Assessment of the Effects of Proposed Locomotive Regulations on Goods Transport Modes and Locomotive Emissions

Contract Number 92-930

Final Report

February 1996

Submitted to:
California Air Resources Board
Mobile Source Division
9528 Telstar Avenue
El Monte, California 91731

Submitted by:
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In cooperation with:
Abacus Technology Corporation
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Executive Summary

The California Air Resources Board (ARB) has determined that locomotives contribute significantly to the air quality problems across the state. In 1987, locomotives accounted for 155 tons per day of oxides of nitrogen emissions (NO_x). This contribution accounts for approximately 5 percent of the state's total NO_x emissions inventory. Currently, locomotives operating in California are not subject to any type of emissions mitigation program, except for some locally adopted opacity limits. Locomotives comprise one of the largest classes of uncontrolled NO_x and oxides of sulfur (SO_x) sources. Consequently, the ARB has determined that substantial NO_x emissions reductions can be achieved by formulating and promulgating control strategies that target this source.

Overview of Study Objectives and Approach

Little is known about the indirect economic impacts of strategies to mitigate emissions from locomotives. For instance, the railroad industry argues that rail, as a low-cost provider of freight transport, is integral to the distribution of goods and services in California. They further argue that emissions regulations that focus on locomotives will increase the cost of providing service and will increase the rates that the railroads charge to their customers. Given the alternative modes that exist to transport freight, increases in rail rates may cause significant shifts from rail to other modes, especially from rail to truck. Mode shifts that result from locomotive emissions regulations may, in turn, be counter-productive to solving the air quality problems attributable to freight transportation, since trucks emit more pollutants per ton of freight moved than does the rail mode. The purpose of this study is to assess the effects of proposed locomotive emissions regulation strategies on mode choice and locomotive emissions and to formulate the framework for an active market for locomotive emissions reduction credits.

The approach employed in this study includes the following five tasks, each of which addresses various study objectives.

- *1) Estimate Commodity Flows by Mode* — Surprisingly, prior to this study little was known about the modal share of freight transport in California. As a result, a major focus of this effort is to estimate modal splits, particularly between rail and rail-competitive trucks.

- *2) Calculate the Contribution of Emissions by Goods Transport Mode* — The air quality planning processes employed by states and metropolitan planning organizations across the country do not focus specifically on emissions from freight transport activities. The relative contribution of freight modes to emissions in a region is seldom reported in State Implementation Plans or regional Air Quality Management Plans. Therefore, one objective of this study is to isolate freight-related emissions by mode and to ascertain changes in modal emissions resulting solely from economic and/or demographic growth.

- *3) Perform a Comprehensive Review and Evaluation of Mode Choice Models* — To ensure that the ARB is fully cognizant of the factors that determine mode choice or mode shifts, and to ensure that the best possible forecasting tools are used in this study, a comprehensive review and evaluation of previously conducted mode shift analyses needs to be performed.

- *4) Assess the Direction and Magnitude of Mode Shifts Attributable to Locomotive Emissions Regulations* — Using the best possible mode shift model, the central objective of this study is to determine the mode choice impacts of various locomotive emissions control strategies and to determine the consequent emissions repercussions.

- *5) Develop the Framework for an Active Locomotive Emissions Market* — The final objective of this study is to determine the best possible framework for an active market in locomotive emissions reduction credits.

Base Year and Forecast Emissions (No-Control Scenario)

The relative NO_x emissions from the four competing freight transport modes are compared in Exhibit E-1. In 1987, this study's base year, railroad locomotives contributed approximately 20 percent of California's NO_x emissions attributable to the four modes representing the freight transportation sector. They also contribute about 6 percent of California's mobile source NO_x emissions and about 4 percent of California's total NO_x emissions.

Marine vessels operating in California waters contribute slightly greater estimated NO_x emissions than locomotives and are therefore good candidates for control measures. Ships offer more flexibility for accommodating the weight and volume of emissions control hardware than trucks and locomotives. On the other hand, enforcing emissions limits on ships is probably more difficult than for any other mode. Nonetheless, such efforts are underway. The potential for diversion of freight from rail to ships, however, is judged in this study to be small. Consequently, this study does not address the potential of modal diversion from rail to commercial marine vessels.

Overall, civil aircraft contribute only about 3 percent of the NO_x emissions from the four modes, and the majority of those emissions are from passenger operations. Air freight operations are therefore not a significant source of NO_x emissions in California. Furthermore, because cargos that are typically shipped by rail are very unlikely to be diverted to air freight, aircraft were not considered in the diversion analysis.

Of the four competing freight shipping modes, heavy-heavy-duty diesel trucks (i.e., diesel trucks weighing over 33,000 pounds GVW) contribute the greatest percentage of NO_x emissions; nearly 52 percent of NO_x emissions attributable to the four freight shipping modes and almost 12 percent of all NO_x emissions in the state. Truck lines are also the primary competitor with railroads for freight revenues. Therefore, the modal diversion analysis only considers the

Exhibit E-1

NO_x Emissions Contributions by Freight Mode (1987)

Freight Mode	NO_x (Tons/Day)	Percent of Total	ROG (Tons/Day)	Percent of Total
Rail	155	20%	7	6%
Truck*	402	52%	68	60%
Water	186	24%	12	11%
Air	27	3%	26	23%
Total	771		112	

* Only includes diesel trucks weighing over 33,000 lbs. GVW (i.e., those trucks that compete with rail for shipments).

possibility of diversions between these two modes.

Exhibit E-2 presents truck and rail NO_x emissions on a ton-mile basis. In 1987, heavy-heavy-duty diesel trucks emitted almost twice the amount of NO_x per ton-mile than rail. Truck movements emit, on average, 0.009 pounds per ton-mile of freight moved, while rail movements emit 0.005 pounds per ton-mile of freight moved in California. This result has important ramifications when developing emissions control strategies for freight transport in the state. Regulations must be developed that approach emissions control at the system level by accounting for the relative contribution of each mode at the margin. Furthermore, strategies that result in large diversion shifts from rail to truck may be counter productive from the perspective of total freight emissions.

The forecast California locomotive NO_x emissions in 2010, under a no-control scenario, is 57,583 tons (or almost 158 tons/day). The 2010 emissions forecast represents an increase of less than one percent over the 1987 base year emissions estimate. It suggests that technical and operational improvements (aerodynamics, dispatching, etc.) will combine with the decreased activity expected in the local and yard sectors to offset increases in emissions from the anticipated increase in linehaul activity, particularly in relatively pollution-intensive intermodal operations. These factors also account for the reduction in locomotive emissions per ton-mile of freight moved. Rail is expected to account for 36,541 million ton-miles of freight by 2010 under a no-control scenario. Consequently, rail is expected to emit 0.003 pounds of NO_x per ton-mile in 2010, a decrease of 40 percent from the 1987 baseline of 0.005 pounds of NO_x per ton-mile.

As shown in Exhibit E-2, NO_x emissions from trucks operating in California during 1987 contributed 0.009 pounds/ton-mile of freight moved. This contribution reflects a fleet average NO_x emissions rate of 7.83 grams/Bhp-hr, as estimated by EMFAC7, and the prevailing NO_x standard during that year of 6 grams/Bhp-hr. In 1991, the NO_x standard was reduced by the ARB to 5 grams/Bhp-hr, and EMFAC estimates the 2010 fleet average NO_x emissions rate to be 4.6 grams/Bhp-hr—not including the proposed drop in the standard to 4 grams/Bhp-hr in 1998. Furthermore, by 2010 many technologies may be incorporated that affect truck emissions rates during a given trip. For example, aerodynamic improvements that are implemented to reduce fuel consumption may have emissions reduction consequences on a grams/Bhp-hr basis. Improvements in fuel management may also result with decreases in emissions rates. These technologies, as well as others that are deployed to comply with more stringent standards, will penetrate the fleet slowly since the operational life of a heavy-heavy-duty diesel truck often exceeds 10 to 15 years. Consequently, this analysis assumes that, on average, heavy-heavy duty diesel trucks will emit NO_x at a rate of 5 grams/Bhp-hr (i.e., the prevailing standard).

Assuming that the percentage change in average emissions from 7.83 to 5 grams/Bhp-hr holds on a ton-mile basis, trucks are expected to emit 0.006 pounds/ton-mile of freight moved in 2010 under the no-further-control scenario. Using this study's forecast for heavy-heavy-duty diesel truck ton-mileage in 2010 of 52,148 million, it is estimated that these vehicles will contribute roughly 410 tons/day of NO_x emissions during that year.

Exhibit E-2

Rail and Truck NO_x Emissions per Ton-Mile of Freight Moved 1987 and 2010 (No-Control)

	1987		2010 (No-Control)	
	Rail	**Truck***	**Rail**	**Truck**
Ton-Miles (millions)	24,592	32,717	36,541	52,148
NO_x Emissions (tons/day)**	155	402	158	410
NO_x Emissions (lbs/ton-mile)	0.005	0.009	0.003	0.006

* According to EMFAC7, the 1987 heavy-duty diesel truck fleet average NO_x emissions rate was 7.83 g/Bhp-hr. The truck emissions estimates shown above reflect this fleet average.

** Numbers may not add up exactly because of rounding.

CALFED and Changes in Rail Cost Advantage by Regulatory Scenario

After reviewing the available modal diversion models that reported parameters which could be used for the current effort, the CALFED modal diversion algorithm was selected as the most useful modal diversion analysis tool for the present study.

CALFED disaggregates freight flows in California by 16 commodity/activity categories, five sub-state regions, and six origin-destination (O-D) regions. Modal diversion is determined as a function of the relative cost of rail and trucking. Diversion is calculated for each commodity and each O-D region. A parameter that measures the sensitivity to service cost (i.e., rail costs as compared to truck costs) has been calculated for each commodity and this is applied to the change in the rail cost advantage per ton-mile for transport of each commodity to or from each O-D region. This parameter is a measure of how much the rail share (expressed in terms of ton-miles) of the shipments of a given commodity will change for every dollar change in the rail cost advantage per ton-mile as compared to truck costs. An adjustment is made which takes into account the current mode split for each commodity shipped between each O-D pair. Thus, flows which have a relatively even mode split are assumed to be very competitive and the sensitivity to each mode's cost of service is the major determinant of mode shift when the relative costs of rail and trucking change. Whereas, flows which are dominated by one mode or the other are less competitive and experience less relative diversion in response to a change in rail or trucking costs. Aside from this adjustment (which implicitly takes into account the importance of non-cost variables on the historic mode split for a given commodity shipped between a given origin and destination), the CALFED modal diversion algorithm only considers explicitly the impacts of changes in the relative costs of rail and trucking and does not consider the impacts of changes in other service variables, such as time delays that might be associated with changing locomotives to comply with California locomotive emissions regulations.

There are several obvious advantages of the CALFED model. These are listed below:

- it is based on actual California shipment data;
- mode cost sensitivities are developed by commodity group and thus reflect the unique commodity characteristics which would favor one mode over another irrespective of mode cost (e.g., commodity value, use rate, shelf life, etc.);
- modal diversion is calculated for O-D pairs which reflects the actual production and consumption patterns of California economic regions and their trade relationships with the rest of the nation;
- it uses aggregate shipment data which are the only data readily available without additional survey work;
- it implicitly considers the impact of length of haul on mode choice through the procedure used to calculate the model parameters; and

- it includes a variable which takes into account the current competitive position of rail versus truck for each commodity group which helps offset some of the bias in other model parameters which are estimated with 1977 data.

In this study, CALFED was employed to estimate the diversion and resulting NO_x emissions impacts under six regulatory strategy scenarios. Since the focus of this study is on the impacts of locomotive emissions, the first four scenarios isolate the effects of the following locomotive NO_x emissions control technologies:

Technology	**Description**
Dual-Fuel (DF)	Natural gas fuel is mixed with engine intake air; ignition in the cylinder is accomplished by injecting a small amount of diesel fuel near top-dead-center of the piston stroke, as in a conventional diesel engine.
Liquid Natural Gas with Spark-Ignited Engine (LNG-SI)	A spark-ignited (Otto cycle) engine is fueled by natural gas.
Selective Catalytic Reduction (SCR)	A chemical reductant (ammonia or urea) is mixed with the engine exhaust gas; this mixture undergoes a catalyst-promoted reaction, reducing NO_x to harmless N_2 and water (and CO_2 if urea is used as the reductant).
Dual Fuel plus Selective Catalytic Reduction (DF+SCR)	A dual-fuel locomotive is equipped with selective catalytic reduction.

The last two scenarios have been designed to capture the range of possible mode shift given combined locomotive and truck control strategies. Scenario 5 assumes that locomotives operating in California will be powered by dual-fuel engines, while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn spark-ignition engines. Dual-Fuel is the least expensive strategy for locomotives investigated in this study. LNG/Lean-Burn SI is the most expensive strategy for trucks investigated in this study. Consequently, this scenario has been designed to represent the high-end of diversion from truck to rail. Likewise, Scenario 6 has been designed to represent the high-end of diversion from rail to truck, since it includes the most expensive locomotive regulation (SCR) and the least expensive truck regulation (CNG/Lean-Burn SI). The six scenarios are summarized below.

- *Scenario 1* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 2* — assumes that locomotives operating in California in 2010 will be powered by LNG-SI engines, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.
- *Scenario 3* — assumes that locomotives operating in California in 2010 will be powered by Dual-Fuel engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.
- *Scenario 4* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.
- *Scenario 5* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.
- *Scenario 6* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will be powered by CNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.

As reported in Exhibit E-3, the change in the cost advantage of rail ranges from -0.08 to -0.31 cents (1977 dollars) for those scenarios that isolate the impacts of locomotive regulations (i.e., Scenario 1 to 4). The change in the cost advantage of rail for Scenario 5 is 0.34, signaling a shift from truck to rail. While that for Scenario 6 is -0.11, signaling a shift from rail to truck. These changes in the cost advantage of rail are employed to calculate mode shifts using CALFED's mode choice sensitivity parameters.

Modal Diversion and Emissions Impacts by Scenario

Exhibit E-4 presents the results of the diversion analysis for each of the six regulatory scenarios. Scenario 1, *Dual-Fuel for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 406 million in 2010, or by 1.1 percent. Consequently, in 2010 heavy-heavy-duty diesel truck ton-miles are expected to increase to 52,554 million from 52,148 million. The estimated diversion impact of Scenario 2, *LNG-SI for Rail and No Further Control for Trucks*, is a decrease in rail ton-miles and a corresponding increase in truck ton-miles of 762 million, representing a drop in rail ton-miles of 2.1 percent. Likewise, Scenario 3, *DF+SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,168 million, or by 3.2 percent, while Scenario 4, *SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,625 million in 2010, or by 4.4 percent. The diversion impact of

Exhibit E-3

Regulatory Scenarios for Diversion and NO_x Emissions Analysis

	New Rail Freight Rate (in Cents/ Ton-Mile, 1987$)	New Truck Freight Rate (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1977$)
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	2.82	22.48	-0.09	-0.08
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	2.90	22.48	-0.17	-0.15
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	3.00	22.48	-0.27	-0.23
Scenario 4 - SCR for Rail no Further Control for Trucks	3.13	22.48	-0.38	-0.31
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	2.82	22.97	0.41	0.34
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	3.13	22.72	-0.13	-0.11

Exhibit E-4

Modal Diversion by Regulatory Scenario (2010)

Scenario	Δ in Rail Ton-Miles (Millions)	% Δ in Rail Ton-Miles	New Rail Ton-Miles (Millions)	New Truck Ton-Miles (Millions)
No Control 2010 Baseline	--	--	36,541	52,148
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	-406	-1.1%	36,135	52,554
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	-762	-2.1%	35,780	52,910
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	-1,168	-3.2%	35,373	53,316
Scenario 4 - SCR for Rail no Further Control for Trucks	-1,625	-4.4%	34,916	53,774
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	+1,727	+4.7%	38,269	50,421
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	-610	-1.7%	35,932	52,758

Note: Numbers may not add up exactly because of rounding.

Scenario 5, *SCR for Rail and CNG/Lean-Burn SI for Trucks*, is estimated to be an increase in rail ton-miles of 1,727 million, since the rail cost advantage increases for this scenario. In contrast, Scenario 6, *Dual-Fuel for Rail and LNG/Lean-Burn SI for Trucks*, is expected to decrease rail ton-miles by 610 million.

This analysis shows the importance of developing emissions control strategies that account for the full economic impacts of regulation. Diversion can result in increases in the activity of higher polluting sources that may negate some of the expected emissions benefits of the regulatory initiative. A system-wide approach is necessary to fully account for the indirect economic and emissions impacts. Depending on the mix of regulations promulgated for each source, or mode, the diversion impact may either increase or decrease the activity of a given source. For example, Scenario 5 resulted in increased rail activity relative to truck, while Scenario 6 resulted in decreased rail activity relative to truck. As a result, regulations that impact competition between modes must be analyzed in conjunction to one another to ensure that the net emissions consequences are accounted for in the promulgation process.

Exhibit E-5 presents the corresponding NO_x emissions impacts of each scenario that result from changes in the NO_x emissions factors of locomotives and trucks and of modal diversion. For each scenario, combined truck and rail 2010 NO_x emissions are significantly lower when compared to the 2010 no-control scenario. Scenarios 5 and 6 provide the largest combined truck and rail NO_x emissions reductions. This is because under Scenarios 1 to 4 no further emissions controls from those currently prevalent are assumed for heavy-heavy-duty diesel vehicles. Consequently, increases in truck activity, resulting mostly from economic and demographic growth, offset benefits accrued from locomotive emissions control strategies.

The results presented in Exhibits E-4 and E-5 highlight the relative importance of diversion versus changes in emissions factors resulting from the regulatory strategies examined in this study. In Scenarios 1 to 4, emissions reductions are mostly driven by changes in the emissions rate of locomotives—since significant emissions reductions are achieved from the 2010 no-control baseline even though only small reductions in rail activity occur as a result of decreases in the rail cost advantage (see Exhibit E-4). For example, 2010 locomotive NO_x emissions under the no control scenario are 158 tons/day. Rail NO_x emissions under Scenario 3 are estimated to be 21 tons/day in 2010, a decrease of 87 percent from the 2010 no control level. However, rail ton-miles under Scenario 3 only decrease by 3.2 percent. Consequently, most of the emissions reductions are associated with the effectiveness of control strategies rather than with modal diversion.

The emissions consequences of the regulatory scenarios investigated in this study are encouraging. Diversion by itself is not expected to have a major impact on emissions by mode. Rather, emissions reductions are mostly driven by changes in the emissions rates of locomotives and heavy-heavy-duty diesel trucks that result from technology deployment.

Exhibit E-5

Resulting NO_x Emissions Impacts by Regulatory Scenario (2010, in Tons/Day)

Scenario	Truck NO_x	Rail NO_x	Total NO_x	Difference From 2010 No-Control
No Control 2010 Baseline	410	158	568	--
Scenario 1 - Dual-Fuel for Rail *no Further Control for Trucks*	413	39	452	-116
Scenario 2 - LNG-SI for Rail *no Further Control for Trucks*	416	23	439	-129
Scenario 3 - DF+SCR for Rail *no Further Control For Trucks*	419	21	440	-128
Scenario 4 - SCR for Rail *no Further Control for Trucks*	423	41	464	-104
Scenario 5 - Dual-Fuel for Rail *LNG/Lean-Burn SI for Trucks*	159	41	200	-368
Scenario 6 - SCR for Rail *CNG/Lean-Burn SI for Trucks*	166	42	208	-360

Note: Results may not add up exactly because of rounding.

Markets for Locomotive Emissions — Recommended Market Design

Three market designs were evaluated in this study: emissions allocation trading, emissions reduction credit (ERC) trading, and emissions averaging.

- *Emissions Allocation Trading* — emissions allocations are distributed to emissions sources within a jurisdiction and the allocations may then be bought and sold in an emissions market. The source (e.g., a railroad) must keep its total emissions in the jurisdiction beneath the level set by its emissions allocation. The jurisdiction may be the state or an air pollution control district.

- *ERC Trading* — emissions reductions are certified prior to the issuance of ERCs by pollution control officials. The ERCs may then be traded. A source creating ERCs must keep its emissions below the new limit approved by officials in granting the ERCs. A source purchasing ERCs may increase its emissions by the amount of the ERC.

- *Emissions Averaging* — no specific limit is placed on a source's total emissions. Rather, a limit is placed on the emissions rate of each piece of equipment. If the emissions rate of a given piece of equipment is lowered below its limit, then the rate for another piece of equipment may be increased. The allowable increase in the emissions rate is determined using a weighting system in which the expected rates of utilization for each piece of equipment are used as the weights. Emissions averaging may be conducted at the state or local level. In the case of locomotives, averaged emissions may reflect one railroad or several railroads.

In this study, the following assumptions govern the evaluation and development of candidate market designs: 1) that declining statewide caps are placed on locomotive emissions; 2) that a simplified approach for emissions calculations is developed by the U.S. EPA in its proposed national locomotive rule, or that alternative approaches based on current methodologies developed by the ARB (e.g., methodologies developed by Booz•Allen or EF&EE) are employed; and 3) that air quality goals are developed in terms of either a SIP for a nonattainment area or an air quality maintenance plan for a "prevention of significant deterioration" area (i.e., emissions limits for locomotives and other sources are developed with respect to local environmental conditions).

Of the three market designs investigated in this study, emissions allocation trading is the best suited strategy when combined with a rigid, declining, statewide cap on locomotive emissions. ERC trading adds a costly step that inhibits market participation (i.e., certifying a proposed ERC increases transaction costs). Emissions averaging does not result with significant economic benefits nor does it ensure adherence to the statewide emissions cap.

Under emissions allocation trading, the statewide cap will be used to determine yearly emissions allocations for each railroad operating in the state's air pollution control district or air quality management district. Allocations should be based on the relative, historical contributions of specific polluters (e.g., railroads, power plants, trucking firms, etc.) to emissions in a given air pollution control district. Once allocations have been prescribed to each polluter participating in the recommended emissions allocation scheme, emissions trading will be possible internally within railroads, between railroads, or between railroads and other emissions sources located in a particular district. The suggested unit of trade is tons of emissions per year. Annual emissions limits could be translated to daily limits to accommodate air quality modeling. The duties of a pollution control agency under the recommended market design include the following: assignment of emissions allocations, recording of trades of emissions allocations, monitoring of emissions, and enforcement of emissions limits. Information on the contribution of emissions by source (i.e., stationary sources, rail operations, trucking, etc.) available from SIPs and air quality management plans can serve as the basis from which rigid caps and emissions allocation strategies can be developed.

Under the recommended emissions allocation trading scheme, the state would collect and certify locomotive emissions from railroad operations in each district and disseminate these data to each air quality district. There are a number of methods for accomplishing this state function. This analysis, however, assumes that a simplified approach for estimating the contribution of locomotives to emissions in each district based on methodologies developed by the U.S. EPA in its proposed national locomotive rule, or that an alternative approach based on methodologies previously developed for the ARB, will be employed by California. If measures taken by a given railroad increase the railroad's contribution to emissions in a given district to levels that exceed the prescribed allocation, the railroad must either 1) reduce emissions from the other sources that it operates within the district, 2) obtain additional allocations from another railroad operating in the given district, or 3) obtain emissions allocations from another source (e.g., a stationary source located in the district). Conversely, if a railroad institutes measures that decrease its contribution to emissions in a particular district to levels below its prescribed allocation, the railroad would be able to trade surplus allocations to other railroads or sources.

The following attributes of emissions allocation trading exemplify its inherent advantages over ERC trading and emissions averaging.

- Emissions allocation trading affords the greatest economic benefit since it provides the largest trading universe (i.e., it provides the greatest opportunity to reduce costs associated with NO_x emissions control).

- Emissions allocation trading preserves the emissions cap, thereby maintaining the desired level of environmental protection.

- Emissions allocation trading results in the lowest transactions costs, thereby maximizing the level of market participation.

- Emissions allocation trading will provide railroads with the easiest method for reducing cost burdens associated with the implementation of rigid, declining statewide emissions caps.

However, to maximize the potential benefits of emissions allocation trading, it is necessary to establish emissions trading systems in all jurisdictions of the state where there is likely to be a demand for emissions allocations, and to ensure that, at least with respect to railroads, emissions allocation programs across jurisdictions operate in a uniform manner. Implementing a trading scheme that maximizes the opportunity for trades provides significant economic benefits to market participants. However, even when comprehensive and uniform schemes are developed there will still be the added burden of identifying trading partners in each jurisdiction. State and local emissions clearing houses will ease this burden.

1. Introduction

The California Air Resources Board (ARB) has determined that locomotives contribute significantly to air quality problems across the state. In 1987, locomotives accounted for 155 tons per day of oxides of nitrogen emissions (NO_x). This contribution accounts for approximately 5 percent of the state's total NO_x emissions inventory. Currently, locomotives operating in California are not subject to any type of emissions mitigation program, except for some locally adopted opacity limits. Along with commercial marine vessels, locomotives comprise one of the largest classes of uncontrolled NO_x and oxides of sulfur (SO_x) sources. Consequently, the ARB has determined that substantial NO_x emissions reductions can be achieved by formulating and promulgating control strategies that target this source.

In order to achieve state and Federal standards for ambient ozone concentrations, the South Coast Air Quality Management District, for example, estimates that NO_x emissions in 2010 must be reduced by 69 percent from the 1987 level. In response to this need, the ARB recently completed a study that investigates possible regulatory strategies for mitigating locomotive NO_x emissions.[1] The study concluded that various feasible and cost-effective strategies for controlling locomotive emissions exist for potential promulgation by the ARB. These include, among others investigated, selective catalytic reduction (SCR), use of liquified natural gas (LNG) fuel with low-emissions dual-fuel or spark-ignition (SI) natural gas engines, and LNG combined with SCR.

However, little is known about the indirect economic impacts of these strategies, particularly as they related to the efficient transport of goods and services in California. For instance, the railroad industry argues that rail, as a low-cost provider of freight transport, is integral to the distribution of goods and services in California. They further argue that emissions regulations that focus on locomotives will increase the cost of providing service and will increase the rates that the railroads charge their customers. Given the alternative modes that exist to transport freight, increases in rail rates may cause significant shifts from rail to other modes, especially from rail to truck. Mode shifts that result from locomotive emissions regulations may, in turn, be counter-productive to solving the air quality problems attributable to freight transportation since trucks (according to the railroads) emit more pollutants per ton of freight moved than does the rail mode.

Therefore, in order to develop a policy that most cost-effectively minimizes NO_x emissions in California, it is essential that the ARB have a complete understanding of the relative contributions of each mode to freight transport and emissions in the state, and of the effects of various strategies to control locomotive NO_x emissions on relative freight rates and mode choice. The purpose of this study is to assess the effects of proposed locomotive emissions regulation strategies on mode choice and locomotive emissions and to formulate the framework for an

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[1] The study was conducted by a contractor. Engine, Fuel, and Emissions Engineering, Inc., *Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness and Regulatory Strategy*, ARB Contract Nos. A032-169 and 92-917, March 29, 1995.

active market for locomotive emissions reduction credits.

Appendix A presents the general methodology that is employed in this study to achieve the following study objectives.

- *Estimate Commodity Flows by Mode* — Surprisingly, prior to this study little was known about the modal share of freight transport in California. As a result, a major focus of this effort is to estimate modal splits, particularly between rail and rail-competitive trucks.

- *Calculate the Contribution of Emissions by Goods Transport Mode* — The air quality planning processes employed by states and metropolitan planning organizations across the country do not focus specifically on emissions from freight transport activities. The relative contribution of freight modes to emissions in a region is seldom reported in State Implementation Plans or regional Air Quality Management Plans. Therefore, one objective of this study is to isolate freight-related emissions by mode and to ascertain changes in modal emissions resulting solely from economic and/or demographic growth.

- *Perform a Comprehensive Review and Evaluation of Mode Choice Models* — To ensure that the ARB is fully cognizant of the factors that determine mode choice or mode shifts, and to ensure that the best possible forecasting tools are used in this study, another objective is to conduct a comprehensive review and evaluation of previous mode shift analyses.

- *Assess the Direction and Magnitude of Mode Shifts Attributable to Locomotive Emissions Regulations* — Using the best possible mode shift model, the central objective of this study is to determine the mode choice impacts of various locomotive emissions control strategies and to determine the consequent emissions repercussions.

- *Develop the Framework for an Active Locomotive Emissions Market* — The final objective of this study is to determine the best possible framework for an active market in locomotive emissions reduction credits.

This report documents the results of the analysis conducted to achieve each of these goals. The report is divided into seven sections, including this introduction. The following section, Section 2, presents the base year (1987) and forecast (2010) commodity flows for rail and rail competitive trucks.

Section 3 illustrates the relative contribution of freight transport modes to emissions in California and develops truck and rail emissions by 2010 associated solely with economic and/or demographic growth.

Section 4 reviews and evaluates the various models that are used to estimate the effect of policies on mode choice in the freight arena. It also discusses the rationale for selecting the CALFED model for use in this study.

Section 5 describes the mode shift and resulting emissions impacts of the various emissions control strategies investigated in this analysis. Both locomotive and truck emissions control strategies are estimated.

Finally, Section 6 presents the results of a comprehensive literature review and evaluation of previous emissions credit programs, while Section 7 presents the framework for an active locomotive emissions reduction credits market.

2. Commodity Flow in California

As stated in the introduction, the main purpose of this report is to estimate changes in locomotive emissions due to potential regulations being considered by the ARB. One possible outcome of any type of regulation on locomotives is that rail traffic could divert to truck traffic due to the relatively higher costs that may have to be passed on to consumers. Since trucks have higher emissions per ton-mile than rail, such diversion would offset reduced locomotive emissions due to the regulations. As a result, in order to estimate how proposed locomotive emissions regulations would affect total emissions levels, it is necessary to calculate the amount of diversion that would likely take place.

To understand the effects that locomotive emissions regulations would have on freight transportation patterns in California, however, it is necessary to become familiar with some basic concepts that economists and transportation planners use to describe goods movement and the choice of freight transportation modes. At the most disaggregate level, there are individual shipments. These shipments consist of a specific commodity that is being shipped and a quantity of that commodity that is being shipped. When examining the choice of transportation mode for this shipment, the commodity characteristics are an important consideration. For example, certain commodities are shipped in bulk, the products have a relatively long shelf life, and the transport time is not that critical to the buyer. Products such as coal and grain are typical of these types of commodities. These commodities are more likely to be shipped by rail than by truck and they are unlikely to be very sensitive to the difference in cost between rail and truck. Thus, in describing goods movement, the commodity and the typical size of shipment are both important variables.

Each shipment also has an origin and a destination. Knowledge of origins and destinations are important when looking at mode choice for individual shipments because they determine the availability of modal options (some locations do not have easy access to rail lines or highways) and the length of the haul (longer haul shipments are more likely to travel by rail than by truck).

In addition to characteristics of the shipment, modal characteristics also determine the choice of mode for freight transportation. Characteristics such as freight rates, transit time between origins and destinations, reliability, and other factors are important to the shipper/receiver in selecting what mode to use for an individual shipment.

Some economists and planners have developed mode choice models taking this disaggregate perspective. **Disaggregate models** essentially predict the probability that any individual shipment will travel on a particular mode (e.g., rail or truck). These models are frequently estimated using regression techniques and can include any or all of the variables described above (e.g., commodity, shipment size, length of haul, freight rates, transit time, etc.). Parameters are estimated for each variable in the model based on the characteristics of a sample of actual shipments. When these disaggregate models are used to predict mode choice, usually there is a data base containing the characteristics of a sample of shipments. The values of individual variables can be altered for each individual shipment and when the results of the model computations are summed over all of the shipments in the sample, the model will predict what proportion of the shipments will select a particular mode. For example, if the assumption is that the only impact of locomotive emissions regulations would be an increase in freight rates (e.g., due to more expensive technology requirements), this could be plugged into the model to determine what share of the shipments would travel by rail given the new freight rates.

Disaggregate, shipment-by-shipment data bases are relatively rare in the freight transportation literature. Typically, they are frequently collected on a case-by-case basis for the use of a particular researcher. More often, data on freight transportation are aggregated into what is described as transportation or commodity flows. For example, all of the shipments of a particular commodity travelling between the same origin and destination locations might be aggregated to describe a particular commodity flow. In some cases, these data bases may include modal split information (i.e., the percentage of the shipments made by rail, truck, air, etc.). One of the ways that these flow data bases differ is in the level of commodity and geographic detail they contain. For example, many data bases which use the Standard Transportation Commodity Classification (STCC) system to classify commodities may report data at the 1-digit level (very aggregate) or the 5-digit level (very disaggregate). Data bases may report commodity flows between states, between regions within a state, or between cities.

