# APPENDIX A:

## Diesel PM Emissions from Eighteen Major California Railyards

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**Table A-1**
**Diesel PM Emissions from Eighteen Major California Railyards**
**2005**
(tons per year)

| Railyard | Locomotive | Cargo Handling Equipment | On-Road Trucks | Others (Off-road, TRUs, Stationary, etc.) | Total§ |
|---|---|---|---|---|---|
| **South Coast Air Quality Management District** | | | | | |
| BNSF Hobart | 5.9 | 4.2 | 10.1 | 3.7 | **23.9** |
| UP ICTF/Dolores | 9.8 | 4.4 | 7.5 | 2.0 | **23.7** |
| BNSF San Bernardino | 10.6 | 3.7 | 4.4 | 3.4 | **22.0** |
| UP Colton | 16.3 | N/A | 0.2 | 0.05 | **16.5** |
| UP Commerce | 4.9 | 4.8 | 2.0 | 0.4 | **12.1** |
| UP City of Industry | 5.9 | 2.8 | 2.0 | 0.3 | **10.9** |
| UP LATC | 3.2 | 2.7 | 1.0 | 0.5 | **7.3** |
| UP Mira Loma | 4.4 | N/A | 0.2 | 0.2 | **4.9** |
| BNSF Commerce Eastern | 0.6 | 0.4 | 1.1 | 1.0 | **3.1** |
| BNSF Sheila | 2.2 | N/A | N/A | 0.4 | **2.7** |
| BNSF Watson | 1.9 | N/A | <0.01 | 0.04 | **1.9** |
| **Bay Area Air Quality Management District** | | | | | |
| UP Oakland | 3.9 | 2.0 | 1.9 | 3.4 | **11.2** |
| BNSF Richmond | 3.3 | 0.3 | 0.5 | 0.6 | **4.7** |
| **San Joaquin Valley Unified Air Pollution Control District** | | | | | |
| UP Stockton | 6.5 | N/A | 0.2 | 0.2 | **6.9** |
| BNSF Stockton | 3.6 | N/A | N/A | 0.02 | **3.6** |
| **San Diego Air Pollution Control District** | | | | | |
| BNSF San Diego | 1.6 | N/A | 0.007 | 0.04 | **1.7** |
| **Mojave Desert Air Quality Management District** | | | | | |
| BNSF Barstow | 27.1 | 0.03 | 0.04 | 0.75 | **27.9** |
| **Placer County Air District/Sac Metro AQMD** | | | | | |
| UP Roseville | 25.1 | N/A | N/A | N/A | **25.1** |
| TOTAL | 136.8 | 25.33 | 31.15 | 17.0 | **210.1§** |
| *Percentage* | *65* | *12* | *15* | *8* | ***100*** |

N/A : Not applicable.

§ : Numbers may not add up due to rounding.

**Table A-2**
**Diesel PM Emissions from 18 Major Railyards Summarized by Source Categories in 2005**

| 18 Major Railyards | Diesel PM Emissions (tons per year) | Percent of Railyard Diesel PM Emissions |
|---|---|---|
| Locomotives | 136 | 65% |
| - Line Hauls | 58.1 | 43% |
| - Switchers | 54.3 | 40% |
| - MechanicalService/Testing | 23.1 | 17% |
| Diesel Trucks | 33 | 16% |
| Cargo Equipment | 26 | 12% |
| TRUs/Other | 13 | 7% |
| **Total** | **210** | **100%** |

**Table A-3**
**Estimated Railyard Diesel PM Emissions and Reductions from 2005 to 2020**
(tons per year)

| YEAR | TOTAL* | Percent Reduction from 2005 | Line Haul Locomotives ** | Switch Locomotives *** | Service/ Test Locomotives | HDD Trucks | Cargo (CHE) | TRUs | Other (Stationary) |
|---|---|---|---|---|---|---|---|---|---|
| **2005** | 210 | - | 58 | 54 | 23 | 33 | 26 | 13 | 2.7 |
| **2010** | 131 | 37% | 50 | 35 | 17 | 13 | 9 | 5 | 2 |
| **2015** | 94 | 55% | 37 | 29 | 13 | 8 | 4 | 2 | 1.6 |
| **2020** | 72 | 66% | 27 | 25 | 9 | 5 | 2.6 | 0.4 | 1.5 |

* Assumes an average of 80 percent diesel PM emission reductions for 18 classification and intermodal railyards.
** Assumes full implementation of 1998 and 2008 U.S. EPA rulemakings, 1998 and 2005 ARB/Railroad Agreements, CARB or ULSD for all California locomotives, and beginning of introduction of Tier 4 locomotives nationally between 2015 and 2020.
*** Assumes statewide replacement with advanced technology switch locomotives at 90% PM control with use of CARB diesel.

Table A-4 below provides an estimate of diesel PM emissions and reductions for 18 railyards through 2020. These estimates are based on the UP and BNSF railyard mitigation plans submitted to date. The estimates include commitments UP and BNSF have made since the release of the railyard mitigation plans.

**Table A-4**
**Estimated Railyard Diesel PM Emissions and Reductions for Eight Railyards**
(tons per year)

| Railyard | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| BNSF Hobart (MICR = 500) [2] | 24.7 | 10.5 | 7.9 | 5.9 |
| | Reduction | 58% | 68% | 76% |
| BNSF Barstow (MICR = 450) [2] | 28.0 | 24.5 | 17.7 | 13.6 |
| | Reduction | 1% | 28% | 45% |
| UP ICTF (MICR = 800) [3] | 23.7 | 14.4 | 7.9 | 6.6 |
| | Reduction | 42% | 68% | 73% |
| UP Roseville (MICR = 645) [2] | 23.4 | 19.3 | 14.3 | 9.6 |
| | Reduction | 22% | 42% | 61% |
| BNSF San Bernardino (MICR = 2,500) [2] | 22.4 | 13.2 | 9.0 | 6.0 |
| | Reduction | 46% | 63% | 76% |
| UP Colton (MICR = 150) [2] | 16.5 | 19.5 | 16.9 | 14.2 |
| | Reduction | 21% | 32% | 42% |
| UP Commerce (MICR = 500) [2] | 12.1 | 11.1 | 7.7 | 5.9 |
| | Reduction | 55% | 69% | 76% |
| UP Oakland (MICR = 460) [2] | 11.2 | 13.0 | 8.8 | 7.1 |
| | Reduction | 47% | 64% | 71% |
| UP City of Industry (MICR = 450) [2] | 10.9 | 10.9 | 7.5 | 5.9 |
| | Reduction | 56% | 70% | 76% |
| UP LATC (MICR = 250) [2] | 7.3 | 15.6 | 10.8 | 9.1 |
| | Reduction | 37% | 56% | 63% |
| UP Stockton (MICR = 150) [2] | 6.9 | 10.1 | 8.2 | 6.9 |
| | Reduction | 59% | 67% | 72% |
| UP Mira Loma (MICR = 100) [2] | 4.9 | 13.6 | 10.1 | 8.2 |
| | Reduction | 45% | 59% | 67% |
| BNSF Richmond (MICR = 100) [2] | 4.6 | 14.1 | 9.0 | 6.7 |
| | Reduction | 43% | 63% | 73% |
| BNSF Stockton (MICR = 120) [2] | 3.6 | 22.7 | 15.5 | 13.5 |
| | Reduction | 8% | 37% | 46% |
| BNSF Commerce Eastern (MICR = 100) [2] | 3.0 | 8.5 | 6.8 | 4.7 |
| | Reduction | 66% | 73% | 81% |
| BNSF Watson (MICR = 175) [2] | 1.9 | 16.2 | 12.1 | 8.9 |
| | Reduction | 34% | 51% | 64% |
| BNSF San Diego (MICR = 70) [2] | 1.7 | 22.8 | 14.3 | 9.1 |
| | Reduction | 8% | 42% | 63% |

1. Potentially achieved through additional locomotive emission reductions and site specific options to the 25 in a million cancer risk level.
2. 2005 MICR (Maximum Individual Cancer Risks) estimate.

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# APPENDIX B:

## U.S EPA Locomotive Emission Standards

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In 1998, U.S. EPA established national emission standards for 1973 and later locomotives (see Table B-1). The applicability of these emission standards is based on the original manufacture date for the locomotive, and follows a tiered system. The most stringent existing standards (Tier 2) provided a significant reduction in locomotive emissions.

**Table B-1**
**1998 U.S. EPA Locomotive**
**NOx and PM Emission Standards**

| Type | Tier | Date of Original Manufacture | NOx Standard (g/bhp-hr) | Percent Control When Engine is New or Remanufactured * | PM Standard (g/bhp-hr) | Percent Control When Engine is New or Remanufactured * |
|---|---|---|---|---|---|---|
| Line-haul locomotives | exempt | Pre - 1973 | NA | NA | NA | NA |
| | Tier 0 ** | 1973-2001 | 9.5 | 30 % | 0.6 | N/A |
| | Tier 1 | 2002-2004 | 7.4 | 45 % | 0.45 | N/A |
| | Tier 2 | 2005 and later | 5.5 | 60 % | 0.20 | 59 % |
| Switcher locomotives | exempt | Pre - 1973 | NA | NA | NA | NA |
| | Tier 0 ** | 1973 - 2001 | 14.0 | 29 % | 0.72 | N/A |
| | Tier 1 | 2002 - 2004 | 11.0 | 44 % | 0.54 | N/A |
| | Tier 2 | 2005 and later | 8.1 | 59 % | 0.24 | 59 % |

* Relative to pre-Tier 0 locomotives.

** New Tier 0 locomotives model years 2000 and 2001. Also, existing 1973 to 1999 model year locomotives remanufactured to meet Tier 0 locomotive emissions standards.

In 2008, U.S. EPA released a new federal locomotive rulemaking. A particular emphasis was placed on reducing PM emissions from existing locomotives and the introduction of new Tier 4 locomotives by 2015. Tier 4 locomotives with DPF and SCR are expected to reduce locomotive emissions, beyond Tier 2 NOx and PM emissions levels, by up to 76 and 85 percent, respectively. See next two tables for NOx and PM standards.

**Table B-2**
**2008 U.S. EPA Locomotive NOx Emission Standards**

| Type | Tier | Date of Original Manufacture | Existing NOx Standard (g/bhp-hr) | New NOx Standard New and Remanufactured (g/bhp-hr) | Percent Control When Engine is New or Remanufactured* |
|---|---|---|---|---|---|
| Line-haul locomotives | *exempt* | *Pre - 1973* | *NA* | *NA* | *NA* |
| | *Tier 0 ** | *1973 – 2001* | *9.5* | *8.0 or 7.4* | *16 or 22 %* |
| | Tier 1 | 2002 – 2004 | 7.4 | 7.4 | 0 % |
| | Tier 2 | 2005-2012 | 5.5 | 5.5 | 0 % |
| | Tier 3 | 2012 | N/A | 5.5 | 0 % |
| | *Tier 4* | *2015-2017* | *N/A* | *1.3* | *76 %* *(vs. Tier 2)* |
| Switcher locomotives | *exempt* | *Pre - 1973* | *NA* | *NA* | *NA* |
| | *Tier 0* | *1973 – 2001* | *14.0* | *11.8* | *16* % |
| | Tier 1 | 2002 – 2004 | 11.0 | 11.0 | 0 % |
| | Tier 2 | 2005-2011 | 8.1 | 8.1 | 0 % |
| | *Tier 3* | *2011* | *N/A* | *5.0* | *48 %* *(vs. Tier 2)* |
| | *Tier 4* | *2015* | *N/A* | *1.3* | *84 %* *(vs. Tier 2)* |

Note: In most cases, gen-set and electric hybrid switchers have been U.S. EPA NOx emissions certified at levels below 3.0 g/bhphr, without aftertreatment. The LNG units have certification test data below 3.0.

* In most cases, except for Tier 4, as compared to pre-Tier 0 emissions levels.

**Table B-3**
**2008 U.S. EPA Locomotive PM Emission Standards**

| Type | Tier | Date of Original Manufacture | Existing PM Standards (g/bhp-hr) | New PM Standards Remanufactured or New (g/bhp-hr) | Percent Control When Engine is New or Remanufactured* |
|---|---|---|---|---|---|
| Line-haul locomotives | *exempt* | *Pre-1973* | *NA* | *NA* | *NA* |
| | *Tier 0* | *1973 - 2001* | *0.60* | *0.22* | *63 %* |
| | *Tier 1* | *2002 - 2004* | *0.45* | *0.22* | *49 %* |
| | *Tier 2* | *2005-2011* | *0.20* | *0.10* | *50 %* |
| | *Tier 3* | *2012* | *N/A* | *0.10* | *50 %* *(vs. Tier 2)* |
| | *Tier 4* | *2014* | *N/A* | *0.03* | *85 %* *(vs. Tier 2)* |
| | *exempt* | *Pre - 1973* | *NA* | *NA* | *NA* |
| Switcher locomotives | *Tier 0* | *1973 - 2001* | *0.72* | *0.26* | *64 %* |
| | *Tier 1* | *2002 - 2004* | *0.54* | *0.26* | *48 %* |
| | *Tier 2* | *2005-2010* | *0.24* | *0.13* | *54 %* |
| | *Tier 3* | *2011* | *N/A* | *0.10* | *58 %* *(vs. Tier 2)* |
| | *Tier 4* | *2015* | *N/A* | *0.03* | *87 %* *(vs. Tier 2)* |

Note: In most cases, gen-set, electric hybrid, and LNG switchers have certification test data at levels below 0.15 g/bhphr, without aftertreatment.
* In most cases, except for Tier 4, as compared to pre-Tier 0 emissions levels.
New federal rule diesel fuel requirements will bring non-road diesel fuel sulfur content from 500 ppmv to 15 ppmv in 2012.

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## APPENDIX C:

## Current Status of Aftertreatment for Existing Locomotives

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## CURRENT STATUS OF AFTERTREATMENT FOR EXISTING LOCOMOTIVES

We have been working with U.S. EPA, SCAQMD, and UP and BNSF to develop and demonstrate aftertreatment for existing (pre-Tier 0 through Tier 2) interstate line haul, medium horsepower (MHP), and switch locomotives. In this section we will examine the status of the locomotive aftertreatment efforts to date.

### A. Background on Aftertreatment

Two aftertreatment options that could be retrofitted to existing locomotives to reduce PM emissions are diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs). Selective catalytic reduction (SCR) could be retrofitted to existing locomotives to reduce NOx emissions. A key question to be addressed is whether the filters can maintain the anticipated level of control and necessary durability over time, particularly in interstate line haul operations. In addition, it is critical that aftertreatment not adversely affect engine exhaust flows and combustion efficiencies and can fit into the limited areas available within a locomotive carbody space. The latter is critical due to considerations of locomotive serviceability and reliability; and such that they are able to travel through tunnels across the nation. Finally, after the aftertreatment has been demonstrated successfully on a single locomotive, the ARB verification process will need to be completed. The final step would be for a manufacturer to make the ARB verified aftertreatment commercially available.

#### *1. Diesel Oxidation Catalysts (DOCs)*

Diesel oxidation catalysts (DOCs) use a catalyst material and oxygen in the air to trigger a chemical reaction that converts a portion of diesel PM and ROG into carbon dioxide and water. These catalysts have been shown to reduce diesel PM emissions by 20 to 50 percent and ROG emissions by up to 38 percent. While diesel particulate filters typically need a low-sulfur content fuel to operate effectively, DOCs are tolerant of higher fuel sulfur contents. DOCs can be effective in controlling soluble organic fraction (SOF – oil and diesel fuel combustion related) emissions from locomotives, but is not as effective as DPFs in controlling fine particulates.

A DOC may be the first line control system needed to enhance the effectiveness of both a DPF and an SCR on locomotives. A DOC can enhance the efficiency of a DPF. A DOC can also increase $NO_2$ generation to improve SCR control efficiencies.

#### *2. Diesel Particulate Filters (DPFs)*

DPFs contain a semi-porous material that permits gases in the exhaust to pass through while trapping the diesel soot, with a PM control efficiency of 85 percent or more. They have been successfully demonstrated in the laboratory and demonstrated on two U.S. switch locomotives (UP and BNSF), where they reduced diesel PM emissions by up to about 80 percent.

