II. LOCOMOTIVE OPTIONS

This chapter discusses the potential options to accelerate further emission reductions from locomotives. These emissions reductions could also provide reductions in risk from exposure to diesel PM, particularly around railyards. For purposes of this analysis, we have divided locomotives into three groups: switch locomotives, medium horsepower (MHP) locomotives, and interstate line haul locomotives. The groupings represent three generally different uses for locomotives within California. The following sections describe each type of locomotive and the potential options to accelerate further locomotive emissions reductions.

There are three major categories of locomotives UP and BNSF operate in California. The first category is switch (or yard) locomotives with between 1,006 and 2,300 horsepower. The second category is medium horsepower (MHP) locomotives with between 2,301 and 3,800 horsepower. The third category is interstate line haul locomotives with between 3,801 and 6,000 horsepower.

Switch locomotives typically meet ARB's CARB diesel fuel regulation definition of an "intrastate" locomotive by operating 90 percent or more of the time in California. Many of the MHP locomotives meet the "intrastate" definition, especially smaller MHP freight and passenger locomotives. The remaining MHP locomotives typically operate between 50 and 90 percent of the time within California. Finally, interstate line haul locomotives typically operate less than 50 percent of the time within California. An interstate line haul locomotive on a typical run from Chicago to Los Angeles may operate within California only about 15 percent of the trip. There are examples where a few interstate line haul locomotives have been assigned to operate in a particular area within California, but this is the exception rather than the norm.

A. Switch Locomotives

Switch locomotives are primarily used to put rail cars together to form trains within or around a railyard. They are also referred to as "yard" locomotives or "switchers." Switchers primarily have four axles to allow for a tight-turning radius within railyards. However, larger switchers that put larger trains together can employ up to six axles (e.g., hump and trim switchers).

1. Types of Switch Locomotives

U.S. EPA defines a switch locomotive as having between 1,006 and 2,300 horsepower. Larger switch locomotives that typically range between 2,000 and 2,300 horsepower in California may also be used, to a certain extent, for local short haul service. Switch locomotives less than 1,006 horsepower are referred to as "industrial" or "critters" and are expressly exempt from U.S. EPA locomotive emissions standards. Industrial locomotives are not addressed in this document as there only about 100 operating in operation within the state, and consume on average less than 25,000 gallons of diesel fuel annually.

There are generally four distinct types of switch locomotives operating in California. There are the traditional large single engine diesel switch locomotives, multi-engine gen-set locomotives, liquefied natural gas (LNG) locomotives, and battery electric hybrid locomotives. The three latter types of locomotives are referred to as ultra low-emitting switch locomotives (ULESL). [5]

In 2008, staff estimates that there are about 244 intrastate UP and BNSF switch locomotives operating in California, with about 139 operating in the South Coast Air Basin. The switch locomotive estimates are based on documentation provided by both UP and BNSF for the intrastate locomotive inventories, health risk assessment emission inventories, and ARB diesel fuel regulation for intrastate locomotives. Primarily as a result of the 1998 ARB/Railroad Agreement, 76 of the 92 intrastate ULESLs are operating in the South Coast Air Basin.

The four types of switch locomotives are described in the following subsections.

Single Engine Diesel Switch Locomotives

Historically, a switch locomotive has been powered by a large single diesel engine manufactured by either EMD or General Electric. In California, the average age of a UP and BNSF conventional single engine switch diesel-electric locomotive is about 40 years old. In 1998, U.S. EPA established national emission standards for 1973 and later locomotives. Tier 0 standards applied to locomotives originally manufactured between 1973 and 2001. The Tier 0 standards apply upon the remanufacturing of the locomotives built between 1973 and 1999. These locomotives were built prior to the new Tier 0 locomotive emission standards for 2000 and 2001 model years. However, there was no explicit requirement that 1973 to 1999 locomotive engines be remanufactured on any defined schedule. In addition, U.S. EPA emission standards do not apply to locomotives manufactured before 1973.

As shown in Table II-1, UP and BNSF operate about 152 intrastate older switch locomotives in California. Of these 152 older switchers, UP and BNSF have remanufactured 49 to meet U.S. EPA Tier 0 emissions standards and 103 are pre-Tier 0 or unregulated switch locomotives. Of the 103 unregulated switch locomotives, about 40 were built before 1973 (which are exempt from U.S. EPA regulations) and 63 were built between 1973 and 1999, the latter mostly built between 1973 and 1980. Staff believes that due to the cost of remanufacturing, and the low residual value of older switch locomotives, it is unlikely that many of these remaining 103 older UP and BNSF

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[5] ARB staff defines an ultra low emitting switch locomotive (ULESL) as a locomotive that meets or exceeds a NOx emissions limit of 3.0 g/bhp-hr and a PM emissions limit of 0.1 g/bhp-hr. For comparison, older pre-Tier 0 switch locomotives can emit up to or more than 17.4 g/bhp-hr of NOx and 0.7 g/bhp-hr of PM.

switch locomotives will be remanufactured to meet the U.S. EPA Tier 0 emissions standards.

Compared to pre-Tier 0 or unregulated switch locomotives, Tier 0 engines are approximately 20 percent cleaner for NOx emissions, but were allowed under the 1998 U.S. EPA locomotive regulations to have higher PM emissions as a tradeoff for the NOx benefits. While an improvement over pre-Tier 0 switch locomotives, Tier 0 locomotives are still considerably dirtier than currently available options as discussed below.

<u>Gen-Set Switch Locomotives</u>

In recent years, a new switch locomotive technology has been pioneered by the railroads in California and Texas that involves the use of two or three smaller offroad engines mounted on the same chassis to replace a single diesel engine. These new switch locomotives are referred to as gen-set switch locomotives and are much lower emitting than existing older switch locomotives.

UP currently operates 70 intrastate gen-set ULESLs, of which 61 are operating in the South Coast Air Basin, 5 in the San Joaquin Valley, and 4 at UP Roseville. BNSF currently operates 6 intrastate gen-set ULESLs, which are assigned to the Bay Area.

Manufacturers build gen-set switch locomotives with Cummins, Deutz, or Caterpillar Tier 3 nonroad engines. National Railway Equipment Company (NREC) and Railpower (RP) combined have built over 250 new gen-set switch locomotives since 2005. In addition, Motive Power Inc. (MPI), Caterpillar/Progress Rail (PR), and Brookville Corporation have all recently built prototypes of three engine gen-set switch locomotives. The three engine gen-set switch locomotive prototypes are currently being evaluated in field testing.

Gen-set switch locomotives can incur initial additional operational costs. As with the transition to most new technologies, there can be a reduction in operational times versus existing switch locomotives. The operational costs should be reduced as manufacturers and railroad personnel gain more experience with gen-set locomotives.

Gen-set switch locomotives can also provide cost-savings. Gen-set switch locomotives can reduce diesel fuel consumption, as compared to older switch locomotives, by 20 to 40 percent. The fuel savings can potentially offset a portion of the initial capital costs over a 30 year life. The cost-savings would not offset the need for new nonroad engine repowers, estimated to occur about every 15 years.

<u>Liquefied Natural Gas Switch Locomotives</u>

Morrison Knudsen, now Motive Power, built four liquefied natural gas (LNG) switch locomotives in the early 1990s. UP owned two of the LNG switch locomotives, but transferred ownership to BNSF in the mid-1990s. As a result, all four of the LNG switch locomotives are operated by BNSF in the Los Angeles area. BNSF's four LNG switch locomotives are the only active operating LNG switch locomotives in the United States.

Battery Electric Hybrid Switch Locomotives (Green Goats)

Railpower built more than 65 Green Goats, or diesel charged battery-electric hybrids, over the past three years. The Green Goats are being operated in different parts of the country, but primarily in California and Texas. Recently, UP and BNSF shifted predominately to the purchase of gen-set switch locomotives over the battery-electric hybrid switch locomotives, largely due to the greater gen-set operational capabilities and flexibility. The Green Goats are primarily limited to light-duty applications due to the relatively quick draw down of battery stored power under heavier workloads, and the time needed to recharge the Green Goat's 330 lead acid batteries. With a recent set of Green Goat battery fires (five of the 65 units), some railroads chose to convert some of the Green Goats to gen-set switch locomotives. Railpower repaired all of the remaining Green Goats, and have returned all of them to their former service (e.g., UP returned all 11 Green Goats to service in California). There are twelve Green Goats operating in California. UP has ten operating in the South Coast Air Basin and one in the San Joaquin Valley; BNSF has one operating in the South Coast Air Basin. A summary of the types of switch locomotives operating in California and the South Coast Air Basin in 2008 is presented in Table II-1.

Table II-1
Summary of the Types of Switch Locomotives Operating in California and the South Coast Air Basin in 2008

Type of Locomotives	**Number of Locomotives**	
	California	**South Coast Air Basin**
Existing Switch Locomotives		
Pre-Tier 0 Manufactured Before 1973	40	19
Pre-Tier 0 Manufactured 1973 or Later	63	15
Pre-Tier 0 Remanufactured to Tier 0	49	29
Subtotal	**152**	**63**
Ultra Low-Emitting Switch Locomotives		
Gen-Set Diesel	76	61
LNG-Powered	4	4
Battery Electric	12	11
Subtotal	**92**	**76**
Total	**244**	**139**

2. Switch Locomotive Duty Cycle

The U.S. EPA locomotive duty cycle assumes switch locomotives idle about 60 percent of the time. This rate of idling does not account for the benefits of idle reduction devices. Some studies suggest that idle reduction devices can reduce switch locomotive idling times by 10 percent or more and line haul locomotive idling times by 3 percent or more. Under the 2005 ARB/Railroad Agreement, idle reduction devices are required to be installed on greater than 99 percent of the intrastate locomotive fleet.

Beyond idling, the U.S. EPA duty cycle assumes switch locomotives primarily operate in the lower locomotive power (notch) settings (i.e., Notch 1-4) for most of the operating times. This duty cycle also reflects the distribution of diesel fuel consumption for a switch locomotive over a range of eight power (notch) settings. On average, UP and BNSF switch locomotives consume up to 140 gallons per day, or up to 50,000 gallons of diesel fuel annually.

3. Emissions from Switch Locomotives

In 2005, ARB staff estimated that switch locomotive emissions were responsible for about 5 percent of statewide locomotive PM and NOx emissions, respectively, or about 0.2 tons per day of PM and 9.3 tons per day of NOx. In the South Coast Air Basin, switch locomotive emissions accounted for about 0.1 tons per day of PM and 4.6 tons per day of NOx. Switch locomotive emissions are summarized in Tables II-2 and II-3.

In 2005, diesel PM emissions from the 18 designated railyards were about 0.58 tons per day. Railyard emissions occur from locomotive and non-locomotive diesel emissions sources. The railyard non-locomotive emissions occur primarily from diesel trucks, cargo handling equipment, and transport refrigeration units. In comparison to the total railyard diesel PM emissions of 0.58 tons per day, locomotives generated about 0.38 tons per day or about 65 percent of total railyard diesel PM emissions. Switch locomotives generated about half of the 18 railyard locomotive diesel PM emissions, at about 0.18 tons per day.

Based on the current ARB locomotive emission inventory and the railyard health risk assessments, over 90 percent of the switch locomotive PM emissions occur at the 18 major railyards in California. Many of the 18 major railyards are also located in highly urbanized areas where railyard diesel PM emissions can create significant public health risks.

