to be viewed in the context of the several-decade lifespan of the infrastructure investment, the cumulative avoided cost of diesel fuel, locomotive maintenance and the pollution impacts of diesel locomotives over the same period. The experience of railroads around the world has shown that the lower operating and maintenance costs of electric locomotives will result in lower costs over the long run.

The RAIL Solution organization and the Solutionary Rail campaign have proposed a Steel Interstate Development Authority (SIDA) infrastructure bank, a nonprofit corporation financed with low-interest, government-subsidized loans to fund electrification infrastructure along a rail corridor that traverses multiple cities, counties or states[52]. It would be chartered with the authority to raise funds for electrified rail infrastructure investment on both publicly and privately owned rights of way, and take advantage of lower cost of capital available through public financing. Under this scenario, funds would be raised from private markets and federal loan funds. The system would be self-financing through user fees paid by railroads drawing energy from the lines and utilities transmitting electricity. Electrification infrastructure would be publicly owned, overcoming the property tax disadvantage private railroads face. The electrification could also be operated on a leased basis by Southern California utilities already familiar with electric passenger rail systems. The SIDA would negotiate with right-of-way owners to site infrastructure, and the same owners would make commitments to use it.

Possible funding sources for clean freight projects in California, described by the California Sustainable Freight Plan include[53]:

- Goods Movement Emission Reduction Program
- Trade Corridors Improvement Programs
- Carl Moyer Memorial Air Quality Standards Attainment Program

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http://reasonrail.blogspot.com/2015/09/a-cost-to-benefit-analysis-of-railroad.html

[52] Bill Moyer, Patrick Mazza and the Solutionary Rail team (http://www.solutionaryrail.org/). *Solutionary Rail: A people-powered campaign to electrify America's railroads and open corridors for a clean energy future,* October 2016, pgs. 56-58.

[53] California Sustainable Freight Plan, pgs. 6-20 to 6-27

- California Infrastructure Revolving Fund Program
- Alternative & Renewable Fuel and Vehicle Technology Program
- California Pollution Control Financing Authority
- California Alternative Energy & Advanced Transportation Financing Agency
- Low Carbon Transportation Investment and Air Quality Improvement Program
- National Corridor Planning & Development Program
- Coordinated Border Infrastructure Program

Delays caused by exchange of locomotive type-

Aside from the capital cost of electric catenary systems, the main disadvantage of electric locomotives is operational flexibility. Conventional electric locomotives must remain on tracks with overhead catenary wire, while diesel locomotives can go on any track.

U.S. railroads have cited the delays from the changing of locomotives at the end of an electrified line as a reason to not electrify. The change-out of locomotives would also require the construction of new dedicated siding tracks and other facilities to inspect, service, stage, and store both diesel and electric locomotives. Possible ways of minimizing locomotive exchange delays need to be studied. There is much experience around the world with large rail networks that started electrification with one or several lines, and later expanded, with diesel locomotives being utilized along with electrics during the transition. Short-haul rail service in Southern California could be the first phase of a nationwide electrification, with later phased expansion to entire long-haul corridors such as the BNSF Southern Transcon or the UP Sunset Corridor.

The business model of U.S. Class I freight railroads such as UP and BNSF is to minimize the number of trains run by maximizing the weight, length and distance travelled by each train. The Class I railroads prefer to run freight trains for a minimum of 500 miles, with no change of locomotives. The U.S. railroads typically run locomotives extremely long distances, often literally coast to coast. The costs from time-delay of the engine change and additional locomotive facilities is a disadvantage that has been cited by U.S. railroads as a reason not to electrify. As described by the April 2016 CARB freight locomotive report[54]:

> UP and BNSF currently operate high priority intermodal unit trains that can leave the West Coast and make the trip to Chicago (>2,000 track-miles) in 48 to 72 hours. Freight interstate line haul locomotives, with about 5,000 gallon fuel tanks, have a refueling range of about 1,000 miles. On the trip from Chicago to Los Angeles, a typical freight train will refuel twice: once in Kansas City, Kansas and then either at Belen, New Mexico or Santa Teresa, New Mexico and then to California.
>
> An isolated freight electrification system in California could create a number of challenges for UP and BNSF operations on the North American freight rail system including:
>
> - Maintenance of two separate types of locomotive technologies – all-electric in California and diesel-electric for the rest of North American freight rail system;
>
> - Delays in operations by having to stop freight trains at an exchange point, just outside the South Coast Air Basin or California border, to switch all-electric to diesel-electric operations (these delays could take anywhere from 2 to 6

[54] *Draft Technology Assessment: Freight Locomotives.* California Environmental Protection Agency, Air Resources Board, Transportation and Toxics Division, April 2016, pg. VIII-4.
https://www.arb.ca.gov/msprog/tech/techreport/freight_locomotives_tech_report.pdf

hours, depending on the configurations of the trains, and based on price and time, could potentially lead to a mode shift to trucks or ships).

As described in the 2012 SCAG report[55] :

> Key operations changes that may result from electrification include:
>
> 1. Increases in travel time from the L.A. region to other parts of the nation as a result of changing out locomotives at the "edge" of the electrified system, for example in Barstow, West Colton, or Indio… It is estimated by the railroads that nearly four hours could be added to a trip as a result of the "change-out" activity, per trip.
>
> 2. Changes in how railroads move and how logistics decisions are made in the regional and national network (for example, keeping a captive fleet of electric locomotives in the region) will change railroad fleet planning and potentially increase constraints on how locomotives can be utilized, which could have cost impacts; and
>
> 3. Operational impacts of not being able to run electrified catenary into major railyards and the Ports of Los Angeles and Long Beach.
>
> 4. Operational impacts of dealing with a shutdown to the electric mainline. In the event of an electric mainline shutdown, train traffic would need to be diverted to non-electric portions of the system. In this case, the railroads would have many idle full electric locomotives and a potential shortfall of diesel locomotives in order to move all of the goods into and out of the region.

The 2012 SCAG report concluded the locating the locomotive "switch out" locations at the end of the electrified segment of track, such as Barstow or Indio, would have the least impact on railroad operations[56]. Located in less-populated areas, such sites also have more opportunities and space for future expansion of track and facilities. Further out 'stateline' sites such as Needles (California), Yuma (Arizona) and Primm (Nevada) could also serve as 'switch out' locations. The 2016 RailTEC report estimated that locomotive exchanging around the perimeters of the South Coast Air Basin, from zero-emissions to conventional diesel locomotives, would add significant costs and delays to rail freight[57]. The costs and delays were speculated to be great enough to make freight rail less competitive with truck, and cause a 'mode shift' of 12.5 million tons of freight from rail to truck each year. This amount would cost the railroads 10% or more of their regional market share. However, it is worth critically evaluating whether such mode shift would be as significant as described in the RailTEC report, or be avoided entirely. What is left unsaid in RailTEC's analysis is how much the estimated mode shift from rail to truck, due to locomotive exchange, would make highway congestion worse by adding potentially thousands of trucks to the roads. This would make trucks less competitive, incur delays and costs for all other highway users, and create additional environmental and economic costs to region as whole.

Possible ways of minimizing locomotive exchange delays need to be studied. Research is needed in collaboration with railroads operating in California, as well as bringing international expertise from electrified freight railroads outside the U.S. Potential solutions to the exchange point delay problem, which could be studied include:

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[55] 2012 SCAG report, pgs. 4-5 to 4-6.

[56] Ibid., pg. 4-28

[57] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016 (https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf), pgs. 90-103.

- Computer simulations to model locomotive change-out, in order to find electrification strategies that have the lowest operational impact.

- Evaluate locomotive change out of dual-mode diesel electric (catenary) and battery compared to that of conventional catenary electric locomotives, to ascertain if this would reduce change-out time.