Diesel PM is mainly composed of elemental carbon (soot), ash and volatile compounds derived from unburned and partially burned fuel and lubricating oil and sulfate. These volatile compounds are also known as the soluble organic fraction or wet portion of diesel PM. Soot particles are formed in the combustion chamber, while volatile organic compounds transform from the gas phase to particle phase as the exhaust cools and dilutes with ambient air after exiting the engine exhaust pipe into the atmosphere. A concern with the use of DPFs with locomotive engines are the high levels of the soluble organic fraction of PM that are emitted from locomotives engines (e.g., EMD two stroke) and can potentially clog a DPF, thereby requiring extensive cleaning and maintenance. Current approaches to reduce the concern of clogging are with the use of a DOC installed before the engine exhaust enters the DPF. Over time soot and ash will accumulate in DPF. A process to manage soot build-up is through the use of "Passive" and "Active" DPF regeneration. Regeneration uses high heat levels to burn off accumulated soot which converts the carbon portion into ash.

A passive DPF regeneration system relies on locomotive exhaust temperatures to burn away soot accumulation in the DPF. However, locomotives can operate a substantial part of their operating cycle in idle and lower notch (i.e., power) settings, where locomotive exhaust temperatures are typically not high enough to burn off soot build up in the DPF. With an active DPF regeneration system relies on auxiliary heat introduced into the exhaust to burn off soot buildup in the DPF. Eventually, even with passive or active regeneration, ash will accumulate in the DPF and must be removed by special cleaning equipment.

### *2. Selective Catalytic Reduction (SCR)*

Another control option for existing locomotives is to retrofit selective catalytic reduction (SCR). SCR is a means of converting NOx with the aid of a catalyst into diatomic nitrogen, $N_2$, and water, $H_2O$. A gaseous reductant, typically anhydrous ammonia, aqueous ammonia, or urea, is added to a stream of flue or exhaust gas and is absorbed onto a catalyst. $CO_2$ is a reaction product when urea is used as the reductant. SCR catalysts are manufactured from various ceramic materials used as a carrier, such as titanium oxide, and active catalytic components are usually either oxides of base metals (such as vanadium and tungsten), zeolites, and various precious metals. SCR has been used on stationary sources (e.g., boilers) and has been shown to reduce NOx emissions by 70 to 95 percent.

One of the key challenges with SCR on an interstate line haul locomotive is being able to design a system that precisely meters urea to approach a one to one conversion ratio between urea to NOx and to minimize potentially toxic emissions from ammonia slip. Further, the lower locomotive engine exhaust temperatures in lower notch settings (i.e., idle to Notch 3) significantly reduce the levels of control from SCR.

## B. Demonstration of DPFs on a Gen-Set Switch Locomotive

Brookville Equipment Company recently installed a passive DPF system on a prototype three engine gen-set switch locomotive built with three Cummins QSK19 Tier 3 nonroad engines. Brookville employed a passive DPF system that relied on locomotive exhaust temperatures to burn away ash and carbon buildup on the DPF. During field testing, Brookville began to experience ongoing ash buildup and cleaning problems with the passive DPF system. As the DPF is not required by any regulation, Brookville chose for the time being to remove the passive DPF system from the prototype gen-set switch locomotive during field testing.

## C. Demonstration of Experimental DPFs on Older Switch Locomotives

ARB and the UP and BNSF entered into the California Emissions Program (CEP) in 2001. The two railroads funded this effort with $5 million, and as of April 2008 about $4 million or more has been expended. The CEP's primary objective was to demonstrate the use of DPFs on older switch locomotives. UP and BNSF each provided an older (both over 25 years old) switch locomotive of about 1,500 horsepower for this program.

After five years of research and bench testing, the UP and BNSF switch locomotives were retrofitted with very large DPFs (two on each locomotive, each about piano size – 1,100 pounds) in front of the cabs of UPY 1378 and BNSF 3703. Baseline emission testing indicates that these switchers can provide up to an 80 percent reduction in particulate matter and 30 percent reduction in hydrocarbon emissions.

UPY 1378 is a Tier 0 EMD MP15DC locomotive and was released into demonstration service in December 2006 to the UP Oakland yard, and then recently transferred to the UP Roseville yard. UPY 1378 has been operating over the past year with only minor mechanical and aftertreatment adjustments. BNSF 3703 was retrofitted with the same DPF technology in late 2006, but for nearly two years remained at the Southwest Research Institute (SWRi) facility in San Antonio, Texas due to ongoing technical challenges in improving the DPF system efficiency. In April 2008, BNSF 3703 arrived in Southern California for demonstration testing.

An important consideration with DPF retrofits on switch locomotives is the recent advances in switch locomotive technology (i.e., gen-set and electric hybrid) since the CEP program was initiated over 7 years ago. Gen-set and electric hybrid switch locomotives can provide up to a 90 percent reduction in both particulate matter and NOx emissions without aftertreatment. These switch locomotives also significantly reduce diesel fuel consumption by 20 to 40 percent.

Due to the DPF and engine rebuild (Tier 0) capital costs ($300,000 to $500,000 or more) and ongoing maintenance costs of DPFs, the new advanced technology switch locomotives may make the retrofitting of older (20-50 year old) switch locomotives with DPFs less cost competitive with the new switch technologies. In California, an important question would be whether to invest limited capital into aftertreatment retrofits of 25 to 50 year old switch locomotives, or whether to purchase new gen-set switch locomotives instead. The gen-set engines provide ongoing fuel savings and these engines can easily be changed (in a few days) for upgrades to future nonroad engines with even more stringent emission standards.

### D. Demonstration of an Experimental Diesel Oxidation Catalyst (DOC) on an Older Freight Line Haul Locomotive

U.S. EPA and UP initiated a demonstration program, in April 2006, on an existing freight line haul locomotive (UP 2368). UP 2368 is an EMD SD60M model interstate freight line haul locomotive built in 1989 and powered by an EMD 16-710-G3A cylinder engine. UP 2368's engine was rebuilt from uncontrolled levels to a Tier 0 level and then retrofitted with a Miratech DOC. UP 2368 was then placed into service in California in October 2006.

UP 2368 baseline emission testing indicated that the DOC could reduce DPM by up to 50 percent. However, during in-field demonstrations in 2007, there were three separate incidents of DOC aftertreatment and DOC support structure failures. The most recent failure resulted in broken catalysts panels and supports. Fortunately, this failure was caught early enough to prevent serious engine damage. Generally, these three DOC related failures have been attributed to the large two-stroke medium speed EMD engine with extreme exhaust pulsations. Miratech worked on a new DOC design and support frames to protect the integrity of the DOC catalysts under locomotive vibration and stresses, and UP 2368 was returned to service in Southern California in May 2008. UP 2368 has performed successfully for over the past six months, and the same DOCs used on UP 2368 have been retrofitted on two Canadian passenger locomotives.

### E. SwRI Bench Test of a Compact SCR on a Locomotive Engine

ARB recently funded a $200,000 research effort with the SwRI. This research consisted of a bench test program of a compact SCR system offered by Engine Fuel and Emissions Engineering, Inc. (EF&EE) (via Haldor Topsoe – a Danish Catalyst Company) and funded by the SCAQMD for use on a MHP Metrolink passenger locomotives. The SWRi bench tests were conducted on an EMD 710 – 12 cylinder engine, which is the same engine family commonly used on pre-2000 freight line haul locomotives (~75 percent), passenger locomotives (most in California), and some marine vessels. The EMD 3000 hp 12-710 G3 engine was retrofitted with the compact SCR device for performance and emission testing. During the performance testing, significant issues occurred with the SCR system's ability to dose the urea properly. Part of this urea dosing imbalance was caused by the un-uniform engine exhaust flows within the turbocharger outlet of the EMD 710 engine and the challenge for the compact SCR system to be able to adjust urea dosing precisely. The poor mixing resulted in large amounts of ammonia slip. EF&EE is currently working to redesign the compact SCR and urea dosing system to try to address these issues. SWRi completed the report for this research effort in March 2008.

**Summary of the Status of Locomotive Aftertreatment**

As of November 2008, ARB staff has not verified any locomotive aftertreatment system. Staff is optimistic that candidates for locomotive aftertreatment systems will be submitted for ARB verification sometime in 2009.

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## APPENDIX D:

## AAR publication on
## “Railroad Service” and “Freight Railroads Operating”
## in California

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*Railroad Service in*

# California

## 2006

### Railroad Service and Employment

| | | |
|---|---|---|
| **Facilities** | Number of Freight Railroads | 24 |
| | Miles Operated (Excluding Trackage Rights) | 5,352 |
| **Traffic** | Total Carloads of Freight Carried | 7,578,456 |
| | Total Tons of Freight Carried | 177,907,810 |
| **Employment and Earnings** | Rail Employees Living in State | 15,268 |
| | Freight Employees Only | 10,478 |
| | Total Wages of Rail Employees | $1,042,945,000 |
| | Freight Employees Only | $726,479,000 |
| | Average Per Freight Rail Employee: | |
| | Wages | $69,300 |
| | Fringe Benefits | $26,900 |
| | Total Compensation | $96,300 |
| **Railroad Retirement** | Railroad Retirement Beneficiaries | 29,196 |
| | Railroad Retirement Benefits Paid | $445,149,000 |

### Freight Railroad Traffic in California

**Tons Originated 2006**

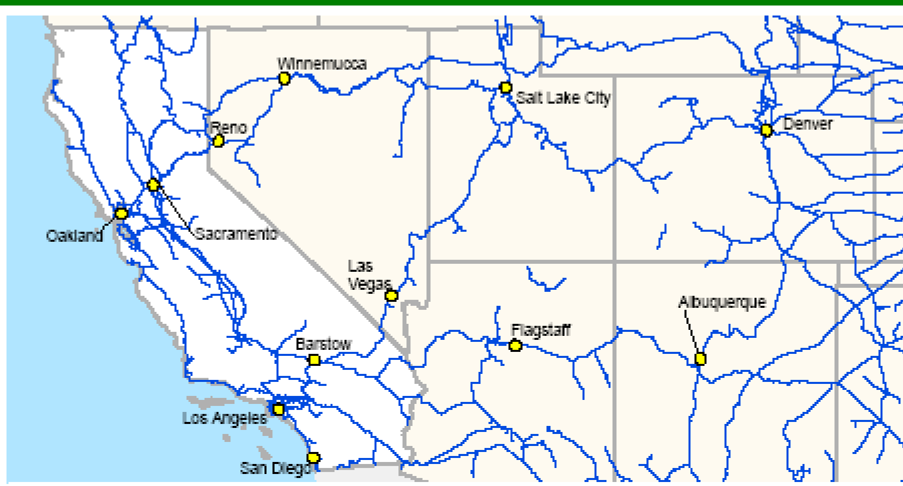
| | Tons | % |
|---|---|---|
| Mixed Freight* | 37,794,104 | 54% |
| Food Products | 6,250,236 | 9 |
| Primary Metal Products | 3,727,429 | 5 |
| Glass & Stone Products | 3,697,956 | 5 |
| Chemicals | 3,616,449 | 5 |
| All Other | 14,980,922 | 21 |
| Total | 70,067,096 | 100% |

*Predominantly Intermodal

**Tons Terminated 2006**

| | Tons | % |
|---|---|---|
| Mixed Freight* | 28,407,880 | 26% |
| Farm Products | 13,696,924 | 12 |
| Food Products | 11,616,124 | 11 |
| Chemicals | 10,977,633 | 10 |
| Lumber & Wood Prod. | 6,843,232 | 6 |
| All Other | 38,575,378 | 35 |
| Total | 110,117,171 | 100% |

### Railroad Map of California




Rail network based upon 2006 National Transportation Atlas Database published by the U.S. DOT, Bureau of Transportation Statistics.

 June 2008

*Freight Railroads Operating in*

# California

## 2006

| | Miles of Railroad Operated in California |
|---|---|
| **Class I Railroads** | |
| BNSF Railway Company | 2,130 |
| Union Pacific Railroad Co. | 3,358 |
| | 5,488 |
| **Regional Railroads** | |
| Central Oregon & Pacific Railroad | 52 |
| San Joaquin Valley Railroad Co. | 351 |
| | 403 |
| **Local Railroads** | |
| Arizona & California Railroad Co. | 133 |
| Carrizo Gorge Railway Inc. | 80 |
| McCloud Railway Co. | 100 |
| Modoc Northern Railroad Company | 96 |
| San Diego & Imperial Valley Railroad | 41 |
| Santa Maria Valley Railroad | 14 |
| Sierra Northern Railway | 99 |
| Stockton Terminal & Eastern Railroad | 30 |
| Trona Railway Co. | 31 |
| Ventura County Railroad Company | 13 |
| West Isle Line, Inc. | 5 |
| Yreka Western Railroad | 12 |
| | 654 |
| **Switching & Terminal Railroads** | |
| California Northern Railroad | 247 |
| Modesto & Empire Traction Co. | 34 |
| Napa Valley Railroad Co. | 21 |
| Oakland Terminal Railway | 6 |
| Pacific Harbor Line, Inc. | 21 |
| Quincy Railroad | 3 |
| Richmond Pacific Railroad Corp. | 10 |
| Santa Cruz, Big Trees & Pacific Railway | 10 |
| | 352 |

| California Totals | Number of Freight Railroads | Miles Operated Excluding Trackage Rights | Miles Operated Including Trackage Rights |
|---|---|---|---|
| Class I | 2 | 3,990 | 5,488 |
| Regional | 2 | 403 | 403 |
| Local | 12 | 640 | 654 |
| Switching & Terminal | 8 | 319 | 352 |
| Total | 24 | 5,352 | 6,897 |


Rail network based upon 2006 National Transportation Atlas Database published by the U.S. DOT, Bureau of Transportation Statistics.

Class I Railroad - As defined by the Surface Transportation Board, a railroad with 2006 operating revenues of at least $346.7 million.
Regional Railroad - A non-Class I line-haul railroad operating 350 or more miles of road and/or with revenues of at least $40 million.
Local Railroad - A railroad which is neither a Class I nor a Regional Railroad and is engaged primarily in line-haul service.
Switching & Terminal Railroad - A non-Class I railroad engaged primarily in switching and/or terminal services for other railroads.
Note: Railroads operating are as of December 31, 2006. Some mileage figures may be estimated.

**APPENDIX E:**

**Options 1 thru 4 -**
**Calculations for Switch Locomotives**

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## Calculations of Switch Locomotive NOx and PM Emissions:

(Source: U.S. EPA Fact Sheet – Emission Factors for Locomotives – U.S. EPA420-F-97-051 – December 1997)
http://www.U.S. EPA.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf

### Switch Locomotive Emission Factors (EF)

| *Tier* | NOx EF *(g/bhp-hr)* | PM EF *(g/bhp-hr)* |
|---|---|---|
| **Pre Tier 0** | 17.4 | 0.72 |
| **Tier 0** | 14.0 | 0.72 |
| **Tier 0+** | 11.8 | 0.26 |
| **ULESL** | **3.0** | **0.10** |
| **Tier 3** | 3.0 | 0.10 |
| **Tier 4** | **1.3** | **0.03** |
| **Tier 4 Nonroad** | **0.3** | **0.01** |

### Conversion Factors

| *bhp-hr/gallon* |
|---|
| 20.8 |

| *tons/g* |
|---|
| 1.10E-06 |

### UP and BNSF Switch Locomotive Fleet Composition (2008)

| *Switchers* | # Locos | Pre Tier 0 | Tier 0 | ULESL |
|---|---|---|---|---|
| **Statewide** | 244 | 103 | 49 | 92 |
| **South Coast** | 139 | 34 | 29 | 76 |
| **Rest of State** | 105 | 69 | 20 | 16 |

### Other Key Assumptions:

Pre-Tier 0 and Tier 0 switch locomotives are assumed to consume 50,000 gallons of diesel fuel per year. ULESLs, Tier 3, and Tier 4 switch locomotives are assumed to consume 40,000 gallons of diesel fuel per year due to 20% reduction with ULESLs: gen-sets, electric hybrids, and LNGs.

## Option 1 - Replace 152 older UP/BNSF switchers with new ULESL

| ***Emission Reduction (TPD)*** | **NOx** | **PM** |
|---|---|---|
| **Statewide** | 6.6 | 0.30 |
| **South Coast** | 2.8 | 0.14 |
| **Rest of State** | 3.8 | 0.16 |

### NOx:

NOx Baseline Emissions – 17.4 g/bhp-hr x 20.8 = 362 grams/gallon.
**103 pre-Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 362 grams/gallon=18,100,000 grams/yr/454 g/lb=39,867.84 lbs/yr/2,000 lbs/ton=19.93 tons/yr/365 days/yr=0.0546 tons/day NOx x 103 pre-Tier 0 switchers = 5.625 tons/day NOx emissions.