Table II-2
Summary of the Emissions from Switch Locomotives Operating in California in 2008

Type of Switcher Locomotives	Number of Locomotives	Emissions (tons per day)	
		PM	NOx
Existing Switch Locomotives			
Pre-Tier 0 Manufactured Before 1973	40	0.09	2.2
Pre-Tier 0 Manufactured 1973 or Later	63	0.14	3.4
Pre-Tier 0 Remanufactured to Tier 0	49	0.11	2.2
Subtotal	**152**	**0.34**	**7.8**
Ultra Low-Emitting Switch Locomotives			
Gen-Set Diesel	76	0.018	0.570
LNG-Powered	4	0.001	0.090
Battery Electric	12	0.003	0.037
Subtotal	**92**	**0.022**	**0.7**
Totals	**244**	**0.36 ***	**8.5 ***

* May not add up precisely due to rounding.

Table II-3
Summary of Emissions from Switch Locomotives Operating in the South Coast Air Basin in 2008

Type of Switcher Locomotives	Number of Locomotives	Emissions (tons per day)	
		PM	NOx
Existing Switch Locomotives			
Pre-Tier 0 Manufactured Before 1973	19	0.043	1.04
Pre-Tier 0 Manufactured 1973 or Later	15	0.034	0.82
Pre-Tier 0 Remanufactured to Tier 0	29	0.066	1.27
Subtotal	**63**	**0.14 ***	**3.13 ***
Ultra Low-Emitting Switch Locomotives			
Gen-Set Diesel	61	0.0147	0.456
LNG-Powered	4	0.0012	0.037
Battery Electric	11	0.0027	0.082
Subtotal	**76**	**0.019 ***	**0.58 ***
Totals	**139**	**0.16 ***	**3.7 ***

* May not add up precisely due to rounding.

4. Summary of Options to Reduce Emissions from Switch Locomotives

Staff has identified four potential options to reduce emissions from switch locomotives. These options are summarized below and described in more detail in the following sections.

Option 1: Replace Existing Switch Locomotives with ULESLs

The first option would be to replace the 152 older existing intrastate switch locomotives with ULESLs. The gen-set, battery-dominant electric hybrid (Green Goats), and LNG ULESLs (yard) are technically feasible, thoroughly tested in-use, and commercially available. However, this evaluation is based on using gen-set ULESLs due to their current market dominance and efficacy in California's Class I railroad operations. Upon completion of this option, UP and BNSF would have an estimated 244 ULESLs. Of the 244 ULESLs, 228 would be gen-sets, 12 would be electric hybrids or Green Goats, and 4 would be LNG switchers.

Option 2: Retrofit Gen-Set Switchers with NOx and PM Emission Controls[6]

The second option builds upon the first option. In this option, the 244 ULESLs would be retrofitted with emission control devices to reduce the emissions of NOx and PM at the time of engine overhaul. The emission control devices would be either diesel particulate filters (DPF) for PM and selective catalytic reduction (SCR) for NOx, or both. The DPF and SCR retrofit emissions reductions would be in addition to the ULESL emissions reductions in option 1 above.

Staff estimates that the ULESLs will need engine overhauls about every seven years. A DPF and SCR could be retrofitted onto the ULESL when it comes in to the mechanical shop for an engine overhaul. The DPF and SCR would need to be ARB verified for ULESLs, and also be commercially available. Both DPF and SCR ARB verification and commercial availability could potentially occur within the next seven years. The DPF and SCR retrofits could enable the 244 ULESLs to approach or meet the U.S. EPA Tier 4 switch locomotive emissions standards.

Option 3: Upgrade Tier 3 Nonroad Gen-Set Switchers to Tier 4 Nonroad Engines

The third option would be to replace the 244 Tier 3 nonroad engine ULESLs that had also been retrofitted with both DPF and SCR, with a new Tier 4 nonroad engine. By 2015, a Tier 4 nonroad engine would come built and equipped with both DPF and SCR. Staff estimates that switch locomotive Tier 3 nonroad engine repowers may be needed about every 15 years. In this option, the 244 ULESLs may need to have the Tier 3 nonroad engines repowered for the gen-sets, Green Goats, and LNGs. Rather than repower the Tier 3 nonroad engine ULESLs with new Tier 3 nonroad engines, and DPF and SCR retrofits, the ULESLs could be upgraded to cleaner new Tier 4 nonroad

[6] DPF and SCR technology for gen-set switch locomotives has not demonstrated or ARB verified.

engines. Tier 4 nonroad engines may be able meet emissions levels significantly below the U.S. EPA Tier 4 switch locomotive emissions standards.

Option 4: Remanufacture Older Switch Locomotives to Meet New U.S. EPA Tier 0 "Plus" Locomotive Emissions Standards

In this option, the remanufacture of the 152 older UP and BNSF switch locomotives would be accelerated and expanded to meet U.S. EPA Tier 0 "plus" remanufacture emission standards (See Table II-4). In 2008, staff estimates that UP and BNSF have 103 pre-Tier 0 and 49 Tier 0 switch locomotives. This would be a less aggressive and less costly approach.

Table II-4
2008 U.S. EPA Switch Locomotive NOx Emission Standards

Type	Tier	Date of Original Manufacture	Existing NOx Standard (g/bhp-hr)	New "Plus" NOx Standards New and Remanufactured (g/bhp-hr)	Percent Control When Engine is New or Remanufactured
Switcher locomotives	*Pre-Tier 0*	*Pre-1973 and 1973-1999***	*17.4 **	***N/A***	*32 percent (vs. Tier 0 plus)*
	Tier 0	*2000-2001 and 1973-1999 ***	*14.0*	***11.8***	*16 percent*
	Tier 1	2002 – 2004	11.0	**11.0**	0 percent
	Tier 2	2005-2011	8.1	**8.1**	0 percent
	Tier 3	*2011*	*N/A*	***5.0***	*48 percent (vs. Tier 2)*
	Tier 4	*2015*	*N/A*	***1.3***	*84 percent (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.

* This is estimated average in-use NOx emissions levels by U.S. EPA in 1998. In-use NOx emissions were estimated to range from 11 to 33 g/bhp-hr.

** 1973-1999 were not built as Tier 0, but can be remanufactured to Tier 0.

Table II-5
2008 U.S. EPA Switch Locomotive PM Emission Standards

Type	Tier	Date of Original Manufacture	Existing PM Standards (g/bhp-hr)	New "Plus" PM Standards Remanufactured or New (g/bhp-hr)	Percent Control When Engine is New or Remanufactured
Switcher locomotives	*Pre-Tier 0*	*Pre-1973 and 1973-1999 ***	*0.41**	***N/A***	*37 percent*
	Tier 0	*2000-2001 and 1973-1999 ***	*0.72*	***0.26***	*64 percent*
	Tier 1	*2002-2004*	*0.54*	***0.26***	*48 percent*
	Tier 2	*2005-2010*	*0.24*	***0.13***	*54 percent*
	Tier 3	*2011*	*N/A*	***0.10***	*58 percent (vs. Tier 2)*
	Tier 4	*2015*	*N/A*	***0.03***	*87 percent (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.
* This is estimated average in-use PM emissions levels by U.S. EPA in 1998. In-use emissions PM emissions were estimated to range from 0.2 to 1.0 g/bhp-hr.
** 1973-1999 were not built as Tier 0, but can be remanufactured to Tier 0.

Table II-6 summarizes the four switch locomotive options based on technical feasibility, potential emissions reductions, costs, and cost-effectiveness. The following sections provide the basis for the information in this table.

Table II-6
Options to Further Reduce Emissions from Switch Locomotives

Options	Switch Locomotive Options	Timeframe	NOx (tons/day)	PM (tons/day)	Cost-Effectiveness (NOx+PM)	Capital Costs (millions)
1	Replace 152 older switchers with new ULESLs ($1.5m/unit)	Near Term (up to 5 years)	6.6	0.31	$2-3/lb	$228
2	Retrofit 244 ULESLs with DPF and SCR ($200k/unit)	Mid Term (up to 10 years)	1.0	0.04	$3-5/lb	$49
3	Repower 244 ULESLs new Tier 4 nonroad engines ($200k additional costs vs Tier 3)	Long Term (up to 15 years or more)	0.6	0.01	$6-10/lb	$49
	SUBTOTAL		**8.2**	**0.36**	**$2-10/lb**	**$326**
4	Accelerate the remanufacture 152 pre-Tier 0 (103) and Tier 0 (49) switchers to meet Tier 0 plus standards *	Near Term (up to 5 years)	2.2**	0.22**	$0.6-1/lb	$38

* May take up to 20 years for a older switch locomotive to be remanufactured versus a gen-set switcher remanufacture of about every seven to ten years. ** Assume Tier 0 switchers will be remanufactured to Tier 0 plus standards upon remanufacture and there would not be any accelerated or surplus emissions reductions. This would reduce potential emissions reductions by at least one-third.

5. Analysis of Option 1 – Replacement of Existing Switch Locomotives with Tier 3 Nonroad Gen-Set Switch Locomotives

<u>Technical Feasibility</u>

Manufacturers currently build gen-set switch locomotives with new Tier 3 nonroad engines either from Cummins, Deutz, or Caterpillar. Since 2005, National Railway Equipment Company (NREC) and Railpower (RP) combined have built over 250 new multiple nonroad engine gen-set switch locomotives nationally. Currently, UP and BNSF operate about 76 gen-set switch locomotives in California, as well as a large number in Texas and other states.

Most new gen-set switch locomotives are three nonroad engine packages, but there are also a small number of two and single engine packages. The smaller engine packages are primarily designed for lighter-duty applications and smaller Class 3 and military and industrial railroads.

Motive Power Inc. (MPI), Caterpillar/Progress Rail (PR), and Brookville Corporation also recently built Tier 3 nonroad engine (three) gen-set switch locomotive prototypes. The gen-set switch locomotive prototypes are currently being evaluated in field testing.

Also, efforts are underway to develop a single medium speed engine for switch locomotives that could also achieve ULESL emission levels.

The gen-set, electric hybrid, and LNG ULESLs (yard) are technically feasible, thoroughly tested in-use, and commercially available. However, we will focus this evaluation on gen-set ULESLs due to their current market dominance and efficacy in California's Class I railroad operations.

To date, there have been significant reductions from the ULESLs that have already replaced existing switch locomotives. Table II-7 presents the emission reductions that have already been achieved from the 92 ULESLs.

Table II-7
Estimated Emission Reductions Already Achieved from the Existing 92 ULESLs

Location	ULESL* Switchers	Emission Reductions (tons per day)		Costs (millions)
		NOx	PM	
South Coast	76	3.6	0.17	$114
Rest of State	16	0.7	0.03	$24
Statewide	**92**	**4.3**	**0.20**	**$138**

* ULESLs: 80 gen-sets, 12 electric hybrids, and 4 LNG locomotives.

<u>Potential Emission Reductions</u>

New Tier 3 nonroad engine gen-set switch locomotives are at or below existing ULESL NOx emission levels of 3.0 g/bhp-hr. In addition, gen-set ULESLs meet or exceed PM emission levels of 0.1 g/bhp-hr. Gen-set switch locomotives also consume 20 to 40 percent less diesel fuel than older medium speed single-engine switch locomotives, providing greenhouse gas emissions reductions. With the use of CARB diesel, the ULESLs provide a reduction in both PM and NOx emissions, respectively, over pre-Tier 0 switch locomotive emissions of about 85 percent.