- Electric 'helper' locomotives carrying freight trains up and down Cajon Pass, carrying 'dead' diesel-electric locomotives. There are different rules for adding 'helper' locomotives, as the air brake line is not broken between the locomotives and the cars, and the crew staying the cab of the original locomotive.

- For long-distance trains, the electrification could be phased in using dual-mode locomotives and electric-diesel mixed locomotive trains .The short-haul freight train service could also begin with dual-mode. When there is a sufficient amount of regional track electrified, commuter passenger rail and short-haul freight services would switch to straight electric, and the dual mode locomotives moved to long-haul freight service. The locomotive types could also be switched where crews are changed, and where diesel-electrics are already refueled and inspected, to reduce costs and delays.

Phasing out of existing diesel locomotive fleet-

There are close to 30,000 operating line-haul freight diesel-electric locomotives in the U.S. Over 10,000 different line-haul freight locomotives operate within California on mainline freight operations each year. Short-line, terminal, industrial, and passenger railroads operate about 800 locomotives in California, most of which stay entirely within the state[58]. Given an average lifespan of diesel-electric locomotive of about 30 years, a phasing-in of all-electric locomotives will happen over several decades, while diesel locomotives also remain in service. Mixed operation of diesel and electric locomotives on the same train, described below, will be part of this process. Battery-electric "slug" or tender locomotives, coupled with conventional diesel-electric locomotives to form battery-hybrid pairs, could also be part of this phasing-in process.

Other challenges of freight rail electrification -

From a reliability perspective, the failure of an electric catenary system is an additional 'single point of failure', along with other possible track failures such was washouts, subgrade failures, or switch/signal system malfunctions. However, experience of electric trains around the world has shown service interruption due to catenary power loss to be uncommon on a well-maintained electric rail system. In California, freight railroads have also expressed concerns about electromagnetic interference to signaling systems, as well as overhead clearance for double-stacked container cars. However, other electric railroads around the world, such as Pennsylvania's Keystone Corridor, for decades have successfully shared catenary tracks with non-electric freight trains, including those with double-stacked container cars. On India's new electrified Dedicated Freight Corridors, an overhead catenary height of 7.47 m (24.5') above ground level was chosen to allow for double-stacked container train[59].

[58] *Transitioning to a Zero or Near-Zero Emission Line-Haul Freight Rail System in California Operational and Economic Considerations, Final Report.* Prepared for State of California Air Resources Board by University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), Spring 2016 (https://www.arb.ca.gov/railyard/docs/uoi_rpt_06222016.pdf), pg. 24.

[59] http://www.indianrailways.gov.in/railwayboard/uploads/directorate/rail_elec/downloads/1_DFC.pdf

5. Southern California Passenger Rail Electrification and Freight Rail

A focus of the state of California's investments in passenger rail is to improve upon the 'LOSSAN' corridor between San Luis Obispo and San Diego via Los Angeles. LOSSAN is used by both the Metrolink commuter rail and Amtrak's Surfliner, which is the second-busiest Amtrak route in the country after the Northeast Corridor between Washington, D.C. and Boston. CalTrans and BNSF have been working on the state-funded $160 million, 17-mile triple-tracking project between Soto Junction (near Downtown LA) and Fullerton since the late 1990s. Presently the corridor is triple-tracked the entire 25 miles between LA and Fullerton, with the exception of the Rosecrans-Marquart road crossing which still has two tracks. This crossing will be upgraded to three or more tracks once a grade separation project is finished in 2022. The Southern California Optimized Rail Expansion (SCORE) program includes construction of a fourth track between Los Angeles and Fullerton, and a third track between Fullerton and San Bernardino by 2028. All three tracks are presently owned by BNSF and shared by passenger (≈ 50 trains per day) and freight (≈ 60 trains a day). This heavy amount of traffic leads to improved economics and higher utilization of electric rail infrastructure. The California High Speed Rail Authority is proposing two electrified tracks on which all passenger service would run (electric or not), and three freight tracks[60], for a total of five tracks between Los Angeles and Fullerton, as shown below in Fig. 16 and Fig. 17.