NOx Baseline Emissions – 14.0 g/bhp-hr x 20.8 = 291 grams/gallon.
**49 Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 291 grams/gallon=14,550,000 grams/yr/454 g/lb=32,048.46 lbs/yr/2,000 lbs/ton=16.0 tons/yr/365 days/yr=0.0439 tons/day NOx x 49 Tier 0 switch locomotives = 2.15 tons/day NOx emissions.

103 pre-Tier 0 UP/BNSF switch locomotives + 49 Tier 0 UP/BNSF switch locomotives=
(5.625 tons/day) + (2.15 tons/day) = 7.776 tons/day NOx or 7.8 tons/day.
**NOx baseline emissions for 152 older UP/BNSF switchers= 7.8 tons/day.**

NOx Control Emissions – 3.0 g/bhp-hr x 20.8 = 62 grams/gallon.
**152 ULESL UP and BNSF Switch Locomotives** (20% Diesel Fuel Reduction)
40,000 gallons/year x 62 grams/gallon = 2,480,000 grams/yr/454 g/lb=5,462.55 lbs/yr/2,000 lbs/ton=2.73 tons/yr/365 days/yr=0.00748 tons/day NOx x 152 ULESLs = 1.1374 tons/day **NOx controlled emissions or 1.14 tons/day NOx controlled**.

NOx baseline emissions (7.776 tons/day) – NOx control emissions (1.1374 tons/day) = 6.6386 tons/day NOx reduced or 6.64 or **6.6 tons/day NOx reduced**.

### PM:

PM Baseline Emissions – 0,72 g/bhp-hr x 20.8 = 15 grams/gallon.
**152 pre-Tier 0 and Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 15 grams/gallon=750,000 grams/yr/454 g/lb=1,651.98 lbs/yr/2,000 lbs/ton=0.826 tons/yr/365 days/yr=.002263 tons/day PM x 152 pre-Tier and Tier 0 switchers =**0.344 tons/day PM baseline emissions**.

PM Control Emissions – 0.1 g/bhp-hr x 20.8 = 2 grams/gallon.
**152 ULESL UP and BNSF Switch Locomotives** (20% Diesel Fuel Reduction)
40,000 gallons/year x 2 grams/gallon = 80,000 grams/yr/454 g/lb=176.21 lbs/yr/2,000 lbs/ton=0.088 tons/yr/365 days/yr=0.00024 tons/day PM x 152 ULESLs = 0.03669 tons/day PM controlled emissions or **0.037 tons/day PM controlled**.

PM baseline emissions (0.344 tons/day) – PM control emissions (0.037 tons/day) = 0.307 tons/day PM reduced or 0.31 or **0.3 tons/day PM reduced**.

**<u>Cost-Effectiveness Calculations</u>:**
Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(6.64+0.31) x (2,000 lbs/ton) x (365 days/yr) = 5,735,000 lbs/yr.
Capital or Project Cost: $1,500,000 x 152 gen-sets or ULESLs = $228,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

<u>PM</u>
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($228,000,000 x 0.5) / (0.31 x 2000 x 365 x 10) = $50.38 / lb
20 yr project life = ($228,000,000 x 0.5) / (0.31 x 2000 x 365 x 20) = $25.19 / lb

<u>NOx</u>
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($228,000,000 x 0.5) / (6.64 x 2000 x 365 x 10) = $2.35 / lb
20 yr project life = ($228,000,000 x 0.5) / (6.64 x 2000 x 365 x 20) = $1.18 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $228,000,000) / 9,373,200 lbs) = $3.00 / lb
(20 yrs) = (0.0736 x $228,000,000) / 9,373,200 lbs) = $1.79 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 2 - DPF and SCR Retrofits of 244 UP/BNSF ULESLs:

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 1.0 | 0.04 |
| **South Coast** | 0.6 | 0.02 |
| **Rest of State** | 0.4 | 0.02 |

## NOx:

NOx Baseline Emissions – 3.0 g/bhp-hr x 20.8 = 62 grams/gallon.
**244 UP and BNSF ULESLs** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 62 grams/gallon = 2,480,000 grams/yr/454 g/lb=5,462.55 lbs/yr/2,000 lbs/ton=2.73 tons/yr/365 days/yr=0.00748 tons/day NOx x 244 ULESLs = 1.825 tons/day NOx baseline emissions or **1.8 tons/day NOx baseline emissions**.

NOx Control Emissions – 1.3 g/bhp-hr x 20.8 = 27 grams/gallon.
**244 UP and BNSF ULESLs Retrofitted with SCR** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 27 grams/gallon = 1,080,000 g/yr/454 g/lb=2,378.85 lbs/yr/2,000 lbs/ton=1.1894 tons/yr/365 days/yr=0.003258 tons/day NOx x 244 ULESLs retrofitted with SCR =
**0.795 tons/day NOx controlled**.

NOx baseline emissions (1.8 tons/day) – NOx control emissions (0.795 tons/day) =
**1.0 tons/day NOx reduced**.

## PM:

PM Baseline Emissions – 0.1 g/bhp-hr x 20.8 = 2 grams/gallon.
**244 UP and BNSF ULESLs** (20% Diesel Fuel Reduction)
40,000 gallons/year x 2 grams/gallon = 80,000 grams/yr/454 g/lb=176.21 lbs/yr/2,000 lbs/ton=0.088 tons/yr/365 days/yr=0.00024 tons/day PM x 244 ULESLs = 0.05856 tons/day PM baseline emissions or **0.059 tons/day PM baseline emissions**.

PM Control Emissions – 0.03 g/bhp-hr x 20.8 = 0.624 grams/gallon.
**244 UP and BNSF ULESLs Retrofitted with DPFs** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 0.624 grams/gallon = 24,960 g/yr/454 g/lb=54.98 lbs/yr/2,000 lbs/ton=0.0275 tons/yr/365 days/yr=0.0000753 tons/day PM x 244 ULESLs retrofitted with DPFs =
**0.018 tons/day NOx control emissions**

PM baseline emissions (0.059 tons/day) – PM control emissions (0.018 tons/day) = 0.041 tons/day PM reduced or **0.04 tons/day PM reduced**.

## Cost-Effectiveness Calculations:

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(1.0+0.04) x (2,000 lbs/ton) x (365 days/yr) x (1 yr) = 759,200 lbs/yr.
Capital or Project Cost: $200,000 x 244 ULESLs = $48,800,000.

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($48,800,000 x 0.5) / (0.04 x 2000 x 365 x 10) = $41.78 / lb
20 yr project life = ($48,800,000 x 0.5) / (0.04 x 2000 x 365 x 20) = $83.56 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($48,800,000 x 0.5) / (1.0 x 2000 x 365 x 10) = $1.67 / lb
20 yr project life = ($48,800,000 x 0.5) / (1.0 x 2000 x 365 x 20) = $3.34 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $48,800,000) / 1,314,000 lbs) = $4.58 / lb
(20 yrs) = (0.0736 x $48,800,000) / 1,314,000 lbs) = $2.73 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 3 - Repower 244 ULESLs, that had been retrofitted with DPF and SCR, with new Tier 4 nonroad engines

*(Emissions Reductions beyond ULESL and DPF/SCR Retrofit)*

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 0.60 | 0.01 |
| **South Coast** | 0.35 | 0.007 |
| **Rest of State** | 0.25 | 0.005 |

## NOx:

NOx Baseline Emissions – 1.3 g/bhp-hr x 20.8 = 27 grams/gallon.
**244 UP and BNSF ULESLs Retrofitted with SCR** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 27 grams/gallon = 1,080,000 g/yr/454 g/lb=2,378.85 lbs/yr/2,000 lbs/ton=1.1894 tons/yr/365 days/yr=0.003258 tons/day NOx x 244 ULESLs retrofitted with SCR =
**0.795 tons/day NOx controlled**.

NOx Control Emissions – 0.3 g/bhp-hr x 20.8 = 6.24 grams/gallon.
**244 UP and BNSF ULESLs Tier 4 Nonroad Engines** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 6.24 grams/gallon = 249,600 grams/yr/454 g/lb=549.78 lbs/yr/2,000 lbs/ton=0.2749 tons/yr/365 days/yr=0.000753 tons/day NOx x 244 ULESLs with Tier 4 Nonroad engines = 0.18376 tons/day NOx baseline emissions or **0.184 tons/day NOx control emissions**.

NOx baseline emissions (0.795 tons/day) – NOx control emissions (0.184 tons/day) =
**0.61 tons/day NOx reduced**.

## PM:

PM Baseline Emissions – 0.03 g/bhp-hr x 20.8 = 0.624 grams/gallon.
**244 UP and BNSF ULESLs Retrofitted with DPFs** (20% Diesel Fuel Reduction)
40,000 gallons/yr x 0.624 grams/gallon = 24,960 g/yr/454 g/lb=54.98 lbs/yr/2,000 lbs/ton=0.0275 tons/yr/365 days/yr=0.0000753 tons/day PM x 244 ULESLs retrofitted with DPFs =
**0.018 tons/day NOx control emissions**

PM Control Emissions – 0.01 g/bhp-hr x 20.8 = 0.208 grams/gallon.
**244 UP and BNSF ULESLs with Tier 4 Nonroad Engines** (20% Diesel Fuel Reduction)
40,000 gallons/year x 0.208 grams/gallon = 8,320 grams/yr/454 g/lb=18.33 lbs/yr/2,000 lbs/ton=0.0092 tons/yr/365 days/yr=0.000025 tons/day PM x 244 ULESLs with Tier 4 Nonroad Engines =
**0.006 tons/day PM baseline emissions**.

PM baseline emissions (0.018 tons/day) – PM control emissions (0.006 tons/day) = 0.012 tons/day PM reduced or **0.01 tons/day PM reduced**.

## Cost-Effectiveness Calculations:

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(0.61+0.01) x (2,000 lbs/ton) x (365 days/yr) = 452,600 lbs/yr.
Capital or Project Cost: $200,000 x 244 ULESLs = $48,800,000.

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($48,800,000 x 0.5) / (0.01 x 2000 x 365 x 10) = $334.25 / lb
20 yr project life = ($48,800,000 x 0.5) / (0.01 x 2000 x 365 x 20) = $167.12 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($48,800,000 x 0.5) / (0.61 x 2000 x 365 x 10) = $5.48 / lb
20 yr project life = ($48,800,000 x 0.5) / (0.61 x 2000 x 365 x 20) = $2.74 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $48,800,000) / 620,500 lbs) = $9.70 / lb
(20 yrs) = (0.0736 x $48,800,000) / 620,500 lbs) = $5.79 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 4 - Remanufacture 152 older UP and BNSF switch locomotives to meet the U.S. EPA Tier 0 Plus emission standards

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 2.2 | 0.22 |
| **South Coast** | 0.8 | 0.09 |
| **Rest of State** | 1.4 | 0.13 |

### NOx:

NOx Baseline Emissions – 17.4 g/bhp-hr x 20.8 = 362 grams/gallon.
**103 pre-Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 362 grams/gallon=18,100,000 grams/yr/454 g/lb=39,867.84 lbs/yr/2,000 lbs/ton=19.93 tons/yr/365 days/yr=0.0546 tons/day NOx x 103 pre-Tier 0 switchers = 5.625 tons/day NOx emissions.

NOx Baseline Emissions – 14.0 g/bhp-hr x 20.8 = 291 grams/gallon.
**49 Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 291 grams/gallon=14,550,000 grams/yr/454 g/lb=32,048.46 lbs/yr/2,000 lbs/ton=16.0 tons/yr/365 days/yr=0.0439 tons/day NOx x 49 Tier 0 switch locomotives = 2.15 tons/day NOx emissions.

103 pre-Tier 0 UP/BNSF switch locomotives + 49 Tier 0 UP/BNSF switch locomotives=
(5.625 tons/day) + (2.15 tons/day) = 7.776 tons/day NOx or 7.8 tons/day.
**NOx baseline emissions for 152 older UP/BNSF switchers= 7.8 tons/day.**

NOx Control Emissions – 11.8 g/bhp-hr x 20.8 = 245 grams/gallon.
**152 Tier 0 Plus UP and BNSF Switch Locomotives**
50,000 gallons/year x 245 grams/gallon = 12,250,000 grams/yr/454 g/lb=26,982.4 lbs/yr/2,000 lbs/ton=13.49 tons/yr/365 days/yr=0.03696 tons/day NOx x 152 Tier 0 Plus switch locomotives = 5.618 tons/day **NOx controlled emissions or 5.6 tons/day NOx controlled**.

NOx baseline emissions (7.776 tons/day) – NOx control emissions (5.618 tons/day) = 2.15775 tons/day NOx reduced or 2.16 or **2.2 tons/day NOx reduced**.

### PM:

PM Baseline Emissions – 0,72 g/bhp-hr x 20.8 = 15 grams/gallon.
**152 pre-Tier 0 and Tier 0 UP and BNSF Switch Locomotives**
50,000 gallons/yr x 15 grams/gallon=750,000 grams/yr/454 g/lb=1,651.98 lbs/yr/2,000 lbs/ton=0.826 tons/yr/365 days/yr=0.002263 tons/day PM x 152 pre-Tier and Tier 0 switchers =
**0.344 tons/day PM baseline emissions**.

PM Control Emissions – 0.26 g/bhp-hr x 20.8 = 5.408 or 5.4 grams/gallon.
**152 Tier 0 Plus UP and BNSF Switch Locomotives**
50,000 gallons/year x 5.4 grams/gallon = 270,000 grams/yr/454 g/lb=594.7 lbs/yr/2,000 lbs/ton=0.297 tons/yr/365 days/yr=0.0008147 tons/day PM x 152 Tier 0 Plus = 0.12383 tons/day PM controlled emissions or **0.12 tons/day PM controlled**.
PM baseline emissions (0.344 tons/day) – PM control emissions (0.12 tons/day) = 0.224 tons/day PM reduced or **0.22 tons/day PM reduced**.

## **Cost-Effectiveness Calculations:**

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(2.16+0.22) x (2,000 lbs/ton) x (365 days/yr) = 1,737,400 lbs/yr.
Capital or Project Cost: $250,000 x 152 locos = $38,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($38,000,000 x 0.5) / (0.22 x 2000 x 365 x 10) = $11.83 / lb
20 yr project life = ($38,000,000 x 0.5) / (0.22 x 2000 x 365 x 20) = $5.92 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($38,000,000 x 0.5) / (2.16 x 2000 x 365 x 10) = $1.20 / lb
20 yr project life = ($38,000,000 x 0.5) / (2.16 x 2000 x 365 x 20) = $0.60 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $38,000,000) / 4,788,800 lbs) = $0.98 / lb
(20 yrs) = (0.0736 x $38,000,000) / 4,788,800 lbs) = $0.58 / lb

1. Capital Recovery factor assumes a four percent discount rate.

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## APPENDIX F:

## Options 5 thru 8 -
## Calculations for Medium Horsepower Locomotives

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## Calculations for Medium Horsepower Locomotives

(Source: EPA Fact Sheet – Emission Factors for Locomotives – EPA420-F-97-051 – December 1997)
http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf

### Medium Horsepower Locomotive Emission Factors (EF)

| *Tier* | NOx EF *(g/bhp-hr)* | PM EF *(g/bhp-hr)* |
|---|---|---|
| **Pre Tier 0** | 13.5 | 0.60 |
| **Tier 0** | 9.5 | 0.60 |
| **Tier 0+** | 8.0 | 0.22 |
| **LEL** | 4.0 | 0.10 |
| **ULESL** | 3.0 | 0.10 |
| **Tier 3** | 3.0 | 0.10 |
| **Tier 4** | 1.3 | 0.03 |

### Conversion Factors

| *bhp-hr/gallon* |
|---|
| 20.8 |

| *tons/g* |
|---|
| 1.10E-06 |

### UP/BNSF/Passenger Medium Horsepower Locomotive Fleet Composition

| *Medium HP* | # Locos | Pre-Tier 0 | Tier 0 |
|---|---|---|---|
| **Statewide** | 400 | 360 | 40 |
| **South Coast** | 150 | 130 | 20 |
| **Rest of State** | 250 | 230 | 20 |

### <u>Other Key Assumptions</u>:

All medium horsepower locomotives are assumed to consume 100,000 gallons of fuel per year.