Potential emission reductions are calculated based on a change in the expected emission factors for gen-set locomotives versus pre-Tier 0 locomotives, or Tier 0 locomotives. These emission factors are presented in Table II-8.

Table II-8
Emission Factors Used to Determine
Potential Emission Reductions for Option 1

Type of Locomotive	Number of Locomotives	Emission Factors (g/bhp-hr)	
		NOx	PM
Pre-1973 Switchers	41	17.4	0.72
Pre-Tier 0 Switchers	62	17.4	0.72
Pre-Tier 0 Switchers Remanufactured to Tier 0	49	14.0	0.72
Subtotal	152		
ULESL (Tier 3 Nonroad Engine)	152	3.0	0.10

The potential emission reductions can be determined using the U.S. EPA emission factors. As Table II-9 shows, replacement of the 152 remaining older intrastate UP and BNSF switch locomotives, with new Tier 3 nonroad engine gen-set ULESLs, could provide additional statewide NOx and PM reductions of about 6.6 and 0.31 tons per day, respectively, beyond current UP and BNSF switch locomotive emissions levels.

Table II - 9
Estimated Potential Emission Reductions From Replacement of
152 Remaining Older UP and BNSF Switch Locomotives
With New Gen-Set Switch Locomotives
(Option 1)

Location	Total # of Older Switcher	Pre-1973 Switcher (Exempt)	Pre-Tier 0 Switcher (1973-1999)	Tier 0 Switcher (1973-1999) *	Emission Reductions	
					NOx (tons/day)	PM (tons/day)
South Coast	63	19	15	29	2.8	0.14
Rest of State	89	21	48	20	3.8	0.16
Statewide	**152 ****	**40**	**63**	**49**	**6.6**	**0.30**

* There are three pre-1973 switch locomotives that have been remanufactured to Tier 0.
** At up to $1.5 million per ULESL, total capital costs estimated to be up to $228 million.

Costs

A new Tier 3 nonroad engine gen-set switch locomotive (i.e., ULESL) can reach total costs of up to $1.5 million. Therefore, to replace 152 existing switch locomotives with gen-set switchers could cost as much as $230 million. Details on the costs are presented below.

A single Tier 3 nonroad engine can cost about $50,000. However, adding a new generator, auxiliary generator, cooling system, and other key parts to complete a total "skid mounted engine package" can cost up to $200,000. As a result, a "three engine" gen-set skid mounted package, to provide the propulsion power for a three engine gen-set switch locomotive, can cost between $500,000 and $600,000.

There are additional costs beyond the three engine gen-set package. For example, a control system is needed to serve as the brain to alternate the work evenly over the three engines in the gen-set package. The engine control system can cost between $100,000 and $150,000. A new locomotive cab to meet federal safety standards can cost about $100,000. New traction motors and wheels can cost about $100,000. Onboard equipment such as a GPS, event recorder, and data loggers can also add to the costs. Depending on whether an existing switch locomotive chassis is used, or a new one is built, costs can vary by up to $200,000 or more. All of these costs above combined can add up to as much as $1.5 million for a new gen-set switch locomotive.

With nonroad engine gen-set switch locomotives, railroads can incur significant future engine repower costs. High speed nonroad engines, being worked under the rigors of a locomotive duty cycle, are not designed or built with the life-time durability of a single medium speed locomotive engine. Currently, manufacturers and railroads mechanical staff estimate that the gen-set switch locomotives powered by Tier 3 nonroad engines may need to be completely overhauled in 10 to 15 years.

A medium speed locomotive engine can operate for 50 years or longer. However, a medium speed engine will need to be remanufactured or rebuilt with new fuel injectors, power assemblies, and other components about every seven to ten years at a cost of about $150,000 to $200,000 per remanufacture.

Cost Effectiveness

Cost-effectiveness to replace an older pre-Tier 0 or Tier 0 switch locomotive, with a new gen-set switch locomotive (ULESL) ranges from $2 to $3 per pound. This assumes the gen-set switch locomotive engines operate for at least ten years, and possibly up to 20 years, before there is a need for complete engine repower. A new ULESL gen-set switch locomotive replacement is very cost-effective when compared to other ARB control measures or options. Details of the cost-effectiveness calculations are presented in Appendix E.

6. Analysis of Option 2 – Retrofit of Gen-Set Switchers with NOx and PM Emission Controls

Technical Feasibility

Technical feasibility is an issue for this option. Neither the ARB nor the U.S. EPA has verified any aftertreatment control technologies for PM or NOx on switch locomotives. These control technologies include diesel particulate filters (DPF) for PM or selective catalytic reduction (SCR) for NOx. However, as a mid-term option, DPF and SCR aftertreatment retrofits for use on nonroad engines should be available by as early as 2011. Appendix C summarizes the status of research efforts on locomotive aftertreatment emission controls.

Nonroad engine manufacturers such as Cummins, Deutz, and Caterpillar are already designing and testing aftertreatment systems to meet the future Tier 4 nonroad engine standards. The emphasis is being placed on DPFs, as the federal Tier 4 nonroad PM standard, and the need for DPFs, becomes effective in 2011. SCR NOx control is more technically challenging, but there is also more time to address the Tier 4 nonroad standard for NOx, with the latter being phased-in between 2011 and 2014. However, existing nonroad engine aftertreatment retrofit systems, like DPF and SCR on Tier 3 nonroad engines, will most likely take a lower priority to designing aftertreatment systems for the new Tier 4 nonroad engines.

Staff believes that retrofitting aftertreatment systems onto Tier 3 nonroad engines could potentially affect engine performance, and the aftertreatment could be subject to ongoing operational and maintenance problems. However, in spite of these potential technical challenges, DPF and SCR retrofits may be able to achieve significant potential cost-effective emissions reductions on ULESLs. As a result, it is important to explore this option to provide interim emissions reductions until new Tier 4 nonroad engines, equipped with DPF and SCR, become commercially available by about 2015.

Based on discussions with engine manufacturers and the railroads, staff estimates that gen-set switch locomotives will need engine overhauls in 10 to 15 years. This would provide a potential opportunity to retrofit DPF or SCR, or both, onto Tier 3 nonroad engines in gen-set switch locomotives as part of a normal locomotive maintenance schedule.

Staff believes ARB verification and commercial production of both DPF and SCR retrofits could potentially be achieved for ULESLs within the next couple of years. Based on discussions with ULESL manufacturers and ARB research efforts, staff believes DPF retrofits for ULESLs could receive ARB verification and become commercially available as early as 2010. SCR retrofits for ULESLs would probably not be ARB verified and commercially available until 2012 or later.

Potential Emissions Reductions

Table II-10 presents the staff estimates of the changes in emission factors that would be achieved by retrofitting gen-set switch locomotives with DPF and SCR emission controls.

Table II-10
Emission Factors Used to Determine
Potential Emission Reductions
(Option 2)

Type of Locomotive	Number of Locomotives	Emission Factors (g/bhp-hr)	
		NOx	PM
ULESL (Tier 3 Nonroad Engine)	244	3.0	0.10
ULESL (with DPF and SCR)	244	1.3	0.03

The retrofit of both DPF and SCR onto ULESLs could approach or meet Tier 4 emissions levels. As shown in Table II-11, Option 2 could provide an additional 1.0 and 0.04 tons per day of NOx and PM statewide, respectively, beyond ULESL replacement of 152 switch locomotives. Of the potential statewide emissions reductions, over half would be achieved in the South Coast Air Basin.

Table II-11
Estimated Emission Reductions from
Retrofit of DPF and SCR onto 228 Gen-Set, 12 Electric Hybrid,
and 4 LNG ULESLs
(Option 2)

Location	Retrofit DPF & SCR to ULESL	Emission Reductions (tons per day)		Costs (millions)
		NOx	PM	
South Coast	139	0.6	0.02	$28 *
Rest of State	105	0.4	0.02	$21
Statewide	**244**	**1.0**	**0.04**	**$50 ***

* May not add up precisely due to rounding.

Costs

A DPF and SCR retrofit of a gen-set switch locomotive powered by a Tier 3 nonroad engine is estimated to cost about $200,000. Retrofitting 244 ULESLs with DPF and SCR could cost about $50 million. Details on the derivation of the $200,000 retrofit costs are presented below.

Retrofit of both DPF and SCR onto Tier 3 nonroad engine gen-set or electric hybrid switch locomotives (ULESL) would cost about $200,000 per three engine gen-set switch locomotive. These initial estimates are based on conversations with nonroad engine and gen-set locomotive manufacturers.

Cost-Effectiveness

A UP and BNSF gen-set switch locomotive fleet (ULESL), powered with Tier 3 nonroad engines, as compared to 152 pre-Tier 0 or Tier 0 switch locomotives, could provide NOx and PM emissions reductions of up to 6.6 and 0.31 tons per day, respectively. In comparison, retrofitting a Tier 3 nonroad engine switch locomotive (ULESL), with both DPF and SCR, could provide additional NOx and PM emissions reductions of only up to 1.0 and 0.04 tons per day, respectively.

Replacement of pre-Tier 0 switch locomotives with Tier 3 nonroad engines provides an incremental reduction in mass emissions that is nearly ten times higher than retrofits of Tier 3 nonroad engines both DPF and SCR. However, the *incremental* cost differences are substantially lower for the retrofit of both DPF and SCR on the Tier 3 nonroad engine, at about an estimated additional $200,000, versus a new Tier 3 nonroad engine gen-set switch locomotive that could cost up to $1.5 million.

Both DPF and SCR retrofitted to an existing three engine Tier 3 nonroad package may cost an additional or incremental cost difference of about $200,000. We estimate the cost-effectiveness for a retrofit of both DPF and SCR onto a Tier 3 nonroad three engine package, to be between $3 and $5 per pound, depending on a 10 to 20 year range of useful life.

7. Analysis of Option 3 – Upgrade Gen-Set Switchers to Tier 4 Nonroad Engines

Technical Feasibility

Initial estimates indicate that new gen-set ULESLs built with Tier 3 nonroad engines will require repowers with new nonroad engines in 10 to 15 years, depending on individual locomotive workloads. The frequency of engine repowers is anticipated because nonroad engines are high speed (about 1,800 rpm) and are not designed or built with the durability of a medium speed (about 1,000 rpm) engine. Medium speed engines can operate in a locomotive for up to 50 years or more.

New gen-set ULESLs are predominately powered by three Tier 3 nonroad engines, with each engine rated at less than 750 horsepower, and the total three engine package roughly equivalent to about 2,000 horsepower.

UP ordered and assigned 61 gen-set switch locomotives to the South Coast Air Basin in 2007; in 2008 four more were assigned to UP Roseville and five to the San Joaquin Valley. Also, BNSF ordered and assigned 6 gen-sets to the Bay Area in 2008. All of the 76 UP and BNSF gen-set switch locomotives may be due for complete nonroad engine repowers in 10 to 15 years. In addition, the 12 electric hybrids are powered by Tier 2 or 3 nonroad engines, usually between 90 and 300 horsepower, that could be upgraded to Tier 4 nonroad engines.

The U.S. EPA and ARB Tier 4 nonroad engine standards should be fully implemented for NOx and PM by 2015. U.S. EPA and ARB require Tier 4 nonroad engines to be phased in between 2011 and 2015. Tier 4 nonroad engines of less than 750 horsepower are expected to be built with diesel particulate filters (DPF) by 2011, and selective catalytic reduction (SCR) between 2011 and 2014. New Tier 4 nonroad engine repowers, when the Tier 3 nonroad gen-set switch locomotives engines need to be repowered, should be technically feasible, thoroughly tested, and commercially available as early as 2015.