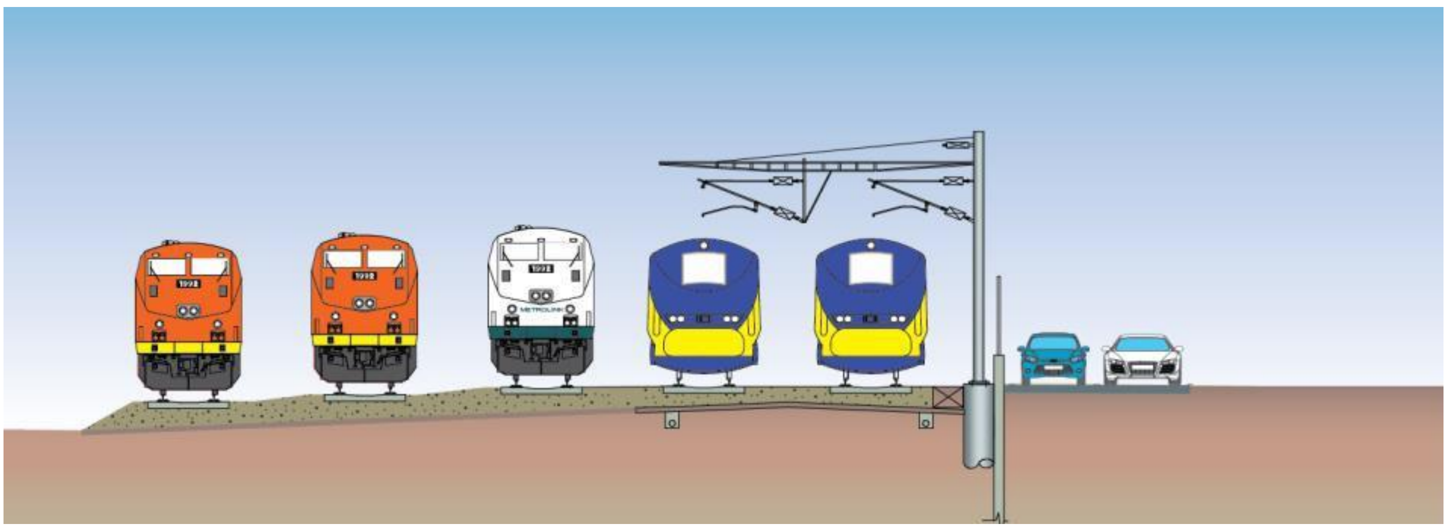
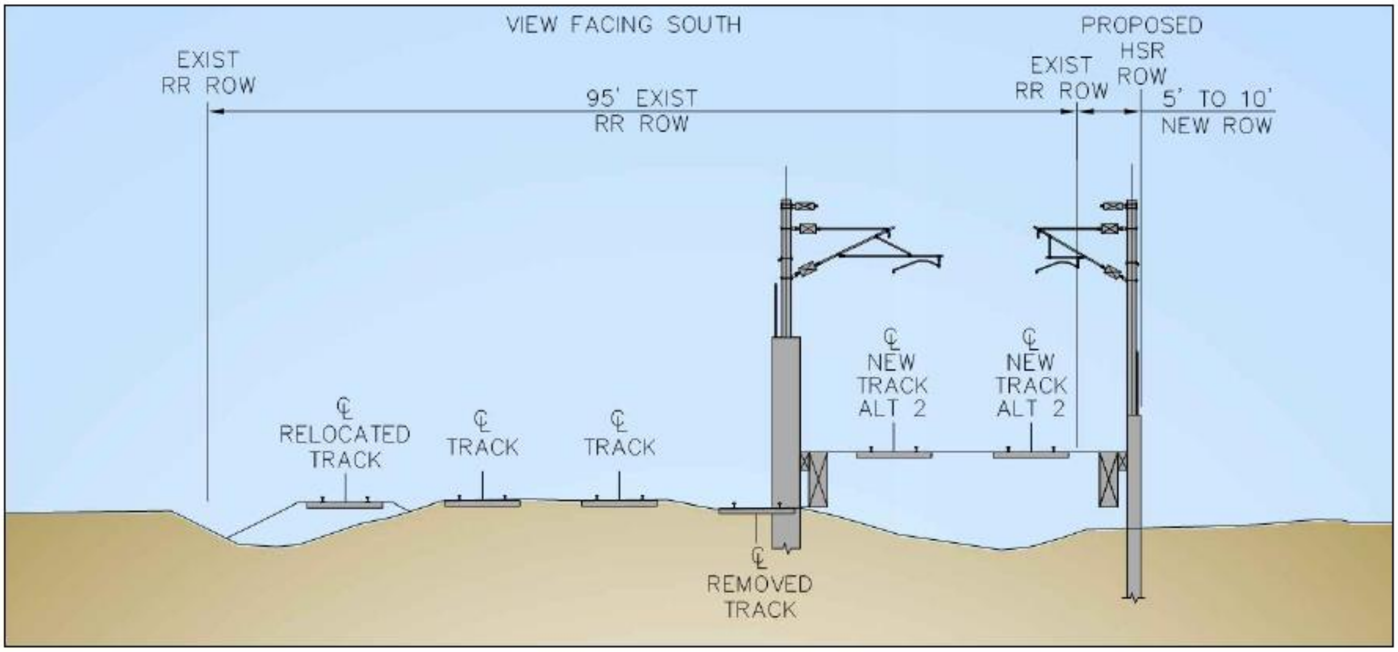