## Option 5 - Repower of 400 older Freight and Passenger MHP locomotives with new LEL engines:

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 23 | 1.25 |
| **South Coast** | 8.6 | 0.47 |
| **Rest of State** | 14.4 | 0.78 |

## NOx:

NOx Baseline Emissions – 13.5 g/bhp-hr x 20.8 = 281 grams/gallon.
**360 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives**
100,000 gallons/yr x 281 grams/gallon=28,100,000 grams/yr/454 g/lb=61,894.27 lbs/yr/2,000 lbs/ton=30.95 tons/yr/365 days/yr=0.08478 tons/day NOx x 360 pre-Tier 0 MHP locomotives = 30.52 tons/day or **30.5 tons/day** NOx baseline emissions.

NOx Baseline Emissions – 9.5 g/bhp-hr x 20.8 = 198 grams/gallon.
**40 UP/BNSF/Passenger Tier 0 MHP Locomotives**
100,000 gallons/yr x 198 grams/gallon=19,800,000 grams/yr/454 g/lb=43,612.33 lbs/yr/2,000 lbs/ton=21.81 tons/yr/365 days/yr=0.0597 tons/day NOx x 40 Tier 0 MHP locomotives = 2.3897 tons/day or **2.4 tons/day** NOx baseline emissions.

360 pre-Tier 0 UP/BNSF/Passenger MHP locomotives + 40 Tier 0 UP/BNSF/Passenger MHP locomotives=
(30.5 tons/day) + (2.4 tons/day) = **32.9 tons/day NOx baseline emissions for 400 older UP/BNSF/Passenger MHP Locomotives.**

NOx Control Emissions – 4.0 g/bhp-hr x 20.8 = 83 grams/gallon.
**400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives**
100,000 gallons/year x 83 grams/gallon = 8,300,000 grams/yr/454 g/lb=18,281.94 lbs/yr/2,000 lbs/ton=9.14 tons/yr/365 days/yr=0.025 tons/day NOx x 400 MHP LEL Engine Repower Locomotives = 10.0175 tons/day **NOx controlled emissions or 10.0 tons/day NOx controlled**.

NOx baseline emissions (32.9 tons/day) – NOx control emissions (10.0 tons/day) =
**22.9 or 23 tons/day NOx reduced**.

**PM:**
PM Baseline Emissions – 0,6 g/bhp-hr x 20.8 = 12.5 grams/gallon.
**400 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives**
100,000 gallons/yr x 12.5 grams/gallon=1,250,000 grams/yr/454 g/lb=2,753.3 lbs/yr/2,000 lbs/ton=1.377 tons/yr/365 days/yr=0.00377 tons/day PM x 400 pre-Tier and Tier 0 MHP Locomotives =
**1.509 tons/day PM baseline emissions**.

PM Control Emissions – 0.1 g/bhp-hr x 20.8 = 2 grams/gallon.
**400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers**
100,000 gallons/year x 2 grams/gallon = 200,000 grams/yr/454 g/lb=440.53 lbs/yr/2,000 lbs/ton=0.22 tons/yr/365 days/yr=0.0006 tons/day PM x 400 MHP Locomotives with LEL Engine Repowers = **0.241 tons/day PM controlled**.

PM baseline emissions (1.51 tons/day) – PM control emissions (0.24 tons/day) = 1.27 tons/day PM reduced or **1.25 tons/day PM reduced**.

## **Cost-Effectiveness Calculations:**

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(22.9+1.27) x (2,000 lbs/ton) x (365 days/yr) = 17,644,100 lbs/yr.
Capital or Project Cost: $1,000,000/ x 400 MHP LEL locomotives = $400,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($400,000,000 x 0.5) / (1.27 x 2000 x 365 x 10) = $21.57 / lb
20 yr project life = ($400,000,000 x 0.5) / (1.27 x 2000 x 365 x 20) = $10.79 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($400,000,000 x 0.5) / (22.9 x 2000 x 365 x 10) = $1.20 / lb
20 yr project life = ($400,000,000 x 0.5) / (22.9 x 2000 x 365 x 20) = $0.60 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x$400,000,000) / 35,259,000 lbs) = $1.34 / lb
(20 yrs) = (0.0736 x$400,000,000) / 35,259,000 lbs) = $0.80 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 6 - Replace up to 200 of the 400 older MHP locomotives with new MHP gen-set locomotives *(Complement and Alternative to MHP LEL Engine Repowers)*

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| Statewide | 13.3 | 0.63 |
| South Coast | 6.65 | 0.315 |
| Rest of State | 6.65 | 0.315 |

## NOx:

NOx Baseline Emissions – 13.5 g/bhp-hr x 20.8 = 281 grams/gallon.
**200 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives**
100,000 gallons/yr x 281 grams/gallon=28,100,000 grams/yr/454 g/lb=61,894.27 lbs/yr/2,000 lbs/ton=30.95 tons/yr/365 days/yr=0.084786676 tons/day NOx x 200 pre-Tier 0 MHP locomotives = 16.957 tons/day or **17 tons/day** NOx baseline emissions.

NOx Control Emissions – 3.0 g/bhp-hr x 20.8 = 62 grams/gallon.
**200 UP/BNSF/ MHP Gen-Set Replacement Locomotives**
100,000 gallons/year x 62 grams/gallon = 6,200,000 grams/yr/454 g/lb=13,656.4 lbs/yr/2,000 lbs/ton=6.83 tons/yr/365 days/yr=0.0187 tons/day NOx x 200 MHP Gen-Set Locomotives =
3.7415 tons/day or **3.74 tons/day NOx controlled emissions**.

NOx baseline emissions (17 tons/day) – NOx control emissions (3.74 tons/day) =
**13.26 or 13.3 tons/day NOx reduced**.

**PM:**

PM Baseline Emissions – 0,6 g/bhp-hr x 20.8 = 12.5 grams/gallon.
**200 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives**
100,000 gallons/yr x 12.5 grams/gallon=1,250,000 grams/yr/454 g/lb=2,753.3 lbs/yr/2,000 lbs/ton=1.377 tons/yr/365 days/yr=0.00377 tons/day PM x 200 pre-Tier and Tier 0 MHP Locomotives =
**0.754 tons/day PM baseline emissions**.

PM Control Emissions – 0.1 g/bhp-hr x 20.8 = 2 grams/gallon.
**200 UP/BNSF/Passenger MHP Locomotives with Gen-Set Replacement Locomotives**
100,000 gallons/year x 2 grams/gallon = 200,000 grams/yr/454 g/lb=440.53 lbs/yr/2,000 lbs/ton=0.22 tons/yr/365 days/yr=0.0006 tons/day PM x 200 MHP Gen-Set Locomotives = **0.12 tons/day PM controlled**.

PM baseline emissions (0.754 tons/day) – PM control emissions (0.12 tons/day) = 0.634 tons/day PM reduced or
**0.63 tons/day PM reduced**.

## **Cost-Effectiveness Calculations:**

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(13.26+0.63) x (2,000 lbs/ton) x (365 days/yr) = 10,139,700 lbs/yr.
Capital or Project Cost: $1,000,000 x 400 MHP LEL locomotives = $400,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($400,000,000 x 0.5) / (0.63 x 2000 x 365 x 10) = $43.49 / lb
20 yr project life = ($400,000,000 x 0.5) / (0.63 x 2000 x 365 x 20) = $21.74 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($400,000,000 x 0.5) / (13.26 x 2000 x 365 x 10) = $2.07 / lb
20 yr project life = ($400,000,000 x 0.5) / (13.26 x 2000 x 365 x 20) = $1.03 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x$400,000,000) / 18,877,800 lbs) = $2.61 / lb
(20 yrs) = (0.0736 x$400,000,000) / 18,877,800 lbs) = $1.56 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 7 - Retrofit 400 LEL or gen-set MHP locomotives with DPF and SCR

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 6.8 | 0.18 |
| **South Coast** | 2.55 | 0.07 |
| **Rest of State** | 4.25 | 0.11 |

## NOx:

NOx Baseline Emissions – 4.0 g/bhp-hr x 20.8 = 83.2 grams/gallon.
**400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives**
100,000 gallons/year x 83.2 grams/gallon = 8,320,000 grams/yr/454 g/lb=18,325.99 lbs/yr/2,000 lbs/ton=9.163 tons/yr/365 days/yr=0.0251 tons/day NOx x 400 MHP LEL Engine Repower Locomotives = 10.042 tons/day or **10.042 tons/day NOx baseline emissions**.

NOx Control Emissions – 1.3 g/bhp-hr x 20.8 = 27 grams/gallon.
**400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives Retrofitted with SCR**
100,000 gallons/yr x 27 grams/gallon=2,700,000 grams/yr/454 g/lb=5,947.17 lbs/yr/2,000 lbs/ton=2.97 tons/yr/365 days/yr=0.0081468 tons/day NOx x 400 MHP LEL Engine Repowered Locomotives with SCR = 3.2587 tons/day or **3.26 tons/day** NOx control emissions.

NOx baseline emissions (10.042 tons/day) – NOx control emissions (3.2583 tons/day) = 6.784 or **6.8 tons/day NOx reduced**.

## PM:

PM Baseline Emissions – 0.1 g/bhp-hr x 20.8 = 2.08 grams/gallon.
**400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers**
100,000 gallons/year x 2.08 grams/gallon = 208,000 grams/yr/454 g/lb=458.15 lbs/yr/2,000 lbs/ton=0.229 tons/yr/365 days/yr=0.0006276 tons/day PM x 400 MHP Locomotives with LEL Engine Repowers = **0.251 tons/day PM baseline emissions.**

PM Control Emissions – 0,03 g/bhp-hr x 20.8 = 0.624 grams/gallon.
**400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers Retrofitted with DPFs**
100,000 gallons/yr x 0.624 grams/gallon=62,400 grams/yr/454 g/lb=137.45 lbs/yr/2,000 lbs/ton=0.06872 tons/yr/365 days/yr= 0.000188281 tons/day PM x 400 MHP Locomotives with LEL Engine Repowers and Retrofitted with DPFs =**0.0753 tons per day PM controlled emissions**.

PM baseline emissions (0.251 tons/day) – PM control emissions (0.0753 tons/day) = 0.1757 tons/day PM reduced or **0.18 tons/day PM reduced**.

## **Cost-Effectiveness Calculations:**

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(6.78+0.18) x (2,000 lbs/ton) x (365 days/yr) = 5,080,800 lbs/yr.
Capital or Project Cost: $500,000 x 400 MHP LEL locomotives retrofitted with SCR and DPF =
$200,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($200,000,000 x 0.5) / (0.18 x 2000 x 365 x 10) = $76.10 / lb
20 yr project life = ($200,000,000 x 0.5) / (0.18 x 2000 x 365 x 20) = $38.05 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($200,000,000 x 0.5) / (6.78 x 2000 x 365 x 10) = $2.02 / lb
20 yr project life = ($200,000,000 x 0.5) / (6.78 x 2000 x 365 x 20) = $1.01 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $200,000,000) / 7,577,400 lbs) = $3.25 / lb
(20 yrs) = (0.0736 x $200,000,000) / 7,577,400 lbs) = $1.94 / lb

1. Capital Recovery factor assumes a four percent discount rate.

## Option 8 - Remanufacture 400 older MHP locomotives to meet U.S. EPA Tier 0 Plus Emission Standards *(Less Expensive Alternative to LEL and Gen-Set Options)*

| ***Emission Reduction(TPD)*** | **NOx** | **PM** |
|---|---|---|
| **Statewide** | 13 | 1.0 |
| **South Coast** | 4.9 | 0.37 |
| **Rest of State** | 8.1 | 0.63 |

**NOx:**
NOx Baseline Emissions – 13.5 g/bhp-hr x 20.8 = 281 grams/gallon.
**360 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives**
100,000 gallons/yr x 281 grams/gallon=28,100,000 grams/yr/454 g/lb=61,894.27 lbs/yr/2,000 lbs/ton=30.95 tons/yr/365 days/yr=0.08478 tons/day NOx x 360 pre-Tier 0 MHP locomotives = 30.52 tons/day or
**30.5 tons/day** NOx baseline emissions.

NOx Baseline Emissions – 9.5 g/bhp-hr x 20.8 = 198 grams/gallon.
**40 UP/BNSF/Passenger Tier 0 MHP Locomotives**
100,000 gallons/yr x 198 grams/gallon=19,800,000 grams/yr/454 g/lb=43,612.33 lbs/yr/2,000 lbs/ton=21.81 tons/yr/365 days/yr=0.0597 tons/day NOx x 40 Tier 0 MHP locomotives = 2.3897 tons/day or **2.4 tons/day** NOx baseline emissions.

360 pre-Tier 0 UP/BNSF/Passenger MHP locomotives + 40 Tier 0 UP/BNSF/Passenger MHP locomotives=
(30.5 tons/day) + (2.4 tons/day) = 32.9 tons/day
**NOx baseline emissions for 400 older UP/BNSF/Passenger MHP Locomotives = 32.9 tons/day.**

NOx Control Emissions – 8.0 g/bhp-hr x 20.8 = 166 grams/gallon.
**400 UP/BNSF/Passenger MHP Locomotives Remanufactured to Tier 0 Plus NOx**
100,000 gallons/year x 166 grams/gallon = 16,600,000 grams/yr/454 g/lb=36,563.87 lbs/yr/2,000 lbs/ton=18.28 tons/yr/365 days/yr=0.05 tons/day NOx x 400 MHP Locomotives Remanufactured to Tier 0 Plus NOx = 20.035 tons/day **or 20.0 tons/day NOx controlled emissions**.

NOx baseline emissions (32.9 tons/day) – NOx control emissions (20.0 tons/day) =
**12.9 or 13 tons/day NOx reduced**.

**PM:**
PM Baseline Emissions – 0,6 g/bhp-hr x 20.8 = 12.5 grams/gallon.
**400 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives**
100,000 gallons/yr x 12.5 grams/gallon=1,250,000 grams/yr/454 g/lb=2,753.3 lbs/yr/2,000 lbs/ton=1.377 tons/yr/365 days/yr=0.00377 tons/day PM x 400 pre-Tier and Tier 0 MHP Locomotives =
**1.509 or 1.51 tons/day PM baseline emissions**.

PM Control Emissions – 0.22 g/bhp-hr x 20.8 = 4.576 or 4.6 grams/gallon.
**400 UP/BNSF/Passenger MHP Locomotives Remanufactured to Tier 0 Plus PM Standards**
100,000 gallons/year x 4.6 grams/gallon = 460,000 grams/yr/454 g/lb=1,013.21 lbs/yr/2,000 lbs/ton=0.5066 tons/yr/365 days/yr=0.001388 tons/day PM x 400 MHP Locomotives Remanufactured to Tier 0 Plus Standards = **0.55518 tons per day or 0.555 tons per day PM controlled**.

PM baseline emissions (1.51 tons/day) – PM control emissions (0.555 tons/day) = 0.955 or 0.96 tons/day PM reduced or **1.0 tons/day PM reduced**.

## **Cost-effectiveness**:

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(12.9+0.96) x (2,000 lbs/ton) x (365 days/yr) = 10,117,800 lbs/yr.
Capital or Project Cost: $250,000 x 400 MHP locomotives = $100,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($100,000,000 x 0.5) / (0.96 x 2000 x 365 x 10) = $7.13 / lb
20 yr project life = ($100,000,000 x 0.5) / (0.96 x 2000 x 365 x 20) = $3.57 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($100,000,000 x 0.5) / (12.9 x 2000 x 365 x 10) = $0.53 / lb
20 yr project life = ($100,000,000 x 0.5) / (12.9 x 2000 x 365 x 20) = $0.27 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $100,000,000) / 23,433,000 lbs) = $0.53 / lb
(20 yrs) = (0.0736 x $100,000,000) / 23,433,000 lbs) = $0.31 / lb

1. Capital Recovery factor assumes a four percent discount rate.

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## APPENDIX G:

## Option 9 -
## Calculations for Interstate Line Haul Locomotives

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## Line Haul Locomotive Emission Factors (EF)

| *Tier* | NOx EF *(g/bhp-hr)* | PM EF *(g/bhp-hr)* |
|---|---|---|
| **Tier 2** | 5.5 | 0.20 |
| **Tier 4** | 1.3 | 0.03 |

### Conversion Factors

| *bhp-hr/gallon* |
|---|
| 20.8 |

| *tons/g* |
|---|
| 1.10E-06 |

### Projected UP and BNSF Interstate Line Haul Locomotive Fleet Composition in 2020

| *Interstate Line Hauls* | # Locos | Tier 2 |
|---|---|---|
| **Statewide** | 1,200 | 1,200 |
| **South Coast** | 600 | 600 |
| **Rest of State** | 600 | 600 |

### Other Key Assumptions:

All line haul locomotives are assumed to consume 100,000 gallons of fuel per year. This assumes an interstate line haul locomotive consumes up to 500,000 gallons per year, traveling across county (e.g., Chicago to Los Angeles), and only 20 percent of annual consumption is within the state of California.