Potential Emission Reductions

Tier 4 nonroad engine repowers could provide greater emissions reductions than Tier 3 nonroad gen-set switch and electric hybrid locomotive (ULESLs) engines retrofitted with both DPF and SCR. The latter would be equivalent to U.S. EPA Tier 4 locomotive emissions levels of 1.3 g/bhp-hr NOx and 0.03 g/bhp-hr PM. Tier 4 nonroad engine emission standards are even more stringent at 0.3 g/bhp-hr NOx and 0.01 g/bhp-hr PM.

As shown in Table II-12, a Tier 3 nonroad engine retrofitted with DPF and SCR could approach or equal U.S. EPA Tier 4 locomotive emissions standards. New Tier 4 nonroad engine repowers could lower these emissions levels further, as Tier 4 nonroad emissions standards represent a reduction of about 77 percent for NOx and about 65 percent for PM over Tier 4 locomotive emission levels. As shown in Table II-13, however, the actual mass emission reductions are substantially less than those achieved with Option 1 – switch locomotive (ULESL) replacements.

The Tier 4 nonroad engine repowers, with Tier 4 nonroad emissions levels applied to 244 ULESLs powered with Tier 3 nonroad engines and retrofitted with DPF and SCR, could provide additional NOx and PM statewide emissions reductions of up to 0.6 and 0.01 tons per day, respectively. See Table II-13 for further details on the Tier 4 nonroad engine repowers that could potentially provide additional emissions reductions beyond a gen-set switch locomotive retrofitted with both SCR and DPF.

Table II-12
Emission Factors Used to Determine
Potential Emission Reductions
(Option 3)

Type of Locomotive	Number of ULESLs	Emission Factors (g/bhp-hr)	
		NOx	PM
ULESL (retrofitted with DPF and SCR)	244	1.3	0.03
ULESL (repowered with Tier 4 nonroad engines and equipped with DPF and SCR)	244	0.3	0.01

Table II-13
Estimated Emission Reductions from Repowering ULESL
with Tier 4 Nonroad Engines Equipped with DPF and SCR
(Option 3)

Location	Repower ULESLs with Tier 4 Nonroad Engines	Emission Reductions (tons per day)		Incremental Costs (millions)
		NOx	PM	
South Coast	139	0.3	0.006	$28 *
Rest of State	105	0.3	0.004	$21 *
Statewide	**244**	**0.6**	**0.01**	**$50 ***

* May not add up precisely due to rounding.

Costs

Repowering a Tier 3 nonroad engine, with a new Tier 4 nonroad engine equipped with DPF and SCR, is estimated to be about $200,000. This cost would only be an incremental cost increase over the cost of a new Tier 3 nonroad engine repower. Therefore, repowering 244 ULESLs with Tier 4 nonroad engines, built with DPF and SCR, could cost about $50 million. Details on the derivation of the $200,000 incremental costs are presented below.

Gen-set locomotive manufacturers have indicated that a skid mounted Tier 3 nonroad engine package would include a single Tier 3 nonroad engine, new generators, new cooling systems, and other components which could cost up to $200,000. For a “three engine” skid mounted package, these costs could add up to $600,000. Staff assumes that the railroads would be replacing the Tier 3 nonroad engines upon repower in 10 to 15 years.

This option evaluates the incremental cost difference between a required repower with a new Tier 3 nonroad engine versus a repower with a new Tier 4 nonroad engine, the latter equipped and built with DPF and SCR.

Due to the easy design, configuration, and installation of Tier 3 nonroad engines on an existing locomotive platform, gen-set engine manufacturers believe similarly (even with DPF and SCR) that future Tier 4 nonroad engine repowers could potentially be completed within two to three workdays. This approach would significantly minimize locomotive downtime and labor costs to perform engine repowers. Staff has spoken to gen-set locomotive manufacturers who indicate they plan to be able to incorporate future Tier 4 nonroad engines onto the existing gen-set switch locomotive platforms.

Initial estimates to retrofit DPF and SCR onto Tier 3 nonroad gen-set switch locomotive engines are about $65,000 per engine, or about $200,000 for a three engine gen-set switch locomotive. This assumes $200,000 per skid mounted engine package (i.e., engine plus generator package) for a three engine gen-set locomotive that would total about $600,000. We assume adding DPF and SCR would bring the total costs to about $800,000, or about a $200,000 incremental cost difference.

New Tier 4 nonroad engines designed with DPF and SCR could cost less than a retrofitted aftertreatment system, but the base Tier 4 nonroad engine might be more expensive than a Tier 3 nonroad engine. To address these potentially offsetting costs, we chose to use the higher aftertreatment cost number of $200,000. The incremental cost differential between a repower with a new Tier 4 versus new Tier 3 nonroad engine gen-set in a three engine package, is estimated to be about $200,000.

Cost-Effectiveness

A 244 gen-set ULESL fleet powered with three Tier 3 nonroad engines, as compared to 152 pre-Tier 0 or remanufactured Tier 0 switch locomotives and 92 existing ULESLs, could provide NOx and PM emissions reductions of up to 6.6 and 0.31 tons per day, respectively. Retrofits of the 244 ULESLs with both DPF and SCR could provide an additional 1.0 and 0.04 tons per day of NOx and PM emissions reductions, respectively. Beyond both repowering 244 old switchers with new Tier 3 nonroad engine ULESLs, and retrofitting the 244 ULESLs with both DPF and SCR, new Tier 4 nonroad engines could provide additional NOx and PM emissions reductions of 0.6 and 0.01 tons per day, respectively.

A new Tier 3 nonroad three engine skid mounted package would cost about $600,000. A retrofit of both DPF and SCR on to a three engine gen-set package may cost an additional $200,000. A new Tier 4 nonroad three engine package, built with DPF and SCR, may cost about $800,000. There would be no cost difference between a new Tier 3 nonroad engine gen-set package that has been retrofitted with DPF and SCR and a new Tier 4 nonroad engine. The incremental cost difference would be limited to the difference between only a repower of new Tier 3 versus new Tier 4 nonroad engine, which would be about $200,000.

Based on the assumptions above, staff estimates the cost-effectiveness for a Tier 3 to new Tier 4 nonroad three engine package upgrade, based on the new engine cost differences, to be between $6 and $10 per pound, depending on a range of useful life between 10 and 20 years. Also, a case could be made that with no cost differential between an ULESL, retrofitted with both DPF and SCR, and a new Tier 4 nonroad engine, the cost-effectiveness would be zero. Staff has chosen to be conservative in this particular cost-effectiveness calculation.

8. *Analysis of Option 4 – Remanufacture Existing Switch Locomotives to Meet U.S. EPA Tier 0 Plus Emission Standards*

Technical Feasibility

There are a couple of key issues with applying the Tier 0 plus remanufacture approach to switch locomotives. Switch locomotives are not remanufactured as often as interstate line haul locomotives (the latter about every 7 to 10 years). Switch locomotives work predominately in the lower power settings, work fewer hours, and place significantly less stress and work on their engines. As a result, switch locomotives may only be remanufactured about every 10 to 20 years.

Another issue is that the U.S. EPA switch locomotive Tier 0 plus emissions standards are applicable only to switch locomotives remanufactured to meet existing Tier 0 standards. Of UP and BNSF's 152 older switch locomotives, a majority (103) have not been remanufactured to meet U.S. EPA Tier 0 locomotive emissions standards.

Staff believes there may be little economic incentive for railroads to remanufacture older pre-Tier 0 switch locomotives to meet U.S. EPA Tier 0 and subsequently Tier 0 plus locomotive emissions standards. Staff is concerned that older pre-Tier 0 switch locomotives may have little, if any, residual value. As a result, it may be cost prohibitive for railroads to incur switch locomotive remanufacture costs that could potentially exceed the value of the switch locomotive. These same concerns may also apply to switch locomotives remanufactured to Tier 0.

Staff does believe that U.S. EPA Tier 0 plus locomotive emission reduction kits could be adapted or commercially produced for pre-Tier 0 older switch locomotives if there were a sufficient market size. Further, there are about 49 older switch locomotives that have been remanufactured to meet U.S. EPA Tier 0 emissions standards and will be subject to the U.S. EPA Tier 0 plus requirements. Staff assumes the railroads will spend the necessary funds to remanufacture older Tier 0 switch locomotives.

U.S. EPA recently promulgated new switch locomotive emission standards as part of the 2008 rulemaking: older locomotives that had been remanufactured to meet existing Tier 0 emission standards, and new Tier 0 units built between 2000 and 2001, are required to meet new Tier 0 plus emission standards. Under the Tier 0 plus standards, PM emissions could be lowered potentially from 0.72 g/bhphr to 0.26 g/bhphr, a 64 percent reduction, and NOx from 17.4 g/bhphr to 11.8 g/bhphr, a 32 percent reduction.

Staff and U.S. EPA believe the Tier 0 plus remanufacture kits could be available much earlier than the required date of 2010, perhaps in early 2009. However, according to U.S. EPA, the Tier 0 plus emission standards were not intended to apply to pre-Tier 0 locomotives. U.S. EPA believed most pre-Tier 0 locomotives would be significantly reduced in numbers in the near future, primarily due to retirement. Therefore, U.S. EPA intended the Tier 0 plus locomotive emission standards to apply only to locomotives built or remanufactured to meet U.S. EPA locomotive Tier 0 emission standards.

Two-thirds (103) of UP and BNSF's 152 older switch locomotives are either expressly exempt (built prior to 1973) or have not been remanufactured yet (built 1973-1999) to meet U.S. EPA Tier 0 emission standards. Staff still believes Tier 0 plus emission kits could be adapted or produced for exempt or pre-Tier 0 switch locomotives in the near future. Further, staff believes many of these older locomotives will continue to operate for the foreseeable future, potentially up to another 10 to 15 years.

Older switch locomotives may be remanufactured only about every 10 to 15 years, or up to 20 years in some cases. Due to remanufacturing costs, railroads may delay remanufacturing older switch locomotives until they are retired from service and not remanufacture them at all.

Potential Emissions Reductions

As discussed above, the Tier 0 plus remanufacture kits could lower pre-Tier 0 and Tier 0 switch locomotive emissions by up to 64 and 32 percent for PM and NOx, respectively. Emission factors are presented in Table II-14.

Table II - 14
Emission Factors Used to Determine
Potential Emission Reductions for Option 4

Type of Locomotive	**Number of Locomotives**	**Emission Factors** (g/bhp-hr)	
		NOx	**PM**
Pre-1973 Switchers	41	17.4	0.72
Pre-Tier 0 Switchers	62	17.4	0.72
Pre-Tier 0 Remanufactured to Tier 0	49	14.0	0.72
Subtotal	152		
Remanufactured Switch Locomotives to Tier 0 "Plus"	**152**	**11.8**	**0.26**

As shown in Table II-15, remanufacturing 152 UP and BNSF switch locomotives (103 pre-Tier 0 and 49 Tier 0) to meet Tier 0 plus emissions standards would provide NOx and PM emissions reductions of about 2.2 and 0.22 tons per day, respectively. However, these potential emissions reductions could be lowered significantly if railroads decide that older switch locomotives will continue to work, via ongoing maintenance and overhauls, and to avoid the expense of remanufacturing to Tier 0 plus emissions standards.