Because commodity flow data are generally more available than disaggregate shipment data, some economists and planners have developed **aggregate models** to predict mode choice. These models assume a set of average characteristics for many of the same variables that are included in disaggregate models (e.g., average length of haul for flows between two states). Nonetheless, these models are useful when the analyst is interested in mode choice effects on aggregate flows (e.g., how do mode shares change for all shipments in California) and disaggregate data are unavailable.

Mode choice models can be used to examine modal diversion questions such as how much freight transportation shifts from rail to trucking if the relative cost of rail increases. The approach is to change the value of one of the variables in the model and compute the new modal shares. In the case of aggregate models, it is necessary to have data on the baseline commodity flows and modal shares in order to exercise the models. If these flow data are not available for a particular time period that is the subject of the analysis, they may often be estimated using economic data and projections. This approach was applied by JFA in this project, as discussed below. Section 4 present detailed reviews of disaggregate and aggregate models.

CALFED, an aggregate model, was chosen to assess the diversion impacts of the proposed locomotive emissions regulations (for a detailed description of CALFED see Section 4). Before CALFED could be used to estimate the amount of diversion that could take place, two tasks had to be completed. First, it was necessary to quantify the amount of base year (1987) traffic by mode for ten commodity groups. These commodities are presented in Exhibit 2-1 and were specified by the model, which calculates the extent of diversion separately for each group. Section 2.1 details the procedure that was used for this purpose. Second, forecasts of the base year traffic had to be developed for the year 2010, the year chosen for evaluating the impacts of the proposed locomotive emissions regulations. The method used to produce these forecasts is presented in Section 2.2.

All traffic estimates were developed in ton-miles.

2.1 Development of Baseline Commodity Flows

No comprehensive source of data has provided complete modal share information by commodity since the 1977 Commodity Trade Survey (CTS); and the 1993 Commodity Flow Survey (CFS) has yet to be published. Since 1977, commodity freight flow data by origin and destination have been collected separately by the Interstate Commerce Commission (ICC) for rail. Similar freight flow data for trucking, however, have been especially scarce. As a result, the base year traffic by truck was estimated in this study. The basic approach consisted of estimating total commodity flows for each commodity, and then subtracting the known flows by other modes to produce a set of trucking residuals.

For each commodity, interstate flows were developed for goods moving between California and other U.S. states. These interstate flows were divided into movements originating in other states and terminating in California and movements originating in California and terminating in other states. Separate flows were estimated for each state. Intrastate commodity flows were also estimated for goods both originating and terminating in California. The flows were initially estimated at the two-digit Standard Industrial Classification (SIC) level and later aggregated into the commodity groups shown in Exhibit 2-1.

The first step in developing these flows entailed deriving 1977 and 1987 supply and consumption estimates by commodity for each U.S. state.[2] State supply was defined to include production and imports that entered U.S. consumption channels via a custom's district in the state. State production estimates were derived by using state employment data to allocate U.S. production data obtained from the U.S. Bureau of Labor Statistics (BLS). The state employment data were taken from the U.S. Bureau of Economic Analysis' *Regional Economic Information System* (REIS) CD-ROM and were adjusted to reflect changes in the SIC codes. Vectors of U.S. imports by state of unlading were developed by Jack Faucett Associates (JFA) in previous work; the major source of this data was the *U.S. Imports of Merchandise* CD-ROM prepared by the U.S. Bureau of the Census. State consumption was defined to include intermediate demand for production and the following final demand categories: personal consumption expenditures, gross private investment, state and local government expenditures, federal government defense expenditures, federal government non-defense expenditures, and U.S. exports with exit points in the respective state. Each state's total intermediate demand for a particular commodity was computed by summing intermediate demands for the commodity across industries. Intermediate demand by commodity for each state industry was calculated by multiplying state industry output by input-output coefficients developed from BLS' national input-output tables. The remaining

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[2] As discussed in Section 4, CALFED is estimated with 1977 CTS data, while 1987 represents the base year in this study.

Exhibit 2-1

Freight Model Commodity Groups

1. Fruits and Vegetables
2. Other Agriculture
3. Construction and Minerals
4. Timber and Lumber
5. Food Products
6. Paper Products
7. Chemicals
8. Primary Metals
9. Machinery
10. Other Manufacturing

final demand components were developed by JFA in previous work. All of these estimates are in constant 1977 dollars.

The 1987 estimates of California supply and consumption were then allocated to each state. These allocations were based upon supply and consumption shares developed from JFA's 1977 Multi-Regional Input Output (MRIO) accounts. These accounts reflect a balanced comprehensive model of the 1977 U.S. economy and trace value and ton flows between producing and consuming states. The supply shares indicate the percentage of California supply that was distributed to each state in 1977. Consumption shares refer to the percentage of California consumption that originated in each state in 1977. These 1977 shares were then adjusted for relative changes in supply and consumption that took place between 1977 and 1987 (developed from the estimates discussed in the preceding paragraph). That is, supply shares were adjusted for relative changes in consumption while consumption shares were adjusted for relative changes in supply. Applying the new supply and consumption shares to 1987 estimates of California supply and consumption generated a preliminary set of value flows between California and each U.S. state. These preliminary flows were not balanced, however. Theoretically, production plus flows into a region should equal consumption plus all flows out of the region. In this study, flows were balanced by adjusting the California 1987 consumption estimates so that the two sets of intrastate flows, generated by applying the supply and consumption shares, were equal to each other.

The resulting value flows were converted into ton flows by multiplying them by ton per dollar ratios developed from the MRIO accounts. The MRIO model yields separate ton per dollar ratios for each commodity and state-to-state origin-destination (O-D) pairing.

Known state-to-state flows by rail and water (in tons) were then subtracted from these total ton flows to produce estimates of the amount of California supply and consumption moved by truck (in tons) in 1987. Rail data were obtained from the confidential *1987 ICC Waybill Sample* controlled by the ICC. These data are more accurate than ICC's public use file, in which they do not provide some of the origin and destination information to prevent disclosure of proprietary information. Data for water flows were taken from *Waterborne Commerce of the United States*, published by the Army Corps of Engineers. For a few commodities, further adjustments had to be made for movements by pipeline.

To use the CALFED diversion model to evaluate the effect of locomotive emissions regulations on mode choice and emissions from freight activities within California, it was necessary to develop estimates of the amount of traffic "within" California. That was accomplished by allocating each state-to-state truck flow to a sub-state origin and/or destination in California. For example, each particular commodity flow that originated in California and terminated in a given state was divided into several different flows with several different sub-state California origins but the same state destination. In a similar fashion, each flow that originated outside of California was divided into several flows with different California sub-state destinations but the same state origin. Available data at the county level are too sparse and are questionable for this purpose. As a result, JFA decided to use data for business economic areas (BEA), which are not as sparse and are more reliable. These eight areas are groups of counties and are presented in Exhibit 2-2.

The allocation of the origin and/or destination of the flows was based upon the distributions of supply and consumption across the BEA regions. These distributions were created by allocating the state level estimates to the areas. For a given commodity, each component of supply and consumption was allocated separately. For supply, distributions of state production estimates were based upon employment data from *County Business Patterns* (CBP). Unlike many data sources, CBP provides employment ranges when data are withheld to avoid disclosing proprietary information; in a few cases, it was necessary to use the midpoint of those ranges to circumvent data disclosure restrictions. CBP does not provide data for the railroad industry or agriculture. Earnings data were used to allocate railroad output and farm employment was used to allocate agricultural output; both data were obtained from *REIS*. Import data on the *U.S. Imports of Merchandise* CD-ROM are reported by districts of unlading. These districts were mapped into the corresponding BEA area and the imports were distributed accordingly.

For consumption, intermediate demand was calculated as follows. Personal consumption expenditures were distributed according to personal income data. State and local government expenditures were distributed according to state and local government employment and federal non-defense expenditures were allocated by federal civilian employment. *REIS* furnished all of the data necessary to make these allocations. The Federal Procurement Data System records data for all government contract awards that exceed $25,000. Data from this system were used to distribute federal defense expenditures. Export data on the U.S. Exports of Merchandise CD-ROM are reported by customs districts that are U.S. exit points. These districts were mapped into the corresponding BEA area and the exports were distributed accordingly. Using capital flow data from the MRIO accounts, gross private investment at the state level was divided into investment by total manufacturing and investment by total non-manufacturing. These two vectors were then distributed to BEA areas using manufacturing and non-manufacturing employment data.

For intrastate truck flows, the allocations of supply and consumption to BEA areas were not that useful by themselves. For example, the allocation of supply resulted in a distribution of supply by California BEA area but it did not yield where in California those flows terminated. Likewise, the allocation of consumption produced a distribution of consumption by California BEA areas but it did not indicate where those flows originated. It was necessary to tie these two allocations together before the results could be meaningful. To do that, JFA developed a simple linear programming algorithm to estimate the flows. First, each BEA region's supply estimate was distributed to the eight California BEA regions according to consumption, yielding an eight by eight matrix of flows for each commodity. These initial matrices were not balanced because the summation of the flows into a region generally did not equal the consumption that had previously been allocated to it. To balance the flows, a linear programming problem was specified that constrained the sum of the flows into a region to equal its consumption and the sum of the flows out of a region to equal its supply. These were not enough constraints to solve the model; additional constraints specified certain ranges within which each flow had to fall (i.e., limiting the amount that the initial values could be perturbed). These ranges were defined in terms of a common percentage, which was the smallest one available for solving the model.

Exhibit 2-2

California Business Economic Areas

BEA Area	County
Redding	Lassen
	Modoc
	Plumas
	Shasta
	Siskiyou
	Tehama
Eureka	Del Norte
	Humboldt
	Trinity
San Francisco	Alameda
	Contra Costa
	Lake
	Marin
	Mendocino
	Monterey
	Napa
	San Benito
	San Francisco
	San Mateo
	Santa Clara
	Santa Cruz
	Solano
	Sonoma
Sacramento	Butte
	Colusa
	El Dorado
	Glenn
	Nevada
	Placer
	Sacramento
	Sierra
	Sutter
	Yolo
	Yuba
Stockton	Alpine
	Amador
	Calaveras
	Mariposa
	Merced
	San Joaquin
	Stanislaus
	Tuolumne
Fresno	Fresno
	Kern
	Kings
	Madera
	Tulare
Los Angeles	Inyo
	Los Angeles
	Mono
	Orange
	Riverside
	San Bernardino
	San Luis Obispo
	Santa Barbara
	Ventura
San Diego	Imperial
	San Diego

The next step in estimating truck traffic within California required converting the ton flows into ton-miles. The CALFED diversion model dictated that those ton-miles refer only to the leg of the trip that occurred within California. For each flow originating in a given BEA region and going to a particular state, it was necessary to guess at the most likely route that would be taken and then compute the mileage along that route between a point in the region and the border. The chosen points were the metropolitan statistical areas that define each BEA region. Mileage was computed from a Rand McNally road atlas. A similar procedure was used to compute flows originating in other states and terminating in California BEA regions. For an intrastate flow between two given BEA areas, the mileage was assumed to be equal to the distance between the two centroids. The mileage estimates were then multiplied by the corresponding ton flows to yield the number of truck ton-miles within California. Highway mileage estimates are shown in Appendix B.

One final adjustment had to be made to these truck ton-mile estimates before they could be used in the diversion model. Not all truck and rail movements are competitive with each other. Local trucking, for example, probably does not compete with rail. Since the CALFED diversion model is based only upon truck traffic that competes with rail, it was necessary to isolate that component of traffic estimates. The *1987 Truck Inventory and Use Survey* (TIUS), published by the U.S. Bureau of the Census, contains data on the number of vehicle miles travelled (VMT) within California by gross vehicle weight (GVW) and primary product carried. For each product, the percentage of VMT by trucks with GVWs over 33,000 pounds was calculated. It is assumed that only trucks with GVWs over 33,000 are competitive with rail and that these percentages reflect the amount of truck ton-mile traffic that is rail competitive. The final adjustment consisted of multiplying the truck ton-miles within California by these percentages, producing ton-mile estimates of truck traffic that is competitive with rail.

For comparison purposes, it was necessary to convert rail ton flows into ton-mile flows within California. The procedure used to make that conversion is similar to the one used for trucking. First, likely routes in and out of the state were determined; then, mileage from the border to the point of origin or destination was assessed using estimates published in the documentation to CALFED. Since the Waybill provides ton-mile estimates for each BEA origin-destination pairing, these numbers were used for the intrastate rail movements. Waybill ton-mile estimates for interstate movements could not be used because they refer to the total length of the trip, not just to that portion that takes place within California. Rail mileage estimates are shown in Appendix C.

Exhibit 2-3 presents the total base year traffic estimates by commodity and mode.

2.2 Forecasts of Commodity Flows

The procedure used to forecast the amount of freight traffic within California in 2010 resulting solely from economic and demographic growth is very similar to the one used to develop the baseline 1987 estimates. The main difference is that supply and consumption figures had to be projected for each state as well as for the California BEA areas. In summary, relative changes in supply and consumption that were predicted to occur at the state level were used to adjust the 1987 supply and consumption shares defined in Section 2.1. The new shares were then applied to California's 2010 supply and consumption estimates, generating state-to-state value flows. Values were converted to tons using ton/value ratios developed from JFA's MRIO accounts. For the 2010 projections, it was assumed that the 1987 modal shares would remain constant for a given commodity and state-to-state O-D pairing. The interstate ton flows were then distributed to California BEA origins and destinations based upon expected changes in supply and consumption in those areas; intrastate flows were generated using the same linear programming algorithm described in Section 2.1. Multiplying the ton flows by the corresponding mileage estimates (shown in Appendix B and Appendix C) resulted in 2010 projections of the amount of ton-mile traffic within California. A final adjustment was made to the truck ton-mile estimates to isolate only the traffic that is competitive with rail.

Two sources were used to project the supply and consumption estimates to 2010. In November 1993, BLS released a publication entitled *The American Work Force: 1992-2005.* This publication forecasts the U.S. economy to the year 2005 and includes projections of employment and output by industry and final demand by category. In addition, every five years the U.S. Bureau of Economic Analysis prepares long-range regional forecasts of population, employment, and income. The last regional projections were released in 1990 and presented state and sub-state level forecasts to the year 2040.

For the supply forecasts, separate projections were made for each commodity and supply component (production and imports). Development of the output projections required using both data sources. The Bureau of Economic Analysis does not make regional projections of output, which were needed to estimate supply and to calculate intermediate demand. The regional employment growth rates are not adequate by themselves for forecasting output because technological change affects labor productivity rates (output per employee). As a result, it was necessary to use changes in labor productivity projected at the national level by BLS in conjunction with the state level employment forecasts developed by the Bureau of Economic Analysis (BEA). BLS labor productivity rates by industry were extended to 2010 using average annual growth rates from 2001-2005. It should be noted that the Bureau of Economic Analysis does not revise its projections when revisions are made to the base year data (1988) on which those projections are based. In order to reflect changes that were made to the base year data, JFA adjusted the regional projections by applying the initial growth rates to the revised data.

Import projections by commodity were made by assuming that each state's share of the total U.S. imports will remain constant. BLS' projected growth rates for imports were used to forecast total U.S. imports to 2010.

In terms of consumption, intermediate demand was estimated by using the same procedure described in Section 2.1. BLS's projected growth rates of the remaining final demand categories (personal consumption expenditures, state and local government expenditures, federal non-defense expenditures, federal defense expenditures, exports, and gross private investment) were used to forecast U.S. totals to the year 2010. 1987 state shares of personal consumption expenditures were adjusted for relative changes in personal income that were projected to take

Exhibit 2-3
1987 Freight Traffic Within California

Commodity	Total Truck Traffic (Millions of Ton-Miles)	Percent of VMT Carried by Heavy-Heavy Duty Diesel Truck	Truck Traffic Competitive With Rail (Millions of Ton-Miles)	Rail Traffic (Millions of Ton-Miles)	Truck Share of Competitive Traffic (Percent)	Rail Share of Competitive Traffic (Percent)
Fruits and Vegetables	13,338	22	2,934	497	86	14
Other Agriculture Products	13,765	24	3,303	2,879	53	47
Construction and Minerals	10,405	41	4,266	2,862	60	40
Timber and Lumber	10,449	17	1,776	4,106	30	70
Food and Kindred Products	14,935	46	6,870	4,451	61	39
Paper and Allied Products	4,127	47	1,940	2,849	41	59
Chemicals and Allied Products	9,448	23	2,173	2,783	44	56
Primary Metals	4,331	31	1,343	1,631	45	55
Machinery	3,423	28	958	199	83	17
Other MFG	21,646	33	7,143	2,337	75	25
Total	105,867		32,707	24,592	57	43

place. 1987 state shares of state and local government expenditures and 1987 state shares of federal non-defense expenditures were adjusted for relative changes in the corresponding employment sectors that are likely to occur. State shares of exports and federal defense expenditures were assumed to remain constant. Adjustments to state shares of gross private investment were based upon projected changes in output.

Except for production, the components of supply and consumption for California BEA areas were projected in the same way as their state counterparts (i.e., BEA shares of California state totals were forecasted and then applied to projected state levels to distribute them). BEA shares of personal consumption expenditures were adjusted for expected changes in income. Shares of state and local government expenditures and of federal non-defense expenditures were adjusted for employment changes projected by the Bureau of Economic Analysis. BEA shares of California imports, exports, and federal defense expenditures were held constant. BEA shares of gross private investment were adjusted for relative changes in output. To forecast intermediate commodity demand for the California BEA areas, it was necessary to develop 2010 production estimates at the two digit SIC level for each BEA region. The Bureau of Economic Analysis projects employment at the two digit SIC level for the state of California. However, BEA only publishes such projections at the one digit SIC level for sub-state regions. Developing projections at the sub-state level required several steps. First, preliminary estimates of output at the SIC two digit level were developed for each BEA region by taking into account each BEA area's initial two digit output levels (described in Section 2.1), growth in two digit output at the state level, and relative growth in one-digit output at the BEA regional level. These estimates were then balanced using a linear programming algorithm similar to the one presented in Section 2.1.

Exhibit 2-4 shows the 2010 traffic estimates that resulted from this procedure.

Exhibit 2-4
2010 Freight Traffic Within California

Commodity	Total Truck Traffic (Millions of Ton-Miles)	Percent of VMT Carried by Heavy-Heavy Duty Diesel Truck	Truck Traffic Competitive With Rail (Millions of Ton-Miles)	Rail Traffic (Millions of Ton-Miles)	Truck Share of Competitive Traffic (Percent)	Rail Share of Competitive Traffic (Percent)
Fruits and Vegetables	20,034	22	4,408	723	86	14
Other Agriculture Products	20,848	24	5,003	4,066	55	45
Construction and Minerals	15,288	41	6,268	4,070	61	39
Timber and Lumber	14,601	17	2,482	5,034	33	67
Food and Kindred Products	14,427	46	6,636	6,387	51	49
Paper and Allied Products	4,188	47	1,968	4,632	30	70
Chemicals and Allied Products	8,728	23	2,007	5,473	27	73
Primary Metals	5,787	31	1,807	2,109	46	54
Machinery	16,023	28	4,486	647	87	13
Other MFG	51,762	33	17,082	3,400	83	17
Total	171,686		52,148	36,541	59	41

3. Emissions Contributions of Goods Transport in California

The previous section described current goods movement in California by freight transport mode and changes in mode shares irrespective of emissions regulations that may be promulgated in the future. The purpose of this section is to characterize the base year (1987) contributions of goods transport modes to California's emissions inventory and to assess future rail emissions in 2010 given no emissions control regulations. Information derived in Section 2 with that presented in this section allows for the computation of mode specific emissions on a per ton-mile basis. In this manner, the relative emissions rate (i.e., emissions/ton-mile) of rail versus trucking operations in the state can be assessed, thereby facilitating the evaluation of emissions control strategies for each mode which is the subject of Section 5.

This section is divided into two sub-sections. Section 3.1 presents the baseline (1987) emissions contributions of rail, heavy-duty trucks, ocean-going commercial marine vessels, and aircraft, although the focus of this study is on rail versus truck. Section 3.2 presents estimates of rail emissions in 2010 under a scenario of "no emissions control" and discusses in detail the forecast methodology employed for this purpose. While the focus of Section 3.2 is on future (uncontrolled) rail emissions, future heavy duty truck emissions are also presented using a simple extrapolation technique which assumes truck emissions on a ton-mile basis remain constant under a no-control scenario.

Together, results presented in Section 2 and in this section provide the basis from which the impact of locomotive emissions regulations can be assessed, assuming that regulations change mode choice and the emissions rates of locomotives and heavy-duty trucks.

3.1 Baseline Emissions Inventory by Mode

To determine the effects of proposed or forecast California emissions regulations on the contribution of rail emissions to air quality, the baseline emissions contribution of this mode, as well as any potential competitors to this mode, must first be determined. Potential competitors with railroads in California were initially determined to be (in descending order of significance): heavy-duty truck lines, marine carriers, and cargo airlines. Considering the types of freight typically shipped by rail and the other modes, and the level of service required by the shippers of that freight, heavy-duty linehaul trucks are the only mode likely to compete significantly with railroads.

The estimated annual emissions from these four modes within California are tabulated in Exhibit 3-1 and discussed in this sub-section, with emphasis on oxides of nitrogen (NO_x) emissions. This study used the 1987 California Air Resources Board (ARB) statewide emissions inventory (March 1990) as the baseline because it contains the most recent estimated emissions inventories for all four modes, as well as for all other sources in California. As discussed below, the ARB inventories were adjusted for this study to reflect improved estimates, where available.

Exhibit 3-1

1987 California Base Year Emissions Inventory (Tons/Day)

Freight Mode	NO_x	ROG	CO	PM	PM10	Sox
Rail	155	7	22	4	3	11
Heavy-Duty Trucks*	622	174	1,847	104	88	58
Gasoline	149	105	1,631	9	4	8
Diesel	473	69	216	95	83	50
Ocean-Going-Commercial (OGC) Marine**	186	12	22	16	--	131
Aircraft (Non-Gov)	27	26	211	0.45	0.44	2
Total Mobile Sources	2,619	2,483	17,943	295	206	231
Total State Emissions	3,487	5,057	24,024	10,237	5,732	424

Source: California Air Resources Board, "1987 Hybrid Emissions Inventory (Statewide)".

* Includes all trucks weighing above 8,500 lbs. GVW

** Source: Booz-Allen & Hamilton, "Inventory of Air Pollutant Emissions from Marine Vessels", March 1991.

3.1.1 Rail Emissions

Railroad operations within the state of California generated approximately 155 tons of NO_x per day on the average in 1987, as shown in Exhibit 3-1. Although this value includes passenger rail operations, these are a small portion of total California rail operations. Therefore, no effort was made (or deemed necessary) to quantify emissions from passenger and freight operations separately in this sub-section.

Estimated California rail emissions are based on the Booz●Allen & Hamilton report, *Locomotive Emission Study*, which was prepared for the ARB in August 1991 (hereafter called the Booz●Allen report). The Booz●Allen estimate was obtained by analyzing distinct trip segments with average locomotive consists[3] based on data supplied by the railroads. For NO_x, the Booz●Allen estimate is approximately 2 percent higher than the estimate shown in Exhibit 3-1 which reflects the most recent ARB inventory estimates by mode for 1987. Booz●Allen estimates that the combined influence in the uncertainty of duty cycle and emissions factor data results in a confidence interval of ± 20 percent.

3.1.2 Heavy-Duty Truck Emissions

As shown in Exhibit 3-1, the ARB estimates that California heavy-duty truck operations generated over 600 tons of NO_x per day in 1987, substantially more than any other freight-shipping mode. Although data on trip routes were not obtained, intuition suggests that a greater percentage of truck emissions occur within nonattainment areas relative to the other three modes. Assuming that this is true, reducing aggregate emissions from trucks would have a greater impact on air quality than identical aggregate reductions from other modes.

Data used in this report were the most reliable data available, however they do not accurately reflect emissions generated due to rail-competitive freight shipments by truck. Used for this purpose, the ARB inventory overestimates such emissions, as it defines heavy-duty trucks as those weighing over 8,500 pounds Gross Vehicle Weight (GVW). Therefore, many types of trucks that do not haul intercity freight, such as local-delivery trucks, fire trucks, garbage trucks, utility service trucks, etc., are included in the inventory totals shown in Exhibit 3-1.

To accurately compare truck versus rail emissions, it is necessary to isolate the emissions contribution of trucks that compete directly with rail. Given the types of commodities that generally are hauled by rail and the distances of the shipments, only those trucks that haul intercity freight and relatively dense commodities are likely to compete directly with rail. Such trucks commonly weigh over 33,000 pounds GVW and have 5 or more axles. Currently, the ARB classifies heavy-duty trucks into three weight classes: light-heavy trucks weighing between

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[3] Most trains are so heavy that several locomotives must be used to generate enough power to climb hills and complete the trip in a reasonable time. The group of locomotives is called a "consist" and may include up to six locomotives, although most consists are made up of three or four locomotives.

8,500 to 14,000 pounds GVW; medium-heavy weighing from 14,000 to 33,000 pounds GVW; and heavy-heavy weighing over 33,000 pounds GVW. Although the ARB's current emissions factor model (EMFAC7F) does not provide emissions by each of these truck classes, the next generation of EMFAC (EMFAC7G) will disaggregate truck emissions in this manner. For this study, the ARB provided estimates of the heavy-duty truck emissions breakdown by truck class. These distributions are shown in Exhibit 3-2. Using these estimates as a proxy for the actual breakdown in 1987, the relative emissions contribution of those trucks that can be expected to compete directly with rail can be approximated. Exhibit 3-3 presents the revised NO_x emissions data for heavy-heavy-duty diesel trucks, as well as emissions from the other modes originally shown in Exhibit 3-1. The heavy-heavy-duty diesel truck emissions estimates and the rail estimates in Exhibit 3-3 form the basis for the rail/truck comparisons investigated in this study.

There are still a number of additional contributors to uncertainty in the emissions estimation process for heavy-duty trucks that should be noted, however. First, actual vehicle-miles-traveled (VMT) data were not collected, rather VMT data are estimated from traffic count data. Second, trip emissions are calculated based on average speeds, average trip lengths, and average emissions factors. Finally, important operational activities that contribute to total emissions, such as idling and engine starts, are not included in current emissions inventory models. The ARB is currently updating the methodology to estimate truck emissions in an effort to address these problem areas.

3.1.3 Marine Emissions

As shown in Exhibit 3-3, ocean-going commercial marine vessels (the only vessels deemed to compete with railroads) generated an estimated 186 tons of NO_x per day in California waters in 1987. This estimate is based on the Booz•Allen report, *Inventory of Air Pollutant Emissions from Marine Vessels*, March 1991.

Although Booz•Allen obtained some of the best data ever compiled on ship movements in California, the emissions factor data available were based on very limited testing, most of which was performed over 15 years ago. Booz•Allen's own estimate of the accuracy of its marine vessel emissions inventory is ± 30 percent.

3.1.4 Aircraft Emissions

The ARB estimated that all civil aircraft operations in California generated approximately 27 tons of NO_x per day in 1987, as shown in Exhibit 3-3. Cargo aircraft operations contributed substantially less NO_x and are not a significant source of this pollutant in California.

Exhibit 3-2

Heavy-Duty Truck Emissions Distribution by GVW Class (1987)

Truck Class	NOx (Tons/Day)	ROG (Tons/Day)
Gasoline	149	105
Light-Heavy	89	56
(% of Total Gasoline)	60%	53%
Medium-Heavy	59	49
(% of Total Gasoline)	40%	47%
Diesel	473	69
Light-Heavy	9	1
(% of Total Diesel)	2%	2%
Medium-Heavy	62	9
(% of Total Diesel)	13%	13%
Heavy-Heavy	402	59
(% of Total Diesel)	85%	85%

Source: California Air Resources Board, L. Hrynchuk

Exhibit 3-3

Adjusted Emissions Contributions by Freight Mode (1987)

Freight Mode	NO_x (Tons/Day)	Percent of Total	ROG (Tons/Day)	Percent of Total
Rail	155	20%	7	6%
Truck*	402	52%	68	60%
Water	186	24%	12	11%
Air	27	3%	26	23%
Total	771		112	

* Only includes diesel trucks weighing over 33,000 lbs. GVW.

3.1.5 Relative Modal NO_x Emissions in California

The relative NO_x emissions from the four freight transport modes are compared in Exhibit 3-4. Railroad locomotives contributed approximately 20 percent of the 1987 California NO_x emissions from the four modes representing the freight transportation sector. They also contribute about 6 percent of mobile source NO_x emissions and about 4 percent of total NO_x emissions.

Of the four competing freight shipping modes, heavy-heavy-duty diesel trucks (i.e., diesel trucks weighing over 33,000 pounds GVW) contribute the greatest percentage of NO_x emissions; nearly 52 percent of the NO_x emissions from the four freight-shipping modes and almost 12 percent of all NO_x emissions in the state. Truck lines are also the primary competitor with railroads for freight revenues. Therefore, the modal diversion analysis only considers the possibility of diversions between these two modes. As shown in Exhibit 2-3 (see Section 2), heavy-heavy-duty diesel vehicles accounted for almost 60 percent of rail-truck competitive freight transport in 1987.

If NO_x emissions from locomotives could be totally eliminated, this would reduce airborne NO_x levels by about 4 percent—a worthwhile, but not dramatic reduction. There is clearly a greater potential to improve California's air quality by reducing NO_x emissions from heavy-heavy-duty diesel trucks. Imposing emissions caps on railroads can only be justified, therefore, as a component of a program to reduce NO_x emissions from all significant sources.

Marine vessels operating in California waters contribute slightly greater estimated NO_x emissions than locomotives and are therefore good candidates for control measures. Ships offer more flexibility for accommodating the weight and volume of emissions control hardware than trucks and locomotives. On the other hand, enforcing emissions limits on ships is probably more difficult than for any other mode. Nonetheless, such efforts are underway. The potential for diversion of freight from rail to ships, however, is judged in this study to be small.[4]

Overall, civil aircraft contribute only about 3 percent of the NO_x emissions from the four modes, and the majority of those emissions are from passenger operations. Air freight operations are therefore not a significant source of NO_x emissions in California. Furthermore, because cargos that are typically shipped by rail are very unlikely to be diverted to air freight, aircraft were not considered in the diversion analysis.