Fig. 16. At-grade alignment of electrified passenger rail tracks alongside three freight tracks, as proposed for the Los Angeles to Fullerton corridor.
(Diagram from California High Speed Rail Authority)

The 25 miles between Los Angeles and Fullerton that overlap with the San Bernardino Subdivision of the BNSF Southern Transcon, which is the only major transcontinental freight rail segment that will share a corridor with Phase I of the CAHSR project. South from Fullerton, the CAHSR would leave the BNSF Southern Transcon and continue to Anaheim and points further south along the double-tracked (both electrified) LOSSAN corridor. Between Fullerton and San Diego, there are just several BNSF freight trains per day on the LOSSAN corridor.

[60] CAHSR website about the Los Angeles to Anaheim corridor:
http://www.hsr.ca.gov/Programs/Statewide_Rail_Modernization/Project_Sections/losangeles_anaheim.html

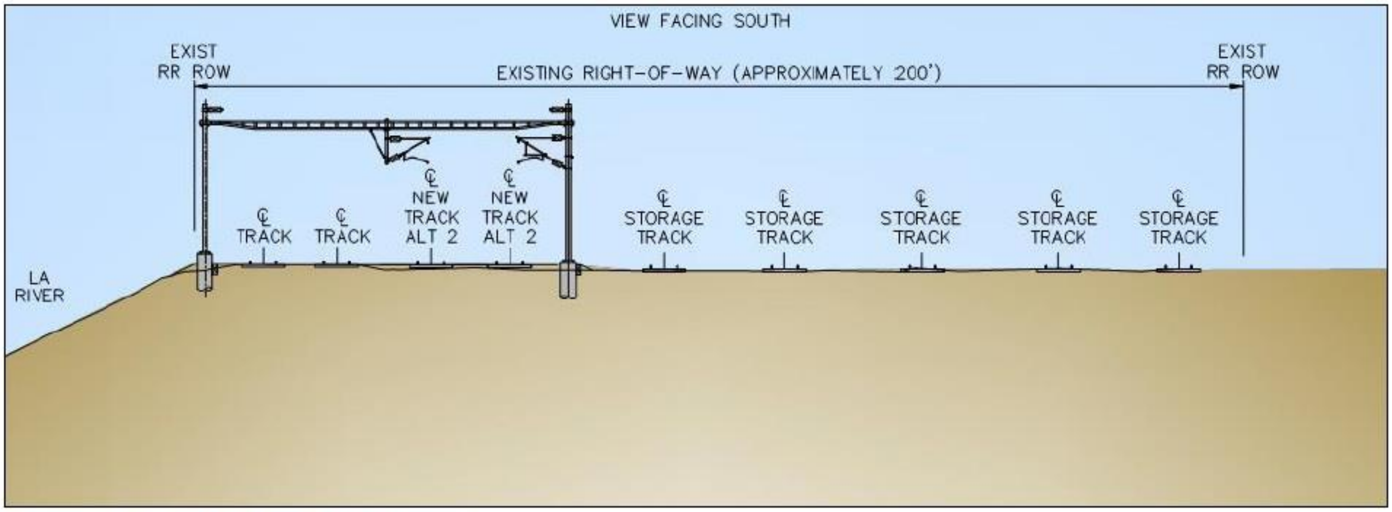


Source: STV, 2015 (Figure not to scale)

Figure 3.4-15 Alternative 2 Typical At-Grade Cross-Section - Fullerton

Fig. 17. Electric catenary infrastructure proposed by California High Speed Rail Authority at Fullerton, on Los Angeles-Anaheim section along BNSF San Bernardino Subdivision.
(Diagram from California High Speed Rail Authority,
Los Angeles to Anaheim Project Section: Supplemental Alternatives Analysis Report, April 2016, pg. 57)

The CAHSR 25-kV overhead catenary system could be designed to support catenary wire over the freight tracks in the future. A 25-kV overhead catenary electrification system is powerful enough to pull heavy freight trains, as demonstrated by existing electric freight railroads around the world. In downtown Los Angeles, the planned CAHSR catenary structure over the tracks along the West Bank of the Los Angeles River is already planned to span over most of the freight tracks as well, as shown below in Fig. 18.



Source: STV, 2015 (Figure not to scale)

Figure 3.4-10 Alternative 2 – Typical Cross-Section –- LA River West Bank: Approaching Redondo Junction

Fig. 18. Electric catenary infrastructure proposed for Los Angeles River West Bank by California High Speed Rail Authority, on Los Angeles-Anaheim section south of LA Union Station

(Diagram from California High Speed Rail Authority,