Table II - 15
Estimated Emission Reductions from Remanufacturing 152 Pre-Tier 0 and Tier 0 Switch Locomotives to Tier 0 "Plus" Emission Standards
(Option 4)

Location	Remanufacture pre-Tier 0 and Tier 0 Switchers to Tier 0 Plus	Emission Reductions (tons per day)		Capital Costs (millions)
		NOx	PM	
South Coast	63	0.8	0.09	$16
Rest of State	89	1.4	0.13	$22
Statewide	**152**	**2.2 ***	**0.22**	**$38**

* May not add up precisely due to rounding.

Costs

Remanufacturing older switch locomotives to Tier 0 plus emission standards would cost about $250,000 per remanufacture to meet Tier 0 plus emissions standards. Therefore, the total cost for 152 pre-Tier 0 and Tier 0 switch locomotives would be about $38 million. Details on the derivation of the $250,000 remanufacture costs are presented below.

The estimated cost to remanufacture an existing pre-Tier 0 older switch locomotive to meet Tier 0 emission levels is up to $200,000, based on actual cost estimates provided by UP and BNSF. U.S. EPA estimated that the Tier 0 plus kits would be less than $50,000, but these costs do not account for labor and testing costs, locomotive downtime, and necessary related parts. Staff expects that the Tier 0 plus remanufacture kit would be about the same price or slightly higher than a Tier 0 kit. Staff estimated the costs of a Tier 0 plus remanufacture kit at a slightly higher level than a Tier 0 kit, or about $250,000.

Cost-Effectiveness

Cost-effectiveness for NOx and PM emissions reductions to remanufacture an older pre-Tier 0 or Tier 0 switch locomotive with a Tier 0 “plus” switch locomotive kit is between $0.5 and $1 per pound, depending on the range of useful life of between 10 to 20 years.

B. Medium Horsepower Locomotives

Medium horsepower (MHP) locomotives are used both in freight and passenger locomotive operations. The different MHP locomotive applications are discussed below.

1. Types of MHP Locomotives

MHP Freight Locomotives

MHP freight locomotives range from 2,301 to 4,000 horsepower. Staff identified three distinct subgroups of freight MHP locomotives. Smaller freight MHP locomotives range from 2,301 to 2,999 horsepower and can serve as large switch (yard) locomotives and also perform local service. A second set of freight MHP locomotives range from 3,000 to 3,300 horsepower. This mid-size group of freight MHP locomotives generally serves as helpers by assisting trains over mountain grades or performing as local and regional short haulers. The third subgroup of freight MHP locomotives is intrastate or regional line haul locomotives. This latter category of locomotives typically moves freight up to 500 miles and ranges from 3,301 to 4,000 horsepower. For comparison, today’s interstate freight line haul locomotives (e.g., Chicago to Los Angeles) are typically 4,000 horsepower or greater.

MHP freight locomotives are typically powered by six axles, though some units may be powered with 4 axles. Nearly all freight MHP locomotives were originally built within a wide range of 10 to 50 years ago. Many were originally interstate line haul locomotives (e.g., Chicago to Los Angeles) that over time were cascaded down to shorter routes and local and regional operations. The UP and BNSF freight MHP locomotive fleet operating in California is on average about 40 years old.

UP and BNSF’s California MHP freight locomotives are predominately pre-Tier 0 and have not been remanufactured to meet U.S. EPA Tier 0 locomotive emissions standards. Many of these locomotives are also expressly exempt from U.S. EPA locomotive emission standards by being built before the 1973 model year. About 10 percent or about 40 of these older MHP line haul locomotives, especially the relatively newer ones (1985-1999 model years), may have recently been remanufactured to meet U.S. EPA Tier 0 locomotive emission standards.

MHP Passenger Locomotives

Another group of MHP locomotives move passengers. California has about 110 intrastate passenger locomotives that average about 3,000 horsepower, with some up to 3,600 horsepower, and use the same or similar engine families as MHP freight locomotives. California's 110 intrastate passenger locomotives on average are about 15 years old. Intrastate passenger operators include Amtrak, Metrolink, California Department of Transportation, Caltrain, Altamont Commuter Express, and North County Transit District in San Diego.

Intrastate passenger locomotives operate predominately in idle or the higher power (Notch 5-8) settings, and on average consume nearly 200,000 gallons of diesel fuel annually. Some of the intrastate passenger locomotives have been documented to consume up to 300,000 gallons or more of diesel fuel annually. Passenger locomotives also typically have large stationary generators of about 500 horsepower or more onboard to provide hotel power, such as lighting, air conditioning, etc., for passenger cars and can operate for up to 24 hours per day.

Estimates of UP and BNSF Intrastate MHP Locomotives

Table II-16 presents staff estimates of the number of intrastate UP and BNSF freight and passenger MHP locomotives operating statewide and within the South Coast Air Basin. These estimates are based on documentation provided by both UP and BNSF for the intrastate locomotive inventories and health risk assessment emission inventories. Also, the estimates are based on the CARB diesel fuel regulation for intrastate UP and BNSF freight and passenger locomotives. For this evaluation, the estimates of UP and BNSF freight and intrastate passenger MHP locomotives were based on an engine power range of between 2,301 and 4,000 horsepower.

Table II - 16
Estimates of Intrastate
UP and BNSF Freight and Passenger MHP Locomotives

Area of State	Intrastate Freight (2,301-2,999 HP)	Intrastate Freight * (3,000-3,300 HP)	Intrastate Regional Freight** (3,301-4,000 HP)	Intrastate Passenger (3,000-3,600 HP)	Total
South Coast	20	12 ‡	~65 ‡	52	~150
Rest of State	83	55	~55 ‡	58	~250
Statewide	**103**	**67**	**~120** ‡	**110**	**~400**

* EMD GP40's, SD39/40's.
** EMD GP50/GP60 (4 axle) and SD50/SD60/SD70 (6 axle).
‡ Preliminary data that still needs to be confirmed with UP and BNSF.

2. MHP Locomotive Duty Cycles

MHP Freight Locomotives

The U.S. EPA freight locomotive duty cycle assumes line haul locomotives idle about 40 percent of the time. This rate of idling does not account for the benefits of idle reduction devices, which, under the 2005 Agreement, have been installed on greater than 99 percent of the intrastate UP and BNSF freight locomotive fleet of which about 150 are MHP freight locomotives. Intrastate passenger locomotives are not required to comply with the 2005 ARB/Railroad Agreement.

Beyond idling about 40 percent of the time, the U.S. EPA duty cycle assumes line haul locomotives primarily operate in the higher locomotive power (notch) settings (i.e., Notch 5-8) for the rest of the operating times. Helpers and larger intrastate line haul freight locomotives operate closer to a line haul locomotive duty cycle. However, intrastate MHP line haul locomotives typically operate fewer hours, travel fewer miles, and consume less diesel fuel annually than interstate line haul locomotives. In contrast to interstate line haul locomotives that may consume only about 15 percent of annual diesel fuel consumption within the state, MHP intrastate locomotives consume at least half of the annual diesel fuel burned annually within the state.

On average statewide, UP and BNSF freight MHP locomotives may consume a wide range of diesel fuel annually. Smaller freight MHP such as helpers and short haulers may consume between 50,000 and 150,000 gallons per year. Larger intrastate line haul locomotives may consume from 100,000 to 300,000 gallons annually. In comparison, a 4,000 horsepower freight interstate line haul locomotive (e.g., Chicago to Los Angeles) operates for significantly more time in the higher power settings (Notch 5-8).

A freight interstate line haul locomotive can consume up to 1,000 gallons per day, or about 360,000 gallons of diesel fuel annually. Some interstate line haul locomotives may consume up to 500,000 gallons or more of diesel fuel annually. However, an interstate line haul locomotive may only consume up to 20 percent of its annual diesel fuel within California, based on a trip between Chicago and Los Angeles.

MHP Passenger Locomotives

U.S. EPA has passenger locomotives perform the same duty cycle for emission testing as line haul locomotives. However, passenger locomotives actually operate on a much different duty cycle than freight locomotives. Typically, passenger locomotives operate predominately in idle for extended periods, or they operate at the other extreme – the higher power settings ranging from Notch 5 to 8. Intrastate passenger locomotives also do not need the tractive effort of a freight line haul locomotive, the latter needs to pull trains up to a mile or longer in length.

3. Medium Horsepower Locomotives: Statewide and Railyard Emissions

Most intrastate MHP freight and passenger locomotives are pre-Tier 0. A significant portion of these older freight locomotives are exempt from federal locomotive emissions standards by being built prior to 1973. Staff has only been able to identify about ten percent, or about 40, of the intrastate UP and BNSF MHP freight and intrastate passenger locomotives that have been remanufactured to meet Tier 0 emissions levels. Freight MHP locomotives also comprise nearly one-third of UP and BNSF's 15,000 locomotive national fleet. UP and BNSF combined may operate up to 290 or more intrastate freight MHP locomotives statewide.

Intrastate passenger locomotives add an additional 110 MHP locomotives to the statewide MHP locomotive fleet. About 52 operate in the South Coast and 58 in the rest of the state. All of the freight and passenger MHP locomotives may add up to a total of up to as much as 400 MHP locomotives statewide or more. Staff believes intrastate freight and passenger MHP locomotives may contribute up to one-third of the total statewide locomotive NOx and PM emission inventory.

4. Summary of Potential Options to Reduce Emissions from Medium Horsepower Locomotives

Staff has identified four possible options to reduce medium horsepower freight and passenger locomotive emissions. These options are referred to as options 5, 6, 7 and 8. In this evaluation, medium horsepower (MHP) locomotives are defined as between 2,301 and 4,000 horsepower. Based on available data, ARB staff identified only about 10 percent of the MHP freight and passenger locomotives that have been remanufactured to meet U.S. EPA Tier 0 locomotive emission standards.

<u>Option 5: Repower Older Locomotives with Low-emitting Engines</u>

The first option is to repower about 400 older pre-Tier 0 (~360) and Tier 0 (~40) MHP freight and passenger locomotives with new LEL engines. A new low emitting locomotive (LEL) engine is defined as a locomotive engine repower with new four or two stroke MHP engines that meets or exceeds 4.0 g/bhphr NOx and 0.1 g/bhphr PM. Staff estimates that UP and BNSF have about 290 intrastate MHP freight locomotives and that there are about 110 intrastate MHP passenger locomotives.

<u>Option 6: Replace Older MHP Locomotives with New MHP Gen-Set Locomotives</u>

An alternative to the first option is to replace up to 200 of the approximately 290 MHP freight locomotives with new gen-set MHP locomotives powered with four 700 horsepower nonroad engines, or about 2,800 horsepower. A four engine gen-set locomotive has not been U.S. EPA certified or ARB verified as of December 2008.

However, gen-set manufacturers have informed ARB staff they are in the process of building four engine MHP gen-set locomotives.

A MHP gen-set locomotive would potentially have as much tractive effort (pulling force exerted) as an EMD SD-40 with 3,000 horsepower. Staff estimates that UP and BNSF have up to 200 of the 290 MHP freight locomotives that could potentially be replaced with MHP gen-set locomotives, depending on the individual duty cycle and horsepower/tractive effort needs of the locomotive being replaced.