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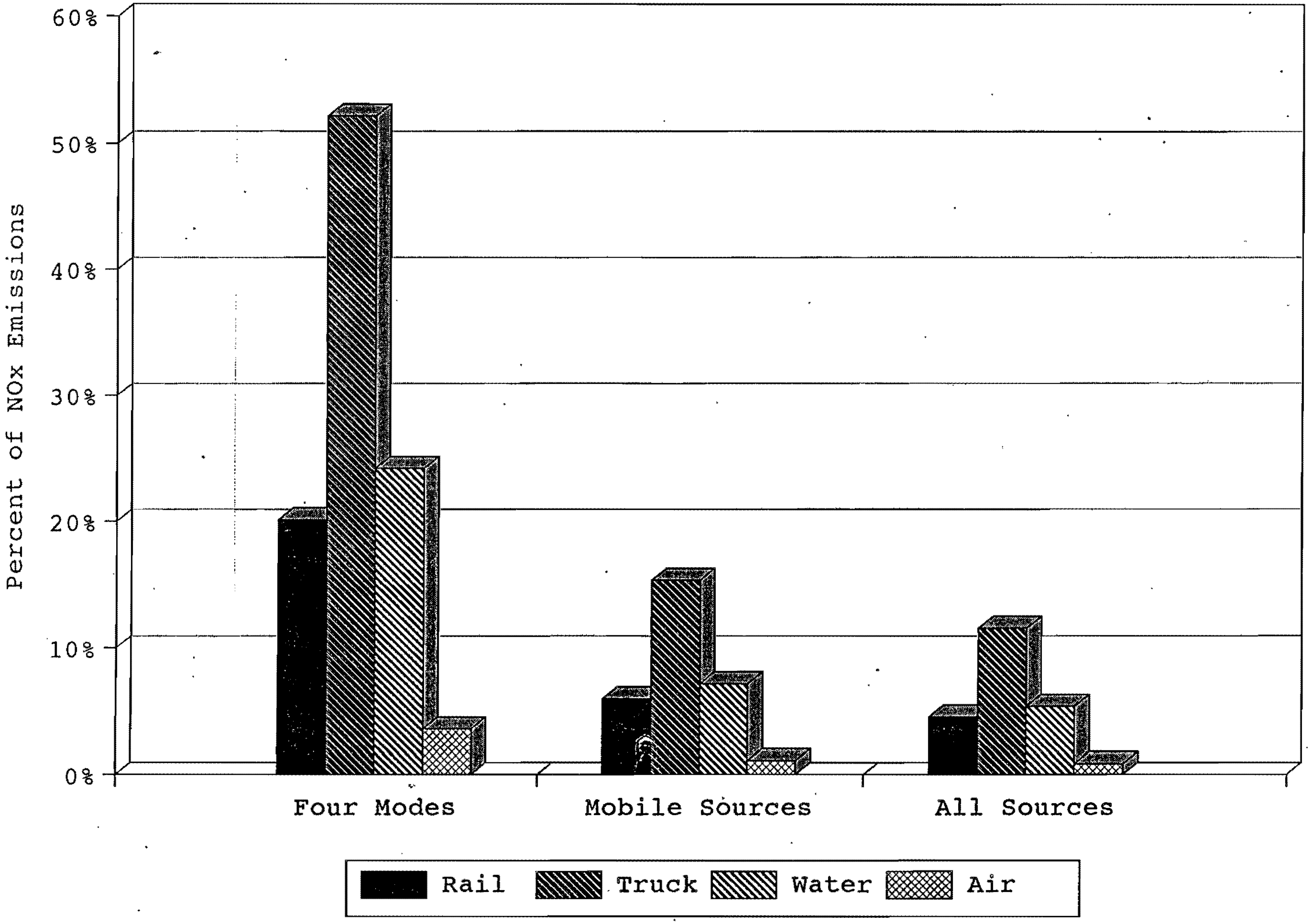
[4] It is possible that increased rail costs could cause diversion of marine cargo from California ports to other West Coast ports. The analysis of this possibility is complicated by a variety of factors including the distribution of origins and destinations of the traffic, the relative in-port and ocean costs of shipments to specific locations from different West Coast ports, the mix of commodities shipped from each port and their sensitivity to changes in relative transportation costs, the availability of facilities (e.g., berthing, loading and unloading, harbor depth), and a host of institutional factors including contractual relationships between shippers and carriers, rotations of ports-on-call, and logistical concerns. The consideration of these issues in diversion analysis is beyond the scope of this study, and conjectures regarding the impact of changes in rail freight rates on port diversion cannot be made with any degree of confidence.

Exhibit 3-4
Relative Modal NOx Emissions



3.1.6 Baseline Rail and Truck Emissions per Ton-Mile

Exhibit 3-5 presents truck and rail NO_x emissions on a ton-mile basis. Emissions per ton-mile for truck and rail simply reflect the NO_x emissions contributions of each mode shown in Exhibit 3-3 (converted to a yearly basis) divided by the truck and rail flows derived in Section 2. In this manner, the relative emissions factors can be compared using a common unit (i.e., pounds/ton-mile).

As demonstrated in Exhibit 3-5, in 1987 heavy-heavy-duty diesel trucks emitted almost twice the amount of NO_x per ton-mile than rail. Truck movements emit, on average, 0.009 pounds per ton-mile of freight moved, while rail movements emit 0.005 pounds per ton-mile of freight moved in California. This result has important ramifications when developing emissions control strategies for freight transport in the state. Regulations must be developed that approach emissions control at the system level by accounting for the relative contribution of each mode at the margin. Furthermore, strategies that result in large diversion shifts from rail to truck may be counter productive from the perspective of total freight emissions. These issues are further investigated in Sections 5, 6, and 7 of this study.

3.2 Predicted Rail and Truck Emissions (No New Regulatory Initiatives)

To fully evaluate the effect of locomotive regulations on mode choice and freight emissions (truck and rail), it is necessary to evaluate first rail and truck emissions under a no-control scenario. This ensures that only the marginal changes in mode-specific emissions are evaluated when regulations are imposed, thereby isolating the actual impacts of the regulations.

This sub-section forecasts both rail and truck emissions in 2010 that are solely attributable to growth in activity and changes in the mix of locomotives. The analysis focuses on locomotive emissions, since the central theme of this study is to evaluate the impact of emissions regulations for this mode of freight transport. A detailed description of the methodology used to estimate locomotive emissions is explained in this sub-section. This methodology is used to estimate rail emissions under a no-control scenario and to estimate rail emissions under the various regulatory options that are the focus of Section 5.

3.2.1 Methodologies Considered to Estimate Rail Emissions

Rail emissions in California were estimated with a spreadsheet-based model utilizing actual or estimated data on California locomotive fleet size, locomotive emissions rates, and locomotive utilization. Three methodologies for estimating baseline and future California rail emissions under various regulatory and economic scenarios were evaluated for the present study. As discussed below, each has certain advantages and disadvantages, both related to the degree of detail.

Exhibit 3-5

1987 Rail and Truck NO_x Emissions per Ton-Mile of Freight Moved

	Rail[5]	Truck*
Ton-Miles (millions/year)	24,592	32,717
NO_x Emissions (tons/day)**	155	402
NO_x Emissions (lbs/ton-mile)	0.005	0.009

* According to EMFAC7, the 1987 heavy-duty diesel truck fleet average NO_x emissions rate was 7.83 g/Bhp-hr. The truck emissions estimates shown above reflect this fleet average.

** Numbers may not add up exactly because of rounding.

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[5] Includes passenger-related operations. Adjustments are made at the end of this section to isolate freight-related contributions.

Specific Trains (with Average Duty Cycles), Specific Emissions Factors, Proportional Consists— The first approach considered was to adapt the railroad emissions estimation methodology developed by Booz•Allen & Hamilton (Booz•Allen) for the California Air Resources Board (ARB).[6] Booz•Allen collected detailed duty cycle data (i.e., locomotive operating time in each throttle notch) for most of the trains—defined as a typical freight movement over a particular route—operating in the state, and used these data to derive duty cycles for trains where data were not available. Booz•Allen also obtained a significant, though far from complete, body of locomotive emissions factor data (i.e., grams of pollutant emitted per hour in each throttle notch) for many locomotive types. Booz•Allen also collected locomotive roster data and used a simple proportionality approach to determine the average locomotive consist (i.e., the number and types of locomotives used to pull a single train) based on the average trailing tons and the average horsepower per trailing ton for each train and for each California railroad's mix of locomotives. Operational emissions for each train were estimated by multiplying the time in each notch by the emissions factor for that notch for each locomotive (or fraction thereof) in the average consist. The statewide emissions inventory was determined by summing the emissions from each train.

Due to the level of detail in Booz•Allen's analysis, the ARB has endorsed the Booz•Allen estimate over its own estimate. Although it is probably the most thorough analysis of California railroad emissions performed to date, the Booz•Allen study was still forced by the available data to make assumptions and generalizations about the makeup of locomotive consists. It is therefore an aggregate model, despite the level of detail of its segment-by-segment duty cycle data.

Specific Emissions Factors, Average Duty Cycles, Assumed Locomotive Populations — The second approach considered was to adapt an aggregate methodology used by Engine, Fuel, and Emissions Engineering (EF&EE).[7] EF&EE developed average California duty cycles for each major type of railroad operation: linehaul (which included mixed freight and intermodal), passenger, local, and yard/switch. These duty cycles were based on data from the Booz•Allen report, with the addition of an "off" throttle notch to account for time when the locomotive is not running. EF&EE also obtained emissions factor data for representative locomotives and estimated the size of the locomotive population in California. To obtain an hourly emissions rate for each locomotive type in each service type, EF&EE multiplied the time in each notch by the appropriate emissions factor and summed the weighted emissions in each notch. The hourly emissions rate was multiplied by the assumed number of hours the locomotive was in service annually to obtain an annual emissions rate. To obtain a statewide emissions inventory, EF&EE multiplied the annual emissions rates for each locomotive type in each service type by the number of such locomotives assumed to be operating in the state and summed the results.

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[6] Booz•Allen & Hamilton, *Locomotive Emission Study*, prepared for the California Air Resources Board, August 1991.

[7] Engine, Fuel, and Emissions Engineering, Inc., *Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness, and Regulatory Strategy*, revised final report under California Air Resources Board Contract Nos. A032-169 and 92-917, Engine, Fuel, and Emissions Engineering, Inc., Sacramento, CA, March 29, 1995.

Although this methodology does not evaluate individual route segments like the Booz●Allen methodology, it still results in very similar predictions of statewide emissions. It is also substantially less difficult to implement than the Booz●Allen methodology, particularly if multiple scenarios are to be modeled.

Ton-Mileage Moved, Ton-Mileage-Based Emissions Factor — The third approach considered for this study was to combine the average "pounds of emissions per 1,000 gallons of fuel" factors from the Booz●Allen report with an average ton-mile-per-gallon factor derived by JFA and Abacus Technology from California rail operations data to develop an emissions factor expressed in pounds of emissions per ton-mile.

This is the most highly aggregated approach considered. It is the simplest, but potentially the least accurate.

3.2.2 Methodology Selected for this Study

The Booz●Allen methodology (or at least the resulting emissions estimate) has been officially endorsed by the ARB, making it an attractive approach. The complexity of this methodology, however, makes it prohibitively time consuming given the resources available for the present study. For example, duty cycles cannot be modified, except by manually re-entering time-in-notch data for all 230 track segments in the state. Furthermore, the accuracy gained by using the train-by-train approach is compromised by the assumption of average locomotive consists based on average locomotive rosters and horsepower requirements.

The ton-mile-based approach is attractive for its simplicity, as well as its direct applicability to other shipping modes. Unfortunately, it does not offer enough flexibility to model the effects of specific regulatory and economic scenarios on rail emissions.

The EF&EE-based methodology combines reasonable accuracy with minimal complexity. Like the Booz●Allen methodology, it can directly indicate the effects on emissions levels of changes in locomotive emissions control technologies, locomotive populations, and locomotive duty cycles arising from both regulatory and economic pressures. It can also easily model the effects of changes that only affect a portion of the locomotive fleet. Unlike the Booz●Allen methodology, it does not require extensive manual revisions when input parameters change. Therefore, an approach based on the EF&EE methodology was selected for this study.

However, the limited time and budget available for this study precluded a thorough re-evaluation of all the existing data required as input to the rail emissions model. Input data were therefore obtained from several previous studies.

Baseline California Locomotive Duty Cycles — Baseline average duty cycles for California rail operations were obtained from the EF&EE report. That report adopted these duty cycles from the Booz●Allen report basically unchanged, except that the percentage of an average 24-hour day that a locomotive spends with its engine off was added to the duty cycle.

The baseline California locomotive duty cycles used in this analysis are presented in Exhibit 3-6. Note that the same locomotive may be operated in different types of service. The SD40-2, for example, is used in significant numbers for both linehaul and local service in California. Sufficient information to predict the changes in average duty cycles for the 2010 forecast year was not available for this study.

There is sufficient variability in the factors that determine the actual duty cycle experienced by an individual locomotive on an individual assignment (e.g., trailing tonnage, schedule requirements, etc.), so that obtaining such data would be prohibitively time consuming given currently available data collection methods. For the same reason, such detailed data would probably not be much more representative of a future assignment than the average duty cycles used for this study. As data acquisition and management technologies continue to improve, however, it may one day be practical to collect extensive duty cycle data based on actual operations, perhaps even in real-time. Future studies of rail emissions could benefit from such highly accurate data.

Representative, or Equivalent, Locomotive Types — The locomotive types used in the present analysis include the GP60, SD40-2, F40-PH, and GP38-2 built by the Electro-Motive Division of General Motors (EMD), and the B40-8 built by General Electric Transportation Systems (GE). These locomotives are representative of the most common types in the fleets of California railroads. Although there are a substantial number of other locomotive types used by the California railroads, most are derivatives of these models and would be expected to produce similar (though not identical) emissions. As a result, locomotive populations developed in this analysis reflect the assumption that the locomotive models described above are representative of the total state population. Populations derived on this basis are referred to as *equivalent* populations in this study.

The methodology used for this study can accommodate a larger number of locomotive types, and emissions factor data were available for some of them. It was not, however, deemed necessary to include this level of detail, considering the unavoidable magnitude of the other uncertainties in the input data and assumptions, as well as the limited budget for this study.

Emissions Factors — Baseline locomotive emissions factors were obtained from the EF&EE report. That report, in turn, obtained emissions factors from a report by the Association of American Railroads (AAR)[8], from the Booz•Allen report, and from data compiled by Caltrans

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[8] Conlon, Peter C.L. (1988), *Exhaust Emission Testing of In-Service Diesel-Electric Locomotives, 1981 to 1983*; AAR Publication R-688.

Exhibit 3-6

Baseline California Locomotive Duty Cycles

Throttle Notch	Percent Time in Notch			
	LINEHAUL	LOCAL	YARD/SWITCH	PASSENGER
off	23.0%	35.8%	31.6%	41.4%
brake	6.1%	1.2%	0.0%	0.4%
idle	39.7%	47.1%	55.4%	29.7%
1	3.0%	2.9%	3.2%	0.0%
2	3.2%	2.7%	3.2%	0.0%
3	3.1%	2.6%	2.2%	6.2%
4	3.9%	2.2%	2.2%	6.0%
5	3.1%	1.4%	0.8%	4.0%
6	2.9%	1.1%	0.4%	2.9%
7	2.2%	1.0%	0.0%	1.1%
8	9.9%	2.1%	0.9%	8.3%
	100%	100%	100%	100%

Source: EF&EE, Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness and Regulatory Strategy, March 29, 1995, Tables 8, 9, 10, and 11.

and the Southwest Research Institute.[9] Some of the emissions factors used are up to approximately 25 percent different than the emissions factors used by Booz●Allen, but as the emissions factors from the more recent EF&EE report are apparently based on more extensive testing than those in the Booz●Allen report, they were selected for the present study.

Modified emissions factors representing the expected NO_x reductions possible with several control technologies were also obtained from the EF&EE report, which again obtained these data from other studies. For the present report, only the most cost-effective NO_x control technologies, as determined by the EF&EE report, were included. These technologies are described in Exhibit 3-7. Exhibit 3-8 presents expected emissions factor reductions with the selected control strategies.

Exhibit 3-9 shows the process by which the annual NO_x emissions of an EMD GP60 locomotive were estimated. Similar spreadsheets for the other representative locomotives are contained in Appendix D. The second column of the spreadsheet contains the average duty cycle data for California linehaul locomotives. The baseline NO_x emissions rates for this locomotive operating in each throttle notch are in the third column, and the emissions rates for locomotives with various control technologies are in the next four columns. The spreadsheet multiplies the time in each notch by the emissions factor for that notch to obtain the weighted hourly emissions rates for each notch, which are in the last five columns. These are summed to obtain the overall weighted average NO_x emissions rate in pounds per hour. This weighted average hourly NO_x emissions rate is multiplied by the number of hours per year, corrected for locomotive availability which accounts for the time a locomotive spends in the shop for scheduled and unscheduled maintenance, and converted from pounds to tons to determine the total annual NO_x emissions from one GP60 locomotive in California linehaul service.

Estimates of Locomotive Population — Estimates of the California locomotive population were developed for the 1987 base year. A second estimate was forecasted for the year 2010. As discussed previously, the estimates are of *equivalent*, rather than actual locomotive populations.

Due to the lack of resources available to perform an estimate of the 1987 California locomotive population, and in the absence of any compelling reason to doubt the EF&EE estimate, its estimate was incorporated into this study. Population estimates by locomotive type are presented in Exhibit 3-10.

The equivalent locomotive population in 2010 was estimated based on Booz●Allen's forecast of future trends in railroad activity, motive power, and supporting technologies. Unfortunately, the Booz●Allen forecast was not presented in a format that cannot be directly applied to the methodology used for this study. Rather, it was expressed as percent increases or decreases in the four general areas of (1) application of rail flange lubrication and aerodynamic improvements, (2) more efficient train dispatching and scheduling, (3) phasing-out of old

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[9] Fritz, S.G. (1992), ***Exhaust Emissions From Two Intercity Passenger Locomotives***; by Southwest Research Institute; for California Department of Transportation, Division of Rail.

Exhibit 3-7
Selected Locomotive NO_x Emissions Control Technologies

Technology	Description
Dual-Fuel (DF)	Natural gas fuel is mixed with engine intake air; ignition in the cylinder is accomplished by injecting a small amount of diesel fuel near top-dead-center of the piston stroke, as in a conventional diesel engine.
Liquid Natural Gas with Spark-Ignited Engine (LNG-SI)	A spark-ignited (Otto cycle) engine is fueled by natural gas.
Selective Catalytic Reduction (SCR)	A chemical reductant (ammonia or urea) is mixed with the engine exhaust gas; this mixture undergoes a catalyst-promoted reaction, reducing NO_x to harmless N_2 and water (and CO_2 if urea is used as the reductant).
Dual Fuel plus Selective Catalytic Reduction (DF+SCR)	A dual-fuel locomotive is equipped with selective catalytic reduction.

Exhibit 3-8

NO_x Emissions Factor Reductions with Selected Control Strategies

Throttle Notch	NOx Emissions in Notch (lb/hr)			
	Dual-Fuel	LNG-SI	SCR	Dual-Fuel+SCR
off	----	----	----	----
brake	85.0%	85.0%	----	85.0%
idle	----	85.0%	----	----
1	----	85.0%	----	----
2	----	85.0%	----	----
3	85.0%	85.0%	----	85.0%
4	85.0%	85.0%	80.0%	97.0%
5	85.0%	85.0%	90.0%	98.5%
6	85.0%	85.0%	90.0%	98.5%
7	85.0%	85.0%	90.0%	98.5%
8	85.0%	85.0%	90.0%	98.5%

Exhibit 3-9

Emissions Calculation for EMD GP60 Locomotive in California Linehaul Service

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	23.0%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	6.1%	6.8	1.0	1.0	6.8	1.0	0.4	0.1	0.1	0.4	0.1
idle	39.7%	3.4	3.4	0.5	3.4	3.4	1.3	1.3	0.2	1.3	1.3
1	3.0%	10.2	10.2	1.5	10.2	10.2	0.3	0.3	0.0	0.3	0.3
2	3.2%	18.1	18.1	2.7	18.1	18.1	0.6	0.6	0.1	0.6	0.6
3	3.1%	32.8	4.9	4.9	32.8	4.9	1.0	0.2	0.2	1.0	0.2
4	3.9%	37.4	5.6	5.6	7.5	1.1	1.5	0.2	0.2	0.3	0.0
5	3.1%	43.6	6.5	6.5	4.4	0.7	1.4	0.2	0.2	0.1	0.0
6	2.9%	51.6	7.7	7.7	5.2	0.8	1.5	0.2	0.2	0.1	0.0
7	2.2%	74.7	11.2	11.2	7.5	1.1	1.6	0.2	0.2	0.2	0.0
8	9.9%	112.3	16.8	16.8	11.2	1.7	11.1	1.7	1.7	1.1	0.2
Weighted Average NOx Emissions (lb/hr)							20.7	5.0	3.1	5.5	2.7
Annual NOx Emissions (tons)				88% Availability			**79.9**	**19.3**	**12.0**	**21.3**	**10.5**

Exhibit 3-10

Estimated Equivalent California Locomotive Population in 1987

Locomotive Type/ Service Type	Estimated Number in California
EMD GP38-2 / Yard	271
EMD SD40-2 / Local	235
EMD SD40-2 / Linehaul	375
EMD GP60 / Linehaul	70
GE B40-8 / Linehaul	141
EMD F40-PH / Passenger	97

Exhibit 3-11

Changes in 2010 Emissions Inventory Forecast by Booz•Allen (1987 Base Year)

Service Type	Rail Flange Lubrication and Aerodynamic Improvements	More Efficient Dispatching and Scheduling	Locomotive Turnover	Changes in Activity Levels	Total
Yard	0	0	-11%	-36%	-43%
Local	-4%	0	-15%	-12%	-28%
Intermodal	-9%	-3%	-14%	+46%	+11%
Mixed Freight	-9%	-3%	-14%	+2%	-23%
Passenger	-9%	-3%	-14%	+27%	-4%

locomotives and replacement by new ones, and (4) changes in overall activity levels. The Booz•Allen forecast is summarized in Exhibit 3-11. Due to its incompatible format, a number of assumptions had to be made to apply the Booz•Allen forecast to the methodology employed in this study.

Rail flange lubrication, improved train aerodynamics, and better dispatching practices directly improve the efficiency of rail operations, with the result that a given freight movement by rail can be accomplished with a smaller amount of horsepower. This effectively reduces the number of locomotives required to perform a given level of service. Therefore, the percentage of emissions reductions forecast by Booz•Allen due to these factors were instead applied to locomotive population estimates developed in this analysis.

New locomotive types were assumed to be phased in under the following assumptions:

- by 2010, all "2nd-generation" locomotives (e.g., SD40-2) will have been replaced by locomotives equivalent to "3rd-generation" locomotives (e.g., GP60 and B40-8);
- three of these new locomotives will replace four of the older types in linehaul and local service, due to their relative maximum horsepower ratings;
- one-third of these new locomotives will be equivalent to the GP60, two-thirds will be equivalent to the B40-8 (based on the California fleet ratio of these types in 1987); and
- passenger and yard locomotives will be upgraded during rebuild and replace cycles to have 3rd-generation-equivalent emissions.

The first and last of the four assumptions are from the Booz•Allen report. The second and third assumptions were necessary for this study. The number of new locomotives that replaced older types was added to the forecast populations of these types that would be expected from changes in efficiency and activity, even without any overall turnover of locomotive types in the fleet. In contrast to the situation for linehaul and local freight locomotives, passenger and yard locomotives would not likely be replaced by 4,000 horsepower freight locomotives. Their baseline emissions factors were, therefore, simply adjusted downward by 15 percent to make their emissions essentially equivalent to 3rd-generation freight locomotive types, as forecast by Booz•Allen.

Booz•Allen provided separate estimates of changes in activity levels for intermodal and bulk/mixed freight operations. Because these service types were lumped together as "linehaul" service, it was necessary to apportion the changes in activity to the two types. This was accomplished by dividing the estimate derived in this analysis of the number of locomotives in linehaul service into intermodal and mixed subgroups based on the 57/43 ratio of 1987 base year emissions estimated by Booz•Allen. The activity adjustments were then made to these subgroups, and then the subgroups were re-combined to obtain the total forecast linehaul fleet in 2010.

The result of applying these assumptions to the assumed equivalent 1987 base year locomotive population yielded a forecast of the equivalent California locomotive population in 2010. This forecast is presented in Exhibit 3-12.

3.2.3 Rail Emissions Under a No-Control Scenario

Using the methodology described above, baseline California rail emissions were estimated for the 1987 base year and emissions were forecast for the year 2010 under a no-control scenario.

1987 Rail Emissions — For comparison purpose, the total annual California locomotive NO_x emissions predicted by the model for the 1987 base year were 57,128 tons (or 156.5 tons/day). Contributions from each type of locomotive are shown in greater detail in Exhibit 3-13. The model's prediction is within two percent of Booz●Allen's estimate of 58,248 tons (or 159.6 tons/day), lending credibility to both methodologies. The estimate of base year rail emissions is also very close to the ARB's estimate of 155 tons/day (see Exhibit 3-3), which is based on the methodology developed by Booz●Allen. The difference between these estimates is smaller than the likely uncertainty in the input data.[10]

2010 Rail Emissions — The forecast California locomotive NO_x emissions in 2010, under a no-control scenario, is 57,583 tons (or almost 158 tons/day). Contributions from each type of locomotive are shown in greater detail in Exhibit 3-14. The 2010 emissions forecast represents an increase of less than one percent over the 1987 base year emissions estimate. It suggests that technical and operational improvements (aerodynamics, dispatching, etc.) will combine with the decreased activity expected in the local and yard sectors to offset increases in emissions from the anticipated increase in linehaul activity, particularly in relatively pollution-intensive intermodal operations. These factors also account for the reduction in locomotive emissions per ton-mile of freight moved. As shown in Section 2, rail is expected to account for 36,541 million ton-miles of freight by 2010 under a no-control scenario (see Exhibit 2-4). Consequently, rail is expected to emit 0.003 pounds of NO_x per ton-mile in 2010, a decrease of 40 percent from the 1987 baseline of 0.005 pounds of NO_x per ton-mile (see Exhibit 3-5).

It should be noted that Booz●Allen's emissions forecast for 2010 is approximately 10 percent less than the estimate developed in this analysis. This can be attributed primarily to the lower hourly emissions factors that Booz●Allen used for the 3rd generation locomotive types (GP60 and B40-8), which are anticipated to dominate the railroads' future fleets. As discussed before, the emissions factors used for this study were based on more recent and numerous locomotive emissions tests and were therefore judged to be more reliable than those used by Booz●Allen.

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[10] Note that the estimate shown in Exhibit 3-13 of 156.6 tons/day includes NO_x emissions from passenger operations. Freight-related rail emissions are estimated to be 134 tons/day in 1987. On a ton-mile basis, this translated to 0.004 pounds/ton-mile.

Exhibit 3-12

Forecast Equivalent California Locomotive Population in 2010

Locomotive Type/ Service Type	Estimated Number in California
EMD GP38-2 / Yard	174
EMD GP60 / Local	50
GE B40-8 /Local	100
EMD GP60 / Linehaul	175
GE B40-8 / Linehaul	353
EMD F40-PH / Passenger	109

Exhibit 3-13

Estimated Unregulated California Railroad NO_x Emissions in 1987

Locomotive and Service Type	Emission Control Strategy	Assumed Number in California fleet	Annual NOx Emissions per Locomotive (tons)	Total Annual NOx Emissions (tons)
EMD GP38-2 / Yard	Baseline (Diesel)	271	16.0	4332.3
	Dual-Fuel LNG		8.8	0.0
	LNG-SI		2.4	0.0
	SCR		10.0	0.0
	DF+SCR		7.9	0.0
EMD SD40-2 / Local	Baseline (Diesel)	235	24.1	5665.5
	Dual-Fuel LNG		10.0	0.0
	LNG-SI		3.6	0.0
	SCR		11.4	0.0
	DF+SCR		8.1	0.0
EMD SD40-2 / Linehaul	Baseline (Diesel)	375	58.1	21768.9
	Dual-Fuel LNG		14.6	0.0
	LNG-SI		8.7	0.0
	SCR		16.1	0.0
	DF+SCR		8.3	0.0
EMD GP60 / Linehaul	Baseline (Diesel)	70	79.9	5594.3
	Dual-Fuel LNG		19.3	0.0
	LNG-SI		12.0	0.0
	SCR		21.3	0.0
	DF+SCR		10.5	0.0
GE B40-8 / Linehaul	Baseline (Diesel)	141	81.2	11443.8
	Dual-Fuel LNG		15.1	0.0
	LNG-SI		12.2	0.0
	SCR		15.6	0.0
	DF+SCR		5.3	0.0
EMD F40-PH / Passenger	Baseline (Diesel)	97	85.8	8323.0
	Dual-Fuel LNG		31.5	0.0
	LNG-SI		12.9	0.0
	SCR		34.1	0.0
	DF+SCR		23.8	0.0
Total Annual California Railroad NOx Emissions (tons)				**57127.7**

Exhibit 3-14

Forecast Unregulated California Railroad Emissions in 2010

Locomotive and Service Type	Emission Control Strategy	Assumed Number in California fleet	Annual NOx Emissions per Locomotive (tons)	Total Annual NOx Emissions (tons)
EMD GP38-2 / Yard	Baseline (Diesel)	174	13.6	2364.4
	Dual-Fuel LNG		7.5	0.0
	LNG-SI		2.0	0.0
	SCR		8.5	0.0
	DF+SCR		6.7	0.0
EMD GP60 / Local	Baseline (Diesel)	50	32.5	1623.9
	Dual-Fuel LNG		12.7	0.0
	LNG-SI		4.9	0.0
	SCR		15.1	0.0
	DF+SCR		10.1	0.0
GE B40-8 / Local	Baseline (Diesel)	100	30.1	3009.6
	Dual-Fuel LNG		7.4	0.0
	LNG-SI		4.5	0.0
	SCR		9.1	0.0
	DF+SCR		4.2	0.0
EMD GP60 / Linehaul	Baseline (Diesel)	175	79.9	13985.7
	Dual-Fuel LNG		19.3	0.0
	LNG-SI		12.0	0.0
	SCR		21.3	0.0
	DF+SCR		10.5	0.0
GE B40-8 / Linehaul	Baseline (Diesel)	353	81.2	28650.1
	Dual-Fuel LNG		15.1	0.0
	LNG-SI		12.2	0.0
	SCR		15.6	0.0
	DF+SCR		5.3	0.0
EMD F40-PH / Passenger	Baseline (Diesel)	109	72.9	7949.7
	Dual-Fuel LNG		26.8	0.0
	LNG-SI		10.9	0.0
	SCR		29.0	0.0
	DF+SCR		20.2	0.0
Total Annual California Railroad NOx Emissions (tons)				**57583.4**

The results of this analysis suggest that California rail emissions will remain essentially unchanged in the future. Predicted increases in linehaul activity will be offset by decreased local and switching activity and technological improvements that will increase the efficiency of all rail operations.

This estimate for the year 2010 is reasonably close to the Booz•Allen estimate for that year. The roughly 10 percent difference is smaller than the difference in emissions factors used for some locomotive types in the two studies. Because both the model developed for this study and the Booz•Allen model require several steps of calculation, small uncertainties in the input parameters of either model produce larger uncertainties in the results. To generate truly accurate estimates of locomotive emissions, it is essential to ensure that the most accurate duty cycle, emissions factor, and activity (population) data are collected.

3.2.4 Truck Emissions Under a No-Further-Control Scenario

Although various regulatory initiatives have been suggested to further control NO_x emissions from heavy-duty diesel vehicles, an assessment of future NO_x emissions from these vehicles is needed that reflects changes that are solely attributable to growth in activity. A rudimentary approach is employed to estimate heavy-heavy-duty diesel truck NO_x emissions for 2010 under a no-further-control scenario. This is due to the scope and focus of this study on rail and associated resource allocation priorities.

As shown in Exhibit 3-5, NO_x emissions from trucks operating in California during 1987 contributed 0.009 pounds/ton-mile of freight moved. This contribution reflects a fleet average NO_x emissions rate of 7.83 grams/Bhp-hr, as estimated by EMFAC7, and the prevailing NO_x standard during that year of 6 grams/Bhp-hr. In 1991, the NO_x standard was reduced by the ARB to 5 grams/Bhp-hr, and EMFAC estimates the 2010 fleet average NO_x emissions rate to be 4.6 grams/Bhp-hr—not including the proposed drop in the standard to 4 grams/Bhp-hr in 1998. Furthermore, by 2010 many technologies may be incorporated that affect truck emissions rates during a given trip. For example, aerodynamic improvements that are implemented to reduce fuel consumption may have emissions reduction consequences on a grams/Bhp-hr basis. Improvements in fuel management may also result with decreases in emissions rates. These technologies, as well as others that are deployed to comply with more stringent standards, will penetrate the fleet slowly since the operational life of a heavy-heavy-duty diesel truck often exceeds 10 to 15 years. Consequently, this analysis assumes that, on average, heavy-heavy duty diesel trucks will emit NO_x at a rate of 5 grams/Bhp-hr (i.e., the prevailing standard).

Assuming that the percentage change in average emissions from 7.83 to 5 grams/Bhp-hr holds on a ton-mile basis, trucks are expected to emit 0.006 pounds/ton-mile of freight moved in 2010 under the no-further-control scenario. Using this study's forecast for heavy-heavy-duty diesel truck ton-mileage in 2010 of 52,148 million, it is estimated that these vehicles will contribute roughly 410 tons/day of NO_x emissions during that year.

4. Review of Mode Shift Models

The principal objective of the study of the economic impacts of proposed locomotive emissions regulations in California is to determine how increased costs of rail freight transportation due to emissions regulations would impact freight movement patterns in the state. Ultimately, impacts on the amount of cargo shipped through California, the modal choice for these shipments, and the relative emissions characteristics of each mode are the significant factors which will determine how changes in the goods movement marketplace due to locomotive emissions regulations will affect overall emissions from freight transportation. In this study, the primary focus is on the extent to which locomotive emissions regulations might cause diversion of freight traffic from rail to trucks. This diversion from rail could occur if the cost of complying with new emissions regulations raises rail rates relative to other modes. It could also occur if rail shipments have to stop at the California border to switch to locomotives with lower emissions rated and these delays are perceived by customers as a reduction in the level of service from the railroads. If freight transportation diverts from rail to another mode which has higher emissions per ton-mile than does rail, the net effect of the regulations may not be a significant reduction in emissions. It is the ARB's intent to investigate this possibility prior to implementing any new regulations.