Assumes UP and BNSF interstate line haul locomotive fleet in California will be a Tier 2 fleet average by 2020. Net emissions reductions would be only difference between a Tier 2 and Tier 4 interstate line haul locomotive emissions (76% NOx and 85% PM).

## Option 9 - Accelerate UP and BNSF national Tier 4 interstate line haul locomotive fleet with orders for up to 4,800 to ensure 1,200 operate in California on any given day in 2020:

| *Emission Reduction(TPD)* | NOx | PM |
|---|---|---|
| **Statewide** | 32 | 1.3 |
| **South Coast** | 16 | 0.65 |
| **Rest of State** | 16 | 0.65 |

## NOx:

NOx Baseline Emissions – 5.5 g/bhp-hr x 20.8 = 114.4 grams/gallon.
1,200 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020
100,000 gallons/year x 114.4 grams/gallon = 11,440,000 grams/yr/454 g/lb=25,198.24 lbs/yr/2,000 lbs/ton=12.599 tons/yr/365 days/yr=0.034518 tons/day NOx x 1,200 UP and BNSF Tier 2 Interstate Line Haul Locomotives = 41.4 tons/day NOx baseline emissions.

NOx Control Emissions – 1.3 g/bhp-hr x 20.8 = 27 grams/gallon.
1,200 UP and BNSF Tier 4 Interstate Line Haul Locomotives in 2020
100,000 gallons/yr x 27 grams/gallon=2,700,000 grams/yr/454 g/lb=5,947.17 lbs/yr/2,000 lbs/ton=2.97 tons/yr/365 days/yr=0.0081468 tons/day NOx x 1,200 UP and BNSF Tier 4 Interstate Line Haul Locomotives with SCR = 9.78 tons/day NOx controlled emissions.

NOx baseline emissions (41.1 tons/day) – NOx control emissions (9.78 tons/day) = 31.62 tons/day NOx reduced.

## PM:

PM Baseline Emissions – 0.2 g/bhp-hr x 20.8 = 4.16 grams/gallon.
1,200 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020
100,000 gallons/year x 4.16 grams/gallon = 416,000 grams/yr/454 g/lb=916.3 lbs/yr/2,000 lbs/ton=0.458 tons/yr/365 days/yr=0.0012552 tons/day PM x 600 1,200 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020 = 1.51 tons/day PM baseline emissions

PM Control Emissions – 0,03 g/bhp-hr x 20.8 = 0.624 grams/gallon.
1,200 UP and BNSF Tier 4 Interstate Line Haul Locomotives in 2020
100,000 gallons/yr x 0.624 grams/gallon=62,400 grams/yr/454 g/lb=137.45 lbs/yr/2,000 lbs/ton=0.06872 tons/yr/365 days/yr= 0.000188281 tons/day PM x 1,200 UP and BNSF Tier 4 Interstate Line Haul Locomotives with DPFs = 0.23 tons per day PM controlled emissions.

PM baseline emissions (1.51 tons/day) – PM control emissions (0.23 tons/day) = 1.28 tons/day PM reduced.

## **Cost-Effectiveness Calculations:**

Annual emission reductions for NOx and PM: (NOx+PM) x (2,000 lbs/ton) x (365 days/yr) =
(31.62+1.28) x (2,000 lbs/ton) x (365 days/yr) = 24,017,000 lbs/yr.
Capital or Project Cost (National): $3,000,000 x 4,800 Tier 4 Line Haul locomotives = $14,400,000,000
Capital or Project Cost (California): $3,000,000 x 1,200 Tier 4 Line Haul locomotives = $3,600,000,000

Cost-Effectiveness by attributing half the project cost to PM and half the project cost to NOx:

PM
10 yr project life = (Project Cost x 0.5) / (PM tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($3,600,000,000 x 0.5) / (1.28 x 2000 x 365 x 10) = $192.64 / lb
20 yr project life = ($3,600,000,000 x 0.5) / (1.28 x 2000 x 365 x 20) = $96.32 / lb

NOx
10 yr project life = (Project Cost x 0.5) / (NOx tons/day x 2000 lbs/ton x 365 days/yr x 10 yrs)
= ($3,600,000,000 x 0.5) / (31.62 x 2000 x 365 x 10) = $7.80 / lb
20 yr project life = ($3,600,000,000 x 0.5) / (31.62 x 2000 x 365 x 20) = $3.90 / lb

Carl Moyer Cost-Effectiveness = (Capital Recovery Factor[1] x Project Cost) / (ROG + NOx + PM10x20):

(10 yrs) = (0.1233 x $3,600,000,000) / 41,770,600 lbs) = $10.63 / lb
(20 yrs) = (0.0736 x $3,600,000,000) / 41,770,600 lbs) = $6.34 / lb

1. Capital Recovery factor assumes a four percent discount rate.

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# APPENDIX H:

## Options 10 thru 15 - Calculations for Cargo Handling Equipment (CHE)

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## Calculations of Cargo Handling Equipment NOx and PM Emissions and Cost-Effectiveness

(Source: ARB Staff Report – Initial Statement of Reasons for Proposed Rulemaking – Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards – October 2005
ARB Staff Report – Carl Moyer Program Guidelines – Part IV, Appendices – November 2005
CALSTART – LNG Yard Hostler Demonstration and Commercialization Project, Final Report - August 2008
Port of Los Angeles – Electric Truck Demonstration Project Fact Sheet – May 2008
National Renewable Energy Laboratory – "Using LNG as fuel in Heavy-Duty Tractors" – July, 1999)

This section provides a discussion of the methodology used to develop emission estimates and cost-effectiveness of potential options to enhance and accelerate non-locomotive emission reductions related to cargo handling equipment within railyards.

### Estimating Emissions

The approach used to develop the cargo handling equipment emission estimates entailed determining the average annual emissions per engine and then multiplying it by the total number of engines in that group.

$$E_{y,t} = pop_x \times HP \times \%\,Load_t \times EF_x \times hrs_t$$

*where:*
- *E = Pollutant specific emissions*
- *HP = Horsepower*
- *pop = Cargo handling equipment type-specific population*
- *% Load = Average Engine Load (Load Factor)*
- *EF = Emission factor*
- *hrs = Annual use in hours*
- *y = Inventory year*
- *t = Equipment type*
- *x = Horsepower range*

Each of these elements and how they are incorporated in to the cargo handling equipment emission estimates is discussed below.

#### Population

Cargo handling equipment populations were developed using information gathered in an effort to develop facility-wide emission inventories for 18 California railyards. The information collected includes equipment type, engine specific information, and annual activity.

#### Horsepower

Average horsepower was estimated by equipment using information gathered to develop emission inventories for 18 California railyards.

#### Activity

Annual use (hours of operation) values for specific equipment was provided by emission inventories developed for 18 California railyards.

#### Engine Load Factor

This number represents engine load under normal operating conditions. Engine load factors were taken from ARB's OFFROAD model for the specific type of cargo handling equipment.

### Emission Factors

Emission factors were taken from ARB's OFFROAD model and are based on the engines rated horsepower. Emission factors for this report do not incorporate deterioration rates associated with zero hour (i.e. brand new) emissions and equipment age.

**Surplus Emission Reductions**

Surplus emission reductions are estimated by taking the sum of all annual surplus pollutant reductions.

$$NOx\ Reductions\ (tons) + [20 \times PM\ Reductions\ (tons)] + ROG\ Reductions\ (tons)$$

To determine surplus emission reductions, annual emissions by pollutant must be estimated for both the baseline technology (technology applied under normal business practices) and the reduced technology (newer technology). The annual baseline technology emissions and the annual reduced technology emissions are compared. All pollutants are given an equal weight except for PM which has been identified as a toxic air and carries a greater weight.

If the reduced technology is an engine repower or replacement (i.e. new purchase) then estimated annual emissions for the reduced technology are subtracted from the estimated annual emissions for the baseline technology.

$$Annual\ Emissions\ for\ the\ Baseline\ Technology - Annual\ Emissions\ for\ the\ Reduced\ Technology$$

If the reduced technology is an engine retrofit then the annual baseline technology pollutant emissions are multiplied by the verified percent of emission reductions for the technology.

$$Annual\ Emissions\ for\ the\ Baseline\ Technology \times Reduced\ Technology\ Verification\ Percent$$

**Annualized Cost**

Annualized cost is calculated by multiplying the total cost of the project by the capital recovery factor (CRF).

$$Total\ Cost \times CRF$$

The CRF uses an interest rate and project life to calculate the rate at which earnings could reasonably be expected if the same funds were invested over the entire project life. For this report staff assumed an interest rate of 4 percent, the prevailing earnings potential for state funds expected by investing in various financial instruments.

$$[(1+i)^n (i)] / [(1+i)^n - 1]$$

*Where:*
$i$ = *discount rate*
$n$ = *project life*

**Cost Effectiveness**

The cost effectiveness for each potential option in this report was determined by dividing the annualized cost of the project by the total amount of surplus emission reductions.

$$Annualized\ Cost / Surplus\ Emission\ Reductions$$

## Option 10 - LNG Yard Truck

### Annual Baseline Emissions:

Yard Truck w/ 2007+ On-road Diesel Engine:

*PM Emissions$_{Baseline}$*:

[(0.01 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.002 ton/yr

*NOx Emissions$_{Baseline}$*:

[(0.27 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.06 ton/yr

*Total Annual Baseline Emissions$_{PM + NOx}$* = **0.062 ton/yr**

8 Intermodal Railyards:

*PM Emissions$_{2005}$*: 14.80 ton/yr
*NOx Emissions$_{2005}$*: 328 ton/yr
**342.8 ton/yr**

*PM Emissions$_{2010}$*: 14.80 ton/yr x 0.36 = 5.3 ton/yr
*NOx Emissions$_{2010}$*: 328 ton/yr x 0.51 = 167 ton/yr
**172.3 ton/yr**

*PM Emissions$_{2015}$*: 14.80 ton/yr x 0.24 = 3.6 ton/yr
*NOx Emissions$_{2015}$*: 328 ton/yr x 0.30 = 98.4 ton/yr
**102 ton/yr**

*PM Emissions$_{2020}$*: 14.80 ton/yr x 0.12 = 1.78 ton/yr
*NOx Emissions$_{2020}$*: 328 ton/yr x 0.09 = 29.5 ton/yr
**31.3 ton/yr**

*Based on emission inventories for 18 railyard health risk assessments finalized in 2007 and 2008. Estimated emission reductions are surplus to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Railyards.*

### Annual Reduced Technology Emissions:

LNG Yard Truck:

*PM Emissions$_{reduced}$*:

N/A

*NOx Emissions$_{reduced}$*:

[(2.68 g/bhp-hr x 170hp x 0.39 x 3196 hr/yr) x (1 ton/907,200g)] = 0.63 ton/yr

*Total Annual Reduced Technology Emissions$_{PM + NOx}$* = **0.63 ton/yr**

### Annual Surplus Emission Reductions:

Total Annual Baseline Emissions$_{PM + NOx}$ + Total Annual Reduced Technology Emissions$_{PM + NOx}$

(0.06 ton/yr – 0.63 ton/yr)$_{NOx}$ + (0.002 ton/yr – 0 ton/yr)$_{PM}$ = ***-0.57 ton/yr*** (2007+ on-road engine)

**Cost Estimates:**

LNG Yard Truck: $120,000
8 Intermodal Railyards: $120,000 x 322 = **$38,640,000**

**Cost Effectiveness:** N/A

## Option 11 - Electric Yard Truck

### Annual Baseline Emissions:

Yard Truck w/ 2007+ On-road Diesel Engine:

*PM Emissions*$_{Baseline}$:
[(0.01 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.002 ton/yr

*NOx Emissions*$_{Baseline}$:
[(0.27 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.06 ton/yr

*Total Annual Baseline Emissions*$_{PM + NOx}$ = **0.062 ton/yr**

8 Intermodal Railyards:

*PM Emissions*$_{2010}$: 14.80 ton/yr x 0.36 = 5.3 ton/yr
*NOx Emissions*$_{2010}$: 328 ton/yr x 0.51 = 167 ton/yr
**172.3 ton/yr**

*PM Emissions*$_{2015}$: 14.80 ton/yr x 0.24 = 3.6 ton/yr
*NOx Emissions*$_{2015}$: 328 ton/yr x 0.30 = 98.4 ton/yr
**102 ton/yr**

*PM Emissions*$_{2020}$: 14.80 ton/yr x 0.12 = 1.78 ton/yr
*NOx Emissions*$_{2020}$: 328 ton/yr x 0.09 = 29.5 ton/yr
**31.3 ton/yr**

*Based on emission inventories for 18 railyard health risk assessments finalized in 2007 and 2008. Estimated emission reductions are surplus to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Railyards.*

### Annual Reduced Technology Emissions:

Electric Yard Truck:

*PM Emissions*$_{reduced}$:
N/A

*NOx Emissions*$_{reduced}$:
N/A

*Total Annual Reduced Technology Emissions*$_{PM + NOx}$ = **0 ton/yr**

8 Intermodal Railyards

*PM Emissions*$_{2010}$: 0 ton/yr
*NOx Emissions*$_{2010}$: 0 ton/yr

*PM Emissions*$_{2015}$: 0 ton/yr
*NOx Emissions*$_{2015}$: 0 ton/yr

*PM Emissions*$_{2020}$: 0 ton/yr
*NOx Emissions*$_{2020}$: 0 ton/yr

### Annual Surplus Emission Reductions:

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(0.06 ton/yr)$_{NOx}$ + (0.002 ton/yr)$_{PM}$] - 0 ton/yr = **0.062 ton/yr** (2007+on-road engine)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(167 ton/yr)$_{NOx}$ + (5.3 ton/yr)$_{PM}$] - 0 ton/yr = **172.3 ton/yr** (2010 Railyard Emissions)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(98.4 ton/yr)$_{NOx}$ + (3.6 ton/yr)$_{PM}$]- 0 ton/yr = **102 ton/yr** (2015 Railyard Emissions)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(29.5 ton/yr)$_{NOx}$ + (1.78 ton/yr)$_{PM}$] - 0 ton/yr = **31.3 ton/yr** (2020 Railyard Emissions)

**Annual Weighted Surplus Emission Reductions:**

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(0.06 ton/yr)$_{NOx}$ + 20(0.002 ton/yr)$_{PM}$] - 0 ton/yr = **0.1 ton/yr** (2007+on-road engine)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(167 ton/yr)$_{NOx}$ + 20(5.3 ton/yr)$_{PM}$] - 0 ton/yr = **273 ton/yr** (2010 Railyard Emissions)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(98.4 ton/yr)$_{NOx}$ + 20(3.6 ton/yr)$_{PM}$]- 0 ton/yr = **170.4 ton/yr** (2015 Railyard Emissions)

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$
[(29.5 ton/yr)$_{NOx}$ + 20(1.78 ton/yr)$_{PM}$] - 0 ton/yr = **65.1 ton/yr** (2020 Railyard Emissions)

**Cost Estimates:**

Electric Yard Truck: $208,700
8 Intermodal Railyards: $208,700 x 322 = $67,201,400

**Annualized Cost:**

Electric Yard Truck: $208,700 x 0.149 = $31,096
8 Intermodal Railyards: = $67,201,400 x 0.149 = $10,013,008

**Cost Effectiveness:**

($31,096 ÷ 200 lbs) = **$155/lb** (2007+on-road engine)

($10,013,008 ÷ 546,000 lbs) = **$18.33/lb** (8 Intermodal Railyards$_{2010\ Emissions}$)
($10,013,008 ÷ 340,800 lbs) = **$29.38/lb** (8 Intermodal Railyards$_{2015\ Emissions}$)
($10,013,008 ÷ 130,200 lbs) = **$76.90/lb** (8 Intermodal Railyards$_{2020\ Emissions}$)

**Option 12 – Hybrid Yard Hostlers**

No calculations.