Option 7: Retrofit Low-Emitting MHP Locomotives with NOx and PM Emission Controls

The third option builds upon the first two options. This option involves retrofitting the 400 MHP LEL freight and passenger locomotives, and potentially MHP gen-set freight locomotives, with both DPFs and SCRs. The second option would be an option only after ARB has verified DPF and/or SCR for retrofit onto a MHP freight and passenger locomotive powered by an LEL or gen-set engines. The combination of an LEL engine repower, or MHP gen-set engine, and DPF and SCR retrofits could approach or meet U.S. EPA Tier 4 locomotive NOx and PM emissions levels.

Option 8: Remanufacture MHP Locomotives to U.S. EPA Tier 0 Plus Standards

The fourth option, though less aggressive and costly, would be to accelerate the remanufacture of 400 pre-Tier 0 (~360) or Tier 0 (~40) freight and passenger MHP locomotives to meet U.S. EPA Tier 0 plus locomotive emissions standards. U.S. EPA requires the Tier 0 plus emission standards upon remanufacture of existing built or remanufactured Tier 0 locomotives, but not for pre-Tier 0 locomotives.

Table II-17 summarizes the four MHP locomotive options based on technical feasibility, potential emissions reductions, costs, and cost-effectiveness. Option 6 is a partial alternative to Option 5. Option 7 can complement both Options 5 and 6. Option 8 is a less expensive alternative to Options 5,6, and 7. The following sections provide the basis for the information in this table.

Table II - 17
Options to Reduce Medium Horsepower (MHP) Locomotive Emissions

Option	Medium Horsepower Locomotive Strategies	Timeframe	NOx (tons/day)	PM (tons/day)	Cost-Effectiveness ($/lb)	Capital Costs (millions)
5	Repower 400 older MHP locomotives with new LEL engines	Near Term (up to 5 years)	22.9	1.27	$0.8-1 (10-20 years)	$400
6	Replace 200 older MHP locomotives with new gen-set MHP locomotives	Near Term (up to 5 years)	13.3	0.63	$2-3 (10-20 years)	$400
7	Retrofit DPF and SCR onto MHP locomotives with repowered LEL engines or gen-sets	Mid Term (up to 10 years)	6.8	0.18	$1-2 (10-20 years)	$200
	SUBTOTAL (Options 5 and 7)	**Near-Mid Term**	**29.8**	**1.45**	**$0.8-2/lb**	**$600**
8	Remanufacture* 400 older MHP locomotives to meet U.S. EPA Tier 0 plus emission standards.	Near Term (up to 5 years)	12.9 **	0.96 **	$0.3-0.5 (10-20 years)	$100

Note: Numbers may not add up precisely due to rounding.
* May take up to 15 years for a remanufacture of an older medium speed engine MHP locomotive. Also, about 40 Tier 0 locomotives will be required to meet Tier 0 plus standards upon remanufacture.
** Assumes all existing older MHP locomotives are pre-Tier 0.

5. Analysis of Option 5 - Repower 400 Older MHP Locomotives with LEL Engines

Technical Feasibility

Intrastate older MHP locomotive engines provide an opportunity to achieve significant additional emission reductions by repowering them with new four or two stroke engines. The new advanced MHP locomotive engines are less emitting, smaller in size but just as powerful, and more combustion and fuel efficient than the older two stroke locomotive engines. The new advanced MHP locomotive engines emit at levels that can meet or significantly exceed the current and most stringent U.S. EPA Tier 2 locomotive NOx and PM emissions standards.

We refer to the new MHP locomotive engine repowers with NOx levels at or below 4.0 g/bhp-hr and PM at or below 0.1 g/bhp-hr as low emitting locomotive (LEL) engines. LEL engine NOx and PM emissions levels represent a 70 and 85 percent reduction, respectively, when compared to pre-Tier 0 NOx and PM emission levels. Staff believes LEL engines are technically feasible and expect them to be commercially available for locomotives in the next two years. Staff expects that some LEL locomotive engine repowers could be in California operation as early as January 1, 2010.

Potential Emission Reductions

LEL engine repowers can significantly reduce existing pre-Tier 0 intrastate MHP freight and passenger locomotive NOx and PM emissions by about 70 and 85 percent, respectively. MHP locomotives consume an estimated 50,000 to 300,000 gallons of diesel fuel annually. In our estimates, we assumed intrastate MHP freight and passenger locomotives consume on average about 100,000 gallons of diesel fuel annually. Staff believes this to be a conservative fuel consumption level, since passenger and larger intrastate MHP line haul locomotives have been documented to consume 200,000 to 300,000 gallons of diesel fuel annually.

Based on the estimated annual activity and fuel consumption levels of 400 freight and passenger MHP locomotives, staff estimated statewide NOx and PM reductions of up to 22.9 and 1.27 tons per day, respectively. Also, note that the new LEL engine may potentially reduce fuel consumption by up to 3 percent, which could mean up to 36 tons per day of greenhouse gas emissions reductions.

Table II-18
Estimated NOx and PM Emissions Reductions
LEL Repowers of 400 Intrastate
Freight and Passenger MHP Locomotives

Location	Number of MHP Locomotives	NOx* (tons per day)	PM* (tons per day)	Cost-Effectiveness ($/lb)	Capital Costs (millions)
South Coast	150	8.6	0.48	$0.8-1	$150
Rest of State	250	14.4	0.79	$0.8-1	$250
Statewide	**~ 400**	**22.9**	**1.27**	**$0.8-1**	**$400**

* May not add up precisely due to rounding.

Costs

A new LEL engine repower of an older MHP locomotive, between 3,000 and 4,000 horsepower, would cost on average about an estimated $1,000,000. Some engine repowers could be as low as $500,000 and some as high as $1,500,000. Therefore, to repower 400 locomotives would be about $400 million.

Cost-Effectiveness

Cost-effectiveness to repower an older pre-Tier 0 or Tier 0 MHP intrastate freight or passenger line haul locomotive with a new LEL engine would be about $1 per pound, depending on the range of useful life of between 10 and 20 years. A MHP locomotive repower, with a new LEL engine, is very cost-effective when compared to most current ARB control measures or options.

6. Analysis of Option 6 - Replace Up to 200 Older MHP Locomotives with New MHP Gen-Set Locomotives

Technical Feasibility

Intrastate older MHP locomotive engines provide an opportunity to achieve significant additional emission reductions by replacing them with new MHP gen-set locomotives. New MHP gen-set locomotives, powered by four nonroad engines, of less than 750 horsepower each, may be able to approach, meet, or exceed ultra low emitting locomotive (ULEL) emissions levels of 3.0 g/bhp-hr NOx and 0.1 g/bhp-hr PM. Current three engine gen-set switch locomotives are able meet and exceed ULESL emissions levels. ARB staff believes a four engine MHP gen-set locomotive would perform in similar duty cycles and may achieve similar levels of emissions.

We refer to a new four engine (roughly equivalent to about 3,000 horsepower) gen-set locomotive, with certified emissions at or below 3.0 g/bhp-hr and PM at or below 0.1 g/bhp-hr, as a MHP gen-set locomotive. A MHP gen-set locomotive NOx and PM emissions levels represent about an 80 percent reduction when compared to pre-Tier 0 line haul locomotive NOx and PM emission levels. Staff believes MHP gen-set locomotives are technically feasible and expects four engine gen-set locomotives to be commercially available within the next one to two years. Staff expects that some MHP gen-set locomotives could be in California operation as early as 2010.

Potential Emission Reductions

New MHP gen-set locomotives could significantly reduce existing pre-Tier 0 MHP freight line haul locomotive NOx and PM emissions by about 80 percent. MHP freight locomotives consume an estimated 50,000 to 300,000 gallons of diesel fuel annually. In our estimates, we assumed MHP freight locomotives consume on average about 100,000 gallons of diesel fuel annually. Staff believes this to be a conservative fuel consumption level, since larger intrastate MHP line haul locomotives have been documented to consume 200,000 to 300,000 gallons of diesel fuel annually.

Based on the estimated annual activity and fuel consumption levels of 200 intrastate freight MHP locomotives, staff estimated statewide NOx and PM reductions of up to 13.3 and 0.63 tons per day, respectively. Also, note that a new MHP gen-set locomotive may also potentially reduce fuel consumption by up to 20 percent or more.

Table II – 19
Estimated NOx and PM Emissions Reductions
Replacement of 200 Freight MHP Locomotives
With New MHP Gen-Set Locomotives
(2,301 to 4,000 horsepower)

Location	Number of MHP Gen-Set Freight Locomotives	NOx (tons per day)	PM (tons per day)	Cost-Effectiveness ($/lb)	Capital Costs (millions)
South Coast	100	6.6	0.32	$2-4	$200
Rest of State	100	6.6	0.32	$2-4	$200
Statewide	**~200**	**13.3**	**0.63**	**$2-4**	**$400**

* Numbers may not add up precisely due to rounding.

Costs

A new MHP gen-set freight locomotive, between 2,500 and 3,500 horsepower, could cost up to an estimated $2,000,000. This cost estimate is based on the cost of a new three engine gen-set switch locomotive at about $1.5 million, with a new engine and related parts, to derive a conservative estimate of $2 million. In 2008 dollars, actual costs might be about $1.8 million. Staff chose to be more conservative on costs, as there is currently no commercial production of a four engine gen-set locomotive. Therefore, the total estimated costs would be about $400 million.

Cost-Effectiveness

Cost-effectiveness to replace an older pre-Tier 0 or Tier 0 MHP intrastate freight line haul locomotive with a new MHP gen-set locomotive could range between $2 and $3 per pound, depending on the range of useful life of between 10 and 20 years. A new MHP gen-set locomotive replacement of an older MHP locomotive is very cost-effective when compared to most current ARB control measures or options.

7. Analysis of Option 7 - Retrofit of DPF and SCR onto 400 MHP Freight and Passenger Locomotives Repowered with LEL Engines or Replaced with New MHP Gen-Set Locomotives

Technical Feasibility

Intrastate MHP freight and passenger locomotives that have been repowered with new LEL engines, or new MHP gen-set locomotives, may be potential candidates for retrofits with DPF and SCR. LEL engines and new MHP gen-set locomotives that are retrofitted with DPF and SCR may be able to approach or meet Tier 4 locomotive NOx and PM emissions levels. The new LEL engines and MHP gen-set locomotives are expected to be more combustion efficient and smaller in size. In addition, with significantly less engine emissions, an LEL engine and new MHP gen-set locomotive can potentially reduce the size needed for DPF and SCR aftertreatment.

Major concerns with locomotive aftertreatment devices are their size and weight. DPFs retrofitted onto UP and BNSF switch locomotives are the size of two pianos (2 x 1,100 pounds or more). An SCR retrofitted onto a locomotive engine has been estimated to weigh over 4,000 pounds. The SCR will also need a urea tank (about 250 gallons or more) and a urea dosing control unit to fit within the locomotive carbody. Another concern is the locomotive carbody space available to accommodate such large aftertreatment devices, and the necessary aftertreatment support equipment, is limited. The combination of a smaller, but equally powerful engine and significantly less emissions, could allow for significant aftertreatment downsizing. A smaller DOC, SCR, and DPF aftertreatment system may be able to fit within the limited locomotive carbody space.

Research is currently underway by the ARB, railroads, and locomotive and engine manufacturers to assess the technical feasibility of retrofits of LEL engines with DPF and SCR. Staff is also working on a research effort to demonstrate DPFs on gen-set locomotives. Staff believes that a DPF and SCR retrofit system for either a MHP locomotive, with an LEL engine repower or gen-set technology, could be ARB verified and commercially available by as early as 2012.