While the potential for new regulations to cause diversion from rail to other modes is the focus of this study, locomotive emissions regulations could cause other changes in the goods movement marketplace that are significant. These impacts include:

- increased rail costs or decreased level of service could cause diversion of international trade from California ports to other West Coast ports;
- increased rail costs could change intermodal shipment patterns by displacing truck-rail transfer points to locations out of state; and
- increased rail costs could cause substitution of non-transport factors for transportation—for example, companies could relocate to reduce transportation requirements or they could invest in new equipment to produce parts internally that were previously out-sourced in order to eliminate high transportation costs.

While these impacts are mentioned here, they are considered to be outside the scope of the current study. These impacts are difficult to analyze with existing models and data bases and would require significant resources beyond those available for this study. Thus, the primary focus of the study is on modal diversion impacts.

The purpose of this section is to present a review of studies and modeling approaches which address modal diversion and to assess the applicability of these studies and models to the current effort. In order to accomplish this task, a comprehensive review of the literature was conducted. The literature review focused on the following topics.

- Modal diversion models and studies. Specifically, models that could be used to estimate diversion of freight traffic from rail to truck given changes in rail costs or level of service. Modal diversion models that could be re-estimated using more current data were also investigated.

- California commodity flow data with some level of origin-destination and modal share detail which could be used to either re-estimate non-California models or as input data into existing models in order to adjust these models to better reflect California freight transportation markets.

- Techniques both for developing base year commodity flows by mode and for forecasting those freight flows.

Two major sources were used to conduct the literature review. The first was a review of *Memorandum on Past and Current Efforts Related to Intermodal Goods Movement*, which was prepared by Mercer Management Consulting, Inc. for the Southern California Association of Governments (SCAG) Interregional Goods Movement Study. This memorandum contains a detailed bibliography of studies on this subject. The memorandum was reviewed to determine the most relevant literature, and efforts were made to obtain as many of these studies as possible. In addition, a thorough literature search was conducted using the University of California's MELVYL bibliographic search system and reports were obtained from the University of California-Berkeley's Institute for Transportation Studies library. A search was also conducted through the Washington Resource Library Consortium.

4.1 Overview of Modal Diversion Models

Based on the literature review, a number of mode choice models were identified as candidates for use in this study. The models are categorized based on the two major types of mode choice models as described above—aggregate models and disaggregate models.

4.1.1 Aggregate Mode Choice Models

California Freight Energy Demand Model — One of the most significant freight forecasting projects which deals specifically with California goods movement is the California Energy Commission's Freight Energy Demand Model (CALFED) which was developed by Jack Faucett Associates in 1983. This model projects VMT by mode and rail-truck modal diversion as part of an overall framework for forecasting freight energy consumption. It was the original intent of JFA to use the modal diversion component of this model to project impacts of the proposed locomotive emissions regulations. Thus, the focus here is an explanation of the modal diversion techniques and their applicability to the current effort.

CALFED disaggregates freight flows in California by 16 commodity/activity categories, five sub-state regions, and six origin-destination (O-D) regions. These are illustrated in Exhibits 4-1, 4-2, and 4-3. Modal diversion is determined as a function of the relative cost of rail and trucking. Diversion is calculated for each commodity and each O-D region. A parameter that measures the sensitivity to service cost (i.e., rail costs as compared to truck costs) has been calculated for each commodity and this is applied to the change in the rail cost advantage per ton-mile for transport of each commodity to or from each O-D region. This parameter is a measure of how much the rail share (expressed in terms of ton-miles) of the shipments of a given commodity will change for every dollar change in the rail cost advantage per ton-mile as compared to truck costs. An adjustment is made which takes into account the current mode split for each commodity shipped between each O-D pair. Thus, flows which have a relatively even mode split are assumed to be very competitive and the sensitivity to each mode's cost of service is the major determinant of mode shift when the relative costs of rail and trucking change. Whereas, flows which are dominated by one mode or the other are less competitive and experience less relative diversion in response to a change in rail or trucking costs. Aside from this adjustment (which implicitly takes into account the importance of non-cost variables on the historic mode split for a given commodity shipped between a given origin and destination), the CALFED modal diversion algorithm only considers explicitly the impacts of changes in the relative costs of rail and trucking and does not consider the impacts of changes in other service variables, such as time delays that might be associated with changing locomotives to comply with California locomotive emissions regulations.

The key parameter in this model is the sensitivity to each mode's cost of service. In order to estimate this parameter for each commodity, JFA used the following data for shipments of each commodity group originating and/or terminating in California.

- Data from the 1977 Commodity Transportation Survey (CTS) were used to determine the mode share for truck and rail at each length of haul. That is, for commodity *x*, the CTS data were used to determine what percent of traffic traveling a distance of *y* miles was carried by rail and by truck.

- Data from the CTS were also used to develop a density function specifying the fraction of <u>all</u> freight transported at each length of haul. If the analyst knows the total amount of freight shipped in California for a particular commodity group, this density function can be used to determine how much of that commodity was shipped for a particular length of haul (say, 500 miles). If the information described above which determines the mode share at each length of haul is multiplied by the total freight shipped at each length of haul, the amount of freight shipped by each mode can be determined.

- Data from the 1977 Federal Railroad Administration (FRA)/ICC waybill files for similar types of shipments as described above were used to develop a rail cost curve which indicates the rail cost per ton-mile at each length of haul.

Exhibit 4-1

CALFED Commodity/Activity Categories

Agriculture

Construction and Mining

Timber and Lumber

Food Products

Paper Products

Chemicals

Primary Metals

Machinery

Other Manufacturing

Household Goods Movement

Motor Homes

Retail Trade

Wholesale Trade

Utilities

Services

Personal-Use Trucks

Exhibit 4-2

California Sub-state Regions Used in CALFED
(Counties contained in each region)

<u>San Francisco</u>

Alameda
Contra Costa
Marin
San Mateo
Santa Clara
Solano
Sonoma
San Francisco

<u>Los Angeles</u>

Los Angeles
Orange
Riverside
San Bernardino

<u>San Diego</u>

San Diego

<u>Sacramento</u>

El Dorado
Placer
Sacramento
Yolo

<u>All Other Counties</u>

Exhibit 4-3

Origin-Destination Regions Used in CALFED

California (Intrastate)

Arizona

Nevada and Utah

Oregon and Idaho

Washington and Montana

The 40 remaining contiguous states

The CALFED documentation[11] describes an approximating procedure which uses the above described data to determine the change in freight shipped by rail for a unit change in the cost advantage of rail relative to truck.

This approach incorporates several important features which determine mode choice. First, by computing the parameter separately for each commodity, the methodology takes into account commodity characteristics which create a preference for one mode relative to another. That is, some commodities are more sensitive to the service characteristics of each mode than they are to cost of service. Second, the methodology takes into account the sensitivity of mode choice for each commodity to the length of haul. That is, longer-haul shipments are more likely to travel by rail than are short-haul shipments. The cost advantage of rail as compared to trucking also tends to increase with length of haul. Third, by computing the mode cost sensitivities using actual mode share data from California, the methodology implicitly takes into account the unique service characteristics of each mode in California, given the flow patterns that were present in California when the shipment data were collected.

Babcock and German's Changing Determinants of Truck-Rail Market Shares — The primary focus of Babcock and German's study was to determine the impact of deregulation on truck and rail market shares at the national level. Two equations are estimated separately for the periods before and after deregulation. For each period, each equation was also estimated separately for seven two digit manufacturing groups.

The equations were estimated using ordinary least squares and specified rail market share as a function of relative rail and truck rates, the nominal interest rate, and relative services. The equations estimated for the post deregulation period also included yearly dummy variables to measure the effects of deregulation and changes in the truck size and weight regulations. Rail market share in all of the equations was defined as rail tons divided by total production. Any change in this ratio was interpreted as diversion to/from trucking. Rates were defined as revenue per ton-mile for all of U.S. traffic for truck and revenue per ton for rail. The authors proxy truck and rail services with interstate highway miles as a percent of total highway miles and average daily freight car miles, respectively.

This model was estimated for the entire U.S. with no origin-destination pairings or length of haul distinctions. The truck and rail rates the authors used are suspect because they employ different units for rail and truck, they assume that trucking rates do not differ by commodity, and they use national rates without O-D detail, which does not account for local variations or distance of haul. For these reasons, the parameters that they estimated could not be used for the current effort. Estimating a new model would be possible, although it would be time consuming and it is unclear whether it would yield satisfactory results. This approach was ultimately rejected for use in this study.

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[11] *California Freight Energy Demand Model: Final Report*, Jack Faucett Associates, for the California Energy Commission, June 1983.

Friedlander and Spady: A Derived Demand Function for Freight Transportation — Friedlander and Spady model the demands for truck and rail services to deliver outbound goods as factors in the production process. Their approach estimates a system of non-linear equations which calculate the total cost of production for an industry and the share of total costs which each input in the production process comprises. The equations included rail cost share equations and truck cost share equations to represent transportation inputs. The equations included among their independent variables truck rates and rail rates. Thus, if rail rates were increased, the model could be used to determine the change in the rail cost share and the truck cost share for a given industry. The model does include service characteristics, such as value of shipment, density of commodity, average length of haul, and average shipment size, as variables but only as determinants of inventory costs and not as determinants of rail or truck costs.

While this model is one of the most sophisticated reviewed as part of this study, and probably rests on the most secure theoretical foundation, there are a number of issues that would make it difficult to use for this effort. The biggest problem is that the model estimates diversion from rail to truck in terms of changes in cost share for each industry (i.e., for a particular industry if you raise the rail rates the model will tell you how much the industry spends on rail transportation and how much it spends on truck transportation, compared to how much it spent before the increase in rail rates). These cost share changes are difficult to translate into units such as shifts in ton-miles which are necessary to determine the emissions impacts of modal diversion. Another concern is that the parameters were estimated with 1972 data that were not specific to California. For use in this study, the model would have to be re-estimated with data that are not readily available.

Oum: A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada — This study is somewhat similar to the Friedlander and Spady study in that the model is based on a system of cost and input demand equations which specifies transportation services used to deliver outbound goods as a factor of production. However, a major difference between the two studies is that Oum estimated his model with cross-sectional data of inter-regional commodity flows rather than regional industry data. For each commodity, truck and rail expenditure shares to deliver a ton on a given link were defined as a function of the modal freight rates on the link, average speeds of the modes on the link, reliability of the modes on the link (i.e., mean transit time or standard deviation of transit time), and distance of the link. This aspect of the model is somewhat appealing. Unfortunately, the model parameters were estimated using 1970 vintage Canadian data. The model would need to be re-estimated for California with data that are generally unavailable without additional survey work.

University of Montreal Box-Cox Logit Model of Intercity Freight Mode Choice — In recently published work[12], Picard and Gaudry of the University of Montreal, describe an approach to calculating mode choice which applies the Box-Cox transformation to explanatory variables in

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[12] Picard and Gaudry, *A Box-Cox Logit Model for Intercity Freight Mode Choice*, Centre de Recherche sur les Transports, Universite de Montreal, September 1993.

a logit model.[13] The Box-Cox transformation is thought to be an improvement over the linear logit form because the impact of a unit change in any of the independent variables changes in a non-linear fashion depending on the value of the independent variable when the change is made. Thus, for example, the impact of a \$1 increase in shipping rates is greater for a \$50 shipment than for a \$100 shipment.

The models estimated by Picard and Gaudry include freight charges and transit time as the independent variables. The models were estimated for Canadian freight flows in 1979. Picard and Gaudry constructed intercity commodity flows for 64 commodity groups using aggregate interprovincial flow data which were disaggregated to the intercity level using input-output techniques and a modified gravity model. Transportation fares and travel times were estimated from regression equations.

While this model provides some useful improvements over earlier aggregate models, it is estimated with Canadian data and these data are as out-of-date as those used by the CALFED model.

4.1.2 Disaggregate Mode Choice Models

The Association of American Railroads (AAR) Intermodal Competition Model (ICM) — The AAR ICM was originally developed at the Massachusetts Institute of Technology (MIT) by Chiang, Roberts, and Ben-Akiva.[14] The model uses a logit formulation to predict mode choice probabilities for each shipment in a sample of shipments. A weighted sum of these probabilities based on the distribution of shipments in the sample, provides an estimate of market share for each mode. The utility functions in the model are a function of transport rates, storage costs,

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[13] The logit model is often used to estimate a variable which is a proportion (for example, mode share). This is a non-linear functional form that is used when it is believed that the impact of a unit change in an independent variables does not have a constant impact on the proportion being estimated. The standard form of the logit model for two choices is:

$$S = \frac{expU_1}{expU_1 + expU_2}$$

where $U_1 = a_0 + a_1 X_1^b$
$U_2 = a_2 X_1^b$
are called utility functions, and there can be as many explanatory variables X_n as are necessary. If the parameter $b=1$, the equation is called the linear logit form, and this applies to a situation in which the impact of the explanatory variable on the share variable, S, is constant over most values of X but which varies as S approaches either 0 or 1. In cases in which the impact of X on S depends on the value of X over all values of X (such as the example provided above for the impact of shipping rates on mode shares), the Box-Cox transformation can be used to convert the terms in the equations for U_1 and U_2 to non-linear terms for all values of the parameter b.

[14] *Development of a Policy Sensitive Model for Forecasting Freight Demand, Final Report*, Y.S. Chiang, P.O. Roberts, and M.Ben-Akiva, Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, MA, for Office of the Secretary, U.S. Department of Transportation, December 1980.

capital costs in transit, loss and damage costs, order costs, loss of value in shipment, shipping distance, shipment value, and commodity use rate.

To estimate the model, a detailed disaggregate data base of shipments needed to be developed. In the original formulation of the model, the intercity freight flows were developed from the 1972 Commodity Transportation Survey. The current version of the model has been updated with data on rail and truck flows, some of which are proprietary and collected for AAR. Commodity use rates were developed using data on production and consumption of commodities derived from *County Business Patterns* and input-output methodologies. Originally, transport rates were estimated using a model developed at MIT. In the current version, rail costs are computed using the Uniform Rail Costing System and truck costs are estimated using a detailed truck costing model developed for AAR. Most other level of service attributes are estimated with models based on survey data collected by AAR or others and maintained in proprietary data bases. Commodity attributes, such as value, shelf life, etc., are contained in a commodity attribute file which has been periodically updated for AAR by Roberts.

The model is solved by taking a sample of rail shipments from the ICC Waybill Sample as a starting point. The rail costs for these shipments are then calculated by the model, taking into account any changes in costs associated with the policy scenario being analyzed. The alternative trucking modes are then identified and the AAR WINET model is then used to compute the trucking costs. Total logistics costs for rail and trucking alternatives for each shipment are calculated, and the logit model is used to determine the probability that the shipment will go by rail. The probabilities for each shipment are weighted by the percent of the total tons that each shipment represents in the sample. These weighted probabilities are summed to get the rail share.

The ICM is an attractive mode share model because of the its level of detail and its disaggregate approach. JFA investigated the possibility of using the model, but the AAR was unwilling to provide access to the ICM for contractor use, nor were they willing to run the model for us. The original published version of the model was estimated with data which by now are extremely dated and much of the input data which are necessary to solve the model are in proprietary data bases which were never published (such as the Commodity Attribute File). Because of the level of detail contained in the model, it is infeasible to construct these data files from published sources given the resources available for this project. Given these problems, use of the ICM was rejected for this analysis.

Winston Disaggregated Qualitative Mode Choice Model for Intercity Freight — This model was developed by Winston at the University of California at Berkeley in the late 1970s at the same time that the original version of the ICM was being developed at MIT. As with the MIT work, Winston sought to model shipper/receiver behavior in mode choice using disaggregate probability techniques. His model is estimated using a probit form and includes variables such as shipment size, commodity value, freight charges, transit time, service reliability, location relative to a rail siding, and annual sales as explanatory variables for mode choice.

Sample data used to estimate the model were taken from a variety of sources. Most of these sources date to the 1973-78 period and were applied to a sample of shipments from the 1975-76 period. These data were determined to be too out of date to be useful in the current project, and the Winston model was therefore rejected.

University of Calgary Logit Model for Intercity Goods Movement — This model approaches the goods movement problem in much the same way as does a disaggregate model. The modelers develop a disaggregate data base from aggregate sources and apply the logit probability form. In a manner similar to the University of Montreal work, interprovincial commodity flow data are disaggregated to intercity flows. The data are further disaggregated to determine the number of shipments by commodity in each of several weight groups for each city pair. Using regression equations developed by Oum[15] and Chiang, et al.,[16] travel times are estimated for each mode and city pair based on distances. Freight rates were obtained from the Canadian Tariff Bureau and the Canadian Freight Association.

A logit model was estimated with rail and truck utility functions determined as a function of travel time and the product of freight rates and shipment size. The test model was estimated for meat shipments only using 1981 data from the Statistics Canada Record. While the model is useful for identifying modeling techniques and their reliability, the actual parameter estimates are only for a single commodity and are based on outdated Canadian data. Therefore, this model was rejected.

4.1.3 Other Relevant Studies

There are no comprehensive models which have been identified which forecast freight movement or modal diversion in California. Several studies have been done which forecast growth of traffic for specific modes and facilities. These are discussed below.

Development of A California Freight Network Model: Phase I Report, by Edward C. Sullivan and Juan Manuel Guell-Camacho, University of California, Berkeley, Institute for Transportation Studies, June 1986, reports on Phase I of the subject project. The project attempted to develop a multimodal freight network model for California. The project chose to adapt the Princeton Transportation Network Model and Graphics Information System (PNTM/GIS) to California conditions. Ultimately, the project intended to "enhance the network to include explicit representation of routes and service frequencies and capacities of established rail and trucking routes, and implement a path-building and traffic assignment procedure which splits traffic among the different available services on the basis of prevailing costs, travel times, and service frequencies. By accomplishing this, the assignment routine applied to the multi-modal network can provide a simultaneous solution to both the mode and route choice problems." At the

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[15] T.H. Oum, *A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada, Bell Journal of Economics 10,* 463-482, 1979.

[16] Y.S. Chiang, P.O. Roberts, and M. Ben-Akiva, *Op Cit.*

conclusion of this phase of the project, work had just begun on adapting and loading the multimodal network model and work had not begun on developing the mode choice components of the model.

In 1989, Munshi and Sullivan continued the development of the California Freight Network Model where the previous project left off. In *A Freight Network Model for Mode and Route Choice* they describe a procedure for determining mode split between rail and truck as a function of delay time, transit time, and headway of each mode. They reason that for commodities for which rail and trucking compete, tariffs yield similar costs per ton-mile for the two modes and they therefore drop out of the mode split equations. The model was tested by computing mode split for lumber shipments between two Northern California counties and San Diego. Reebie Associates' 1989 **Transearch** data on commodity flows and telephone surveys of sawmills, rail companies, and trucking firms were used to estimate the model. The calculated rail shares tended to be lower than the actual shares and several explanations are offered. After this project was completed, there was no further funding for the California Freight Network Model, and the work was discontinued.

In 1989, the Ports Advisory Committee for SCAG published *International Trade and Goods Movement: The Southern California Experience and Its Future*, which forecasts international trade impacts on the SCAG region. The capacity of the current goods movement corridors and their ability to handle forecasted increases in international trade are discussed. This was not viewed as terribly useful for this analysis because of its local orientation and concern specifically with port intermodal connections. Several similar studies were conducted for the San Francisco Bay Area ports and the San Pedro Bay ports which have similar limitations.

In October 1990, Wilbur Smith Associates conducted *A Study of Goods Movement at Los Angeles International Airport* for SCAG. This study forecasts future growth in air cargo movements at Los Angeles International Airport and establishes a relationship between truck traffic on major arterials and the effects of growth in air cargo on access traffic. This study is too localized to be of use to the current effort and does not deal with modal competition.

There are three other studies that were reviewed which have potential relevance to the development of a modal diversion analysis methodology for use in this project. The first is a study funded by the National Cooperative Highway Research Program (NCHRP) in 1983.[17] In this study, Memmott developed a methodology for freight forecasting which is based loosely on the traditional four-step urban transportation planning process. For the first two steps in the process, trip generation and trip distribution, Memmott proposes a methodology for forecasting commodity flows and assigning these to origin-destination pairs based on economic modeling techniques. These techniques are very similar to the approaches used to estimate baseline commodity flows, which are described in Section 2 of this report. The approach to mode split

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[17] *Application of Statewide Freight Demand Forecasting Techniques*, F.W. Memmott, Roger Creighton Associates, Inc., for the National Cooperative Highway Research Program, Report No. 260, Washington, DC, September 1983.

analysis suggests that mode choice be based on the cost differential between competing modes, and the report focuses most of its attention on defining approaches to estimating modal costs for each freight mode. Sparse detail is provided as to methods for determining how costs will influence mode choice in a modeling context. There appear to be no published applications of this methodology and the lack of detail on how to model the cost sensitivity aspects of mode choice make it difficult to apply to the current project. NCHRP is currently funding another study to develop freight forecasting techniques for state departments of transportation and metropolitan planning organizations (MPO). However, this new study will not be completed for another year.

The second study of interest is a truck size and weight study conducted by Sydec, Inc. with assistance from Jack Faucett Associates. This study was conducted for the Federal Rail Administration (FRA) and the Federal Highway Administration (FHWA) in order to examine how changes in the truck size and weight limits on interstate and other major highways would influence the costs of freight movement. A major element of the study was a determination of the effects which increased size and weight limits would have on modal diversion between rail and trucking. Increases in truck size and weight limits will, for the most part, reduce trucking costs for long haul freight movements and this could cause diversion from rail to trucking. For Sydec/JFA's study, the AAR made runs of the ICM to evaluate rail-truck diversion using cost data supplied by Sydec/JFA. Several scenarios were examined. In each case changes in trucking costs were calculated and the corresponding decrease in rail ton-miles was determined. One possible way of using these data would be to plot a relationship between the change in the relative costs of rail and trucking per ton-mile and the rail share of competitive freight movements. This relationship could then be used in this study to determine how rail share would change for a given change in the relative costs of rail and trucking. This approach was not elected for use in this study for several reasons. First, the number of scenarios which could be use to fit the curve is relatively small and the fit to the data is not likely to be very good. Second, the levels of modal diversion calculated in the study are very sensitive to the nature of the scenarios defined and it is not clear that the same relationship between relative costs of rail and trucking and rail share would hold for a different set of scenarios.

The third study of interest is the previously mentioned SCAG Interregional Goods Movement Study which provided a bibliography that was used in the initial identification of modeling methodologies for this project. In April 1995, Mercer Management Consulting released an evaluation of key methodologies for mode choice modeling.[18] The report presents evaluations of 14 mode choice models. Two of these are proprietary models developed by Mercer and these are based on stated preference surveys rather than actual mode choices in the marketplace. Of the remaining 12 methodologies, six are already reviewed in this report. While the remaining six methodologies include some interesting approaches. For the most part these are unacceptable for the following reasons:

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[18] *Interregional Goods Movement Study, Task 2C Report: Evaluation of Key Methodologies*, Mercer Management Consulting for Southern California Association of Governments, April 25, 1995.

- they do not address mode choice directly;
- they lack sufficient detail with respect to how critical variables (e.g., non-transport logistics costs) are calculated
- the model parameters were estimated with data that are extremely dated (pre-1977)
- they would require substantial resources to collect new data for inputs and calibration.

For these reasons, and given the late date at which these models were identified, they were not considered for further application in this study.

4.2 Modal Diversion Methodologies: Summary of Key Issues

Exhibits 4-3 and 4-4 provide a critical review and summary of the models that are discussed above. One of the most disconcerting findings to come out of the literature review was that, with the exception of the current AAR model (which is proprietary), few of the models reviewed were estimated with post-1977 data. In the U.S. this is because no comprehensive shipper survey has been conducted since the 1977 CTS. While there are more current data for rail shipments, there are no other shipment data bases for trucking. The U.S. Census Bureau is in the process of disseminating information contained in the 1993 Commodity Flow Survey (CFS) which will replace the old CTS as a primary commodity flow data base. However, these data were not available during the preparation of this report. At present, any current data that can be developed or used to estimate modal diversion has an aggregate nature, meaning that an aggregate model will have to be used for this effort.

Unfortunately, the parameters that were estimated with these models are now all biased because freight markets have undergone tremendous changes since 1977. For instance, the 1980 Motor Carrier Act (MCA) and the 1982 Surface Transportation Assistance Act (STAA) both relaxed federal regulations in the trucking industry. Prior to deregulation, trucking firms competed through levels of service rather than through rates, since rates were regulated. Rates, therefore, probably did not accurately reflect differences in service between truck and rail. After deregulation, however, rates began to more accurately reflect those differences. As a result, the information contained in rate variables today is different than it was in 1977. The STAA also helped to bias parameters estimated in 1977 because it led to efficiency improvements through changes in average shipment sizes.

Another factor contributing to the bias of these parameters is the change in the product mix of aggregate commodity groups that has taken place since 1977. As commodity groups change in consistency from relatively heavy, lower valued goods to relatively light, higher valued goods, the likelihood increases that certain commodities will be hauled by truck.

Exhibit 4-4

Aggregate Models

Model	Variables	Pros	Cons
California Freight Energy Demand Model (1983)	● Transport Cost ● Prior Year Mode Split	● Provides O-D detail ● Provides commodity detail ● Modal cost sensitivities based on length of haul ● Based on California shipment data	● Estimated with 1977 CTS data ● Does not include time variable or other non-transport logistics costs
Babcock and German: Changing Determinants of Truck-Rail Market Shares (1989)	● Truck and rail rate ● Prime interest rate ● Truck/rail services ● 1982 STAA	● Simple regression ● Requires minimum amount of data ● Accounts for inventory costs	● National level study: no length of haul, shipment size, or OD distinction. ● Can't use parameter estimates ● Model is based on time series
Friedlander and Spady: A Derived Demand Function for Freight Transportation (1980)	● Prices and quantities of production inputs ● Price and quantity of output ● Truck and rail rates ● Density, length of haul, shipment size	● Models freight transportation as a factor in production process. ● Addresses simultaneity of transport rates, inventory costs, length of haul, and shipment size. ● Translog specification	● Estimated with 1972 cross-sectional data of 3-digit manufacturing industries. ● Inventory specification suspect ● Difficult to implement, especially at BEA regional level
Oum: A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada (1979)	● Total tons by commodity by mode for each link ● Modal freight rates ● Distance of link ● Transit time ● Reliability	● Freight transportation modeled as input into production process ● Designed around same data limitations faced in this study. ● Translog specification ● Addresses speed, distance, reliability, commodity characteristics. ● Feasible to estimate	● Estimated with 1970 Canadian traffic flows ● Specification may be more accurate for commodities delivered primarily by private trucks ● Assumes constant returns to scale and strict separability of transport related variables
Picard and Gaudry: A Box-Cox Logit Model of Intercity Freight Mode Choice (1993)	● Transport Cost ● Transit time	● Provides O-D and commodity detail ● Includes important policy variables ● Non-linear model	● Estimated with 1979 Canadian data ● Difficult to implement; required data are not available

Exhibit 4-5

Disaggregate Models

Model	Variables	Pros	Cons
AAR Intermodal Competition Model	• Transport Cost • Inventory Carrying Cost • Ordering Cost • Loss and Damage Cost • Loss of Value in Shipment • Distance • Shipment Value	• Detailed representation of mode choice with all relevant decision variables • Commodity characteristics and shipment characteristics specified in detail • Focuses on rail-truck diversion • Parameters and commodity attributes estimated with recent data: e.g., rail shipment taken from recent ICC Waybill	• Published version of the model uses 1977 CTS and earlier data sources • Current parameters and commodity attributes are proprietary • Relies on survey data to estimate values of key variables • Most variables are not policy sensitive for ARB analyses
Winston Disaggregated Qualitative Mode Choice Model for Intercity Freight Transportation (1979)	• Shipment Size • Commodity Value • Freight Charges • Transit Time • Reliability of Service • Location relative to rail siding	• Estimates separate models by commodity group • Includes most of relevant service characteristic variables • Estimates rail and truck diversion in both directions	• Parameters estimated with 1975-77 data • Requires survey data to solve model, which are generally unavailable
Sargious and Tam: Data Disaggregation Procedure for Calibrating a Logit Model for Intercity Goods Movement (1984)	• Transport Cost • Transit time • Shipment Value • Length of haul (dummy)	• Simulates a disaggregate approach with disaggregated data • Provides commodity and O-D detail • Includes all key policy variables	• Estimated with 1981 Canadian data for one commodity group • Costly to estimate with U.S. data • The quality of disaggregated data are questionable

Other changes that could have biased parameters estimated in 1977 are the length of haul distributions of commodities. Shifts in these distributions toward longer or shorter hauls will increase the tendency for a commodity to move by rail or truck, respectively. Furthermore, deregulation resulted in changes in the relative costs of truck and rail.

4.2.1 Selecting the Modal Diversion Model

In view of the above considerations, JFA evaluated the possibility of estimating a new model. However, given the resource constraints associated with this project and the improvements in source data which will become available in the next few years, it would not be cost-effective to use this project's funds to develop a new modal diversion model. Besides, both Caltrans and the California Energy Commission have plans to develop new modal diversion analysis capabilities in the next year and the resources available in each of these efforts are very substantial as compared to the current project. After reviewing the available modal diversion models that reported parameters which could be used for the current effort, the CALFED modal diversion algorithm was selected as the most useful modal diversion analysis tool for the present study. There are several obvious advantages of the CALFED model. These are listed below:

- it is based on actual California shipment data;
- mode cost sensitivities are developed by commodity group and thus reflect the unique commodity characteristics which would favor one mode over another irrespective of mode cost (e.g., commodity value, use rate, shelf life, etc.);
- modal diversion is calculated for O-D pairs which reflects the actual production and consumption patterns of California economic regions and their trade relationships with the rest of the nation;
- it uses aggregate shipment data which are the only data readily available without additional survey work;
- it implicitly considers the impact of length of haul on mode choice through the procedure used to calculate the model parameters; and
- it includes a variable which takes into account the current competitive position of rail versus truck for each commodity group which helps offset some of the bias in other model parameters which are estimated with 1977 data.

The one option which was considered the leading alternative to CALFED was the AAR ICM. This model, because of its emphasis on shipper behavior, its highly disaggregate method of choice simulation, its use of current data sources, and its preference by the rail industry, seemed to be a strong candidate for use in this study. The complexity of this model would require that an experienced user be available to actually run the model. JFA approached the AAR to determine if an arrangement could be agreed upon whereby JFA would supply critical model inputs and AAR, or its contractors, would actually run the model. This approach was used by Sydec and JFA for the previously mentioned truck size and weight study. AAR stated that their current policy is to not make the model available for analysis by outside contractors, primarily because they want control over how the results are used. AAR feels that in the past contractors have made extrapolations and modifications of results that violated the theoretical assumptions and methodology inherent in the ICM. Yet, these extrapolations were represented as based on the ICM in order to give them a certain legitimacy. To prevent this from happening in the future, AAR no longer makes the model available and does not provide any documentation on the current version of the model.

Since the ICM was considered the favored analytical tool by the rail industry, it seems appropriate to ask how the results of an analysis conducted with CALFED might compare with results from the ICM. Such a comparison was conducted by JFA for the truck size and weight study.[19] In assessing which model to use for the truck size and weight study, JFA compared cross-elasticities produced by ICM and CALFED for comparable policy scenarios.[20] In order to use any of these comparisons as an indicator of the relative performance of the two models in the analysis of proposed locomotive emissions regulations, the appropriate cross elasticities to use are those associated with scenarios which represent across the board reductions in trucking costs for rail-competitive shipments. This is because locomotive emissions regulations will raise costs on all rail shipments, even those which have low modal cost sensitivities due to the characteristics of the commodities being shipped, such as low value bulk commodities (e.g., coal). The outcome of such a comparison is that the two models produce similar results in order of magnitude: 0.39 for CALFED and 0.52 for ICM.[21]

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[19] In that study, various changes in truck size and weight regulations were being evaluated with respect to how they would affect the competition between rail and trucking. Various policy scenarios were evaluated which, for the most part, increased truck size and weight limits on different parts of the national highway network. The effect of these regulatory changes in most cases would be to lower the cost of trucking for some types of operations. Thus, competitive traffic might shift to trucking from rail.