Staff assumes that railyard non-locomotive electrification and replacement with Wide Span Gantry (WSG) Cranes would nearly eliminate all CHE (i.e., Cranes, Yard Hostlers, and related CHE equipment) emissions.

## Option 13 - Energy Storage Systems

### Annual Baseline Emissions:

RTG Crane w/ Tier 4 Off-road Diesel Engine:
*PM Emissions$_{Baseline}$*:
[(0.01 g/bhp-hr x 300hp x 0.43 x 4,380 hr/yr) x (1 ton/907,200g)] = 0.006 ton/yr

*NOx Emissions$_{Baseline}$*:
[(0.27 g/bhp-hr x 300hp x 0.43 x 4,380 hr/yr) x (1 ton/907,200g)] = 0.168 ton/yr

*Total Annual Baseline Emissions$_{PM + NOx}$* = **0.174 ton/yr**

8 Intermodal Railyards

*PM Emissions$_{2005}$*: 4.95 ton/yr
*NOx Emissions$_{2005}$*: 147.3 ton/yr
**152.5 ton/yr**

*PM Emissions$_{2010}$*: 4.95 ton/yr x 0.58 = 2.9 ton/yr
*NOx Emissions$_{2010}$*: 147.3 ton/yr x 0.91 = 134 ton/yr
**136.9 ton/yr**

*PM Emissions$_{2015}$*: 4.95 ton/yr x 0.43 = 2.1 ton/yr
*NOx Emissions$_{2015}$*: 147.3 ton/yr x 0.79 = 116.4 ton/yr
**118.5 ton/yr**

*PM Emissions$_{2020}$*: 4.95 ton/yr x 0.43 = 1.45 ton/yr
*NOx Emissions$_{2020}$*: 147.3 ton/yr x 0.79 = 100.16 ton/yr
**101.6 ton/yr**

*Based on emission inventories for 18 railyard health risk assessments finalized in 2007 and 2008. Estimated emission reductions are surplus to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Railyards.*

### Annual Reduced Technology Emissions:

Energy Storage System:
*PM Emissions$_{reduced}$*:
0.006 ton/yr x 0.25 = 0.0045 ton/yr

*NOx Emissions$_{reduced}$*:
0.168 ton/yr x 0.25 = 0.126 ton/yr

*Total Annual Reduced Technology Emissions$_{PM + NOx}$* = **0.131 ton/yr**

8 Intermodal Railyards

*PM Emissions$_{2010}$*: 2.9 ton/yr x 0.75 = 2.2 ton/yr
*NOx Emissions$_{2010}$*: 134 ton/yr x 0.75 = 100.5 ton/yr
**102.7 ton/yr**

*PM Emissions$_{2015}$*: 2.1 ton/yr x 0.75 = 1.6 ton/yr
*NOx Emissions$_{2015}$*: 116.4 ton/yr x 0.75 = 87.3 ton/yr
**88.9 ton/yr**

*PM Emissions$_{2020}$*: 1.45 ton/yr x 0.75 = 1.08 ton/yr

*NOx Emissions$_{2020}$*: 100.16 ton/yr x 0.75 = 76.2 ton/yr

**77.3 ton/yr**

**Annual Surplus Emission:**

*Total Annual Baseline Emissions$_{PM + NOx}$* - *Total Annual Reduced Technology Emissions$_{PM + NOx}$* =

$(0.168$ ton/yr – $0.126)_{NOx}$ + $(0.006$ ton/yr – $0.0045)_{PM}$ = **0.043 ton/yr** (Tier 4 Off-road Diesel Engine)
$(134$ ton/yr – $100.5)_{NOx}$ + $(2.9$ ton/yr – $2.2)_{PM}$ = **34.2 ton/ yr** (8 Intermodal Railyards$_{2010\ Emissions}$)
$(116.4$ ton/yr – $87.3)_{NOx}$ + $(2.1$ ton/yr – $1.6)_{PM}$ = **29.6 ton/yr** (8 Intermodal Railyards$_{2015\ Emissions}$)
$(100.16$ ton/yr – $76.2)_{NOx}$ + $(1.45$ ton/yr – $1.08)_{PM}$ = **24.3 ton/yr** (8 Intermodal Railyards$_{2020\ Emissions}$)

**Annual Weighted Surplus Emission:**

$(0.168$ ton/yr – $0.126)_{NOx}$ + $20(0.006$ ton/yr – $0.0045)_{PM}$ = **0.072 ton/yr** (Tier 4 Off-road Diesel Engine)
$(134$ ton/yr – $100.5)_{NOx}$ + $20(2.9$ ton/yr – $2.2)_{PM}$ = **47.5 ton/ yr** (8 Intermodal Railyards$_{2010\ Emissions}$)
$(116.4$ ton/yr – $87.3)_{NOx}$ + $20(2.1$ ton/yr – $1.6)_{PM}$ = **39.1 ton/yr** (8 Intermodal Railyards$_{2015\ Emissions}$)
$(100.16$ ton/yr – $76.2)_{NOx}$ + $20(1.45$ ton/yr – $1.08)_{PM}$ = **31.36 ton/yr** (8 Intermodal Railyards$_{2020\ Emissions}$)

**Cost Estimates:**

Energy Storage System: $160,000 - $320,000
Eight Intermodal Railyards: $10,720,000 - $21,440,000

**Annualized Cost:**

Energy Storage System: $160,000 x 0.074 = **$11,840**
$320,000 x 0.074 = **$23,680**
Eight Intermodal Railyards: $10,720,000 x 0.074 = **$793,280**
$21,440,000 x 0.074 = **$1,586,560**

**Cost Effectiveness:**

($11,840 ÷ 144 lbs) = **$82.22/lb** (Tier 4 Off-road engine)
($23,680 ÷ 144 lbs) = **$164.44/lb** (Tier 4 Off-road engine)

($793,280 ÷ 95,000 lbs) = **$8.35/lb** (8 Intermodal Railyards$_{2010\ Emissions}$)
($1,586,560 ÷ 95,000 lbs) = **$16.70/lb** (8 Intermodal Railyards$_{2010\ Emissions}$)

($793,280 ÷ 78,200 lbs) = **$10.14/lb** (8 Intermodal Railyards$_{2015\ Emissions}$)
($1,586,560 ÷ 78,200 lbs) = **$20.29/lb** (8 Intermodal Railyards$_{2015\ Emissions}$)

($793,280 ÷ 62,720 lbs) = **$12.65/lb** (8 Intermodal Railyards$_{2020\ Emissions}$)
($1,586,560 ÷ 62,720 lbs) = **$25.29/lb** (8 Intermodal Railyards$_{2020\ Emissions}$)

## Option 14 - Railyard Wide Span Gantry Cranes and Railyard Electrification

### Annual Baseline Emissions:

CHE Equipment at 8 intermodal Railyards:
*PM Emissions*$_{2005}$: 25 tons/yr
*NOx Emissions*$_{2005}$: 543 tons/yr
**568 tons/yr**

*PM Emissions*$_{2010}$: 25 tons/yr x 0.48 = 12 tons/yr
*NOx Emissions*$_{2010}$: 543 tons/yr x 0.65 = 353 tons/yr
**365 tons/yr**

*PM Emissions*$_{2015}$: 25 tons/yr x 0.34 = 8.5 tons/yr
*NOx Emissions*$_{2015}$: 543 tons/yr x 0.53 = 287.8 tons/yr
**296.3 tons/yr**

*PM Emissions*$_{2020}$: 25 tons/yr x 0.2 = 5 tons/yr
*NOx Emissions*$_{2020}$: 543 tons/yr x 0.2 = 108.6 tons/yr
**113.6 ton/yr**

*Based on emission inventories for 18 railyard health risk assessments finalized in 2007 and 2008. Estimated emission reductions are surplus to the ARB Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Railyards.*

### Annual Reduced Technology Emissions:

WSG Crane at 8 intermodal Railyards:
*PM Emissions*$_{reduced}$:
N/A

*NOx Emissions*$_{reduced}$:
N/A

*Total Annual Reduced Technology Emissions*$_{PM + NOx}$ = **0 ton/yr**

### Annual Surplus Emission Reduction:

Total Annual Baseline Emissions$_{PM + NOx}$ - Total Annual Reduced Technology Emissions$_{PM + NOx}$

[(353 ton/yr)$_{NOx}$ + (12 ton/yr)$_{PM}$] – 0 ton/yr = **365 ton/yr** (2010 Emissions)
[(287.8 ton/yr)$_{NOx}$ + (8.5 ton/yr)$_{PM}$] – 0 ton/yr = **296.3 ton/yr** (2015 Emissions)
[(108.6 ton/yr)$_{NOx}$ + (5 ton/yr)$_{PM}$] – 0 ton/yr = **113.6 ton/yr** (2020 Emissions)

### Annual Weighted Surplus Emission Reduction:

[(353 ton/yr)$_{NOx}$ + 20(12 ton/yr)$_{PM}$] – 0 ton/yr = **593 ton/yr** (2010 Emissions)
[(287.8 ton/yr)$_{NOx}$ + 20(8.5 ton/yr)$_{PM}$] – 0 ton/yr = **457.8 ton/yr** (2015 Emissions)
[(108.6 ton/yr)$_{NOx}$ + 20(5 ton/yr)$_{PM}$] – 0 ton/yr = **208.6 ton/yr** (2020 Emissions)

### Cost Estimates:

WSG Crane Installations at 8 intermodal Railyards: $1,200,000,000

### Annualized Cost:

WSG Crane Installations at 8 intermodal Railyards: $1,200,000,000 x 0.074 = **$88,800,000**

**Cost Effectiveness:**

(\$88,800,000 ÷ 1,186,000 lbs) = **<u>\$74.87/lb</u>** (8 Intermodal Railyards$_{2010\ Emissions}$)
(\$88,800,000 ÷ 915,600 lbs) = **<u>\$96.98/lb</u>** (8 Intermodal Railyards$_{2015\ Emissions}$)
(\$88,800,000 ÷ 417,200 lbs) = **<u>\$212.84/lb</u>** (8 Intermodal Railyards$_{2020\ Emissions}$)

**Option 15 – Idle Reduction Devices For Cargo Handling Equipment (CHE)**

ARB staff does not currently have actual emission reductions and costs data for idle reduction devices on CHE. As a result, staff has not calculated emissions or cost-effectiveness.

## APPENDIX I:

## Option 16 -
## Calculations for Transport Refrigeration Unit (TRU) Plug In Electrification

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**Option 16 - TRU PLUG-IN ELECTRIFICATION EMISSION CALCULATIONS**

*PM Emission Reductions if installed at BNSF BNSF Hobart, BNSF San Bernardino, UP ICTF, UP Oakland, UP Commerce, UP City of Industry, UP LATC and BNSF Commerce Eastern assuming 100% mitigation:*
PM Emission Reductions = Emissions x Emission Reduction Factor
PM Emission Reductions = 13.5 TPY x 0.08 = **1.08 TPY or 0.003 TPD**

*NOx Emission Reductions if installed at BNSF BNSF Hobart, BNSF San Bernardino, UP ICTF, UP Oakland, UP Commerce, UP City of Industry, UP LATC and BNSF Commerce Eastern assuming 100% mitigation:*
NOx Emission Reduction = PM Emission Reductions * 10
NOx Emission Reduction = 1.08 TPY x 10 = **10.8 TPY or 0.03 TPD**

## COST-EFFECTIVENESS CALCULATIONS

TRU plug-in electrification Cost-Effectiveness Estimates
New reefer racks and associated electric infrastructure
Cost for reefer racks for 8 railyards= $1,000,000 ($1 million)
Cost for electric infrastructure for 8 railyards = $500,000,000 ($500 million)
Total Costs = $501,000,000 ($501 million)

(1) Cost-Effectiveness Calculation for New TRU plug-in electrification of 8 intermodal railyards
Cost for 8 New Reefer Racks and associated electric infrastructure $ 1,000,000

$$\text{Carl Moyer Cost-Effectiveness} = \frac{\text{(Project Cost x CRF)}}{\text{(ROG + NOx + PMx20) x 365 days/yr x 2000 lbs/ton}}$$

Cost Effectiveness (10 years) = ($501,000,000 x 0.1233) / (0.03 + 0.003x20)x365x2000
= $940.23 / lb

Cost Effectiveness (20 years) = ($501,000,000 x 0.1233) / (0.03 + 0.003x20)x365x2000
= $561.24 / lb

Electric infrastructure costs:
The $500 million dollar value for infrastructure was determined by taking the electrification cost of 1.2 billion for eight intermodal railyards (see Table III-5), and subtracting an estimated WSG equipment cost of 700 million (close to the $804 million figure determined using an average cost of $6 million per crane).

**References:**


(1) Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate (2004 ARB)

(2) Email Communication with Tim Leong at the Port of Oakland (2008)

(3) Railyard HRAs (2008 ARB)

(4) Intermodal Container Transfer Facility (ICTF) Modernization Project (2007 UP)

(5) Staff Report: Initial Statement of Reasons for Proposed Rulemaking: Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities Where TRUs Operate (2003 ARB)

# APPENDIX J:

## Options 17 thru 20 -
## Calculations for Port and Intermodal Railyard Drayage Trucks

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**Option 17 – New 2007 HD Diesel Trucks**

The new 2007 diesel truck PM and NOx emission standards are required in intermodal railyards by 2014 per the CARB Drayage Truck Regulation.

Assuming there are no emissions reductions when comparing 2007 HD diesel trucks with new 2007 HD diesel trucks, as required by the ARB drayage truck regulation by 2014. Therefore, there is no cost-effectiveness calculation for new 2007 HD diesel trucks.

**Option 18 - LNG HD trucks**

2007 HD truck NOx emission level = 5 g/mile
Average VMT = 40,000 miles/year (fleet average VMT by ARB Goods Movement Plan)
LNG HD truck NOx emissions compared to 2007 models = approximately 67%
NOx emission reduction from LNG HD trucks = (5 g/mile) x (40,000 miles/yr) X (1-67%)
= 146lb/yr

Carl Moyer Cost-Effectiveness = $\frac{\text{Capital Cost x Capital recovery factor}}{\text{(NOx+20PM+ROG)}}$

Capital cost = $210,000/unit
Cost-effectiveness (15 years) = ($210,000 x 0.08994)/[(146lb/yr) = $129 / lb

Capital cost = $100,000/unit
Cost-effectiveness (15 years) = ($100,000 x 0.08994)/[(146lb/yr) = $61.6 / lb

**Option 19 - CNG HD trucks**

2007 HD truck NOx emission level = 5 g/mile
Average VMT = 40,000 miles/year (fleet average VMT by ARB Goods Movement Plan)
CNG HD trucks NOx emissions compared to 2007 models = approximately 10%
NOx emission reduction from CNG HD trucks = (5 g/mile) x (40,000 miles/yr) X (1- 10%)
= 397 lb/yr

Carl Moyer Cost-Effectiveness = $\frac{\text{Capital Cost x Capital recovery factor}}{\text{(NOx+20PM+ROG)}}$

Capital cost = $120,000/unit
Cost-effectiveness (15 years) = ($120,000 x 0.08994)/[(397 lb/yr) = $27.19 / lb

Capital cost = $10,000/unit
Cost-effectiveness (15 years) = ($10,000 x 0.08994)/[(397 lb/yr) = $2.27 / lb

**Option 20 - Electric HD trucks**

2007 HD truck NOx emission level = 5 g/mile
Average VMT = 40,000 miles/year (fleet average VMT by ARB Goods Movement Plan)
NOx reduction from electric HD trucks = (5 g/mile) x (40,000 miles/yr) X (100%)
= 441 lb/yr

Carl Moyer Cost-Effectiveness = $\frac{\text{Capital Cost x Capital recovery factor}}{\text{(NOx+20PM+ROG)}}$

Capital cost = $210,000/unit
Cost-effectiveness (15 years) = ($210,000 x 0.08994) / (441 lb/yr) = $42.83 / lb

Capital cost = $100,000/unit
Cost-effectiveness (15 years) = ($100,000 x 0.08994) / (441 lb/yr) = $20.39/lb

## APPENDIX K:

## Option 21 -
## Calculations for Advanced Locomotive Emission Control System (ALECS)

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**Cost-Effectiveness**

DPM reduction from the UP Roseville maintenance facility = ~1 ton/year (about 0.8 tpy)
NOx reduction (a factor of 20 from DPM reduction) = 20 tons/year
Capital cost = $25,000,000
Cost-effectiveness (20 years) =