Potential Emission Reductions

UP and BNSF combined may operate about 290 older MHP two stroke engine locomotives. Staff estimates about 70 older UP and BNSF MHP locomotives in the South Coast Air Basin and an additional 230 or more statewide. California also has about 110 intrastate passenger locomotives with typically two stroke Electro-Motive Diesel (EMD) engines of about 3,000 horsepower. Combined, freight and passenger MHP locomotives may total up to 400 statewide.

Intrastate freight and passenger MHP locomotives consume an estimated 50,000 to 300,000 gallons of diesel fuel annually. In our calculations, we assumed intrastate MHP freight and passenger locomotives consume an average of about 100,000 gallons of diesel fuel annually. Staff believes this to be a conservative fuel consumption level, since intrastate passenger and larger freight MHP line haul locomotives have been documented as consuming 200,000 to 300,000 gallons of diesel fuel annually.

Based on the estimated annual activity and fuel consumption levels, staff estimates that 400 intrastate MHP freight and passenger locomotives powered by new LEL engines, or new MHP gen-set locomotives, could provide additional emissions reductions if also retrofitted with DPF and SCR. The additional NOx and PM reductions from the DPF and SCR retrofits could be up to 6.8 and 0.18 tons per day, respectively.
See Table II-20 for estimated emissions reductions.

Table II - 20
Estimates of NOx and PM Emissions Reductions
Retrofit of DPF and SCR onto 400 Intrastate MHP Locomotives
With LEL Engine Repowers or Gen-Set Replacements
(2,301 to 4,000 horsepower)

Location	Number of MHP Freight and Passenger LEL or Gen-Set Locomotives	SCR NOx (tons per day)	DPF PM (tons per day)	Capital Costs (millions)
South Coast	150	2.6	0.07	$75
Rest of State	250	4.2	0.11	$125
Statewide	**400**	**6.8**	**0.18**	**$200**

* Numbers may not add up precisely due to rounding.

Assuming 400 intrastate MHP freight and passenger locomotives are repowered with LEL engines, or replaced with new MHP gen-set locomotives, and also retrofitted with DPF and SCR, both options combined could provide up to 29.8 and 1.45 tons per day of NOx and PM statewide, respectively. See Table II-21 for the estimates of the combined NOx and PM emissions reductions.

Table II - 21
Estimates of NOx and PM Emissions Reductions
Combination of LEL Engine Repowers and Retrofit of DPF and SCR
400 Intrastate MHP Locomotives
(2,301 to 3,800 horsepower)

Location	Number of Locomotives	Emission Reductions (tons/day)					
		LEL NOx	LEL PM	SCR NOx	DPF PM	Total NOx	Total PM
Freight							
South Coast	98	5.6	0.32	1.7	0.04	7.3	0.35
Rest of State	192	11.0	0.60	3.3	0.09	14.3	0.68
Passenger							
South Coast	52	3.0	0.17	0.9	0.02	3.9	0.19
Rest of State	58	3.3	0.18	1.0	0.03	4.3	0.21
Statewide *	**400**	**22.9**	**1.27**	**6.8**	**0.18**	**29.8**	**1.43**

* Numbers may not add up precisely due to rounding.

Costs

Initial estimates of the costs to retrofit SCR and DPF onto an existing older freight or passenger MHP locomotive, that has been repowered with a LEL engine or replaced with a new MHP gen-set locomotive, is up to $500,000. The DPF and SCR retrofit costs of $500,000, would be in addition to the cost of a new LEL engine repower of about $1 million, or replacement with a new MHP gen-set locomotive at about $2 million.

Cost-Effectiveness

The cost-effectiveness of a retrofit of a DPF and SCR system onto an older intrastate MHP locomotive, that has also been repowered with a LEL engine or replaced with a new MHP gen-set locomotive, is between $2 and $3 per pound, depending on a range of useful life of between 10 and 20 years. A retrofit of DPF and SCR onto an intrastate or MHP locomotive, after a LEL engine repower or replacement with new MHP gen-set locomotive, is cost-effective when compared to most current ARB control measures or options.

8. Analysis of Option 8 - Accelerate Remanufacture of 400 Pre-Tier 0 (~350) or Tier 0 (~50) Freight and Passenger Locomotives to Meet U.S. EPA Tier 0 Plus Emissions Levels

Technical Feasibility

In 2008, U.S. EPA promulgated new locomotive emission standards. The new U.S. EPA locomotive remanufacture emission standards require new and remanufactured Tier 0 locomotives to meet the more stringent Tier 0 plus emission standards. The Tier 0 plus PM line haul locomotive emission standards were lowered from 0.6 g/bhphr to 0.22 g/bhphr, a 63 percent reduction, and NOx from 13.5 g/bhphr (pre-Tier 0 NOx) or 9.5 g/bhphr (Tier 0 NOx) to 8.0 g/bhphr or 7.4 g/bhphr (Tier 0 plus NOx), or up to a 49 percent reduction. U.S. EPA and ARB staff believes certified Tier 0 plus emissions standards remanufacture kits could be commercially available by as early as 2009.

The Tier 0 plus option is already required by the 2008 U.S. EPA locomotive rulemaking for existing Tier 0 locomotives. However, the requirements do not apply to pre-Tier 0 line haul locomotives. This option would primarily provide benefits if Tier 0 plus emission kits become available for California's large number of pre-Tier 0 MHP locomotives. According to available data, UP and BNSF and intrastate passenger operators only have about ten percent (or about 40) of intrastate MHP freight and passenger locomotives that have been remanufactured to meet the U.S. EPA Tier 0 emission standards.

The extent of implementation may be dependent on how often older two stroke MHP locomotives come in for complete remanufactures. Interstate line haul locomotives are typically remanufactured every five to seven years due to the higher hours of operation, especially in the higher power settings (i.e., Notch 5-8). However, older medium speed engine MHP locomotives usually are remanufactured at a much slower pace, due to lower hours of operation and the predominate use of lower and mid power settings. Older MHP locomotives may only be remanufactured about every 10 to 15 years. Also, due to the costs of remanufacturing, which can equal or exceed the residual value of older locomotives, railroads may decide to avoid remanufacturing until the units are retired.

Potential Emissions Reductions

As discussed above, the Tier 0 plus remanufacture kits could lower pre-Tier 0 and Tier 0 MHP locomotive emissions by up to 63 and 49 percent for PM and NOx, respectively. Remanufacturing 400 pre-Tier 0 and Tier 0 MHP locomotives to Tier 0 plus emissions standards would provide NOx and PM emissions reductions of up to about 13 and 1 tons per day, respectively, depending on the number of MHP locomotives not already subject to the federal Tier 0 plus requirements (about ten percent of California's MHP locomotives) and the rate of remanufactures for MHP locomotives in California.

Costs

The remanufacture of an existing pre-Tier 0 older MHP locomotive to Tier 0 plus emission levels could cost up to $250,000. This estimate is based on prior costs for Tier 0 remanufacturing kits of up to $200,000. U.S. EPA estimated that the Tier 0 plus kits would be less than $50,000, but these costs do not account for labor and testing costs and other related parts. Staff expects that the Tier 0 plus remanufacture kits would be about the same price or slightly higher than actual Tier 0 remanufacturing costs. Therefore, we have estimated the costs of a Tier 0 plus remanufacture kit at a slightly higher level than a Tier 0 remanufacture or about $250,000.

Cost-Effectiveness

Cost-effectiveness to remanufacture an older pre-Tier 0 or Tier 0 MHP freight or passenger locomotive, with a U.S. EPA Tier 0 plus package, is estimated to be between $0.3 and $0.5 per pound, depending on the range of useful life between 10 and 20 years.

C. Interstate Line Haul Locomotives

1. Types of Line Haul Locomotives

Freight interstate line haul locomotives typically have large diesel-electric engines of greater than 4,000 horsepower and operate on 6 axles. UP and BNSF's interstate line haul locomotives are on average about 15 years old or so. Interstate line haul locomotives are typically the newest and highest horsepower locomotives available to railroads. Interstate line haul locomotives can move the most volume of freight, most efficiently and reliably, and over the greatest distances. Interstate line haul locomotives in a consist, usually three or more locomotives, pull trains with railcars as long as one to two miles long. Interstate line haul locomotives traverse mountains, desert, and other challenging terrains as they cross the country from destinations like Chicago to Los Angeles.

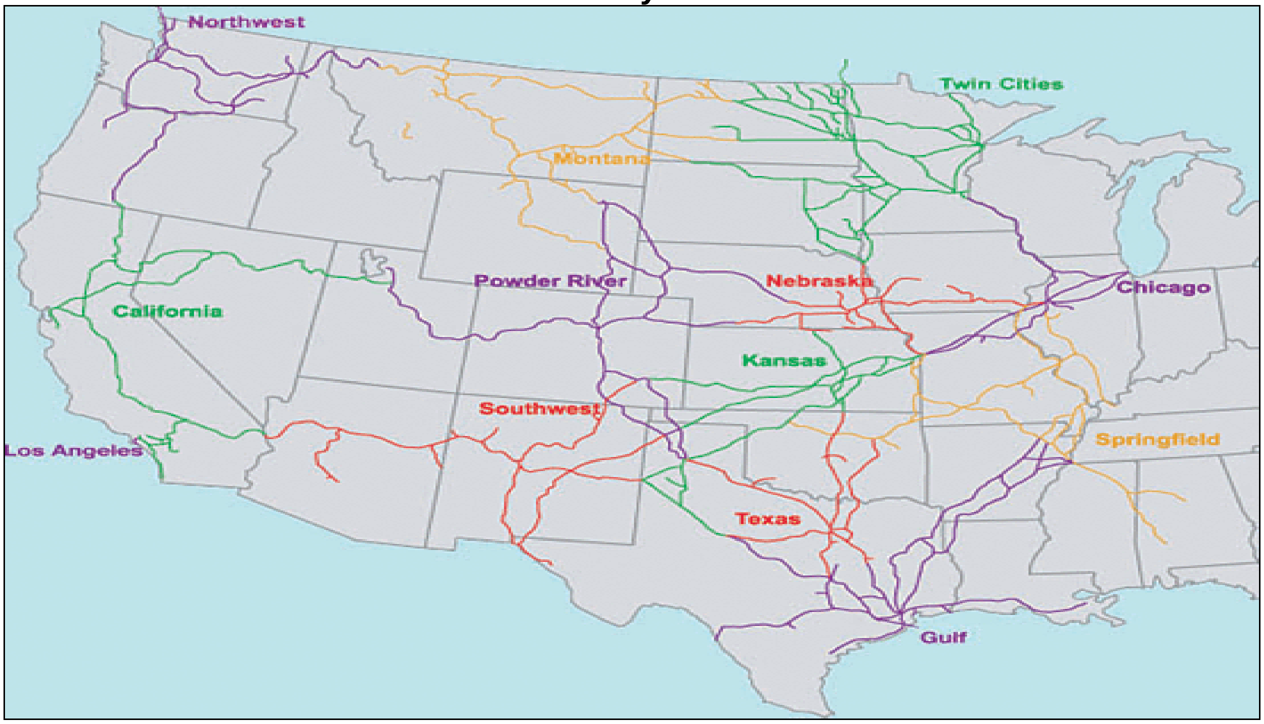
2. BNSF and UP Major Cross-Country Rail Line Routes

The predominant California UP and BNSF interstate line haul locomotive routes are from the Ports of Los Angeles and Long Beach and Port of Oakland both to Chicago. BNSF's major southern route is from the Port of Los Angeles and Long Beach via San Bernardino and north over the Cajon Pass towards Barstow and then east to Needles, California. From Needles, the BNSF route goes north towards Winslow, Arizona and then east to Belen, New Mexico which is a major BNSF refueling depot. Ultimately, the route runs north via through Texas and to Kansas City and to as far east as Chicago. This BNSF transcontinental route is referred to as the Transcon.