[20] These elasticities were defined as the percentage change in rail share due to a one percent change in the truck rate. While cross elasticities are not given explicitly in CALFED, there were sufficient data from the original CALFED report with which to compute cross elasticities for each of the commodity/activity groups in CALFED, as well as a weighted average based on base year ton-mile distributions across commodities.

[21] Unlike the studies referenced above, this study is concerned with the percentage change in rail ton-miles associated with a percentage change in the relative costs of rail and trucking. It is possible to use the cross-elasticities reported above for the ICM and CALFED models to calculate an elasticity which represents the percentage change in rail ton-miles per percentage change in the rail cost advantage as compared to trucking. The same relationship between these elasticities would exist as was demonstrated above for the rail ton-mile to truck cost elasticity (i.e., the elasticity of rail ton-miles to rail cost advantage calculated with CALFED would be 25 percent lower than if it were calculated using ICM data). For example, if a particular decrease in the rail cost advantage relative to trucking caused a 6 percent reduction in rail ton-miles as calculated with CALFED, it should cause an 8 percent reduction in rail ton-miles as calculated with the ICM model. The reader should be reminded, however, that since the elasticities calculated with these models can change depending on how the scenario is specified, the numbers reported herein are only illustrative of how the two models compare.

It is expected that using CALFED will result in an underestimation of modal diversion. The biases outlined above should all bias the parameters downward, since many of the changes since 1977 have increased the tendency of goods to move by truck. As pointed out, one impact of deregulation has been a change in the content of freight rates. Those rates now reflect more information than they did in 1977, which means that modal shares will now be more responsive to changes in them. In addition, if the 1980 MCA or the 1982 STAA reduced the cost advantage of rail proportionately across all lengths of haul, it is likely that trucking has picked up a portion of the longer haul markets. A shift in the distribution of commodities from long haul movements to short haul movements would also bias diversion parameters downward. Such a shift could have occurred if long haul rail movements shifted to intermodal movements. Since intermodal movements in the 1977 data are treated as two separate moves (a long haul rail move and a short haul truck move), a density function determined in like fashion with current data showing more intermodal movements would show an increase in the share of total ton-miles shipped shorter distances at the expense of moves shipped longer distances. The fact that these biases move in the same direction allows a floor to be placed on the estimated amount of diversion. From that point, sensitivity analyses will be conducted in this study to determine a range within which the actual amount of diversion is thought to lie. Sensitivity analyses are presented in Section 5.

One other disadvantage of the CALFED parameters is that they do not incorporate non-transportation costs as explanatory variables for mode share. While transport costs are taken into account in the calculation of the mode cost sensitivity parameters, the impact of changes in these other factors cannot be determined. For instance, the CALFED parameters cannot be used to evaluate a regulatory strategy which causes an increase in the travel time associated with rail. Other aggregate models include transit time in their specification. However, these models are generally estimated with data sets which are inappropriate for the current analysis.

The following section presents the mode choice and associated emissions impacts of proposed locomotive emissions regulations for trains operating in California.

5. Impacts of Locomotive Emissions Regulations

The central purpose of this section is to assess the effects of proposed locomotive emissions regulations on mode choice and locomotive emissions. Currently, locomotives operating in California are not subject to NO_x emissions regulations. The promulgation of regulations is expected to result in changes in the cost of moving freight by rail, possibly leading to an increase in the amount of freight transported via truck. Mode shifts from rail to truck will also impact the emissions contribution of each mode, and possibly result in higher overall emissions levels since, as shown in Section 3, trucks pollute more on a ton-mile basis. However, focusing solely on the impact of locomotive emissions regulations on mode choice and freight emissions ignores the impacts of more stringent future NO_x emissions regulations that likely will be promulgated for heavy-heavy-duty diesel trucks operating in California. Consequently, to fully assess the net impact of locomotive regulations on mode choice and emissions, it is necessary to evaluate the impacts of regulatory strategies recommended for each mode.

But before doing so, a more comprehensive description of the CALFED diversion sensitivity parameters employed in this analysis is provided in Section 5.1. As discussed in Section 5.1, CALFED estimates diversion from rail to truck using sensitivity parameters that measure the impacts of the change in the cost advantage (in cents/ton-mile) of transporting freight by rail versus truck. Section 5.2 discusses baseline freight rates for rail and truck from which changes in the relative rates will be determined for each regulatory scenario to calculate the change in the cost advantage needed to determine diversion using CALFED. Section 5.3 presents the regulatory scenarios that are investigated in this study, and estimates the effect of each scenario on rail and truck freight rates. Section 5.4 presents the modal diversion impacts of each regulatory scenario and the associated emissions consequences. Finally, Section 5.5 places confidence intervals on the estimated diversion using sensitivity analysis that adjusts the CALFED mode shift parameters.

5.1 CALFED Modal Sensitivity Parameters

As discussed in Section 4, CALFED determines modal diversion as a function of the relative cost of transporting freight by rail versus truck. The methodology employed in CALFED results in modal sensitivity parameters to which changes in the rail cost advantage are applied to determine diversion from rail to truck. Modal sensitivities were estimated in CALFED for each commodity group, defined in Section 2 of this report, from mode share data for movements originating and/or terminating in California as reported in the 1977 Commodity Transportation Survey (CTS), and from railroad rate data for such movements as reported in the 1977 Waybill files. CALFED's modal sensitivities are shown in Exhibit 5-1 for each of the ten commodities included in the CALFED methodology. The development of these sensitivities is described below.

Exhibit 5-2 shows the generalized effect of distance on transport cost (to the shipper) per ton-mile for rail and truck shipments. Both modes demonstrate economies of scale with increasing

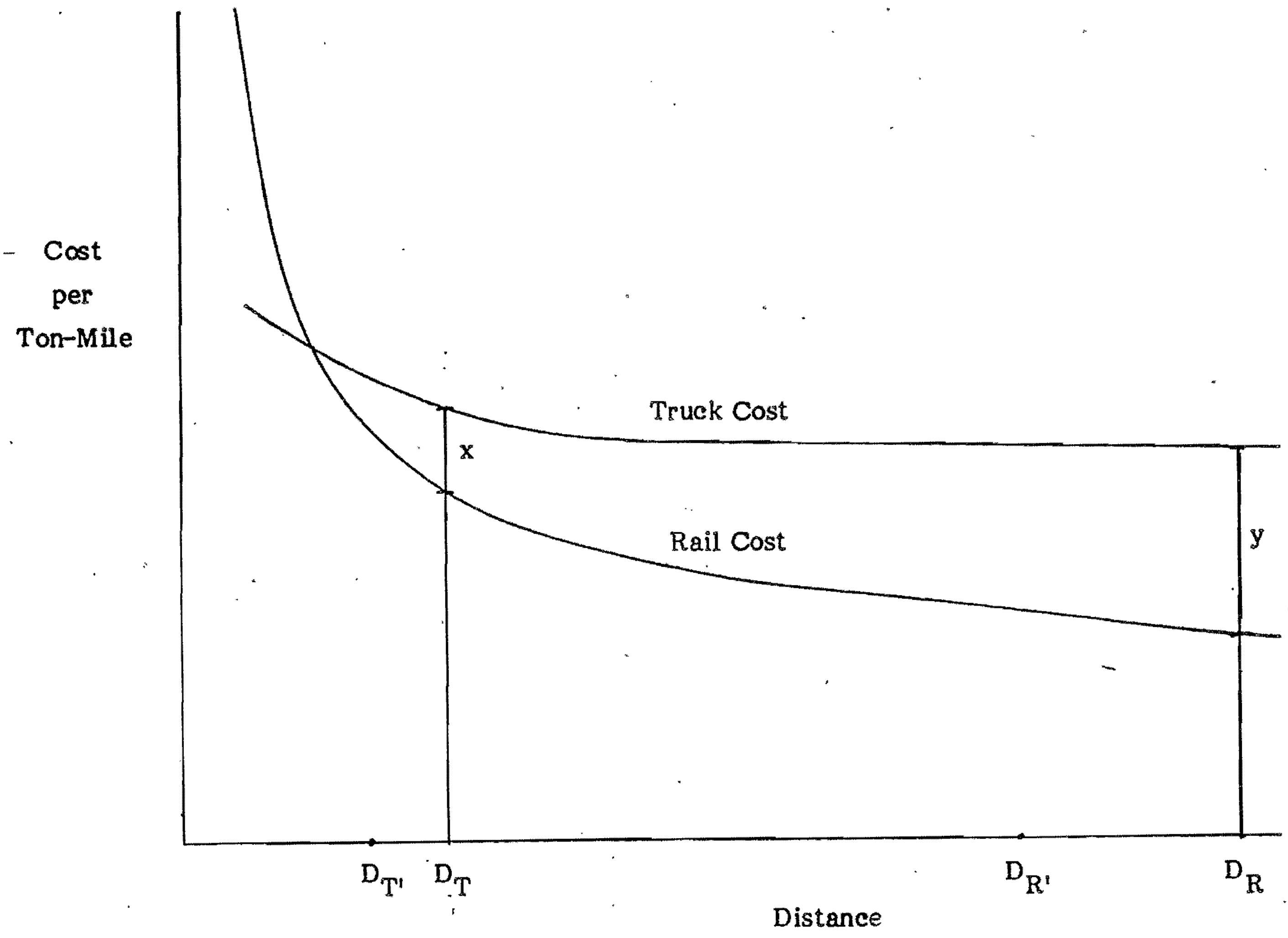
Exhibit 5-1

CALFED's Modal Sensitivity Parameters (per Ton-Mile, in 1977$)

Commodity Group	Modal Sensitivity Parameter
1. Fruits and Vegetables	0.0268
2. Other Agricultural Products	0.1201
3. Minerals and Construction Materials	0.1112
4. Timber and Lumber	0.0837
5. Food Products	0.0261
6. Paper Products	0.0787
7. Chemicals	0.0568
8. Primary Metals	0.0263
9. Machinery	0.0269
10. Other Manufactured Products	0.0268

Exhibit 5-2

Generalized Rail and Truck Costs per Ton-Mile as a Function of Distance



distance—that is, as distance increases, cost decreases. However, these economies are greater for rail than for truck. The curves shown in Exhibit 5-2 are meant to represent average costs for transporting relatively competitive freight (e.g., freight that can be transported by heavy-heavy-duty diesel trucks or by rail).

As depicted in Exhibit 5-2, for most moderate-size shipments, truck is likely to be the cheaper mode for very short hauls. At distance D_T, the rail cost advantage is represented by x. This cost advantage ensures that rail will compete for hauls moving a distance of D_T—for example 20 percent of ton-miles transported this distance may move by rail and 80 percent may move by truck since D_T represents a relatively short haul. Similarly, for some (but not all) commodity groups there will be a rail cost advantage, y, which corresponds to a distance, D_R, at which there is, for instance, an 80 percent probability that tonnage will move by rail. However, for distances that are less than D_T, rail becomes a decreasingly significant competitive factor and truck is the dominant mode. On the other hand, for distances greater than D_R, truck is decreasingly important and rail becomes the dominant mode. For intermediate distances, both modes are competitive.

Consider next the effect of a change in the cost advantage—for example, an increase in this advantage resulting from either a decrease in the cost of shipping freight by rail and/or an increase in the cost of shipping freight by truck. As the rail cost advantage increases, rail becomes the dominant mode at shorter haul distances, represented by a shift from D_R to D'_R. Likewise, the length of haul required for trucking to be the dominant mode decreases from D_T to D'_T, as shown in Exhibit 5-2. The resulting increase in the rail share of tonnage is approximated through the following equation:

$$\textit{Increase in Rail Share} = \sum_{D=D_T,D_R} \frac{f(D)*\Delta C}{2*(m_{CT}(D) - m_{CR}(D))} .$$

where

ΔC = the increase in the rail cost advantage (in cents per ton-mile);
$m_{CT}(D)$ = the slope of the truck cost curve at distance D (in cents/ton-mile);
$m_{CR}(D)$ = the slope of the rail cost curve at D; and
$f(D)$ = a density function specifying the fraction of freight transported D miles.

Recognizing that for all but the shortest distances, the slope of the truck-cost curve is almost zero—that is, the curve is almost flat—the equation described above collapses to the following expression:

$$\textit{Increase in Rail Share} = \sum_{D=D_T,D_R} \frac{f(D)*\Delta C}{2*m_{CR}(D)} .$$

This last equation is used in CALFED to estimate the effect of a change in the cost of transport by rail and/or truck on mode shares, as represented by the modal sensitivity parameters shown in Exhibit 5-1. As shown in Exhibit 5-1, the most cost-sensitive commodity groups are "other agricultural products" and "minerals and construction materials", while the least cost-sensitive commodity groups are "fruits and vegetables", "food products", "primary metals", "machinery", and "other manufactured products" which basically represents general freight.

Given that CALFED estimates mode shifts resulting from changes in the relative rates of transporting freight by truck, or more precisely from changes in the cost advantage of rail, which is expressed by

$$\frac{\text{Rail Rate (cents/ton-mile)}}{\text{Truck Rate (cents/ton-mile)}},$$

the impact of emissions regulations on this relative transport cost must be assessed to estimate mode shift in this analysis. Before doing so, however, the baseline freight rates for rail and truck must be determined. These will form the basis from which changes in the cost advantage of rail versus truck will be estimated.

5.2 Baseline Freight Rates (Truck and Rail)

The purpose of this part of the analysis is to collect and analyze information on the rates charged for transport by railways operating in California. Those rates then provide a basis from which to estimate the costs those railways incur in their own operations within the state.

Railway lines consider their shipping rates to be highly proprietary. Limited, if any, specific information about prices and rates are published in trade, business, or scientific journals. As part of this effort, two previous attempts to obtain transport or shipping rate information for California—both by literature reviews and by direct inquiry to the railways—were unsuccessful.

The initial scope of this investigation was limited to rates for shipments within California. However, that scope was extended slightly during the course of this particular effort for reasons explained later in this sub-section.

5.2.1 Railway Shipping Lines

California has three commercial rail transport lines. Each of the three lines has specific rail routes within the state that are closely regulated by government agencies. Customers may transport goods with any one of the lines only along the specific rail routes allocated to that rail line. To get to a destination outside of the approved route or range of a rail carrier, goods may be transferred from one rail line to another. However, that transfer would entail an extra charge to the customer.

The three rail transport lines that serve California are as follows.

1. *Union Pacific Lines* — Union Pacific runs east-and-west and it serves California primarily as an interstate carrier. It is the primary rail carrier for California goods transported to the Northeast and Northern Midwest. Union Pacific has destination points in both Northern and Southern California, but the line has no direct north-south routes within the state. Therefore, its intrastate shipping business is limited. Any north-south shipments (e.g., between San Francisco and Los Angeles) must go through a hub of Union Pacific located in Salt Lake City, UT. Such shipments not only are cumbersome, but they also take longer and are more costly to the customer.

2. *Santa Fe (a.k.a. Atchison Topeka & Santa Fe)* — The Santa Fe mostly is an east-west interstate carrier that connects California with the Southwestern and Southeastern U.S. Within California, Santa Fe also serves as a short line carrier in the southern parts of the state. Santa Fe's most northern depot in California is Stockton. Shipments going to or coming from north of Stockton transfer to or from Southern Pacific Lines. Santa Fe sometimes collaborates with Burlington Northern for longer hauls in the west.

3. *Southern Pacific Lines* — Southern Pacific is the principal intrastate carrier for California. It runs north-south through almost the whole state. Because of California's geographic shape, any railway lines that run north and south will span much greater distances than lines running east and west. Southern Pacific also extends along the coast into Oregon for interstate shipments going north. Currently, Southern Pacific is in the process of relocating its headquarters staff and operations from San Francisco to Denver.

5.2.2 Rail Freight Rate Estimates

Intrastate price quotations from each of the three rail lines were solicited in order to estimate the normal cost of rail shipping in California. The request was for transportation from Northern California to Southern California for a bulk product that required no special handling.

Commodity Selection — The railways that operate in California do not have a single fee or rate structure that can be applied to all types of product shipments. The cost of shipments may vary considerably depending upon the type of commodity being transported. For example, perishable products often entail more expense in transport than nonperishable products because of losses (e.g., spoilage) that might result from any delays. Usually, insurance protection is added to the cost of shipments of perishables as protection against such losses. Therefore, the total cost paid by the customer would be greater for perishable products than for nonperishables.

Likewise, virtually all commodities that are the result of a manufacturing or refining process will possess a value greater than the raw materials from which they were made. For example, automobiles will have far greater value than the steel from which they are made because of their labor intensive manufacturing process. Steel, in turn, will have greater value than the iron ore from which it was made because of the refining process it underwent. Therefore, the shipment of those commodities may entail the additional costs of insurance protection against loss or damage during transport.

Exhibit 5-3 provides the potential cost considerations that factor into the freight rate for select commodities shipped by railways in California.[22] For each of these seven commodities, Exhibit 5-3 also provides examples of some of the more frequent considerations entailed in the cost of rail transport. Not all of the cost considerations shown in Exhibit 5-3 necessarily apply to the shipment of all products in their respective categories. For example, some shipments of paper products may require weather protection, depending upon how they were packaged, but lumber may not require such protection.

Commodity for Shipment Estimation — The product that was selected as part of this effort for transport pricing was scrap fire wood. As a transportation commodity, it was non-fragile, nonperishable, and it not did not need special packaging, liability insurance, or hazard protection. All of those factors would have increased the transportation costs. Therefore, the only components of the prices that were obtained were the weight and volume of the product and the distance it needed to travel.

In order to determine the typical rate for shipping this commodity, the points of origin and destination were specified to each railroad. The selected O-D points provided about as long of a distance as possible for intrastate shipment. The selected origin also appeared to be reasonably consistent with the origin of a forestry products shipment.[23]

Rail Car Classification — Data were categorized according to the type of rail car used for commodity transport. Five types of cars are commonly used in the state's commercial rail transport.

- *Box Car* — A box car is the "classic" rail car. It is a rectangular car with four walls (usually made of metal) and a roof. Sliding doors on two sides of the car allow access to the interior for loading and unloading freight. Box cars provide a moderate amount of protection from weather elements and, for additional costs, they can be sealed and refrigerated. Box cars hold approximately 150 to 160 tons of freight.

- *Gondola* — A gondola is an open car that allows loose materials to be piled up higher than in a box car. That allows a gondola to hold more freight—approximately 180 tons—than a box car of the same size. It is often used for shipping ores and loose minerals. Loading often is performed by pouring or dropping commodities into the car. Unloading may be performed by opening a hatch in the floor of the car and allowing the

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[22] Although the commodity groupings shown in Exhibit 5-3 are more general than those used in CALFED, they are discussed here to exemplify the factors that may determine variability in rail freight rates. For the purpose of developing mode shift estimates, CALFED's commodity groupings will be retained later in this section.

[23] Actual city names are not provided in the discussion for reasons of confidentiality.

Exhibit 5-3

Cost Implications for Commodities Transport

#	*Commodity Type*	*Potential Cost Considerations*
1	Food, agricultural and consumer products	Perishable or non-perishable Refrigerated or non-refrigerated Protection from weather elements Sanitation Insurance against damage or spoilage
2	Forestry and paper products	Protection from weather elements Fire insurance
3	Metals and ores	Refined or unrefined Chemical contents Contamination potential
4	Coal	Chemical contents Contamination potential
5	Construction materials and machines	Size Fragility Insurance against damage
6	Chemicals, plastics & petroleum products	Perishable or non-perishable Refrigerated or non-refrigerated Sanitation Protection from weather elements Contamination potential
7	Automobiles and trucks	Fragility Insurance against damage

contents to pour out.

- *Flat Car* — A flat car is a platform on wheels. It has no walls or ceiling, making it easy to load and unload. Large machinery and equipment, such as a tractor or bulldozer, usually travel on flat cars. Loose freight must be bundled together securely. Flat cars do not hold specific ranges of weight. Instead, they are classified by length—either greater or lesser than 67 feet long.

- *Container Car* — Containers are miniature box cars, and they hold approximately 40 tons each. Because of their smaller capacity, container cars are used less frequently than the preceding three car types for intrastate shipments of bulky commodities. Their use in multimodal transport has increased considerably over the past 15 years, since containers can be transferred directly to cargo ships and to trucks without needing to be unloaded.

- *Tanker* — Several different types and sizes of tanker cars are used to haul liquid freight, such as water, petroleum products, and liquefied gases.

Only the first three classifications of rail cars were used as part of this effort to assess typical rail freight rates in California. Container cars were inappropriate (i.e., too expensive) for the type of freight and destination specified. Tanker cars were designed for a different type of freight. Rates obtained for flat cars could not be further classified according to weight. The capacity of flat cars is heavily dependent upon packaging and the freight's unit volume.

All distances between the shipment origin and destination were calculated as highway miles. Those usually were shorter than the rail miles because the shortest highway routes make use of more choices. For example, the distance between two cities in California was stated as 594 miles by one of the rail lines. For this analysis, however, 450 miles was used as the distance between those two cities which may reflect a more direct route than is available to the rail line.

5.2.3 Results of Primary Rail Rate Data Collection Effort

Data were collected on total cost to the customer at the point of destination. Costs did not include loading or unloading, nor did they include storage after a normal two-day unloading period after arrival at the destination. To ensure confidentiality, costs shown below do not identify the specific railroad, but are used solely to exemplify the types of cost considerations that form the basis for rail freight rates in the state.

The results for Railway #1 are summarized in Exhibit 5-4. Points of origin and destination are specified, along with highway mileage, types of rail cars used, weight, and costs per three units of rate—car, ton, and ton-mile.

Exhibit 5-4

Transportation Cost Estimate: Sample for Railway #1

#	*Origin*	*Destination*	*Miles*	*Car*	*Tons*	*Cost ($) per*		
						Car	*Ton*	*Ton-Mile*
1	City 1	City 2	665	Boxcar	150	2750	18.333	0.0276
			665	Gondola	180	2941	16.339	0.0246
2	City 3	City 2	700	Boxcar	150	2750	18.333	0.0262
			700	Gondola	180	2941	16.339	0.0233
3	City 4	City 2	800	Boxcar	150	2750	18.333	0.0229
			800	Gondola	180	2941	16.339	0.0204
						Arithmetic Mean		0.0242
						Range		0.0072
						Midrange		0.024

The initial inquiry was only for intrastate shipments. However, for this particular railway, charges are the same even for longer shipping distances. Both City 3 and City 4 could be points of origin at the same price as City 1, thus yielding slightly lower ratios of cost per mile. For that reason, those origins are shown in Exhibit 5-4 along with the costs of shipping from the selected origin of City 1.

Data on costs per car were used to calculate costs per ton and costs per ton-mile. The data in Exhibit 5-4 illustrate two features about pricing. First, the type of car influenced shipping prices. Gondola cars offered the potential of carrying more weight than did box cars and, if fully loaded, gondolas provided lower ratios on a cost per ton basis. Second, the costs per mile diminished as the route increased in distance. Since the same price governs for three shipping distances, the longest distance provided the best bargain in cost per mile.

Two measures of central tendency were calculated as the average cost per ton-mile, and those measures are presented in Exhibit 5-4. The arithmetic mean is the most common calculation of average, and it needs no further explanation. The midrange is an alternative measure of central tendency that may be useful for small sample statistics, and for data from distributions that have unknown characteristics (e.g., that potentially are not normally distributed). The mean and the midrange will be approximately equal to one another when data come from a normal distribution (or from a non-normal distribution that is not highly skewed).

The mean cost per ton-mile based for shipping the chosen commodity on Railway #1 was $0.0242, or 2.42 cents per ton-mile. The midrange for those same data was $0.0240, which was nearly identical to the mean. Costs per ton-mile ranged from a low of $0,0204 to a high of $0.0276 for a gondola originating at City 4 and a boxcar originating at City 1, respectively.

Results of the data for Railway #2 are summarized in Exhibit 5-5.[24] As with Railway #1, this railroad's costs per ton for gondolas were lower than for boxcars. All other comparisons between the two railway lines indicated that the rates for the Railway #2, shown in Exhibit 5-5, are higher than those for Railway #1, shown in Exhibit 5-4. Both the mean and midrange cost per ton-mile was $0.0294 per ton-mile for the second railway. Compared to average of $0.024 for the first, this represents a difference of about 23 percent.

It is likely that the shorter distance used as the basis for the Railway #2's price contributed to that railway's higher cost (i.e., originating at City 5 instead of City 1 or City 4). However, it could not be determined whether the differences in distance could fully account for the differences in cost between the two railways. The directness of the two railways' shipping routes also could have contributed, for example. The second railroad's price showed that the railway distance between City 5 and City 2 was 594 miles instead of the 450 highway miles reported in Exhibit 5-5. It is possible that this railway based its price on a route to City 2 that went by way of other cities in California such as Los Angeles.

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[24] One of the three railroads abstained from providing price data.

Exhibit 5-5

Transportation Cost Estimate: Sample for Railway #2

Origin	*Destination*	*Miles*	*Car*	*Tons*	*Cost per*			
					100 Wt.	*Car*	*Ton*	*Ton-Mile*
City 5	City 2	450	Boxcar	150	1.37	2055	13.7	0.0304
		450	Gondola	180	1.28	2304	12.8	0.0284
		450	Flat 67'			1691		na
		450	Flat > 67'			1857		na
					Arithmetic Mean			0.0294
					Range			0.002
					Midrange			0.0294

If railway miles were used as the basis for calculating cost per ton-mile, the resulting ratio for Railway #2 would have been $0.0231 per ton-mile, or slightly lower than the rate of Railway #1. Railway miles were not obtained from Railway #1, however, so further analyses of this question could not be performed.

5.2.4 Conclusions of Typical Rail Rate Analysis

Based upon all the price data collected, the single best estimate of the cost per ton-mile was the average of the figures obtained from the two railways that participated in this study. The combined mean of the cost per ton-mile was calculated to be $0.0267, or 2.67 cents. The accuracy of that estimate can be improved upon if more information about railway prices, routes, and traffic volume were available. For example, if it were found that Railway #1 carried twice as much freight as Railway #2, then applying an appropriate statistical weight to the Railway #1's mean (in this example, the appropriate weight would be 2.00) would make the combined mean more accurate.

This analysis was of limited scope, but it has provided a quantitative indication of railway transport costs in California. Two of the three major railways that serve the state participated in this part of the study. Combined, those two lines probably account for a clear majority of the railway traffic in California. A variety of issues on railway pricing remain to be explored by further research. Those include factors related to *direct* customer costs, such as different types of commodities, rail cars, and shipping distances. Sources of *indirect* costs also remain unexplored, such as charges for different types, sources, and amounts of freight insurance charged to customers by the different rail lines.

Nevertheless, the average cost of moving a typical shipment by rail in California likely approximates the estimate developed in this analysis of 2.67 cents per ton-mile. The following sub-section compares this estimate with information available from secondary data sources on rail rates at the national level.

5.2.5 Average National Rail and Truck Shipment Rates

Truck shipment rates specific to freight movements within California were not readily available for this study. Furthermore, in order to ensure that the estimates derived above for typical rail shipment rates in California reflect actual rates, data against which those estimates can be compared are required. As a result, effort was expended to gather average freight rates by mode. Secondary data sources, however, only provide national level freight rate estimates. It is expected that given the interstate nature of freight movements, national estimates will generally resemble California-specific freight shipping rates for truck and rail.

Exhibit 5-6 presents historic national average freight rates for both rail and truck shipments. These data actually reflect the average revenue (in cents) per ton-mile accrued by each mode for an average shipment. However, assuming that the freight transport industry is competitive,

Exhibit 5-6

Historic National Average Freight Rates for Rail and Truck (Current Dollars)

Year	Average Rail Price Cents per Ton-Mile	Average Truck Price Cents per Ton-Mile	Relative Price (Rail/Truck)
1977	2.29	12.70	0.18
1978	2.36	13.40	0.18
1979	2.61	15.20	0.17
1980	2.87	18.00	0.16
1981	3.18	20.00	0.16
1982	3.21	20.77	0.15
1983	3.12	21.23	0.15
1984	3.09	21.54	0.14
1985	3.04	22.90	0.13
1986	2.92	21.63	0.13
1987	2.73	22.48	0.12
1988	2.72	23.17	0.12
1989	2.67	23.91	0.11
1990	2.66	24.83	0.11
1991	2.59	24.82	0.10
1992	2.58	22.40	0.12
1995*	2.67	23.18**	0.12

Source: Eno Transportation Foundation, *Transportation in America, 12th Edition*, 1994.

* Reflects California-specific estimate derived from primary data.

** Based on 1.03 times the 1992 rate of 22.40. The adjustment factor of 1.03 reflects the difference between the California-specific rail rate of 2.67 in 1995 and the 1992 national rate of 2.58.

average revenue will correspond with the average price that is charged to customers. Consequently, data on the average revenue per ton-mile can be employed as a close proxy for the average price per ton-mile charged by providers of transport services.

Data shown in Exhibit 5-6 demonstrate the relative price of shipping freight by rail versus truck. The truck mode has historically been much more expensive that the rail mode on a ton-mile basis. In 1987 (this study's base year), for example, the relative price of moving one ton-mile of freight on rail as opposed to truck was 0.12 (i.e., 2.73/22.48). This relative price index steadily decreased in value from 1977 to 1987, indicating that the cost advantage of rail has increased during that period. Various factors led to this increase in the rail cost advantage. Principal among them was the effect of ICC deregulation in the early 1980s. Deregulation promoted increased modal competition and the railways responded by implementing strategies that increased the efficiency of operations and the productivity of their equipment. For example, deployment of more modern locomotives resulted in large fuel efficiency benefits to the railways that helped to reduce operating costs and increase the rail cost advantage over truck. This trend continued until 1992.

Data in Exhibit 5-6 for 1992 also demonstrate the comparability of rail shipment cost estimates derived for California-specific movements from primary sources that were discussed earlier in Section 5.2. That investigation demonstrated that the average price of moving a specific shipment by rail in California is currently 2.67 cents per ton-mile. Exhibit 5-6 demonstrates the national average, presumably across all shipments, to be 2.58 cents per ton-mile in 1992. The difference is well inside the range that could be expected given the differences in geographic scope and the isolation of the California-specific estimate on one commodity. As a result, this study employs the national freight rates per ton-mile shown in Exhibit 5-6 for 1987 (i.e., 2.73 cents per ton-mile) as the basis from which changes in rail cost advantages will be developed for each emissions control regulatory scenario. The following section describes the regulatory scenarios employed in this study and the resulting impacts on rail and truck freight rates.

5.3 Impact of Emissions Regulations on Rail and Truck Freight Rates

The effects of locomotive and/or truck emissions regulations on mode shifts and overall emissions from these two sources will be directly related to the impact of regulations on the prices that railways and trucking firms charge shippers once compliance is mandated. Given the competitive nature of the freight transport industry, increases in transport costs associated with compliance likely will be passed on to customers. Consequently, an assessment of the price impacts of various proposed regulatory strategies is necessary to determine indirect economic effects, as measured by mode shift, and subsequent emissions repercussions.

This section defines the regulatory strategies for both rail and truck that have been proposed for implementation in California. As discussed in Section 3, four regulatory strategies for locomotives are investigated in this study: the deployment of dual-fuel locomotives (DF), the deployment of locomotives that are powered by spark-ignited engines fueled by LNG (LNG-SI), the use of selective catalytic reduction equipment in locomotive engines (SCR), and the deployment of dual-fuel locomotives with selective catalytic reduction devices (DF+SCR). These strategies were deemed to be the most cost-effective by EF&EE in its analysis of strategies to control locomotive emissions operating in California. This section reviews the annual costs of each strategy and estimates the effect of each strategy on rail freight rates.

As with locomotives, various regulatory strategies have been proposed for heavy-heavy-duty diesel vehicles. This analysis draws on information developed by Acurex Environmental Corporation for the ARB on the costs and potential emissions reductions of various technologies that reduce both NO_x and particulate matter (PM) emissions from heavy-duty diesel engines.[25] Although many strategies are investigated in Acurex's study, only two are considered in this analysis. These are compressed natural gas (CNG) with lean-burn spark-ignition and liquified natural gas (LNG) with lean-burn spark-ignition.[26]

This section also develops the regulatory scenarios for which the mode shift and emissions impacts will be estimated. Given that the focus of this study is to determine the specific mode shift and emissions repercussions of locomotive emissions regulations, regulatory scenarios are developed that only account for changes in the rail cost advantage attributable to locomotive emissions policy. In this manner, the effects of each of the four strategies on mode shift and emissions are isolated. However, more stringent truck emissions regulations will also be promulgated by 2010. Consequently, scenarios are also formulated that account for the combined effects of locomotive and heavy-heavy-duty diesel truck regulations on the rail cost advantage, mode shifts, and rail and truck emissions.