= (Funded Amount x Capital recovery factor) / (Nox+20PM+ROG)

= ($25,000,000 x 0.07358) / (20*1+20 ton/yr x 2000lb/ton)

= $23/lb

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## Calculations for Total Diesel PM Emissions for Service and Maintenance Area for UP Roseville Railyard

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| TOTAL TPY FOR SERVICE AND MAINTENANCE FOR UP ROSEVILLE RAILYARD | | | | |
|---|---|---|---|---|
| IDLING LOCOMOTIVES AT SERVICE TRACKS, MODSEARCH BUILDING, MAINTENANCE SHOP, AND READY TRACKS | | | | |
| **YARD LOCATION** | **ANNUAL NUMBER OF LOCOMOTIVES** | **DURATION OF EACH EVENT (mins)** | **ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)** | **ANNUAL DIESEL PM EMISSIONS (tpy)** |
| **Service Tracks** | | | | |
| Inspection pits | 19,380.00 | 120.00 | 168.42 | 1.62 |
| SUB-TOTAL | 19,380.00 | 120.00 | 168.42 | 1.62 |
| **Modsearch Building** | | | | |
| Idling | 7,200.00 | 120.00 | 15.67 | 0.15 |
| SUB-TOTAL | 7,200.00 | | 15.67 | 0.15 |
| | | | | |
| **Maintenance Shop** | | | | |
| East side Idling | 5,400.00 | 120.00 | 47.02 | 0.454 |
| West-side Idling | same as above | 60.00 | 23.51 | 0.227 |
| SUB-TOTAL | 5,400.00 | | 70.53 | 0.68 |
| | | | | |
| **Ready Tracks** | | | | |
| Idling | 21,547.49 | 120.00 | 148.15 | 1.43 |
| SUB-TOTAL | 21,547.49 | | 148.15 | 1.43 |
| **GRAND-TOTAL** | | | | **3.88** |
| **Source: UP Roseville Railyard Study (emission estimation baseline year 2000)** | | | | |

| MOVEMENT OF LOCOMOTIVES AT SERVICE TRACKS AND MAINTENANCE SHOP | | | | |
|---|---|---|---|---|
| **YARD LOCATION TO YARD LOCATION** | **ANNUAL NUMBER OF LOCOMOTIVES** | **DURATION OF EACH EVENT (mins)** | **ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)** | **ANNUAL DIESEL PM EMISSIONS (tpy)** |
| **SERVICE TRACKS Area** | | | | |
| In-bound to Wash Racks | 19,380.49 | 5.00 | 10.3 - 14.4 | 0.10 - 0.14 |
| Wash Racks to Service Trks | 19,380.49 | 5.00 | 10.3 - 14.4 | 0.10 - 0.14 |
| Service Trks to Ready Trks | 14,251.47 | 5.00 | 7.54 - 10.60 | 0.073 - 0.102 |
| Service Trks to Modsearch | 7,200.00 | 15.00 | 8.13 - 12.80 | 0.08 - 0.12 |
| SUB-TOTAL | 19,380.49 | | 36.27 - 52.2 | 0.35 - 0.50 |
| **AVERAGE TOTAL** | | | **44.24** | **0.43** |
| **Maintenance Shop Area** | | | | |
| **Modsearch Buildings** | | | | |
| To East-side Maint. Shop | 5,400.00 | 30.00 | 12.20 - 19.20 | 0.12 - 0.19 |
| To Ready Tracks | 1,800.00 | 10.00 | 1.35 - 2.13 | 0.013 - 0.021 |
| **Maintenance Shop** | | | | |
| West-side to Ready Tracks | 5,400.00 | 10.00 | 4.06 - 6.40 | 0.039 - 0.062 |
| SUB-TOTAL | 5,400.00 | | 17.61 - 27.73 | 0.039 - 0.062 |
| **GRAND-TOTAL** | **21,451.47** | | **53.81 - 80.02** | **0.52 - 0.77** |
| **AVERAGE GRAND TOTAL** | | | **66.92** | **0.645** |

**Source: UP Roseville Railyard Study (emission estimation baseline year 2000)**

| LOCOMOTIVE TESTING AT SERVICE TRACKS, MODSEARCH BUILDING,AND MAINTENANCE SHOP | | | | |
|---|---|---|---|---|
| **YARD LOCATION** | **ANNUAL NUMBER OF TESTS** | **DURATION OF EACH EVENT (mins)** | **ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)** | **ANNUAL DIESEL PM EMISSIONS (tpy)** |
| **Service Tracks** | | | | |
| Pre-test emissions | 1,354.00 | * | 19.47 | 0.19 |
| Post test emissions | 1,525.00 | ** | 21.13 | 0.20 |
| SUB-TOTAL | 2,879.00 | | 40.6 | 0.39 |
| | | | | |
| **Modsearch Building** | | | | |
| Pre-test emissions | 4,508.00 | * | 62.95 | 0.61 |
| Post test emissions | none | ** | none | none |
| SUB-TOTAL | 4,508.00 | | 62.95 | 0.61 |
| | | | | |
| **Maintenance Shop** | | | | |
| **East-side** | | | | |
| Pre-test emissions | 799.00 | * | 9.25 | 0.089 |
| Post test emissions | none | ** | none | none |
| SUB-TOTAL | 799.00 | | 9.25 | 0.09 |
| **West-side** | | | | |
| Pre-test emissions | none | * | none | |
| Post test emissions | 3,581.00 | ** | 55.39 | 0.534 |
| SUB-TOTAL | 3,581.00 | | 55.39 | 0.53 |
| **GRAND-TOTAL FOR TABLE 2.3** | **11,767.00** | | | **1.62** |
| **GRAND TOTAL FOR ALL TABLES** | | | 682.12 | **6.15 TPY** |
| **Grand total for Service and Testing is 6.15 tons per year according to Roseville Railyard study emissions estimation baseline year 2000.** | | | | |

Note1- The length of the ready tracks is approximately 600 yards or 1800 feet.
The length of the of the inspection pit Area (part of the service track is) approximately 250 yards or about 750 feet.
The length of the Area on the east and west side of the maintenance shop is approximately 200 yards each side or about 600 feet.
Note 2-The emission estimation source is UP Roseville railyard Report.

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**Figures of UP Roseville Service and Maintenance Area**

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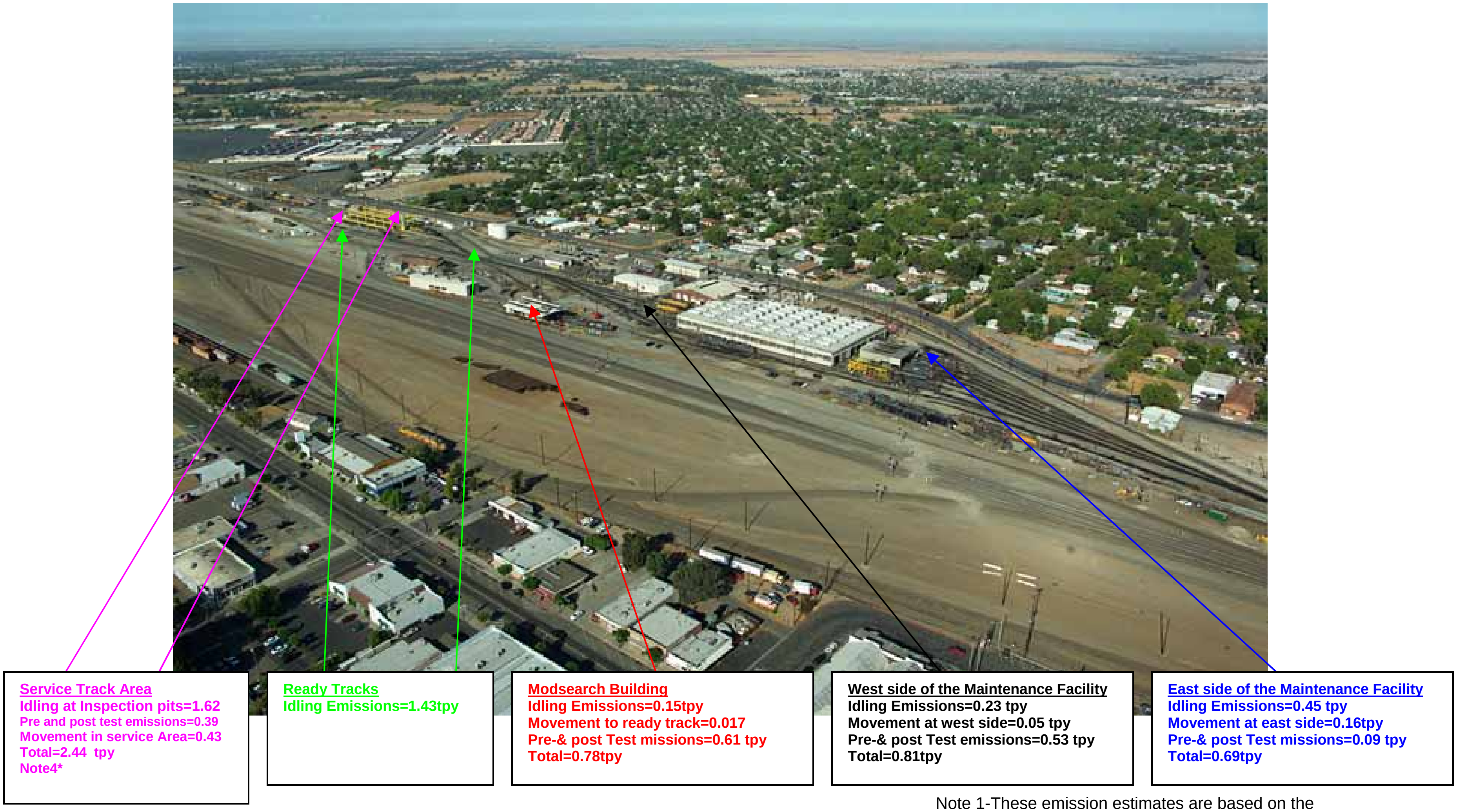
**Figure K-1: Aerial Picture of Roseville Railyard with Description of different Areas**

## Figure K-2: Descriptions of the Different Areas of the UP Roseville Railyard



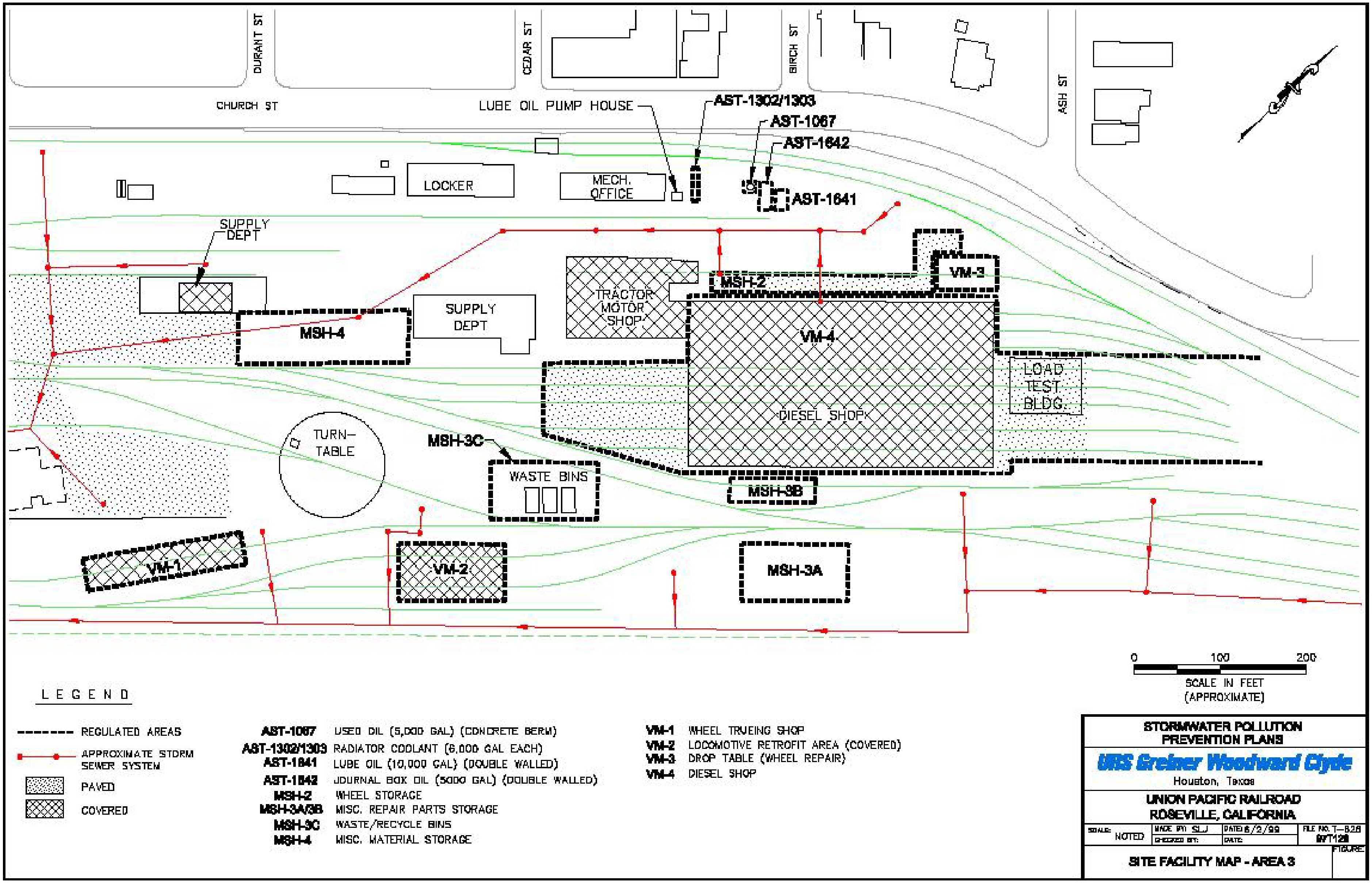

Note 1-These emission estimates are based on the emissions for baseline year 2000

Note 2- Service Track Emissions Occur over the whole length of the service tracks.

Note 3-Idling Emissions may have been significantly reduced since 2000 due to installation of Idle reduction Devices and Idling reduction requirements under the 2005ARB/Railroad MOU.

*Note 4=Movement in service Area emissions are further divided into 4 different areas as follows In-bound to Wash Racks=0.12tpy, Wash Racks to Service Trks=0.12tpy, Service Tracks to Ready Tracks=0.09tpy, Service Tracks to Modsearch=0.1tpy.

**Figure K-3 Schematic Diagram of the Service and Maintenance Area of the UP Roseville Railyard.**



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**Photos of Service and Maintenance Area at UP Roseville Railyard**

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**Figure K-4: Near-Source Picture of the Service Track Area as Shown in Figure 2**

**Figure K-5: Picture of the East Side of the Maintenance Shop as Mentioned in Figure K-2.**

**Figure K-6: Picture of the Service and maintenance area as shown in Figure K-1.**

**Figure K-7: Near- Source Picture of maintenance Area as Shown in Figure K-1 and K-2.**

**Figure K-8: Near-Source Picture of East side of the Maintenance Area**

## Cost Elements for Cost Effectiveness of ALECS

Cost elements are broken down into Initial Capital Costs, Operating and Maintenance Costs including Utility/Energy Costs, Repair and Replacement Costs, Downtime Costs, Environmental Costs, and Salvage Value.

**A) Initial Capital Costs** include engineering and design (drawings and regulatory issues), bidding process, purchase order administration, hardware capital costs, testing and inspection, inventory of spare parts, foundations (design, preparation, concrete and reinforcing), installation of equipment, connection of process piping, connection of electrical wiring and instrumentation, one-time licensing/permitting fees, and the start up (check out) costs.
**B) Operating and Maintenance Costs** include items such as labor costs of operators, inspections, insurance, warranties, recurring licensing/permitting fees, and all maintenance (corrective and preventive maintenance). Also included are yearly costs of consumables such as the utility/energy costs (electricity, natural gas, and water) and chemical costs (such as sodium hydroxide and urea).

**C) Repair and Replacement Costs** are the costs of repairing and replacing equipment over the life of the ALECS. This would also include catalyst material replacement.

**D) Environmental Costs** are associated with the disposal of wastewater, solid waste, used chemicals, and used parts.

**E) The Salvage Value** of the system would be the net worth of the ALECS in its final year of the life cycle period. If the system can be moved and salvaged for useful parts/purposes, there would be a reduction in life cycle costs.