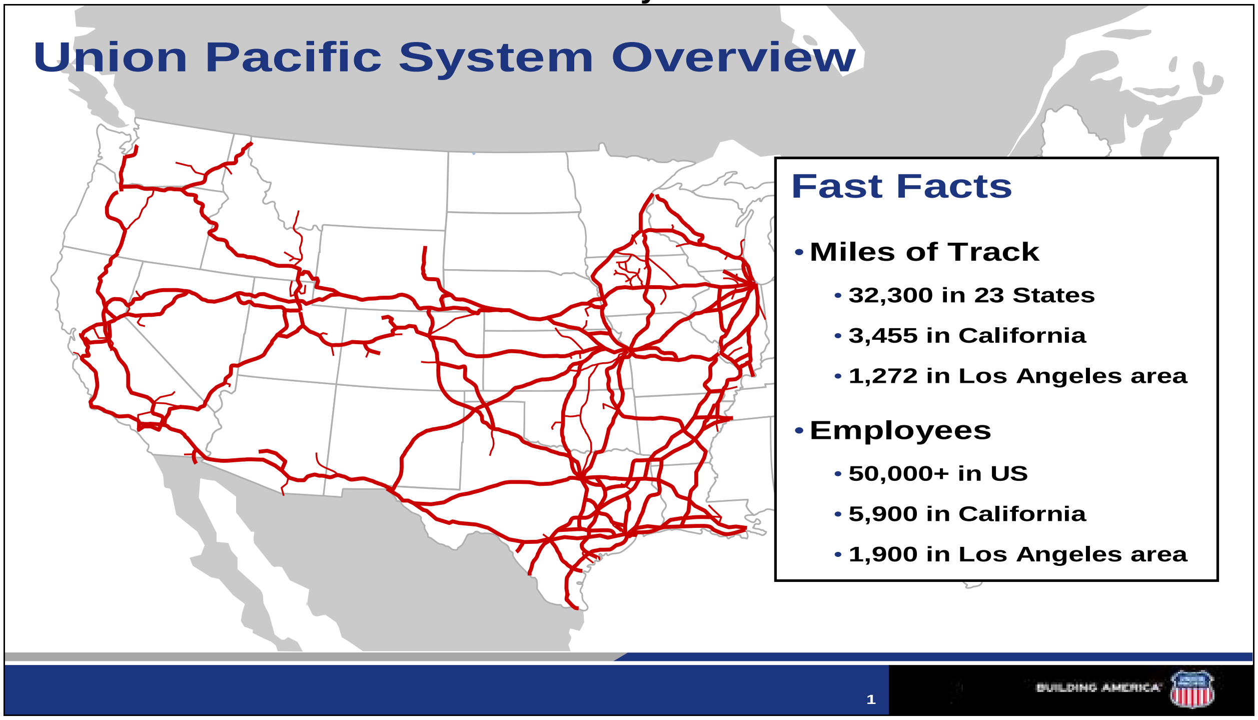
UP also has a similar route which is from the Los Angeles ports via Colton, then north over the Cajon Pass and through Barstow to Yermo, California. From Yermo, the UP line runs northeast through Las Vegas and Salt Lake City. From Salt Lake City the route runs east through Rawlins, Wyoming – a major refueling depot for UP – and east past the UP Bailey Yard in Nebraska and ultimately east to Chicago. UP's southern route from the Los Angeles Ports via Colton, but then turns south to Yuma, Arizona and then east to El Paso, Texas, and can then continue through the south or can go north to Chicago. This UP southern line is referred to as the Sunset Route.

From the Port of Oakland, BNSF trains typically route through the San Joaquin Valley to Barstow, and then to Needles, and then onto the Transcon. UP trains typically use the route from the Port of Oakland east towards UP Roseville and east through Nevada and ultimately east to Chicago. UP, also to a lesser extent than BNSF, uses the San Joaquin Valley route towards Southern California.

BNSF Railway's
Interstate Line Haul Locomotive – System Routes in the United States



Union Pacific Railroad's
Interstate Line Haul Locomotive – System Routes in the United States



3. Interstate Line Haul Locomotive Operational Duty Cycles

The operational duty cycles of newer high horsepower interstate line haul locomotives are dominated by higher power (notch) settings (i.e., Notch 5-8) when traveling cross country on main rail lines. When interstate line haul locomotives do operate within railyards (e.g., to trim with railcars to form trains or receive fuel, service, or maintenance) they typically operate in idle or lower power settings, which is about 40 percent of their total operational time. As a comparison, the effects of line haul locomotive power settings on diesel fuel consumption are significant. In idle or power setting Notch 1 a line haul locomotive may consume about 5 to 10 gallons per hour, whereas in Notch 8 a line haul locomotive may consume up to 200 gallons per hour.

A typical interstate line haul locomotive may consume 250,000 to 500,000 gallons or more of diesel fuel annually. However, interstate line haul locomotives might spend only about 15 percent (e.g., 600 miles round trip – Needles to the Ports of Los Angeles/Long Beach and back) of a cross-country 4,200 mile round trip operating in California. Under the latter assumption, interstate line haul locomotives would consume about 50,000 to 75,000 gallons of diesel fuel annually within the state.

4. Interstate Line Haul Locomotives: Statewide and Railyard Emissions

The ARB emission inventory estimates that interstate line haul locomotives (e.g., Los Angeles to Chicago) contribute about 90 percent of the statewide locomotive NOx and PM emissions. Interstate line haul locomotives emissions do not concentrate their operations in specific local or regional areas like many switchers and medium horsepower locomotives. Instead, interstate line haul locomotive operations are distributed over many areas of the state.

Between 2015 and 2020, California should have nearly a statewide Tier 2 locomotive fleet average, largely due to the 1998 Locomotive NOx Fleet Average Agreement in the South Coast Air Basin (required by January 1, 2010) and normal locomotive fleet turnover in UP and BNSF national fleets that would benefit the rest of the state. Under this latter assumption, the primary difference in interstate line haul locomotive emissions would be the difference between Tier 2 and Tier 4 new interstate line haul locomotives. That difference would be about a 76 and 85 percent reduction in NOx and PM emissions, respectively, between Tier 2 and Tier 4 interstate line haul locomotives.

5. Analysis of Option 9 – Accelerated Replacement of Line Haul Locomotives

Based on prior experience, it may take more than 30 years for national fleets to turnover (or from 2015 to 2045) to the new Tier 4 interstate line haul locomotives and to fully realize the Tier 4 emission benefits. This option would evaluate the accelerated use of new Tier 4 interstate line haul locomotives in California after 2015.

If the options to replace switchers and repower and replace MHP locomotives were fully implemented, there would be no other California locomotives left to provide the flexibility for a California Tier 4 interstate line haul locomotive fleet average. Hence, this option would simply accelerate the number of Tier 4 interstate line haul locomotives directed by UP and BNSF to operate in California, without any averaging elements.

Technical Feasibility

GE and EMD are currently on schedule to commercially produce new Tier 4 interstate line haul locomotives by 2015. Prototypes of Tier 4 interstate line haul locomotives should be built by about 2013, which would allow two years for field testing prior to commercial production.

Note that U.S. EPA included compliance flexibility provisions as an option for locomotive manufacturers in complying with the Tier 4 emission standards. One option allows locomotive manufacturers to meet a 2.6 g/bhphr NOx standard in-use for three model years (i.e., 2015/2016/2017). The other option allows locomotive manufacturers to meet a 1.9 g/bhphr NOx standard in-use for seven model years (i.e., 2015-2022). GE and EMD may not seek the compliance flexibility. However, if GE and EMD do seek the compliance flexibility, it could reduce the actual emissions reductions provided by early models of Tier 4 locomotives over the operational life of the Tier 4 locomotive.

Potential Emissions Reductions

The ARB emission inventory estimates that 1,200 interstate line haul locomotives will operate in California on any given day by 2020. We have assumed only the emissions differences between Tier 2 and Tier 4 locomotives in California by 2020. With these assumptions, a statewide Tier 4 interstate line haul locomotive fleet of 1,200 could provide up to 31.62 tons per day of NOx and 1.28 tons per day of PM emission reductions, respectively.

Costs

Interstate line haul locomotives are manufactured either by General Electric (GE) or Electro-Motive Diesel (EMD). Currently, new Tier 2 locomotives can cost from $1.8 million to $2.2 million, depending on accessories and options. With new Tier 4 line haul locomotives, DPF and SCR aftertreatment may increase new locomotive capital costs by up to $500,000. As a result, a new Tier 4 interstate line haul locomotive, with advanced engine design and upgrades, may cost between $2.5 to $3.0 million with GE and EMD commercial production of Tier 4 locomotives in 2015. Staff has assumed the upper end capital costs of $3.0 million per Tier 4 line haul locomotive.

A UP and BNSF Tier 4 fleet available to operate in California would require at least 1,200 Tier 4 interstate line haul locomotives operating in California on any given day by 2020. At up to $3 million per Tier 4 interstate line haul locomotive, UP and BNSF would need to spend about $3.6 billion for a 1,200 Tier 4 locomotive fleet dedicated to California only.

UP and BNSF argue, however, that up to a national pool of 4,800 UP and BNSF Tier 4 interstate line haul locomotives would be needed to ensure 1,200 of them were operating in California on any given day. See Table II-22 for an illustration.

Table II - 22
Estimated Number of UP and BNSF National Fleet Tier 4 Locomotives Needed to Ensure 600 in California on Any Given Day in 2020

UP Tier 4 Locomotives	**BNSF** Tier 4 Locomotives	**Total UP and BNSF** Tier 4 Locomotives	**California** (Number On Any Given Day) Tier 4 Locomotives
2,880	1,920	4,800	1,200 [1]

[1] Estimate by ARB staff using available railroad data.

A national pool of 4,800 UP and BNSF Tier 4 interstate line haul locomotives directed to operate towards California would cost an estimated $14.4 billion. It should be noted, that as the interstate line haul locomotives move from primarily Chicago to California, a number of other states would be receiving the Tier 4 emission reductions benefits, too. Therefore, a case could be made that potential costs should be shared proportionally over the other states enroute to California in the UP and BNSF operating systems. California's share would be $3.6 billion for 1,200 Tier 4 dedicated interstate line haul locomotives.

Cost-Effectiveness

By 2015, staff estimates UP and BNSF may pay up to $3.0 million for each new Tier 4 interstate line haul locomotive. The cost-effectiveness of a Tier 4 interstate line haul locomotives, consuming 500,000 gallons per year, would be within a range $3-$8 per pound NOx and PM reduced nationally. Assuming operations of only 20 percent within California, and consuming 100,000 gallon per year in California, the cost-effectiveness might range between $6 and $11 per pound or more of NOx and PM reduced within the state.