5.3.1 Locomotive Emissions Regulations

The results of EF&EE's study show that substantial control of emissions from locomotives is possible at moderate cost. The following emissions control measures were investigated by EF&EE:

- changes in diesel fuel composition;
- improvements in operating efficiency to reduce fuel consumption;
- modifications to existing diesel engines to reduce their emissions;
- replacement and rebuilding of diesel locomotives with lower-emitting engine designs;

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[25] Acurex Environmental Corporation, *Technical Feasibility of Reducing NO_x and Particulate Emissions from Heavy-Duty Engines*, ARB Contract No. A132-085, 1993.

[26] CNG with lean-burn spark ignition represents the lowest cost strategy investigated by Acurex (low-end estimate), while LNG with lean-burn spark ignition represents the highest cost strategy (high-end estimate) and exhibits the largest difference between the low-end and high-end cost estimates as illustrated below on page 5-21.

- alternative fuels (methanol and natural gas);
- retrofitting selective catalytic reduction (SCR) to existing diesel locomotives;
- a combination of natural gas plus SCR; and
- electrification of linehaul operations.

Of these regulatory approaches, only four are investigated in this study, as discussed in Section 3. The rationale for choosing Dual-Fuel, LNG-SI, LNG+SCR, and SCR as the control strategies in this study included the following criteria.

- First, the impact of a specific regulation on mode shift will be directly related to the cost of the regulation on freight rates. Consequently, a spectrum of program costs is needed to evaluate the range of mode shift effects that may occur in the future.
- Second, strategies that showed relatively poor cost-effectiveness, such as rail electrification, are not likely to be promulgated by the ARB on a state-wide basis. So, including such strategies in this analysis is not warranted.
- Third, strategies that have small emissions impacts, such as low aromatic fuel, are not attractive from the standpoint of emissions mitigation. Such strategies also have relatively poor cost-effectiveness ratios.

EF&EE calculates the cost-effectiveness of the four strategies included in this study to be as follows: Dual-Fuel shows a cost-effectiveness of \$858 per ton of NO_x reduction, LNG-SI shows a cost-effectiveness of \$1,376 per ton of NO_x reduction, DF+SCR shows a cost-effectiveness of \$1,911 per ton of NO_x reduction, and SCR shows a cost-effectiveness of \$2,909 per ton of NO_x reduction. These cost-effectiveness estimates reflect the deployment of the control strategies on locomotives used in linehaul, local, and switcher operations. The four strategies chosen in this analysis are the most cost-effective for linehaul operations, exactly those operations that will compete with truck for market share.

Exhibit 5-7 presents the impact of the four strategies investigated in this analysis on the cost per ton-mile. The promulgation of a locomotive emissions regulation that requires dual-fuel, for example, will cost an estimated \$21.5 million per year (1987 dollars). On a ton-mile basis, this cost translates to 0.09 cents in 1987 dollars. At the other end of the spectrum, SCR will cost an estimated \$92.9 million per year, or 0.38 cents per ton-mile in 1987 dollars. Given that the CALFED sensitivity parameters were calculated in 1977, the impact of each strategy on the cost per ton-mile must be deflated to 1977 dollars, since these impacts will be used to calculate the change in the cost advantage of rail versus truck needed to determine mode shift. Impacts expressed in 1977 dollars are also shown in Exhibit 5-7.

Exhibit 5-7

Cost of Locomotive Regulations

	Dual-Fuel (DF)	**LNG-SI**	**DF+SCR**	**SCR**
Strategy Cost (1987$) (1) in millions	21.5	42.1	65.5	92.9
1987 Ton-Miles in millions	24,592	24,592	24,592	24,592
Cost/Ton Mile in Cents (1987$)	0.09	0.17	0.27	0.38
Cost/Ton Mile in Cents (1977$)	0.08	0.15	0.23	0.31

Source: (1) Engine Fuel, and Emission Engineering Inc., "Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness and Regulatory Strategies", March 29, 1995.

5.3.2 Truck Emissions Regulations

A wide range of regulatory strategies to control emissions from heavy-duty vehicles operating in California have been proposed for the period between 1987 and 2010. Strategies focus on both further controlling the emissions of newly sold vehicles and on controlling emissions of in-use vehicles. The following exemplifies the range of control strategies that have either been implemented since 1987 or are under consideration by the ARB for future implementation.

- *1988 New Heavy-Duty Truck PM Standard of 0.6 Grams per Horsepower-Hour* — which requires all newly sold trucks beginning with the 1988 model year to meet this PM standard. The ARB has estimated the cost of this program to be an additional $115 per vehicle. Because fuel savings would be achieved, there would be a lifetime savings on the cost of the engine.

- *1990 Heavy-Duty Gasoline Biennial Inspection Program* — which requires that all 1990 and beyond model year heavy-duty gasoline trucks be inspected on a biennial basis for emissions. The inspection includes visual, functional control, and tailpipe tests. Tailpipe emissions criteria are for hydrocarbons and carbon monoxide and vary by the age of the vehicle. The California Bureau of Automotive Repair estimates the costs of the inspection to average $33.45 per vehicle inspected.

- *1991 Roadside Smoke and Emissions Control System Inspection Program for All In-Use Heavy-Duty Diesel and Gasoline Powered Vehicles Operating in California* — In 1988, the California Legislature passed Senate Bill 1997 to establish a program to reduce the number of heavy-duty diesel vehicles that emit excessive smoke and that exhibit forms of emissions control tampering and mal-maintenance. The ARB adopted the program in 1990. Prior to adoption of this program, a pilot program was implemented to provide information on the cost of repairs for vehicles that failed the smoke test cutpoint. The pilot program showed the average repair cost to be $693. In addition, vehicles cited are required to pay a penalty ranging from $300 to $1,800, depending on prior citations.

- *1991 New Heavy-Duty Truck Engine PM Standard of 0.25 Grams/Bhp-hr* — This control strategy requires that all newly sold heavy-duty trucks be certified to the revised PM standard, beginning with the 1991 model year. The ARB estimates an additional $458 per vehicle as compared with 1988 costs.

- *1993 Fuel Specifications for Sulfur and Aromatic Content for Diesel Fuel* — This strategy proposed changes to the content of diesel fuel sold in California. The ARB estimated an associated increase of $0.06 per gallon prior to the introduction of the new fuel. However, wholesale prices increased by 11 to 15 cents per gallon after implementation of the strategy. Another cost associated with the introduction of "clean diesel" may be increases in needed engine repairs and maintenance. The California Trucking Association has stated publicly that the costs of the "clean diesel" program have been dramatically underestimated by the ARB. The "clean diesel" program is currently under review by the ARB.

- *1994 New Heavy-Duty Truck PM Standard Revised to 0.10 Grams/Bhp-hr* — The ARB estimates the additional cost of the revised standard to be $163 per new vehicle sold in addition to the incremental cost of the 1991 standard.

- *1995 Regulation Requiring Periodic Smoke Self-Inspection Program for Heavy-Duty Diesel Powered Vehicle Fleets of Two or More Vehicles* — This program complements the roadside inspection program discussed above by requiring that owners of vehicles of 6,001 pounds GVW or more test their vehicles annually for excessive smoke emissions. The estimated annual cost estimated by the ARB for the self-test program is $243 per vehicle inspected for small fleets (5 vehicles or less) and $93 per vehicle inspected for larger fleets (6 or more vehicles).

The strategies listed above exemplify the wide range of regulations that heavy-duty vehicles must currently, or will have to, comply with if they are to operate in California. These strategies will undoubtedly result in increases in the cost of operating and maintaining heavy-duty vehicles in the state. However, the evaluation of each of these strategies on mode shift and NO_x emissions is beyond the scope of this study. First, the strategies listed above do not specifically focus on reducing NO_x. Second, if the strategies impact truck freight rates, the impact will occur over time, and diversion would need to be calculated independently for each year. Third, program cost data were not available for this study. Fourth, truck and/or rail ton-mileage data were not available for those years when the strategies would come into effect. Finally, the strategies impact both new trucks and in-use trucks, thereby requiring the use of a vehicle stock model to fully assess the impact of each strategy.

Since the focus of this study is on the impact of NO_x emissions regulations on mode shift and truck and rail emissions in 2010, future regulations that may be implemented to control truck NO_x emissions should be considered in this analysis. Section 43013 (b) of the California Health and Safety Code requires that the ARB adopt standards and regulations for heavy-duty vehicles on or before December 31, 1993. While the ARB was not able to meet that deadline, it has conducted preliminary studies to determine the types of control technologies that will be able to reduce NO_x emissions to needed levels for ozone attainment by 2010. This study draws on those studies to identify the control strategies for heavy-heavy-duty diesel trucks that may prevail by 2010.

In a study conducted for the ARB, Acurex Environmental Corporation concluded that it is currently possible to achieve low NO_x and PM emissions with alternatively-fueled heavy-duty engines, and that diesel engines will be able to achieve low NO_x and PM emissions in the future as well. Existing methanol and natural gas engines can now meet emissions rates of less than 2.0 grams/Bhp-hr of NO_x and 0.05 grams/Bhp-hr of PM. Acurex identified the following approaches for reducing emissions of heavy-heavy-duty diesel trucks to levels as low as 2.0 to 2.5 grams/Bhp-hr of NO_x.[27]

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[27] Op. cit.

Fuel	Vehicle/Technology	Cost (1992 $) (Cents/Mile)	
		Low	High
1993 Diesel	Baseline DI diesel	40	42
Diesel	DI Diesel w/EGR & Catalytic Trap	44	47
Diesel	DI Diesel w/NO_x Catalyst	43	46
M100	DI Compression-Ignition 2-Stroke	44	48
M100	DI Glow-Plug-Ignition 4-Stroke	44	47
CNG	Lean-Burn Spark-Ignition	42	46
LNG	Lean-Burn Spark-Ignition	44	50
LPG	Lean-Burn Spark-Ignition	45	47

For the purpose of developing scenarios to estimate the mode shift and corresponding emissions impacts of rail and truck regulations, this study investigates only two of these strategies: CNG/Lean-Burn SI using the estimated cost of 42 cents/mile, or an incremental cost of 2 cents/mile from the baseline DI diesel scenario developed by Acurex; and LNG/Lean-Burn SI using the estimated cost of 44 cents/mile, or an incremental cost of 4 cents/mile from the baseline. For each truck scenario, this analysis assumes the following:

- in 2010, all heavy-heavy-duty diesel trucks will be either powered by CNG/Lean-Burn SI or LNG/Lean-Burn SI; and
- the impact on truck freight rates only will reflect the additional cost per mile above the baseline DI diesel baseline scenario developed by Acurex.

The low end of the corresponding incremental cost for these two mitigation strategies was selected to minimize increases in truck freight rates and thus maximize the shift from rail to trucking resulting from locomotive emissions regulations. This ensures that conservative estimates of mode shifts are developed in this study.[28]

Exhibit 5-8 demonstrates the effect of each strategy on the cost/ton-mile of heavy-heavy-duty diesel truck movements. The incremental costs per mile of each strategy are translated to a ton-mile basis using data on the population of heavy-heavy-duty diesel vehicles and average yearly vehicle miles travelled (VMT). These data are used to derive the total cost for each strategy, which when divided by total ton-mileage results in estimates of strategy cost per ton-mile. As

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[28] Also, note that the incremental costs developed by Acurex are expressed in 1992 dollars. However, because of rounding, conversion to 1987 dollars or 1993 dollars (see Exhibit 5-8) does not change the incremental costs associated with each strategy of 2 and 4 cents.

Exhibit 5-8

Cost of Heavy-Heavy-Duty Diesel Truck Regulations

	CNG/Lean-Burn SI	LNG/Lean-Burn SI
Heavy-Heavy Diesel Truck Pop.(1)	102,400	102,400
Average VMT (1993) (2)	40,000	40,000
Total VMT in millions (1993)	4,096	4,096
Strategy Cost ($/Mile) (2)	0.02	0.04
Strategy Cost (1993$)	81,920,000	163,840,000
Strategy Cost (1987$)	80,117,760	160,235,520
1987 Ton-Miles in millions	32,717	32,717
Cost/Ton-Mile in Cents (1987$)	0.24	0.49
Cost/Ton-Mile in Cents (1977$)	0.21	0.41

Source: (1) California Energy Commission (CEC) DMV-Derived Registration Data (1993)
(2) Acurex Environmental Corporation, "Technical Feasibility of Reducing NO_x and Particulate Emissions from Heavy-Duty Engines", 1993.

shown in Exhibit 5-8, CNG/Lean-Burn SI is expected to increase trucking cost by 0.24 cents/ton-mile, while LNG/Lean-Burn SI is expected to increase this cost by 0.49 cents/ton-mile (1987 dollars).

5.3.3 Regulatory Scenarios for Diversion and Emissions Analysis

Exhibit 5-9 describes the regulatory strategy scenarios for which diversion and emissions impacts will be estimated in this study. Since the focus of this study is on the impacts of locomotive emissions, the first four scenarios isolate the effects of Dual-Fuel, LNG-SI, DF+SCR, and SCR independently. The last two scenarios have been designed to capture the range of possible mode shift given combined locomotive and truck control strategies. Scenario 5 assumes that locomotives operating in California will be powered by dual-fuel engines, while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn spark-ignition engines. Dual-Fuel is the least expensive strategy for locomotives investigated in this study. LNG/Lean-Burn SI is the most expensive strategy for trucks investigated in this study. Consequently, this scenario has been designed to represent the high-end of diversion from truck to rail. Likewise, Scenario 6 has been designed to represent the high-end of diversion from rail to truck, since it includes the most expensive locomotive regulation (SCR) and the least expensive truck regulation (CNG/Lean-Burn SI). The six scenarios are summarized below.

- *Scenario 1* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.[29]

- *Scenario 2* — assumes that locomotives operating in California in 2010 will be powered by LNG-SI engines, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 3* — assumes that locomotives operating in California in 2010 will be powered by Dual-Fuel engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

- *Scenario 4* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will experience no further control beyond that of the current NO_x standard of 5 grams/Bhp-hr.

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[29] As discussed in Section 3.2.4 of this report, this analysis assumes that trucks will emit (on average) 0.006 pounds of NO_x per ton-mile in 2010 under the no-further-control-scenario, a 36 percent decrease from the contribution that prevailed in 1987 (see Exhibit 3-5). The 0.006 lbs/ton-mile estimate reflects the current NO_x standard of 5 g/Bhp-hr, while the 1987 estimate of 0.009 lbs/ton-mile reflects a fleet average of 7.83 g/Bhp-hr developed using EMFAC7.

Exhibit 5-9

Regulatory Scenarios for Diversion and NO_x Emissions Analysis

	New Rail Freight Rate (in Cents/ Ton-Mile, 1987$)	New Truck Freight Rate (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1987$)	Change in the Cost Advantage of Rail (in Cents/ Ton-Mile, 1977$)
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	2.82	22.48	-0.09	-0.08
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	2.90	22.48	-0.17	-0.15
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	3.00	22.48	-0.27	-0.23
Scenario 4 - SCR for Rail no Further Control for Trucks	3.13	22.48	-0.38	-0.31
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	2.82	22.97	0.41	0.34
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	3.13	22.72	-0.13	-0.11

- *Scenario 5* — assumes that locomotives operating in California in 2010 will be powered by engines that use either natural gas or diesel (i.e., dual-fuel), while heavy-heavy-duty diesel trucks will be powered by LNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.

- *Scenario 6* — assumes that locomotives operating in California in 2010 will be powered by engines with SCR devices, while heavy-heavy-duty diesel trucks will be powered by CNG/lean-burn SI engines, reducing NO_x from 5 grams/Bhp-hr to 2.0 grams/Bhp-hr in 2010.

As reported in Exhibit 5-9, the change in the cost advantage of rail ranges from -0.08 to -0.31 cents (1977 dollars) for those scenarios that isolate the impacts of locomotive regulations (i.e., Scenario 1 to 4). The change in the cost advantage of rail for Scenario 5 is 0.34, signaling a shift from truck to rail. While that for Scenario 6 is -0.11, signaling a shift from rail to truck. These changes in the cost advantage of rail are employed to calculate mode shifts using the CALFED sensitivity parameters discussed in Section 5.1.

5.4 Modal Diversion and Emissions Impacts by Scenario

This section describes the diversion and NO_x emissions impacts of each of the six regulatory scenarios discussed above. Diversion impacts are derived by employing the change in the cost advantage of rail (1977 dollars) shown in Exhibit 5-9 and the CALFED modal sensitivity parameters presented in Exhibit 5-1. Specifically, the change in rail ton-miles resulting from a change in the rail cost advantage is estimated via the following equation:

$$NRS_{i,j} = ORS_j + (\Delta RCA_i * MSP_j)$$

where $NRS_{i,j}$ is the new rail share in 2010 for scenario *i* and commodity group *j*;
ORS_j is the old rail share in 2010 for commodity *j*;
ΔRCA_i is the change in the rail cost advantage for scenario *i*; and
MSP_j is the modal sensitivity parameter for commodity *j*.

In this manner, new rail ton-mile flows are estimated by applying the new rail shares to the total flows estimated for 2010 (see Section 2). The new truck ton-mile flows are simply the difference between the total flows and the new rail flows.

The resulting NO_x emissions impacts for rail are calculated using the emissions spreadsheet model developed for this study and described in Section 3. Specifically, for each scenario, the population of locomotives expected to be operating in California in 2010 is adjusted to reflect the percentage change in rail ton-miles resulting from diversion, as estimated via the CALFED sensitivity parameters. This assumes that the change in the share of rail ton-miles will affect proportionally the population of locomotives needed to transport the new rail ton-miles after diversion. This proportionality approach is discussed in detail in Appendix A.

As discussed in Section 3, in 1987 emissions from heavy-heavy-duty diesel trucks on a pounds per ton-mile basis are estimated to be 0.009. This "emissions factor" is expected to decrease to 0.006 lbs/ton-mile by 2010 under the no-control scenario. However, the implementation of regulations that require CNG/Lean-Burn SI or LNG/Lean-Burn SI technology by 2010 will directly impact the emissions rate of trucks. As discussed in Section 5.3, the deployment of these technologies is expected to reduce NO_x emissions from 5 grams/Bhp-hr to 2 grams/Bhp-hr by the forecast year of 2010. Assuming that the resulting percentage decrease holds on a ton-mile basis, the effect of Scenarios 5 and 6 on heavy-heavy-duty diesel truck emissions can be expected to be a decrease in the "emissions factor" from 0.006 pounds/ton-mile to 0.002 pounds/ton-mile.

The following sub-sections present the results of the diversion and subsequent emissions impact analysis by regulatory scenario.

5.4.1. Diversion Impacts by Regulatory Scenario

Exhibit 5-10 presents the results of the diversion analysis for each of the six regulatory scenarios. Scenario 1, *Dual-Fuel for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 406 million in 2010, or by 1.1 percent. Consequently, in 2010 heavy-heavy-duty diesel truck ton-miles are expected to increase to 52,554 million from 52,148 million. The estimated diversion impact of Scenario 2, *LNG-SI for Rail and No Further Control for Trucks*, is a decrease in rail ton-miles and a corresponding increase in truck ton-miles of 762 million, representing a drop in rail ton-miles of 2.1 percent. Likewise, Scenario 3, *DF+SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,168 million, or by 3.2 percent, while Scenario 4, *SCR for Rail and No Further Control for Trucks*, is expected to reduce rail ton-miles by 1,625 million in 2010, or by 4.4 percent. The diversion impact of Scenario 5, *SCR for Rail and CNG/Lean-Burn SI for Trucks*, is estimated to be an increase in rail ton-miles of 1,727 million, since the rail cost advantage increases for this scenario. In contrast, Scenario 6, *Dual-Fuel for Rail and LNG/Lean-Burn SI for Trucks*, is expected to decrease rail ton-miles by 610 million.

This analysis shows the importance of developing emissions control strategies that account for the full economic impacts of regulation. Diversion can result in increases in the activity of higher polluting sources that may negate some of the expected emissions benefits of the regulatory initiative. A system-wide approach is necessary to fully account for the indirect economic and emissions impacts. Depending on the mix of regulations promulgated for each source, or mode, the diversion impact may either increase or decrease the activity of a given source. For example, Scenario 5 resulted in increased rail activity relative to truck, while Scenario 6 resulted in decreased rail activity relative to truck. As a result, regulations that impact competition between modes must be analyzed in conjunction to one another to ensure that

Exhibit 5-10

Modal Diversion by Regulatory Scenario (2010)

Scenario	Δ in Rail Ton-Miles (Millions)	% Δ in Rail Ton-Miles	New Rail Ton-Miles (Millions)	New Truck Ton-Miles (Millions)
No Control 2010 Baseline	--	--	36,541	52,148
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	-406	-1.1%	36,135	52,554
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	-762	-2.1%	35,780	52,910
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	-1,168	-3.2%	35,373	53,316
Scenario 4 - SCR for Rail no Further Control for Trucks	-1,625	-4.4%	34,916	53,774
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	+1,727	+4.7%	38,269	50,421
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	-610	-1.7%	35,932	52,758

Note: Numbers may not add up exactly because of rounding.

the net emissions consequences are accounted for in the promulgation process. With this in mind, the following sub-section presents the emissions consequences of each scenario.

5.4.2 NO_x Emissions Impacts by Regulatory Scenario

Exhibit 5-11 presents the corresponding NO_x emissions impacts of each scenario that result from changes in the NO_x emissions factors of locomotives and trucks and of modal diversion. For each scenario, combined truck and rail 2010 NO_x emissions are significantly lower when compared to the 2010 no-control scenario. Scenarios 5 and 6 provide the largest combined truck and rail NO_x emissions reductions. This is because under Scenarios 1 to 4 no further emissions controls from those prevalent in 1987 are assumed for heavy-heavy-duty diesel vehicles. Consequently, increases in truck activity, resulting mostly from economic and demographic growth, offset benefits accrued from locomotive emissions control strategies.

The results presented in Exhibits 5-10 and 5-11 highlight the relative importance of diversion versus changes in emissions factors resulting from the regulatory strategies examined in this study. In Scenarios 1 to 4, emissions reductions are mostly driven by changes in the emissions rate of locomotives—since significant emissions reductions are achieved from the 2010 no-control baseline even though only small reductions in rail activity occur as a result of decreases in the rail cost advantage (see Exhibit 5-10). For example, 2010 locomotive NO_x emissions under the no control scenario are 158 tons/day. Rail NO_x emissions under Scenario 3 are estimated to be 21 tons/day in 2010, a decrease of 87 percent from the 2010 no control level. However, rail ton-miles under Scenario 3 only decrease by 3.2 percent. Consequently, most of the emissions reductions are associated with the effectiveness of control strategies rather than with modal diversion.

The emissions consequences of the regulatory scenarios investigated in this study are encouraging. Diversion by itself is not expected to have a major impact on emissions by mode. Rather, emissions reductions are mostly driven by changes in the emissions rates of locomotives and heavy-heavy-duty diesel trucks that result from technology deployment. Nevertheless, it is useful to conduct a sensitivity analysis to determine the possible ranges of diversion impacts. This is the subject of the next section.

5.5 Sensitivity Analysis — Changes in the Modal Sensitivity Parameters

In the section of this report that discusses the selection of the CALFED model to perform modal diversion calculations, several shortcomings of the model were noted. One of the most significant shortcomings is that the model parameters were estimated using 1977 data. As already mentioned, freight transportation markets have undergone significant changes since 1977. What is most important in this analysis is isolating those changes which would cause the modal cost sensitivity parameters in CALFED to change; since in this analysis, cost of service is the

Exhibit 5-11

Resulting NO_x Emissions Impacts by Regulatory Scenario (2010, in Tons/Day)

Scenario	Truck NO_x	Rail NO_x	Total NO_x	Difference From 2010 No-Control
No Control 2010 Baseline	410	158	568	--
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	413	39	452	-116
Scenario 2 - LNG-SI for Rail no Further Control for Trucks	416	23	439	-129
Scenario 3 - DF+SCR for Rail no Further Control For Trucks	419	21	440	-128
Scenario 4 - SCR for Rail no Further Control for Trucks	423	41	464	-104
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	159	41	200	-368
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	166	42	208	-360

Note: Results may not add up exactly because of rounding.

only variable which is directly influenced by the proposed emissions regulations. Since 1977, trucking has gained market share at the expense of rail, rail and trucking costs have changed relative to each other, and the types of service offered by rail and trucking have changed. But these changes do not clearly indicate that specific commodity groups have become more or less responsive to changes in cost when making mode choice decisions.

One of the biggest changes that has occurred since 1977, and which would have an impact on shippers' responsiveness to relative cost changes, was the deregulation of shipping rates for both trucking and rail. When rates were regulated, competition often occurred on the basis of differences in levels of service and these differences were not reflected in costs of service. Today's rates incorporate much more information about the services offered than did those of the past, making shippers' choices more likely to be responsive to cost changes. Changes in truck size and weight limits allowed trucking to compete in long-haul markets in which they were previously less competitive. This made shippers in these markets more responsive to price as a determinant of mode choice. The product mix in each of the major commodity groups has also shifted since 1977. Different products within a broad commodity group could have significantly different sensitivities to modal costs and the changing mix within a group could significantly affect the aggregate modal cost sensitivity parameter. Lastly, emphasis on "just-in-time" inventory requirements has made some industries less responsive to cost changes and more responsive to service levels.

There is a general consensus that the net effect of all of these changes is to that broad segments of the market have become more sensitive to cost changes than they were before deregulation. In this sensitivity analysis, an assessment is conducted of how much of an impact these changes might have on conclusions drawn from this report. The approach used is to selectively vary the modal cost sensitivity parameters in CALFED to see how this affects the results of the analysis.

There is no clear cut way to determine how much to vary the parameters. Since the data necessary to re-compute the parameters are not available, some reasonable judgements need to be made in selecting alternative parameter values for sensitivity analysis. One point of reference is the comparative analysis of CALFED results and results from the AAR's Intermodal Competition Model described in Section 4 of this report. In that comparison it was shown that CALFED predicts that a one percent reduction in <u>truck</u> costs would result in 0.39 percent reduction in <u>rail</u> ton miles. If the same analysis were conducted using the ICM, the result would be 33 percent greater diversion from rail to trucking (i.e., a 0.52 percent reduction in rail ton-miles for a one percent reduction in trucking costs). Using this as a basis for determining the magnitude of the underestimation of modal diversion which results from using CALFED, the modal cost sensitivity parameters in CALFED are increased by 100 percent for the sensitivity analysis. In other words, the sensitivity analysis assumes that twice as much traffic will shift away from rail per unit increase in rail costs today as was the case when the CALFED parameters were originally estimated. Given the comparison with ICM alluded to above, this appears to be a worst case magnitude for how much more diversion there might be as a result of locomotive regulations as compared to the estimates from CALFED, and allows for the development of an estimate of a range within which the results are most likely to fall.

Some commodity groups are unlikely to have experienced a change in responsiveness to modal cost changes and this should be accounted for in the sensitivity analysis. These are commodity groups that have not experienced major changes in the mix of products shipped and whose rail and truck shares are determined largely by commodity characteristics which cause one mode or the other to dominate the market. One such commodity group is fruits and vegetables. These perishable commodities are very service sensitive, and while the precise mix of specific fruits and vegetables may change over time, their relative shipping characteristics remain the same. Comparisons of modal split in 1977 and 1987 also shows that trucking has held over 80% of this market with little change over the ten year period. The second such commodity group is timber and lumber which is largely a bulk shipment type commodity that has been shipped predominantly by rail (approximately 70% of the market with little change between 1977 and 1987). Therefore, in the sensitivity analysis, the modal cost sensitivity parameters for these commodity groups have not been changed. The modal cost sensitivity parameters used in the sensitivity analysis are shown in Exhibit 5-12.

To determine the range of impacts associated with these changes in modal cost sensitivity parameters, the analysis that follows considers three scenarios. The first scenario assumes no additional truck emissions regulations beyond those already incorporated and assumes that locomotive emissions standards will be met with dual-fuel engine technology (i.e., Scenario 1, as defined above). This was found to be the most cost-effective rail control strategy and it results in the least diversion from rail to trucking.

The second and third scenarios are equivalent to Scenarios 5 and 6, as described above, and assume adoption of more stringent emissions regulations for trucking as are currently being considered by the ARB. This takes into account that if there is pressure to reduce emissions from rail, there may be similar pressure for further reductions in other freight modes. The second scenario assumes that the truck emissions control strategy will be LNG with lean burn in spark ignition engines and the rail control strategy will be dual-fuel. This combination of strategies actually results in a significant diversion of traffic from truck to rail. The third scenario combines the least cost control strategy for trucking investigated in this study (i.e., CNG/Lean-Burn SI) with the highest cost rail control strategy (SCR).

Exhibit 5-13 presents the results of the sensitivity analysis for Scenarios 1, 5, and 6. The discussion presented below compares the diversion and NO_x emissions impacts of the sensitivity analysis with those of the original analysis presented in Section 5.4. Increasing the modal sensitivity parameters by 100 percent for the selected commodities does not result in proportional increases in diversion. Under Scenario 1, rail ton-miles decrease by 751 million, compared to a 406 million decrease in the earlier analysis (see Exhibit 5-10)—a difference of 85 percent. The increase in diversion, however, only increases combined truck and rail emissions by 2 tons/day. Under Scenario 5, rail ton-miles increase by 85 percent, from 1,727 million more ton-miles to 3,194 million, resulting in a decrease in NO_x emissions of 3 tons/day. Finally, under Scenario 6, rail ton-miles decrease by 1,127 million as compared to a decrease of 610 million in the original analysis, also representing a change of 85 percent. Combined rail and truck emissions increase by 1 ton/day under Scenario 6. As a result, although the sensitivity analysis shows significant changes in the amount of diversion, the impact on NO_x is small. This again suggests

Exhibit 5-12

Cost Sensitivity Parameters for Sensitivity Analysis

Commodity Group	Parameter
Fruits and Vegetables	0.0268
Other Agricultural Products	0.2402
Minerals and Construction Materials	0.2224
Timber and Lumber	0.0837
Food Products	0.0522
Paper Products	0.1574
Chemicals	0.1136
Primary Metals	0.0526
Machinery	0.0538
Other Manufactured Products	0.0536

Exhibit 5-13

Results of the Sensitivity Analysis
(2010)

Scenario	Δ in Rail Ton-Miles (Millions)	% Δ in Rail Ton-Miles	New Rail Ton-Miles (Millions)	New Truck Ton-Miles (Millions)	Truck NO_x (Tons/Day)	Rail NO_x (Tons/Day)
Scenario 1 - Dual-Fuel for Rail no Further Control for Trucks	-751	-2.1%	35,790	52,900	416	38
Scenario 5 - Dual-Fuel for Rail LNG/Lean-Burn SI for Trucks	+3,194	+8.7%	39,735	48,955	154	43
Scenario 6 - SCR for Rail CNG/Lean-Burn SI for Trucks	-1,127	-3.1%	35,414	53,275	168	41

Note: Numbers may not add up exactly because of rounding.

that NO_x reductions are mostly driven by changes in the emissions rates of locomotives and heavy-heavy-duty diesel trucks resulting from the deployment of advanced technology needed to comply with regulation.

6. Markets for Locomotive Emissions — Marketability Review

The discussion of markets for locomotive emissions consists of two parts. This section reviews issues related to the applicability of markets to the regulation of NO_x emissions from locomotives in California. Section 7 presents three market designs and JFA's recommended approach.

This section reviews issues related to the applicability of markets to the regulation of NO_x emissions from locomotives operating in California. It consists of five parts: an introduction, an overview of emissions credit programs, a discussion of emissions trading programs for mobile sources, a discussion of economic factors affecting locomotive emissions market design, and conclusions and preliminary recommendations.

6.1 Introduction

The objective of this sub-section is to review emissions trading concepts relevant to markets for locomotive emissions. Specifically, the objective is to uncover information pertinent to the development of emissions trading programs which are capable of implementing the concepts outlined by the ARB, especially as related to the use of caps for the phased reduction of NO_x emissions from locomotives operating in California. Such emissions trading programs could be used for NO_x, PM, or any other pollutant emitted by locomotives. They would be applicable in nonattainment areas for each affected pollutant as well as in attainment areas where growth of emissions is of concern.