Los Angeles to Anaheim Project Section: Supplemental Alternatives Analysis Report, April 2016, pg. 53)

The 'blended' CAHSR Burbank-Los Angeles-Anaheim-Irvine corridor could serve as a catalyst for the Electrolink electric regional rail concept for Southern California, proposed by the Rail Passenger Association of California and Nevada. The Electrolink proposal would start with electrifying the existing shared Amtrak/Metrolink route between northern Los Angeles and southern Orange County, and then expand to the rest of the LOSSAN (Los Angeles to San Diego), or Surfliner passenger rail corridor.

6. Next Steps for Freight Rail Electrification in Southern California

1. A comprehensive feasibility study is needed to assess the economic feasibility and benefits of electrifying in-Port rail and the Alameda Corridor, along with short-haul rail service from the Ports of Los Angeles and Long Beach to an ‘Inland Port' or other types of intermodal facilities in the Inland Empire. This comprehensive study should include:
    - Preliminary design and cost estimation
    - Cost/benefit analysis: what lines are the best candidates for electrification?
    - Viable strategies for funding the high upfront infrastructure costs of electrification.
    - Environmental and social impact assessment of possible electrification alternatives.
    - Cost assessment of modifying/replacing existing infrastructure, such as bridges and tunnels for overhead catenaries, impacts on rail operations and safety, impacts to regional power grids.
    - Operational impacts to existing freight and passenger rail service.
    - Carefully assess present and future patterns of truck and rail traffic from the Ports to the Inland Empire.
    - Evaluation of Inland Port sites, in the Inland Empire, or sites in the further inland desert areas.
    - Legal/legislative/regulatory actions needed to support rail electrification.
    - Further questions that must be addressed by such a study:
        - Match the electrified-Inland Port model with regional objectives
        - Best ways for more freight to be shifted from truck to rail, and to reduce truck VMT and highway congestion
        - Environmental impact of short-haul freight rail and related intermodal freight facilities
        - Economic development opportunities of short-haul freight rail
        - Identify effective project “champions”