**F) Rail yard impact costs include** estimates of costs incurred by the Union Pacific Railroad. An example would be if the ALECS was shut down for repairs and locomotives that normally would be serviced or stored in a specific area needed to be relocated and serviced/stored elsewhere. Rail yard impact costs would also include the costs to change rail yard operations that are different from what is practiced today (including structural changes, if needed, to accommodate ALECS). For example, the additional time and costs (including labor) of rerouting locomotives to the ALECS area if the locomotives may not have been normally required to be moved. Locomotive downtimes can be very expensive to the rail yard and may result in loss of revenue. Costs may also be negative (a benefit to the rail yard) if the implementation of ALECS produced increased efficiencies such as decreased dwell time (time a locomotive is in the rail yard). At the current time, Union Pacific Railroad does not have an estimate (positive or negative) as to the effect ALECS would have on rail yard operations. This cost is not included in the Analysis.

## APPENDIX L:

## Option 23
## Calculations for Interstate Line Haul Locomotives Operating with Idle Reduction Devices

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Assuming on a conservative basis for a switch (yard) locomotive (assumed 10% idle reduction device benefits - some studies suggest up to 50% idle reduction benefits):

## CONSERVATIVE CALCULATION OF IDLING REDUCTION EMISSION REDUCTION BENEFITS

**<u>KEY ASSUMPTIONS</u>**

| | |
|---|---|
| • Total Hours in a Calendar Year (365 x 24): | 8,760 hours per year. |
| • Industry Standard for Locomotive Availability: | 90 percent (10% maintenance/shutdown) |
| • Net Potential Hours Locomotive Available Per Year: | up to 7,884 hours |

**<u>SWITCH LOCOMOTIVES</u>**

| | |
|---|---|
| Average Hours Work Per Day: | 15 hours/day |
| Number of Days Available Per Year (90%) | 329 day/year |
| Annual Hours Worked Per Year | 4,935 hours/year work |
| U.S. EPA Duty Cycle – Idle Time (60%) | 2,961 hours per year idle (~9 hours/day). |

| | |
|---|---|
| Hours per year idle mode | 2,961 hours/year |
| Gallons per hour in idle mode | x 5 gallons/hour |
| Gallons/Year Burned in Idle Mode | 14,805 gallons/year |
| Idle Reduction Device | <u>10% idle reduction</u> |
| Gallons Diesel Fuel Unburned Due Idle Device | ~1,500 gallons/year |

**<u>NOx Emissions Calculations</u>**: 17.4 g/bhp-hr NOx (switch pre-Tier 0) x U.S. EPA bhp-hr conversion 20.8=362 grams/gallon.

~1,500 gallons/year x 362 grams/gallon = 543,000 grams/year/454 g/lb=**1,196.0 lbs/year**/2,000 lbs/ton=0.6 tons/year/365 days/year=0.0016 tons/day NOx reduced.

**<u>PM Emissions Calculations</u>**: 0.72 g/bhp-hr PM (switch pre-Tier 0) x U.S. EPA bhp-hr conversion 20.8=15 grams/gallon.

~1,500 gallons/year x 15 grams/gallon = 22,500 grams/year/454 g/lb=**49.6 lbs/year**/2,000 lbs/ton=0.025 tons/year/365 days/year=0.00007 tons/year PM reduced.

NOx (1,200 lbs/year) + PM (50 lbs/year) = 1,250 lbs/year of NOx and PM reduced.

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## APPENDIX M:

## Option 29 -
## Calculations to Electrify Major Freight Lines in the SCAB to Barstow and Niland

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**FREIGHT ELECTRIFICATION EMISSION CALCULATIONS:**

ARB Emission Inventory Forcast for NOx [1]:

| Source Category | Pollutant – Oxides of Nitrogen "NOx" (Tons per Day) Year | | | |
|---|---|---|---|---|
| | 2008 | 2010 | 2020 | % of 2020 |
| Line Haul | 21.264 | 14.241 | 18.389 | 71 |
| Switch | 4.314 | 2.597 | 2.588 | 10 |
| Passenger | 3.371 | 2.847 | 4.839 | 19 |
| Total | 28.949 | 19.686 | 25.816 | 100 |

ARB Emission Inventory Forcast for PM [1]:

| Source Category | Pollutant – Particulate Matter "PM" (Tons per Day) Year | | | |
|---|---|---|---|---|
| | 2008 | 2010 | 2020 | % of 2020 |
| Line Haul | 0.688 | 0.685 | 0.733 | 83.4 |
| Switch | 0.090 | 0.082 | 0.076 | 8.7 |
| Passenger | 0.079 | 0.079 | 0.070 | 7.9 |
| Total | 0.857 | 0.846 | 0.878 | 100 |

1. Source: ARB Emission Inventory, Other Mobile Sources – Trains, 2009 Almanac Data, Base Year 2008, South Coast Air Basin, Grown & Controlled, Annual Average. Note: This ARB inventory does not include emissions benefits from 2008 U.S. EPA Locomotive Rulemaking.

*NOx Emissions in the SCAB:*
Emissions = Total Emissions – Emissions from line haul Locomotives
Emissions = 25.82 TPD – 18.39 TPD = 7.43 TPD

*Diesel PM Emissions in the SCAB:*
Emissions = Total Emissions – Emissions from line line Locos
Emissions = 0.86 TPD – 0.73 TPD = 0.13 TPD

**COST EFFECTIVENESS CALCULATIONS:**

Freight Electrification Cost Estimates:
*ARB Analysis:*
New Electric Freight Locomotive
Cost = approx $8,000,000 (8 million)
Number of Locomotives = 775

Electric Retrofit of Existing Track
Cost = approx $15,000,000/mile (15 million per mile)
Miles of Track = 460

| | |
|---|---|
| Cost of Locomotives | $8,000,000/loco x 775 locos = $6,200,000,000 |
| Cost of Track | $15,000,000/mile x 460 miles = $6,900,000,000 |
| Total Project Cost | $6,200,000,000 + 6,900,000,000 = $13,100,000,000 |
| Carl Moyer Cost-Effectiveness | = (Project Cost x CRF) / (ROG + NOx + PM10x20) |
| | = ($13,100,000,000 x 0.0578) / (18.39 + 0.73x20) |
| | = $31.54 / lb |

Note:
Cost Effectiveness assumes a project life of 30 years.

*SCAG Analysis:*
Renovation and purchase of electric locomotives:
Cost = approx $6,400,000,000 (6.4 billion)

| | |
|---|---|
| Carl Moyer Cost-Effectiveness | = (Project Cost x CRF) / (ROG + NOx + PM10x20) |
| | = ($6,400,000,000 x 0.0578) / (18.39 + 0.73x20) |
| | = $15.36 / lb |

Note:
Cost Effectiveness assumes a project life of 30 years.

**References:**


(1) ARB Emission Inventory (2007 ARB)

(2) Caltrain Electrification Program Environmental Assessment/ Draft Environmental Impact Report (Peninsula Corridor Joint Powers Board, 2004)

(3) Final Program EIR/EIS for the Proposed California High-Speed Train System (California High Speed Rail Authority, 2005)

(4) Freight Rail Emission Reduction Strategy to Help Meet 2014 Air Quality Standards for PM 2.5. (SCAG, 2007)

(5) Letter to SCAG from Kirk Markwald of The California Railroad Industry (CRI, 2008)

(6) Analysis of Good Movement Emission Reduction Strategies (SCAG, 2007)

(7) Comments on LA Times Article re Railway Electrification (M. Iden - Union Pacific, 2008)

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## APPENDIX N:

## Option 30 -

## Calculations for Maglev Electrification From the Port of LA/LB to ICTF/SCIG

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## MAGLEV ELECTRIFICATION EMISSION CALCULATIONS:

Off Facility PM Emissions = (Trips/day) x (Trip Length) x (# Facilities) x (grams DPM/mile) x (tons/g) x (365 days/year)
Off Facility PM Emissions = (6300 trips/day) x (4.7 miles) x 2 x (0.3 g/mile) x ($1.1x10^{-6}$ tons/g) x (365 days/year) = 7.1 TPY

On Facility PM Emissions = (Emissions from ICTF) x 2 Facilities
On Facility PM Emissions = 2.5 TPY x 2 = 5.0 TPY

Total PM Emissions = Off Facility Emissions + On Facility Emissions
Total PM Emissions = **12.1 TPY**

## COST EFFECTIVENESS CALCULATIONS:

1. Cost Effectiveness of Maglev Electrification (Low)

Installation of Maglev from Ports to ICTF/SCIG
Cost = approx $65,000,000/mile (65 million)
Miles of Track = 4.7 miles

| | |
|---|---|
| Cost | $65,000,000/mile x 4.7 miles = $305,500,000 |
| Carl Moyer Cost-Effectiveness | = (Project Cost x CRF) / (ROG + NOx + PM10x20) |
| | = ($305,500,000 x 0.0899) / (484,000 lbs) |
| | = $56.74 / lb |

Note:
Cost Effectiveness assumes a project life of 15 years.

2. Cost Effectiveness of Maglev Electrification (High)

Installation of Maglev from Ports to ICTF/SCIG
Cost = approx $170,000,000/mile (170 million)
Miles of Track = 4.7 miles

| | |
|---|---|
| Cost | $170,000,000/mile x 4.7 miles = $799,000,000 |
| Carl Moyer Cost-Effectiveness | = (Project Cost x CRF) / (ROG + NOx + PM10x20) |
| | = ($799,000,000 x 0.0899) / (484,000 lbs) |
| | = $148.41 / lb |

Note:
Cost Effectiveness assumes a project life of 15 years.

**References:**

(1) Press Release of Shanghai Maglev Gets Official Approval (China Daily, 2006)

(2) Nagoya builds Maglev Metro (International Railway Journal, 2004)

(3) Intermodal Container Transfer Facility (ICTF) Modernization Project (UPRR, 2007)

(4) The Evaluation and Implementation Plan for Southern California Maglev Freight System (CCDTT, 2007)

(5) Proceedings of the Federal Transit Administrations Urban Maglev Workshop (DOT, 2005)

# Shanghai maglev gets official approval

By Miao Qing (China Daily)
Updated: 2006-04-27 06:11

After two years of operation, China's first magnetic levitation line has formally passed State examination and appraisal.

Yesterday's announcement augurs well for the proposed construction of a line connecting Shanghai and Hangzhou.

The existing line was started in March 2001 and completed 22 months later. The 30-kilometre track connects Shanghai's Pudong Airport with the city, and is largely based on German magnetic levitation (maglev) technology.

Maglev trains can travel at a speed of up to 430 kilometres per hour, whizzing passengers to their planes in less than eight minutes.

According to the National Development and Reform Commission (NDRC), which carried out the examination, the maglev trains had carried 6.23 million passengers by the end of March this year, both for transportation and sightseeing.

The cost of line was revealed to be 9.93 billion yuan (US$1.2 billion), slightly below budget.

The successful construction and operation of the Shanghai maglev line is regarded by many as a good prelude to the construction of 175-kilometre line connecting Shanghai with Hangzhou, provincial capital of East China's Zhejiang Province.

Technology will remain a big concern in the construction of the new line, officials said. The Shanghai-Hangzhou maglev line will in part use German technology, but the State Council is encouraging engineers "to learn and absorb foreign advanced technologies while making further innovations."

Since accomplishing the first maglev line, China has mastered the core technology required to build maglev rail tracks, one of four major systems supporting the advanced mode of transportation, and gained 20 patents in the field.

"Lowering the cost of a maglev system is a significant issue in the study and construction of the Shanghai-Hangzhou maglev railway we are now confident we can achieve that," said Zhang Xiaoqiang, vice-minister of the NDRC.

"Our aim is to limit the cost of each kilometre of maglev line to approximately 200 million yuan (US$24.6 million)." This means that the unit cost will be cut by one third.

The government also suggests the Shanghai maglev line operator could improve its operating management and efficiency, extend operation hours and attract more passengers.

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# APPENDIX O:

## Option 31 -
## Calculations to Retrofit Existing Rail Infrastructure with LIMs in the SCAB

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## Option 31 - RETROFIT OF EXISTING RAIL WITH LIMS EMISSION CALCULATIONS

| **PM** | TPY (ton/year) | | TPD (ton/day) | |
|---|---|---|---|---|
| Source | 2010* | Electrification | 2010* | Electrification |
| Main Line | 252 | 0 | 0.69 | 0 |
| Passenger | 29 | 29 | 0.08 | 0.08 |
| Switching | 29 | 29 | 0.08 | 0.08 |
| Total | 310 | 58 | 0.85 | 0.16 |
| | | | | 81% |

| **NOx** | TPY (ton/year) | | TPD (ton/day) | |
|---|---|---|---|---|
| Source | 2010* | Electrification | 2010* | Electrification |
| Main Line | 5198 | 0 | 14.24 | 0 |
| Passenger | 949 | 949 | 2.6 | 2.6 |
| Switching | 1040 | 1040 | 2.85 | 2.85 |
| Total | 7187 | 1989 | 19.69 | 5.45 |
| | | | | 72% |

* ARB Emission Inventory Data 2010 for South Coast Air Basin

*NOx Emissions in the SCAB:*
Emissions = Total Emissions – Emissions from Main line Locos
Emissions = 19.69 TPD – 14.24 TPD = **5.45 TPD**

*Diesel PM Emissions in the SCAB:*
Emissions = Total Emissions – Emissions from Main line Locos
Emissions = 0.85 TPD – 0.69 TPD = **0.16 TPD**

**COST EFFECTIVENESS CALCULATIONS**

Retrofit of existing rail with LIMs
Cost / mile = $16,000,000/mile
Miles of track = 460 miles
Cost to retrofit locomotives: $3,000,000,000 ($3 billion)

| | |
|---|---|
| Track Cost | $16,000,000/mile x 460 miles = $7,360,000,000 |
| Retrofit Cost | $3,000,000,000 |
| Total Cost | $7,360,000,000 + $3,000,000,000 = $10,360,000,000 |
| Carl Moyer Cost-Effectiveness | = (Project Cost x CRF) / (ROG + NOx + PM10x20) |
| | = ($10,360,000,000 x 0.0578) / (20,469,200 lbs) |
| | = $29.25 / lb |

Note:
Cost Effectiveness assumes a project life of 30 years.

**References:**


(1) Alternative Container Transportation Technology Evaluation and Comparison (Ports of Long Beach and Los Angeles, 2008)

(2) ARB Emission Inventory (Air Resources Board, 2008)

(3) Maglev and Linear Motors for Goods Movement (SCAQMD, 2007)

## APPENDIX P:

### Cost-Effectiveness Calculation Methodology

Note: The following was excerpted from the 2008 Carl Moyer Program Guidelines, Appendix C, Cost-Effectiveness Calculation Methodology. For further detail see http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

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## I. Introduction

To receive Carl Moyer Program funding, each project must meet the maximum cost-effectiveness limit of $16,000 per weighted ton of surplus NOx, ROG, and PM10 (PM10 means combustion PM) emissions reduced. Only Carl Moyer Program funding, funding under the district's fiduciary budget authority, or funding provided by a port authority (to meet the match fund requirement) are included in determining the cost-effectiveness of surplus emission reductions. For more details see Part IV, Administration of the Carl Moyer Program.

## II. General Cost-Effectiveness Calculations

The cost-effectiveness of a project is determined by dividing the annual cost of the potential project by the annual weighted surplus emission reductions that will be achieved by the project as shown in formula C-1 below.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton):

$$\frac{\text{Annualized Cost (\$/yr)}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

Descriptions on how to calculate annual emission reductions and annualized cost are provided in the following sections.

### A. Calculating the Annual Weighted Surplus Emission Reductions

Annual weighted emission reductions are estimated by taking the sum of the project's annual surplus pollutant reductions following formula C-2 below. This will allow projects that reduce one, two, or all three of the covered pollutants to be evaluated for eligibility to receive Carl Moyer Program funding. While NOx and ROG emissions are given equal weight; emissions of combustion PM10 (such as diesel exhaust PM10 emissions) have been identified as a toxic air contaminant and thus carry a greater weight in the calculation.

Formula C-2: Annual Weighted Surplus Emission Reductions:

NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM10 reductions (tons/yr)]

The result of formula C-2 is used to complete formula C-1 to determine the cost effectiveness of surplus emission reductions.

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## OPTIONS INDEX Page

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