The analytical approach that was taken to achieve this goal was to conduct a literature review supplemented by consideration of existing and proposed emissions trading systems and by observations based on JFA's extensive experience in dealing with emissions trading concepts. Sources used included papers from the economic literature and descriptions and discussions of programs promulgated or proposed by state and local governments and by the U.S. Environmental Protection Agency (U.S. EPA).

The subsequent parts of this section present the results of this review and analysis. Section 6.2 provides an overview of emissions credit programs. This includes existing programs such as the RECLAIM program for the South Coast Air Quality Management District (SCAQMD) and the programs for emissions averaging discussed in the Federal Implementation Plan for California recently withdrawn by the U.S. EPA. Section 6.3 describes special considerations related to the design of mobile source emissions credit programs. Section 6.4 assesses factors affecting the design of markets for emissions from locomotives. Section 6.5 discusses general conclusions and preliminary recommendations.

6.2 Overview of Emissions Credit Programs

Emissions trading is a concept developed by economists in the 1970s to allocate emissions reductions more cost-effectively than the "command and control" approach, once the reduction target is determined. Emissions trading is one of two economic incentive approaches, the other being emissions fees, that have optimal efficiency properties. Another economic incentive approach, based on subsidies to those who reduce emissions, does not share the efficiency properties of emissions trading and emissions fees.

Emissions trading can take many forms, based on the pollution control objective. Three basic approaches to emissions trading are discussed below.

1. *The Emissions Budget Approach.* This approach bases emissions trading on the rule that the sum of all emissions released within a jurisdiction shall not exceed a predetermined limit. The limit is often referred to as an emissions budget. The emissions increase allowed to one party of the trade would equal the emissions decrease guaranteed by the other.

2. *The Ambient Air Quality Approach.* In this approach, emissions trading is based on the rule that the ambient air quality after the trade be no worse than it was before the trade. This approach accounts for the pollution impact of each source at each location.[30] It assumes that air quality was acceptable before the trade. If it was not, the ambient limit required after the trade may become the limiting criterion for the trade. The criterion for the ambient air quality approach is more complicated to apply than the one for the emissions budget approach because it requires use of some form of air quality modeling.

3. *The Damages Approach.* This approach requires an additional step beyond the ambient air quality approach. The step is to measure the economic impacts on health, crops, materials, and the environment due to changes in emissions patterns resulting from a trade. The decision rule associated with this approach would state that net damages be zero or that there be no negative impacts. The requirement to measure the economic effects of the trade adds a great deal of complexity to trading.

Obviously, the emissions budget approach is the easiest approach to implement, because neither economic nor air quality modeling must be performed in conjunction with the trade. The emissions budget can be based on cost and air quality considerations, and the boundaries of the trading area can be set to ensure that the impacts of the emissions involved in the trade are similar. Moreover, most of the emissions trading programs being implemented or proposed follow the emissions budget approach. The rest of this sub-section focuses on the emissions

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[30] Krupnick, Alan J.; Oates, Wallace E.; and Van De Verg, Eric. *On Marketable Air-Pollution Permits: The Case for a System of Pollution Offsets.* Journal of Environmental Economics and Management, 1983, 10(3), pp. 233-247.

budget approach to emissions trading.

There are three basic formats for emissions trading and two institutional settings. The three formats are as follows.

- *Emissions Reduction Credit (ERC) Trading* which is a form of emissions trading in which an ERC is approved by the regulatory agency based on emissions reductions already attained. Before the ERC is approved, the agency has assessed the amount by which the altered control technologies and operating procedures have reduced the level of emissions of a source below its emissions limit. ERCs can then be sold to other emissions sources to be used to meet their emissions control requirements.

- *Emissions Allowance (EA) Trading* involves the assignment of a certain number of emissions allowances to each source. Sources must install controls or institute programs to meet those limits. If emissions are less than the limit, sources may sell their surplus EAs. If emissions are in excess of the limit, sources must obtain additional Eas or are deemed to be out of compliance with the limit.

- *Emissions Averaging* is a form of emissions trading in which no specific limit is placed on a source's total emissions. Rather, a limit is placed on the emissions rate of each piece of equipment. If the emissions rate of a given piece of equipment is lowered below its limit, then the rate for another piece of equipment may be increased. The allowable increase in the rate is determined using a weighting system in which the expected rates of utilization for the various pieces of equipment are used as the weights.

The design of an emissions trading system depends on which formats and institutional settings prevail. The two pertinent institutional settings for these forms of emissions trading can be summarized as follows.

- Constant emissions limits have been set for the foreseeable future. The limits may be in the form of emissions caps on each source or emissions rates per unit of activity for each source.

- Baseline emissions limits for each source have been set and the limits are then reduced according to a schedule—referred to as declining caps.

6.2.1 Examples of Existing Emissions Trading Programs

The first major application of emissions trading was the emissions offset program developed as part of the new source review (NSR) program included in the Clean Air Act of 1977. The NSR program required that major new sources (i.e., those that would emit, or have the potential to emit, over 100 tons per year of an air pollutant) in a nonattainment area undergo a close review of their design and operating plans, install the most advanced form of pollution control equipment available to them, and induce other sources to lower emissions by at least as much as the new source's expected emissions (known as the offset requirement). Major new sources had to obtain an offset unless the region had required existing sources to reduce emissions by an extra amount in order to create an allowance for growth. Growth allowances were abandoned by the 1990 Clean Air Act Amendments (1990 CAAA).

The offset program has been in effect since the late 1970s. During this time, each nonattainment area in each state has had to develop a state implementation plan (SIP) to implement emissions offsets if it is to accommodate the location of a facility that would be classified as a major new source. SIPs for offset trading are the source of most currently available information on the practical workings of emissions trading. Offset trading traditionally has focused on industrial sources of emissions.

The offset trading conducted under NSR and implemented though the SIP process in various states is a special case of emissions trading. Specifically, it does not encompass previously existing sources or smaller sources, except as sources of emissions reductions. Emissions trading programs to reduce the costs to existing sources subject to emissions reduction retrofits have also been proposed and some have been implemented. A recent example is the RECLAIM program implemented by the SCAQMD. This program implements a "declining cap" on emissions of NO_x and SO_2 from a universe of both new and existing sources. The cap declines by three percent per year from a pre-established baseline. Emissions reductions at existing sources must exceed emissions increases due to growth by this amount.

The U.S. EPA is involved in emissions trading in several ways. In addition to its role in the NSR program, the U.S. EPA has released guidelines for emissions trading on two occasions. In 1986, the agency released its Emissions Trading Policy Statement (ETPS). On March 15, 1994, the U.S. EPA released its Economic Incentive Program (EIP) Rules. These rules establish guidelines to states for the development of emissions trading programs, emissions fee programs, and other economic incentive programs that will be subject to approval as part of a SIP.

Concurrently, the U.S. EPA published its proposed Federal Implementation Plan (FIP) for California. After a comment period, the FIP was revised and published in final form on February 14, 1995. The FIP used several concepts (such as emissions averaging) from the EIP and addressed specific issues relevant to the control of railroad and truck emissions. Although the FIP has since been withdrawn, it serves as a statement of programs that were acceptable to EPA as of February 1995.

The U.S. EPA's EIP Rules define nine issues relevant to the development of any economic incentive program that will function as part of a SIP. They also constitute guidelines applicable in most trading situations that may arise with respect to criteria air pollutants (CAPs)—including attainment areas when maintenance of air quality is an issue. These issues are discussed below.

1. <u>Program Goals:</u> For discretionary programs, such as locomotive emissions trading, no specific requirement exists, except that the overall SIP "ensure expeditious attainment of the national ambient air quality standards (NAAQS)" regardless of the nature of the proposed program.

2. *Interface With Reasonably Available Control Technology (RACT) Requirements:* RACT is the set of control standards developed for certain types of existing stationary sources by the U.S. EPA in response to the Clean Air Act Amendments (CAAA). The EIP Rule allows emissions trading involving RACT and non-RACT sources. Nothing in the final EIP Rule limits the design of an expanded trading universe incorporating stationary sources and mobile sources.

3. *Program Baseline:* The importance of this issue is to eliminate double counting in SIP demonstrations. The rule requires that in a nonattainment area for ozone, the choice of a baseline cannot interfere with meeting "reasonable further progress" requirements for actual emissions. One baseline rule that meets this criterion is the "lower-of-actuals-or-allowables" baseline. This means that the baseline emissions are less than or equal to emissions measured in recent years and less than or equal to what emissions would be under any regulation applicable to the source but not yet implemented. Regions are free to develop baselines as they see fit as long as "reasonable further progress" requirements are met.

4. *Emissions Quantification:* Two issues concerning emissions quantification are discussed in the EIP Rule:

   a) *Criteria for Adequacy of Approach:* The methods used to quantify emissions should be credible, workable, and replicable. The methods will necessarily vary between source categories depending on the nature of a specific source. The proposed FIP suggested a computational methodology for calculating emissions from locomotives and from trucks based on fuel use. The same methodological approach is applied to both. In the final FIP, EPA did not finalize its proposed fee-enforced fleet averaging programs for heavy-duty vehicles. For the emissions averaging applicable to railroads in the SCAQMD that have an increase in traffic, the final FIP states that "such railroads will be required to demonstrate that their fleet average emissions do not exceed national Tier I or Tier II operating emissions levels based on the methodology established in the national locomotive rule for calculating emissions from locomotives." The national locomotive rule is under development.

   b) *Extended Averaging Times:* Air quality models use a source's emissions for a typical summer day as input. If sources state their emissions limits in terms of a longer-term average, such as annually or monthly, they are required to also place a cap on daily emissions. The EIP Rule considers approaches that would allow longer-term averaging in defining the emissions allocation that would be traded. In the proposed FIP for California, although RECLAIM uses annual averages in its trading program, the U.S. EPA proposed monthly averages. The additional flexibility of the proposed rule is required for either of these approaches to be used effectively.

5. *Monitoring, Record Keeping, and Reporting:* The U.S. EPA has developed guidance regarding monitoring, record keeping, and reporting. It is important to develop a reliable system for monitoring emissions—or monitoring the data that will be used to calculate emissions—in an emissions allowance trading system (such as declining caps), because monitoring is the key mechanism for determining compliance. In such a system, no specific controls are required. The U.S. EPA recognizes that optimal systems for monitoring, record keeping, and reporting emissions will vary across source types. Monitoring, record keeping, and emissions reporting comprise a cost item that may be increased by emissions trading. The proposed FIP recommended that locomotive emissions be calculated by multiplying fuel usage for each locomotive by the appropriate emissions factor. The final FIP proposed using a rule to be developed as part of the national locomotive rule.

6. *SIP Creditability:* This issue concerns methods for predicting the expected emissions reductions attributable to an EIP. The method must account for emissions reductions due to incomplete compliance with previous emissions reduction programs. In addition, the method must account for the likelihood of noncompliance and for any uncertainty inherent in the program. According to the EIP Rule, in a cap program such as that proposed for locomotive emissions, the only uncertainty is due to problems in measuring the true emissions levels. The effects of a program such as capping locomotive emissions on the emissions of another source, such as trucks, may need to be considered in the context of SIP creditability. Note that the issue of SIP creditability is valid in attainment areas as well as nonattainment areas. In attainment areas, air pollution officials have to implement plans for prevention of significant deterioration.

7. *Audit/Reconciliation Procedures:* Audits and reconciliations must occur frequently enough to provide input in assessing milestones for the "reasonable further progress" requirements of the 1990 CAAA. The U.S. EPA has solicited comments on how audits should be performed for mobile sources.

8. *Penalties for Noncompliance:* If the state submits an EIP that is not specified on a per day-per source basis, then the state must develop a procedure for assessing the number of days of violation and for identifying the responsible parties. The procedure must not dilute the incentive to comply.

9. *Interface With Existing Emissions Trading Policies:* The U.S. EPA reiterates its fundamental rule for emissions trading as follows: "... SIP credited trading activity must be quantifiable, enforceable, surplus, permanent within the time frame specified by the program, and consistent with all other statutory and Federal regulatory requirements." It specifies that although the ETPS can be used to devise an EIP that can be approved, it is not necessary to use the guidance of the ETPS in devising an EIP. The EIP Rule is more general and applies to a broader range of possible programs than the ETPS.

Attention to these nine requirements will ensure that the trading program developed by the ARB will conform to the U.S. EPA's guidance, thereby facilitating the SIP approval process.

It should be noted that emissions trading concepts have also been established for situations other than the nonattainment of ambient standards for criteria air pollutants. For example, a market for lead levels in gasoline during the lead phase out period illustrates the best potential for the emissions trading concept. Most of the potential trading opportunities were realized and trading proceeded smoothly.[31] In contrast, little use of emissions trading was made by owners of emissions sources in an effort to reduce control costs under the ETPS.

6.2.2 Special Consideration for Mobile Source Emissions Trading

In general, emissions trading programs involving mobile sources must meet the same criteria as programs for stationary sources. Emissions reduction credits must be quantifiable, enforceable, surplus, permanent within the time frame specified by the program, and consistent with all other statutory and Federal regulatory requirements. The only significant differences between emissions trading for stationary sources and emissions trading for mobile sources is that in some cases mobile source emissions are more difficult to quantify and the location and ownership of specific sources is highly variable. This is especially true of private automobiles. As a result, many proposals for the trading of mobile source emissions deal with fleets of vehicles under common ownership. In such cases, the emissions are likely to be easier to quantify and one owner has the ability to reduce larger quantities of emissions by his/her decisions regarding emissions controls, fuel use, maintenance programs, and vehicle miles traveled. The following section discusses emissions trading programs for mobile sources.

6.3 Emissions Trading Programs for Mobile Sources

In this sub-section, emissions trading programs that are specifically designed for mobile sources are discussed. Because emissions trading has been applied to mobile sources only recently, few systems have actually been in place long enough to assess relevant execution processes and impacts. Accelerated vehicle retirement programs constitute the majority of emissions trading schemes implemented to date for mobile sources. However, "vehicle scrappage programs" are not investigated in this study for controlling locomotive emissions.

The most relevant issues for mobile source emissions trading addressed by the EIP Rule include the requirement for a satisfactory method for monitoring emissions and SIP creditability. A method for satisfying the emissions monitoring requirements for mobile sources, based on applying emissions factors to the amount of fuel used, was suggested in the FIP, as discussed above. However, this proposed method was subsequently withdrawn by EPA. In this analysis, SIP creditability involves the impact of a locomotive emissions trading market on truck

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[31] Stavins, Robert N., *Transaction Costs and the Performance of Markets for Pollution Control.* Presented at the American Economics Association Meeting, Boston, MA, January 1994.

emissions.

Furthermore, all of the emissions trading concepts discussed in the previous sub-section apply to mobile sources. These include:

- emissions reduction credits,
- emissions allocations,
- declining caps, and
- emissions averaging.

A critique of mobile source emissions trading programs that have actually been implemented, if only briefly, is conducted below, followed by a description of mobile source trading concepts being considered in California. Finally, analyses of how trading issues have been addressed by the U.S. EPA and of possible refinements that could improve the currently accepted approach are performed.

6.3.1 Critique of a Current Mobile Source Emissions Trading Program and Recent Trial Programs

Two important demonstrations of mobile source emissions trading—the UNOCAL accelerated vehicle retirement demonstration program and the Delaware Vehicle Retirement Program—have been completed and the results examined.[32] In addition, the SCAQMD (and other jurisdictions) has included mobile source emissions trading for NO_x and oxides of sulfur (SO_x) in its RECLAIM program. These three programs are discussed below.

The Union Oil Company (UNOCAL) conducted a demonstration project in 1990 in which it purchased over 8,000 pre-1971 vehicles in the Los Angeles basin. The program required that automobiles be operated in the region for a minimum of six months and that they be driven to the scrap yard by the registered owner. UNOCAL paid $700 for each vehicle.

The focus of UNOCAL's program was to determine how much regional emissions were reduced by scrapping older vehicles. First, UNOCAL had to estimate the emissions that the vehicles would have emitted under a no-scrappage scenario. This was accomplished via the execution of surveys to obtain data on the driving habits of 800 of the motorists that participated in the program and by the subsequent execution of the Federal Test Procedure on 74 of the 8,000

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[32] Alberini, Anna; Edelstein, David; Harrington, Winston; and McConnell, Virginia. *Reducing Emissions From Old Cars: The Economics of the Delaware Vehicle Retirement Program.* Resources for the Future, Washington, DC, 1994.

vehicles purchased by UNOCAL. Second, UNOCAL estimated the emissions related to the mode of transportation used by participants after the sale of their vehicles. By relying on fleet averages for this calculation, UNOCAL estimated that reductions of hydrocarbon emissions, the emissions of concern for this program, cost between $2,200 and $2,900 per ton. The emissions reductions were not accepted in an emissions trading program, but were accepted in lieu of an employee ridesharing program.

The Delaware Vehicle Retirement Program was a demonstration program similar to the UNOCAL program. It was designed as an experiment, so certain vehicles thought to have exceptionally high emissions were targeted and follow-up surveys were conducted. Since the major concerns of the program were the calculation of regional emissions reductions due to the program and its acceptability in providing emissions reduction credits, great attention was paid to examining the emissions characteristics of the automobiles that participated in this program. The Delaware Vehicle Retirement Program also focused on hydrocarbon emissions.

In 1993, the SCAQMD released Rule 1610 establishing guidelines for allowing trading between mobile and stationary sources. Emissions are calculated by a simple rule incorporating generalized assumptions about the miles an automobile is driven annually and its expected remaining life—based on its year and model. UNOCAL has applied for emissions reduction credits under this rule.

The accelerated vehicle retirement programs discussed above highlight a more complex issue related to the estimation of emissions reductions than do most stationary source emissions reduction programs. Vehicle retirement programs require estimation of data that can never be observed (i.e., a retired vehicle's emissions profile). In contrast, most stationary source emissions trading programs can measure the actual emissions that occur once the controls are in place and compare them to an emissions limit that has been placed on the source. The emissions trading program proposed in Section 7 of this study for locomotive emissions is more like the stationary source programs than the accelerated vehicle retirement programs in this respect.

6.3.2 Programs That Have Been Proposed for Trading of Mobile Source Emissions in California

James Boyd—the executive officer of the California Air Resources Board—recently presented a paper on mobile source emissions trading.[33] After discussing the advantages and challenges of "market controls" relative to more traditional approaches to reducing pollution, Boyd listed three categories of mobile source emissions reduction credits (MSC), including:

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[33] Boyd, James D. *Mobile Source Emissions Reduction Credits as a Cost Effective Measure for Controlling Urban Air Pollution*. in Cost Effective Control of Urban Smog, (papers presented at a conference sponsored by Workshop on Market-Based Approaches to Environmental Policy, Federal Reserve Bank of Chicago, and Chicago Council on Foreign Relations), Federal Reserve Bank of Chicago, November 1993, pp. 149-157.

- manufacturer credits;
- low emissions, heavy-duty vehicle credits for industrial/utility use; and
- credits derived from existing light-duty cars and trucks.

Manufacturer credits represent a form of emissions averaging in which the number of motor vehicles sold in California per year by vehicle class (five major classes and numerous subclasses) are tallied and used to determine the fleet average vehicle emissions for hydrocarbons. The fleet average is compared to the fleet average vehicle limits. Boyd described this as a "fleet bubble." The specific mix of vehicles produced and sold is left to the discretion of the manufacturers. Fleet averages below the limits are available for trading or may be banked for use against limits in future years.

Low emissions, heavy-duty vehicle credits for industrial/utility use is a concept aimed at reducing NO_x emissions. The credits may be used by local air quality districts after developing specific rules. For example, if low emissions buses are purchased, the difference in their emissions and those of buses just meeting the standards may be used as the basis for an emissions reduction credit that could be used by industrial or utility sources to facilitate economic growth.

Vehicle retirement programs (such as the "cash for clunkers" programs that have been demonstrated in Delaware and written into RECLAIM) represent approaches for reducing automotive hydrocarbon emissions below the levels required by regulations. The credits generated by these programs have been used by industrial or utility sources.

Each of these concepts allows emissions trading between different types of mobile sources or between mobile and stationary sources. Boyd stated, "To be recognized for credit, any emissions reduction project must meet two basic criteria: (1) the reductions are real, measurable, and enforceable, and (2) the reductions are 'surplus,' meaning they are not required by or credited to any other programs."

Although positive about the promise offered by these approaches, Boyd cautioned that challenges are to be met in implementing them. These challenges include the calculation of credits (many factors in the calculations must be estimated), and the possibility of developing a "green book" of emissions values for each type of vehicle. This book will determine the type(s) of vehicle(s) creating the most pollution; and therefore, target it (them) first to maximize cost-effectiveness. Boyd also cautioned that no region should be allowed to suffer adverse air quality impacts. He closed by stating that numerous efforts exist to develop similar concepts which will increase the opportunities to provide incentives for reducing emissions from categories of mobile sources not currently being regulated.

Boyd's discussion touched on the most widely discussed concepts for involvement of mobile sources in emissions trading programs and made it clear (as does the U.S. EPA) that the opportunity for emissions trading among mobile sources and between mobile and stationary sources is available as long as the criteria in the EIP Rule are met.

6.3.3 Issues to be Addressed in Market Design for Railroad Emissions Trading

The two primary issues for the design of mobile source emissions trading programs, emissions monitoring and SIP creditability, have been the focus of this sub-section. For locomotive emissions, SIP creditability for an emissions capping approach depends on whether the regulatory treatment of truck emissions constitutes a cap. This issue is discussed in Section 6.4.

The issue of emissions measurement was temporarily resolved by the U.S. EPA's proposal to multiply emissions factors by fuel use. The merit of this approach is that it can be applied to all mobile sources. Issues of mode of operation (which affects the emissions per gallon of fuel) and location of use are not resolved in this study. However, relatively simple refinements, applicable to both trucks and trains, are feasible. For example, a log book showing the hours a vehicle was in motion, as opposed to idling, would improve emissions estimates and allow estimation of the emissions released in each jurisdiction. The solution suggested by EF&EE, in which computer logs show the mode of operation of locomotives in real time may be feasible, especially if the necessary computer equipment has been installed previously for other purposes. However, unless all truck operators also install similar computer systems, a uniform approach to measuring emissions from rail and trucking activities would not prevail. The most interesting conclusion regarding emissions monitoring is that the U.S. EPA seems willing to accept a simple method that provides only a first-order approximation of emissions. This is a much less stringent method than they have required for stationary sources.

In addition to the regulatory criteria presented in the EIP Rule, other critical economic issues affecting the design of emissions trading programs for locomotives must be addressed. These are discussed in the following sub-section.

6.4 Economic Factors Affecting Locomotive Emissions Market Design

In this sub-section, four issues are discussed that are vital to the successful application of emissions trading programs to rail operations and to achieving the goal of reducing NO_x emissions to desired levels. These issues are as follows:

- capping locomotive NO_x emissions,
- ensuring the viability of long-term markets;
- reducing transactions costs, and
- overlapping jurisdictions.

6.4.1 Capping Locomotive NO_x Emissions

As shown in Section 5, the relative change in the marginal cost of reducing NO_x emissions from trucks and trains will determine mode shifts which, in turn, affect emissions from freight transport. The mode shift and emissions analyses presented in that section demonstrate that reductions gained from reducing rail emissions more than offset any increase in truck emissions, even if trucks are not subject to any further controls. The analyses formulated in Section 5 are based on "command and control" approaches to mitigating freight related emissions (i.e., emission standards that newly sold locomotives or trucks must adhere to). However, the ARB is considering market-based mitigation strategies that strive to allocate emissions reductions more cost-effectively across polluters. One approach is to cap locomotive emissions.

A cap on locomotive emissions means that total NO_x emissions within a given geographic area may not go above a prescribed level. The caps envisioned by the ARB would limit emissions from each rail line's operation within each nonattainment area in California. Railroads could trade emissions within each air shed to meet the cap at the least cost. However, before locomotive emissions caps are considered, an important regulatory issue must be addressed—whether or not similar caps will be placed on truck emissions. This discussion will show that in some circumstances, depending on how truck emissions are treated, a cap on locomotive emissions may be detrimental to the achievement of air quality goals.

A cap that fluctuates with the number of rail ton-miles was considered by the ARB. The concern expressed by the ARB that led to consideration of a flexible cap is that if the cap on locomotive emissions becomes too tight to accommodate increased freight demand, particularly for rail services, increases in freight transport demand will be accommodated by trucks. Since trucks emit more than rail on a ton-mile basis (see Section 3), a binding cap may be detrimental to achieving regional air quality goals. The proposed remedy under consideration by the ARB is to adjust the cap to accommodate increases in the demand for rail services.

The concern that a non-adjusted cap on rail emissions would increase emissions from trucks is certainly valid.[34] If the cap is placed on emissions from locomotives only, and the only recourse is to trade emissions between locomotives, increased shipping activity will be difficult to accommodate. At some future point, the only options for railroads will be to refuse shipping of additional freight or to invest in major technological changes such as electrification of the rail lines. If trucks are not subject to a similar cap, they will be available to take up the slack. The cost of shipping by truck will impose an upper limit on the cost of economically viable investments in abatement technology by the railroads.

However, two problems exist with the flexible cap approach. First, the air quality management districts need to know the emissions budgets for locomotives so that they can allocate emissions reduction requirements to other pollution sources, such as area and stationary sources. An

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[34] Oates, Wallace E. and Schwab, Robert N. *Market Incentives for Integrated Environmental Management: The Problem of Cross-Media Pollution*. Unpublished paper.

increase in locomotive emissions for a future year will cause an air quality violation, unless another source is required to further reduce emissions. Second, the flexible cap does not put pressure on the railroads to reduce the mileage involved in moving a shipment from point A to point B. To minimize this problem, the program should provide incentives to ship goods via the shortest route, unless another route provides advantages, such as fewer grades. Incentives to reduce traffic in switch yards, or to redesign and/or relocate switch yards, also contribute to the most efficient emissions control strategy. In general, the economic incentives created by the market based controls should be designed to apply uniformly to all factors affecting locomotive emissions.

Likewise, the regulatory system should treat emissions from all freight modes (i.e., rail, truck, air, and marine) uniformly. Obviously, this does not imply that if one mode is required to reduce its emissions rates (e.g., in terms of grams of NO_x per Bhp-hr), other modes should be required to meet the same emissions rate. If an emissions rate strategy is chosen, it should entail differential emissions rates between modes such that control costs are balanced, or it should be specified in terms of emissions per ton-mile of goods.

Uniformity means applying uniform pressure on all modes to reduce emissions. If emissions rate strategies are chosen, modes should be allowed to use emissions averaging to allow greater flexibility and reduce costs. However, the best way to achieve uniformity is to subject all modes to emissions caps and allow trading of emissions within and between the caps.[35] If all transportation systems are subject to caps, mode shifts will be economically efficient and total emissions will be limited by the caps. The greatest benefit will be realized when trading systems embrace all transportation emissions, as well as emissions from stationary sources.

This analysis recognizes the difficulty in capping truck emissions of NO_x due to the large number of trucks on the road that would have to be monitored in order to keep track of total NO_x emissions. Other factors to consider include the following: 1) the difficulty of recording all the accelerations, decelerations, and loads on the engines experienced in a trip and the emissions released in each situation; and 2) the problem of asserting regulatory authority over all trucks, especially those registered outside of California. However, with the advent of Intelligent Transportation Systems, specifically advanced vehicle identification, location, and monitoring systems, trucks based-plated out-of-state can be identified. For example, the Heavy Vehicle Electronic License Plate (HELP)/Crescent Project, which affixes transponders to trucks and monitors their locations, has shown these systems to be effective. A number of trucks are now participating voluntarily and the project hopes to include all trucks operating in a crescent of states from Texas to Washington within the next two decades. Once these technologies are deployed on a wide-scale basis, data on truck populations, usage, and activity patterns can be improved upon for emissions forecasting purposes.

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[35] As discussed in Section 7, this approach is recommended in this study.

Another factor that advances the issue of the treatment of truck emissions is the proposed FIP, signed in February 1994 by the U.S. EPA.[36] Although it has since been withdrawn in favor of local planning processes for meeting air quality goals, the proposed FIP envisioned major restrictions on the emissions rates of new and in-use California heavy-duty trucks, limited stops by non-California trucks to two per trip in California and just one in the SCAQMD, established statewide emissions averaging for truck fleets, and established emissions averaging for locomotives operating in the SCAQMD. The proposed emissions averaging program would have collected data necessary for the demonstration of compliance under an emissions cap scenario. In the final FIP, the U.S. EPA withdrew emissions averaging for trucks and the one stop-two stop program for trucks. The U.S. EPA predicated this change on a national truck rule that would reduce truck emissions to levels similar to those originally proposed.

The U.S. EPA's conformity rules[37] (i.e., transportation conformity and general conformity) issued in November, 1993, also could be used in the development of a program that caps truck emissions. These rules require that the emissions budgets used in demonstrating that the SIP will bring the region into compliance with ambient air quality standards are either met or formally amended so that regional transportation plans conform to regional air quality plans. Since truck emissions are implicitly or explicitly budgeted in all SIPs for ozone, air pollution districts and air quality management districts will be responsible for ensuring that truck emissions meet the cap implicit in the emissions budget. However, localities only need be concerned with the effect of transportation projects on regional air quality. Increases in emissions due to increases in truck traffic are not necessarily an issue in conformity assessments. In any case, capping truck emissions would assist localities in demonstrating that road improvement plans would not cause increased emissions while, concurrently, the emissions budgets developed by localities would provide useful inputs in the development of caps for truck emissions.

However, Federal requirements currently are not sufficient to place implicit caps on trucks. Truck emissions remain a concern when considering the capping of locomotive emissions, or any other approach which addresses locomotive emissions without specific attention to the impact on mode choice. For example, an emissions averaging approach to locomotive emissions could cause modal diversion from rail to truck if the marginal cost of reducing locomotive emissions is increased by a larger amount than the marginal increase in the cost of reducing truck emissions. A cap that reduces locomotive emissions by a modest amount could have a smaller

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[36] U.S. EPA. *Approval and Promulgation of Implementation Plans; California--Sacramento and Ventura Ozone Federal Implementation Plans; South Coast Ozone and Carbon Monoxide State and Federal Implementation Plans; California Motor Vehicle and Fuels Program; California Nonroad Engine Program; California Consumer Product Rules; California Pesticides Rule; California Architectural Coatings Rule; Sacramento Ozone Area Reclassification*, Federal Computer Bulletin Board, February 15, 1994. This will be referred to as "the proposed FIP."

[37] U.S. EPA, *Determining Conformity of General Federal Actions to State or Federal Implementation Plans*, Federal Register, Vol. 58 No. 228, Tuesday, November 30, 1993 and U.S. EPA, *Air Quality: Transportation Plans, Programs, and Projects; Federal or State Implementation Plan Conformity; Rule*, Federal Register, Vol. 58 No. 225, Wednesday, November 24, 1993.

impact on truck emissions than an emissions averaging requirement that requires the most stringent controls on locomotives.

6.4.2 Ensuring the Viability of Long-Term Markets

Emissions trades may be made in spot, short-term, or long-term markets. In a **spot market**, emissions traders are interested in immediate concerns. In terms of rail operations, suppose the clean locomotive malfunctions and emissions from the substitute locomotive exceed the planned amount of available allowances by 5 percent. The railroad would look to the spot market to supply allowances to make up the difference. In a **short-term market**, emissions credits would be purchased or sold to accommodate operational adjustments affecting emissions. These adjustments are low cost and generally reversible. They do not represent a grand investment strategy. In a **long-term market**, emissions credits are purchased and sold based on a railroad's capital investment strategy. Such a strategy may include electrifying a segment of track or purchasing a fleet of alternatively fueled locomotives. Of the spot, short-term, and long-term markets, the one most likely to contribute to market inefficiency, thereby stifling trading activity, is the long-term market.

Long-term markets are the most vulnerable to design inefficiency because long-term investment strategies will require the purchase or sale of streams of emissions allowances. The railroads must project their emissions needs in each year of the strategy and consider how they can obtain allowances to cover them. They would need to be able to purchase or sell streams of emissions allowances for future years (or for perpetuity) to implement this planning. Long-run planning is needed to accommodate new business. Some long-run plans could be accommodated by purchasing allowances on the spot market each year, but this would involve increased risk. Lack of well-defined market instruments far into the future will motivate railroads to place less reliance on emissions markets.