2. Increased research and development on all types of low-emissions or zero-emissions freight rail and truck technology, for railroad yards, intermodal shipping facilities, and ports. To compliment and build upon existing efforts in the region, a research program or center in Southern California should be established, dedicated to electric rail technology. Such a research program would partner with organizations such as the American Association of Railroad's Transportation Technology Center in Colorado, the University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (RailTEC), and other research centers located in other countries experienced with electric heavy freight rail.

3. Construction in Southern California of a short, test track of overhead catenary at a freight rail yard or short-line freight railroad. This demonstration site could serve as a test bed to evaluate an all-electric locomotive such as modified Siemens ACS-64, a converted freight rail locomotive, a dual-mode locomotive such as a modified Bombardier ALP-45DP, a smaller all-electric switcher (yard) locomotive, or catenary hybrid/ battery tender/ZEBL technology (discussed below in section 6). If at first such a test site could not be built in California, new electric freight rail locomotives could be tested on the existing electric rail test tracks of the Transportation Technology Center near Pueblo, Colorado.

4. Selection of an initial freight rail corridor in Southern California to electrify.

5. Demonstration site, at a freight yard or passenger train station/yard, with charging infrastructure for battery electric and hybrid locomotives, including emerging technologies such as wireless power transfer.

6. Explore co-deployment of electrification along corridors shared with passenger service trains of Metrolink, Amtrak, and California High Speed Rail.

7. Phasing-in of all-electric operations with existing fleet of diesel-electric locomotives, and opportunities for dual-power, or 'mixed-unit' trains pulled by both all-electric and diesel electric power.

8. Negotiated agreements between railroads and electric utility companies, and thorough analysis of the economic value and benefits to electric utilities from railroad-hosted transmission line routes and energy storage capacity.

The electrification of freight rail lines in the region is a major undertaking with a long development timeline. A cooperative partnership must be forged between with the freight carriers (UP, BNSF, Pacific Harbor Line, trucking companies), transportation industry trade associations, locomotive and electrical manufacturers, electric utilities and the government organizations listed below:

- Port of Los Angeles
- Port of Long Beach
- Alameda Corridor Transportation Authority
- Alameda Corridor-East Construction Authority
- Southern California Regional Rail Authority
- Cities along rail lines
- Counties of Los Angeles, Orange, San Bernardino and Riverside
- Southern California Association of Governments
- Los Angeles County Metropolitan Transportation Authority
- South Coast Air Quality Management District
- University transportation research centers (UTC San Bernardino, UTC Long Beach – METRANS, others)
- California Department of Transportation
- California State Transportation Agency
- California Air Resources Board
- California High Speed Rail Authority
- California Energy Commission
- California Public Utilities Commission
- Federal Railroad Administration

In addition, there is a need to build a broad base of support in the region for rail electrification from community organizations, environmental and public health public advocacy groups, along with local businesses, labor unions, trade associations and community activists. Local engineering, construction, and transit agency experience with electric rail transit could be applied to electrifying freight rail. Global and national experts in electric rail should also be invited to Southern California. A regional rail electrification task force was created in the early 1990s for the 1992 *Southern California Accelerated Rail Electrification Program* study, with committees for planning, engineering, analysis, operations & maintenance, environmental analysis, funding/financing, legislative, legal and regulatory applications[61]. Such a regional task force should be created again for the 21st century.

[61] *Southern California Accelerated Rail Electrification Program, Draft Executive Summary.* Prepared for Southern California Regional Rail Authority, February 10, 1992, pgs. ES-1, ES-2: http://libraryarchives.metro.net/DPGTL/Metrolink/1992-ExecSummary-SoCal-Accelerated-Rail-Electrification.pdf

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