Three types of government activity introduce uncertainty into long-term markets:[38]

- the manner in which emissions trading would be treated in regulated industries,
- the possibility that various levels of government may enact environmental laws limiting or revoking emissions allowances, or move in the opposite direction and repeal existing laws, and
- the reluctance of some factions at the U.S. EPA to let go of the "command and control" approach.

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[38] Hausker, Karl. *The Politics and Economics of Auction Design in the Market for Sulfur Dioxide Pollution.* Journal of Policy Analysis and Management, 1992, 11(4), pp. 553-572.

The third type is manifested in the regulations to implement Title IV of the 1990 CAAA. For instance, sources holding allowances to emit SO_2—having installed continuous monitors and subject to large fines if their emissions are in excess of their allowances—are also required to submit detailed compliance plans for the U.S. EPA's approval. This requirement means that firms cannot respond quickly to trading opportunities or to rapidly changing market conditions. The command and control overlay effectively eliminates the flexibility granted to firms in meeting emissions limits, over riding a key virtue of market incentives.

To ensure efficiency in long-term NO_x markets, Federal, state, and local governments must ensure the long-term stability of the regulatory structure. This does not necessarily mean that they need to determine, once and for all, the emissions allocations for the next several centuries. But it does mean that, should they establish a market mechanism, the rules of the market should not be altered indifferently.

Some economists question government's long-term commitment to economic incentives. For example, R. W. Hahn and Robert Stavins question whether governments are capable of "making the type of long-term credible commitments under markets that would be required to encourage affected firms to adopt new and improved technologies."[39]

6.4.3 Reducing Transaction Costs

Transaction costs are the costs to individual firms and government agencies that are related to completion of an exchange of emissions allocations. They include the following: search costs, payments to brokers, negotiating costs, costs of demonstrating compliance, documentation and filing costs, fees (in money or in kind—such as an offset ratio), and costs of enforcement.

In the brief history of emissions trading, transaction costs have varied greatly from one trading system to another.[40] The magnitude of transaction costs is thought to be a primary determinant of the success of a trading system. For example, the market for lead rights, in effect between 1982 and 1987, is thought to have had relatively low transaction costs. The trading unit and trading universe were well defined, with the trading universe consisting of gasoline refiners who were in the habit of frequent transactions with each other in other markets. Over half of all lead rights were involved in market activity, and half of eligible firms participated. Transactions in this market consisted of external trades (i.e., trades between firms).

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[39] Hahn, R. W. and Stavins, R. N. *Economic Incentives for Environmental Protection: Integrating Theory and Practice*, American Economic Review, May 1992, 82(2), pp. 464-468.

[40] Stavins, Robert N., *Transaction Costs and the Performance of Markets for Pollution Control*. Presented at the American Economics Association Meeting, Boston, MA, January 1994. Stavins reviews several papers that depict the link between transactions costs and the performance of emissions trading systems and then develops a model to illustrate how transactions costs affect the optimal control levels of a pollutant. This paragraph is based on his review.

The level of trading activity in the lead market contrasts with that under the U.S. EPA's ETPS program, which was characterized by a low level of external trades—less than one percent of possible situations—and a high level of internal trades (i.e., trades between sources owned by the same firm). Differences between the number of external and internal trades in the ETPS program partly are attributable to differences in transactio costs. Under the ETPS program, transaction costs of internal trades are thought to be substantially lower than those of external trades.

Transaction costs may be felt in many ways. They may be experienced as the amount of time the firm's employees spend on executing a trade rather than on some other task. Also, the elapsed time required for the firm's employees or agency personnel to complete the transaction may cost the firm in terms of lost business opportunities. There is evidence of the magnitude of monetary transaction costs as well. As an example of the magnitude of costs that occur in some trading systems, AER*X, an emissions brokerage firm, has reported that when emissions offsets were purchased in Los Angeles for new sources, the fixed fee was $3,000 per trade with $10,000 to $25,000 for administrative costs, such as documentation and filing costs.[41]

The nature of each type of transaction cost must be discerned in order to ascertain how or if it can be reduced. The evidence concerning transaction costs is drawn from the NSR program, which concerns new or expanding firms requiring an offset. As will be seen, NSR is not necessarily a good example for determining the costs of trading locomotive emissions. A firm subject to NSR must first develop the design specifications of the plant to be constructed, then project emissions based on the specifications and expected operating parameters. Projected emissions are then included in air models to determine their ambient impacts. Based on these projections, the location and quantities of emissions reductions needed to offset the new emissions are estimated.

Once the firm's emissions permit needs are determined, it must search for other firms with emissions profiles capable of providing the required reductions, purchase the emissions credits, and register them with the agency. Costs associated with these steps are discussed below.

- <u>Search costs</u> are the costs of finding a firm that will reduce emissions to provide the offset. The search frequently consists of a broker developing a list of firms with potential to provide the offset and then contacting each firm to explore offers, often keeping the name of the prospective purchaser anonymous. The firm will have to make a <u>payment to the broker</u> for its expenses, which may run from $20,000 to $85,000 per trade.[42]

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[41] Stavins, <u>Op. Cit</u>.

[42] AER*X, Inc. in conjunction with Jack Faucett Associates, <u>Analysis of the nature and costs of Emission Offsets</u>, Prepared for U.S. EPA, Ambient Standards Branch, Air Quality Management Division, December 1992.

- *Negotiation costs* are incurred once a candidate firm is located. The firms' lawyers will discuss terms and contractual conditions for the development and sale of the offset.

- *Costs of demonstrating compliance* of the offset with all requirements are incurred when the firms take the proposed offset to the pollution control agency.

- *Costs of filing all required documents, and paying fees* are the next category of costs the firm encounters. Fees may be a dollar amount or they may be in the form of an offset ratio—an extra reduction beyond the amount needed to maintain current ambient levels of pollution. Determining the trading ratio between emissions increases and offsetting emissions decreases requires a balanced approach.[43] Too low a ratio between the increase and the decrease stymies interest in trading participation. Too high a ratio jeopardizes air quality. Uncertainties concerning the effects of altered emissions on air quality provide a rationale for discounting an ERC. Discounting the ERC adds a "margin of safety," but simultaneously decreases the cost-effectiveness of the program.

- *Costs of enforcement* are additional cost items that are sometimes included under transaction costs. They should only be included if the enforcement costs for a firm involved in trading are higher than for a firm not involved in trading.

It should be noted that the transaction costs involved for pollution offsets (i.e., the relevant type of trading) are higher than they would be in most other cases. First, the purchasers of offsets are major new sources. By the definitions prevailing until recently, major sources emitted over 100 tons per year of a pollutant. These sources constitute a captive market, whereby the cost is a required cost of entry or expansion. As long as the projected scale of the operation is sufficient to qualify the facility as a major new source, its options regarding the purchase of an offset are to do so, to find an alternative production technology, or to abandon the project. A major new source seeking an offset is different from an existing source whose options are to trade, to reduce production levels, or to install more pollution control equipment. The major new source has a higher upper limit on the total costs it would pay for an offset, including transaction costs. The firm will pay for an offset as long as the cost is less than the cost of not constructing or modifying the facility. Second, the search for offsets is complicated by the need to determine the potential emissions reductions from firms that would not have to reduce emissions otherwise. Hence, part of the search cost consists of preliminary engineering studies of potential emissions controls by potential sources. Third, the offset is a one time expense and its costs are amortized over the life of the facility.

Because offsets have been purchased since the late 1970s, more information is available about them than about other forms of emissions trading. The remaining discussion will consider how

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[43] Tom Tietenberg, *Discussion.* in Cost Effective Control of Urban Smog, (papers presented at a conference sponsored by Workshop on Market-Based Approaches to Environmental Policy, Federal Reserve Bank of Chicago, and Chicago Council on Foreign Relations), Federal Reserve Bank of Chicago, November 1993, pp. 158-165.

the transaction costs experienced by major sources purchasing offsets may be reduced, as well as how costs for different trading systems are likely to be lower.

Search costs are lowered significantly in an emissions trading system in which all participants are identified in advance and are required to reduce emissions. Such programs are referred to in the U.S. EPA's FIP and EIP Rules as "declining caps." In a system of declining caps with trading, all participants must consider their options for reducing emissions in both the short run and long run. This knowledge will be developed by all participants regardless of their propensity to trade. Search costs for the participants can be lowered further if the agency establishes a clearing house for trading. Any party seeking to initiate a sale or purchase of emissions allotments needs to only provide basic information regarding the proposed number of allotments and prices. All others will be informed of these prices and quantities and may then determine if they can make use of them.

As part of the establishment of the clearing house, specific rules are developed. Trades of emissions allocations are credited immediately upon agreement between the participants. This system reduces the major components of search costs because engineering studies are no longer a cost factor for trading and because information on the prices and quantities of allocations offered for sale are public. The clearing house need not publish the identity of those making offers, but it may, through established procedures, bring offerers and purchasers together.

Negotiation costs will also be reduced in such a system because the only negotiable items would be price and quantity. All other issues will be determined by the air quality regulations and clearing house rules. Because each firm would be required to meet its emissions limit, whether or not the limit was altered by trading, enforcement costs would not be affected by trading.

The only other form of transaction costs, filing costs and fees, is in the control of the governing agency. Filing costs are influenced by the amount of detail requested in the filing. These costs are trivial if the only information filed with respect to a trade is the identity of the purchaser and seller, the price per unit of trade, and the number of units exchanged. If fees are charged to all sources subjected to declining caps whether they trade or not, then fees will not be a transaction cost for trading. The basis for the fee would then be independent of trading and the fee would cover all aspects of regulatory costs, not just trading. Alternatively, the expenses of the agency could be supported by general funds.

6.4.4 Overlapping Jurisdictions

The ARB's rulemaking on locomotive emissions is being developed in a complex regulatory setting. The rule will interface with: 1) regions such as the SCAQMD that must develop SIPs for ozone and that will need large percentage reductions of NO_x from locomotives and all other sources; 2) regions such as Santa Barbara that will not need as large a reduction; 3) the California Clean Air Act; and 4) Federal standards for new locomotive emissions. Part of the difficulty is in the timing. The ARB may not know the U.S. EPA's final rule on locomotive emissions before setting its own rule. Similarly, the regions developing SIPs may not know details of relevant rules set by others.

Besides timing, when a higher jurisdiction sets a rule, it may reduce the flexibility of the lower jurisdictions. Thus, the U.S. EPA's decision on the definition of new locomotives and a single, national set of emissions limits for new locomotives, preempts the ARB's authority to set limits for new locomotives. Similarly, the ARB's rule may limit the flexibility of air quality districts in developing their SIPs.

A related issue is what criterion should be used to set the level of reduction of locomotive emissions. From the perspective of the SCAQMD, the rule should allow them to reduce NO_x emissions from any source by as much as they need to reach attainment. This would be similar for other jurisdictions, except that they will not need as large a reduction. The U.S. EPA may be looking for the largest emissions reduction that can be achieved at a reasonable cost. Meanwhile the railroads (who are not a jurisdiction) would prefer that their expenditures on controls not be increased beyond the amount that can easily be accommodated for by their rate structure. In addition, the railroads would prefer equipment requirements that do not inhibit their plans to upgrade the speed and dependability of their service.

Given these conflicting goals and concerns, it may be well to return to the bottom line: what emissions reductions are required to meet the NAAQS and the California ambient air quality standards. Thus, the ARB's best option may be to develop its own rule, independent of the U.S. EPA, keeping in mind the assistance it provides to nonattainment areas and attainment areas in applying declining caps—with reductions of a magnitude needed for conditions prevailing in the local jurisdiction—in the preparation of their SIPs. The flexibility of emissions caps or emissions averages will mitigate the uncertainty of not knowing the precise rule that the U.S. EPA will promulgate with respect to locomotive emissions. The U.S. EPA has endorsed such an approach in its EIP and its FIP, even though the percentage emissions reductions required for railroads may be larger than the percentage emissions reductions for new locomotives.

Since the locomotives which railroads would have to place in service in the SCAQMD may be cleaner than those required in other jurisdictions, such as Ventura and Santa Barbara, railroads may have credits to sell to other emissions sources (such as stationary sources) in non-SCAQMD markets. Thus, factories or power plants may, in the final analysis, assist railroads in paying for cleaner equipment.

6.4.5 Summary of Issues and Implications

The following four issues have been discussed in this section of the report: capping locomotive NO_x emissions, ensuring the viability of long-term markets, reducing transactions costs, and overlapping jurisdictions.

First, the overall regulatory structure is not sufficiently strict with respect to truck emissions as to constitute a cap on them. If a cap or any other method is used to reduce locomotive NO_x emissions, care should be taken so that the resulting marginal pollution reduction costs do not trigger an increase in truck mileage and emissions. A cap is still the least costly way of obtaining a reduction in locomotive emissions and would result in the least amount of additional truck emissions.

Second, it is very important to ensure the long-term viability of emissions markets by developing a stable set of rules conducive to planning long-term investment strategies. Governments at all levels must make long-term commitments to these rules.

Third, declining caps is a form of emissions trading for which transactions costs are intrinsically low, as long as government sets fees at levels consistent with the low level of costs actually incurred for necessary activities such as recording the prices for and quantities of emissions trades and providing a clearing house.

Fourth, the complexities of the regulatory environment can be mitigated by establishing rules for emissions trading based on declining caps within nonattainment areas and attainment areas where maintenance of the ambient air quality is an issue. Each nonattainment area would set its cap based on the amount of reduction needed to meet its ambient air quality limits.

These considerations demonstrate that declining emissions caps set in advance will provide a stable environment for emissions trading and the development of long-term investment strategies, provided government makes a commitment to the long-term stability of the rules and works to keep fees at a level that just covers the costs associated with the efficient provision of basic services in the market.

6.5 Conclusions and Preliminary Recommendations

The conclusion of this analysis is that emissions caps are a viable option, because they will provide a given decrease in rail emissions at the lowest cost, and recommends that specific details be developed to implement them. However, care should be taken that the stringency of the cap or of any other method adopted for reducing locomotive emissions does not promote increases in truck activity. The rules adopted to implement an emissions cap should provide a uniform framework for individual air pollution control districts to apply once the magnitude of emissions reductions required from railroads in the district is determined.

The design of the trading program should incorporate the following elements:

- the trading goal, that is, the emissions limit or ambient air quality goal to be met by the trading system;
- the universe of sources of NO_x emissions;
- baseline emissions for each source;
- the unit of trade; and

- the trading rule.

Section 7 develops a trading rule for NO_x emissions from locomotives in California nonattainment areas based on the declining cap concept. The rule is designed to allow interface between emissions allocations for locomotives, other transportation sources, and stationary sources.

7. Markets for Locomotive Emissions — Market Design

In Section 6, various issues related to the application of markets to the regulation of NO_x emissions from locomotives operating in California were reviewed. In this section, three market designs are developed for using economic incentive approaches in conjunction with a statewide cap on NO_x emissions from locomotives operating in California. Although the discussion focuses on NO_x emissions, emissions of other pollutants (especially criteria air pollutants) could be regulated in the same manner.

The discussion is organized as follows. Section 7.1 presents the analytic assumptions used in the development of a market for locomotive emissions. Section 7.2 discusses issues relevant to the evaluation of alternative market designs. Section 7.3 defines three candidate market designs and evaluates differences among them. Section 7.4 presents the recommended market design (i.e., emissions allocation trading) which includes locomotive emissions in a total emissions allocation trading program that also includes stationary, area source, and other mobile source emissions. Finally, Section 7.5 summarizes the conclusions of the analysis.

7.1 Analytic Assumptions

In this study, the following assumptions govern the development of candidate market designs:

- that declining statewide caps are placed on locomotive emissions;
- that a simplified approach for emissions calculations is developed by the U.S. EPA in its proposed national locomotive rule, or that alternative approaches based on current methodologies developed by the ARB (e.g., methodologies developed by Booz•Allen or EF&EE) are employed; and
- that air quality goals are developed in terms of either a SIP for a nonattainment area or an air quality maintenance plan for a "prevention of significant deterioration" area (i.e., emissions limits for locomotives and other sources are developed with respect to local environmental conditions).

These three assumptions are discussed below.

7.1.1 Caps on Locomotive Emissions

This analysis assumes that declining statewide caps will be placed on locomotive NO_x emissions. These statewide caps will serve as the baseline for determining emissions limits for each railroad operating in each jurisdiction.

A rigid cap is recommended for this purpose, as opposed to a flexible cap that accounts for growth in the demand for freight transport services. Rigid caps allow for more precise emissions budgeting by air pollution control districts and air quality management districts. From an equity standpoint, most jurisdictions employing emissions trading programs (especially the SCAQMD) are placing rigid, declining caps on those area, stationary, and mobile sources involved in emissions trading. Although participating sources have growth plans, their plans must now be predicated on developing strategies for reducing emissions sufficiently to accommodate growth. In the case of rail operations, however, the stringency of the emissions cap is an integral issue since highly stringent caps may cause mode shifts from rail to trucks, and thereby possibly increase combined emissions. Measured in terms of marginal abatement costs, stringency is also the most important determinant of equity under a trading system characterized by rigid emissions caps.

Initial statewide caps should be based on current equipment usage. To ensure this, actual emissions from locomotives operating in each jurisdiction (e.g., during the last three years) must be estimated. Initial statewide caps must, therefore, reflect the emissions that would result from each railroad's typical operations in each jurisdiction.

Initial statewide caps should then be followed by an across-the-board rollback of NO_x emissions from locomotives. The basis for determining the percentage rollback should reflect the needs of the air pollution control districts and air quality management districts in terms of emissions abatement to reach air quality goals. Each region would prepare its SIP or air quality management plan allocating emissions among various sources. The emissions allocated to railroads operating within the jurisdiction in subsequent years would be compared to the emissions baseline to determine the total percentage reduction required from this source. From this calculation, the necessary annual reduction to meet the overall goal by the target date can be determined.

It will not be necessary to require that the statewide rollback be large enough to meet the emissions reduction needs of the most polluted jurisdiction. That is, the statewide percentage rollback need not be as large as would be required to meet the emissions reduction needs of the SCAQMD. The statewide cap can accommodate different percentage emissions reductions in each jurisdiction as long as statewide emissions reduction goals are achieved. Thus, in some jurisdictions the statewide cap could result in larger percentage reductions, while in other jurisdictions smaller reductions could be applied.

7.1.2 Emissions Calculations

This analysis further assumes that emissions calculations will be performed using the approach proposed by the U.S. EPA in its pending national locomotive rule, or via an appropriate alternative such as methodologies developed by Booz•Allen or EF&EE. The U.S. EPA approach is likely to be a simple method in light of recent proposals that estimate locomotive emissions by multiplying fuel usage for each locomotive by the appropriate emissions factor. Methodologies based on the duty cycle of locomotives (e.g., time-in-notch) would provide more realistic emissions estimates, while the collection of real time data on route and mileage using transponders potentially could provide the basis for yet another approach. More sophisticated (and possibly more costly) methodologies are available and could be used if associated development costs are not too great. Nevertheless, to achieve economies of scale and reduce the number of agencies dealing with the railroads, it is assumed that state pollution control officials will perform the calculations and provide them to local jurisdictions.

7.1.3 Local Responsibility for Air Quality Plans

Finally, this analysis assumes that two jurisdictional levels will be involved in economic incentives programs for locomotive emissions: air pollution control districts (or air quality management districts) and the state. While state involvement is necessary to coordinate the activities of local jurisdictions and to certify locomotive emissions attributable to each railroad, local jurisdictions will have to determine what level of locomotive emissions reductions are required as part of their SIPs or air quality management plans. If emissions trading is to take place, it must be part of a local emissions trading system based on coordinated plans for meeting and maintaining air quality goals. The state should provide guidelines to ensure consistency in emissions trading rules across jurisdictions.

7.2 Issues in Evaluating Alternative Market Designs

The evaluation of market designs for mitigating locomotive emissions must address the following issues:

- direct and indirect economic impacts,
- environmental impacts, and
- participation levels in proposed emissions markets.

These issues are discussed below.

7.2.1 Economic Gains Associated with Emissions Markets

The purpose of economic incentives is to minimize the economic cost of environmental regulation subject to environmental goals. This is accomplished when marginal costs of emissions reduction are equal across sources contributing to air pollution in a region and when total emissions are consistent with stated emissions targets. To achieve this objective, it is necessary to include as many sources as possible in well designed emissions markets. When sources are excluded from market participation, there is no mechanism for equating marginal costs.

Market designs based on emissions trading potentially can maximize the number of sources participating in emissions markets. For example, the SCAQMD's RECLAIM program for NO_x and SO_x addresses NO_x emissions from power plants and other major sources. As RECLAIM is expanded to include smaller sources, its economic efficiency will increase.

In contrast, a market design based on emissions averaging isolates emissions from a specific source, thereby resulting in only small economic efficiency gains arising from compliance flexibility. It is unlikely that the marginal costs associated with emissions control will approach optimal levels under an emissions averaging market design.

7.2.2 Environmental Impacts

The primary purpose of implementing declining caps is to reduce emissions to a desired level. The discussion of declining caps thus far has been sensitive to the emissions control needs of the individual air pollution control districts and air quality management districts in California, since a statewide emissions cap on a particular source is an amalgamation of local caps. When economic incentives are introduced, it is desirable that the emissions limits defined by the caps are adhered to.

Market designs based on emissions trading preserve the emissions caps within each jurisdiction. This is especially true if caps concurrently are placed on all relevant sources of emissions. In some cases, emissions trading schemes may result in actual emissions being below the governing cap. However, emissions averaging does not resolve this potential problem since it offers no guarantee that emissions will be below the cap.

7.2.3 Market Activity and Transactions Costs

A major concern about the functioning of emissions markets is the level of market activity. In the past, some environmental markets have not performed well due to lack of participation. Economic incentives based on declining caps such as the one used in the RECLAIM program, however, have positive implications for market activity. Declining caps force sources to consider participation in the market. For example, if a source's cap declines by 3 percent each year, the source must always be evaluating measures to meet each year's cap. For instance, the source may decide to implement process changes designed to meet the cap ten years into the future, although such changes can be completed in two years. For the remaining eight years, the source will have surplus emissions reductions and is likely to consider participation in the emissions market where surplus emissions have economic value. By dating emissions allocations, a source can purchase or sell allocations just for the years of projected need. A source planning a major revamping of its equipment to meet future emissions requirements can cover the temporary short fall with purchased allocations. Consequently, a market design based on emissions allocation trading fosters participation by creating many opportunities for small, medium, and large trades. Sources can learn to use the market while concurrently minimizing risk.

However, participation depends on the magnitude of transaction costs. Transaction costs include two major components: recording costs and search costs. Recording costs are similar to closing costs incurred in a real estate transaction. They include the costs of activities undertaken by pollution control authorities to verify and record information about a trade. Emissions allocation trading, for example, is characterized by low recording costs. A document is prepared transferring the allocation and the resulting allocations for each source are recorded in a database. Search costs are the costs of identifying a trading partner and negotiating a trade.

Both recording and search costs can be influenced by governing agencies. For instance, California can develop, or encourage local air pollution control districts to develop emissions clearing houses. Clearing houses would provide information on ownership of emissions allocations and on the asking and/or offer price and quantity of proposed transactions. The clearing house could be designed to conceal the identity of parties offering to buy or sell emissions allocations. Clearing houses, therefore, reduce search costs.

Another determinant of the magnitude of transaction costs is the number of regional markets necessary for achieving air quality goals. The total number of regional markets could simply be constrained by the number of nonattainment areas. Although attainment areas may use a cap to maintain air quality levels, such areas probably will not have to establish emissions markets to accommodate locomotive emissions. Emissions from locomotives will be constrained by the railroads' responses to emissions limits promulgated by air quality management districts in the most highly polluted region. For example, a railroad that meets requirements in the SCAQMD likely will have surplus allocations in the attainment regions it traverses since it will have lowered its emissions from a level consistent with meeting or maintaining the ambient air quality standard in attainment regions. Emissions markets in attainment areas will be needed only if other types of NO_x sources seek to increase activity in an attainment area, or if a railroad wishes to increase the number of locomotives operating in an attainment area.

7.3 Three Alternative Market Designs

In this sub-section, three market designs are introduced: emissions allocation trading, emissions reduction credit (ERC) trading, and emissions averaging.

- *Emissions Allocation Trading* — emissions allocations are distributed to emissions sources within a jurisdiction and the allocations may then be bought and sold in an emissions market. The source (e.g., a railroad) must keep its total emissions in the jurisdiction beneath the level set by its emissions allocation. The jurisdiction may be the state or an air pollution control district.

- *ERC Trading* — emissions reductions are certified prior to the issuance of ERCs by pollution control officials. The ERCs may then be traded. A source creating ERCs must keep its emissions below the new limit approved by officials in granting the ERCs. A source purchasing ERCs may increase its emissions by the amount of the ERC.

- *Emissions Averaging* — no specific limit is placed on a source's total emissions. Rather, a limit is placed on the emissions rate of each piece of equipment. If the emissions rate of a given piece of equipment is lowered below its limit, then the rate for another piece of equipment may be increased. The allowable increase in the emissions rate is determined using a weighting system in which the expected rates of utilization for each piece of equipment are used as the weights. Emissions averaging may be conducted at the state or local level. In the case of locomotives, averaged emissions may reflect one railroad or several railroads.

Exhibit 7-1 shows how the basic components of an economic incentive program are handled for each of the three candidate market designs. Components include the trading goal, the universe of NO_x sources to be involved in trading, the baseline emissions for each source, the unit of trade, and the enforceable trading rule. For each of the market designs presented in Exhibit 7-1, it is assumed that allocations, caps, credits, or averages would be replaced annually to reflect the percentage decrease from the previous year. The result of this process is referred to as "dated permits." For example, if the rate of emissions decrease in a jurisdiction is 3 percent each year for twenty years, the first year's permit would be for 100 percent of the baseline emissions calculation. The second year's permit would be three percent less than the first year's permit, the third year's permit three percent less than the second year's permit, and so on for the twenty years. Permits for subsequent years could be issued for the emissions level reached in the twentieth year: The jurisdiction could issue permits for as many years in advance as are necessary. The jurisdiction would retain the option of readjusting the permit in future years. The method for making such an adjustment, if it becomes necessary, should be part of the initial plan. An equal percentage rollback of all allocations, caps, ERCs, and averages for all sources participating in the system is recommended.

Market designs based on emissions allocation and ERC trading are identical with respect to the first three components presented in Exhibit 7-1. However, they differ with respect to the unit of trade. In ERC trading, the source providing the ERC must demonstrate to pollution control officials that proposed equipment modifications and/or process changes will reduce emissions by a predetermined amount. The cap for the firm is then reduced by that amount. This approach, which is more stringent than that used in emissions allocation trading, is also more burdensome for both the source and the pollution control agency. However, both systems provide pollution control officials the means by which compliance can be ensured.

For the purpose of developing a locomotive emissions market, certifying ERCs is a cumbersome extra step requiring effort by both the pollution control agency and a railroad to design and evaluate a control process. ERC trading was first proposed in the late 1970s and early 1980s in a climate in which pollution control officials were distrustful of the emissions trading concept.

Exhibit 7-1
Components of Three Economic Incentive Programs Applicable to NO_x Emissions from Locomotives Operating in California

Component	Emissions Allocation Trading	Emissions Reduction Credit Trading	Emissions Averaging
Trading Goal	Meet emissions limits established to attain ambient air quality standards for ozone or NO_x in air pollution control districts (APCD) or air quality management districts (AQMD).	Meet emissions limits established to attain ambient air quality standards for ozone or NO_x in APCD or AQMD.	To maintain average NO_x emissions per unit of activity for each railroad or grouping of railroads at a predetermined level. Average could be a statewide or regional average.
Universe of NO_x Sources to be Involved in Trading	All railroad controlled NO_x sources and other NO_x emissions sources included in SIP or Air Quality Maintenance Plan.	All railroad controlled NO_x sources and other NO_x emissions sources included in SIP or Air Quality Maintenance Plan.	Locomotives owned by the participating railroad or railroads and other equipment as long as the emissions rate measure is uniform.
Baseline Emissions for Each Source	Initially, the lowest of actual or allowable emissions during previous N years. Then decline at a predetermined rate (say 3 % per year) until total desired reduction (say 50%) is achieved.	Initially, the lowest of actual or allowable emissions during previous N years. Then decline at a predetermined rate (say 3 % per year) until total desired reduction (say 50%) is achieved.	Initially, the lowest of actual or allowable emissions during previous N years. Then decline at a predetermined rate (say 3 % per year) until total desired reduction (say 50%) is achieved.
Unit of Trade	An "Emissions Allocation," defined as the number of tons (pounds) of NO_x allocated to an emissions source by the jurisdiction. Specified in terms of pounds per hour or tons per year.	"Emissions Reduction Credits," defined as a credit earned by a source when it demonstrates to authorities that it has put into effect the means to keep its NO_x emissions below a lower cap than it originally was assigned. Specified in terms of pounds per hour or tons per year.	Emissions per unit of activity (e.g., pounds of NO_x per ton mile).
Enforceable Trading Rule	The parties trading the Emissions Allocation must register the trade with state and local authorities. This could be accomplished with a notarized form submitted locally. Any source having emitted more than the amount permitted by the allocations in its possession at the end of the allocation period would be in violation.	The sale of an ERC must be recorded with state and local authorities. Any firm violating its current cap is in violation.	Total NO_x emissions from a group of equipment divided by total units of activity of the group of equipment should be less than or equal to the average emissions rate assigned to that group of equipment.

By certifying the emissions reduction and lowering the source's emissions cap prior to trading, officials could be assured that emissions would not increase as the result of trading. However, experience with Title IV of the Clean Air Act Amendments, which established a national market in emissions allocations for SO_2 and the operation of the SCAQMD's RECLAIM program for NO_x and SO_2 has helped to alter attitudes about emissions trading. The stringent step of certifying ERCs—which increases transactions costs and reduces market activity—is no longer necessary. Therefore, ERC trading is not the recommended approach for developing a locomotive emissions market.

With the exception of baseline emissions determinations, emissions averaging is different than emissions allocation and ERC trading. First, the trading goal is more vague since caps are not set under emissions averaging. Second, emissions rates are rolled back, but total emissions may vary from the expected level without triggering a violation. Third, the unit of trade for emissions averaging is emissions per unit of activity. Each piece of equipment would be assigned an emissions rate and the rates could be altered as long as their average rate per unit of activity does not increase. Fourth, in the case of railroad operations the trading universe under an emissions averaging scheme is limited to locomotives. But, it is conceptually possible to include trucks if the unit used to measure emissions and activity is consistent (e.g., ton-miles). In contrast, the two emissions trading programs are highly adaptable to large numbers of sources regardless of the type of activity for which they are used.

Under an emissions averaging scheme for controlling emissions from locomotives, the trading goal is to maintain an average emissions rate that accounts for activity (e.g., tons of NO_x per ton-mile). However, such a goal does not satisfy the first assumption described in Section 7.1 (i.e., maintenance of a statewide emissions cap) because ton-miles (and emissions) could increase as long as the average emissions rate of the fleet is maintained at predetermined levels. Concurrently, the nature of emissions averaging constrains the types of sources that are able to participate in the program, since an emissions averaging scheme relies on emissions limits that are expressed in tons of emissions per unit of activity. Therefore, stationary sources would not be able to participate, while trucks could be included. Furthermore, under emissions averaging two issues must be monitored: emissions from rail operations and ton-miles. The introduction of ton-miles complicates the ability of railroads and pollution control agencies to implement, monitor, and execute market initiatives. Each would have to track the weight of the cargo—or possibly the train—and calculate ton-miles for each segment of the run.

In sum, emissions averaging is incompatible with caps, is lax in meeting environmental goals, and provides only limited economic benefits.

7.4 The Recommended Market Design—Emissions Allocation Trading

Emissions allocation trading is the recommended market design for mitigating locomotive emissions via the use of market-based economic incentives. Emissions allocation trading is the best suited strategy when combined with a rigid, declining, statewide cap on locomotive emissions, as proposed in this study.

Under the recommended market design, the statewide cap will be used to determine yearly emissions allocations for each railroad operating in the state's air pollution control district or air quality management district. Allocations should be based on the relative, historical contributions of specific polluters (e.g., railroads, power plants, trucking firms, etc.) to emissions in a given air pollution control district. Once allocations have been prescribed to each polluter participating in the recommended emissions allocation scheme, emissions trading will be possible internally within railroads, between railroads, or between railroads and other emissions sources located in a particular district. The suggested unit of trade is tons of emissions per year. Annual emissions limits could be translated to daily limits to accommodate air quality modeling. The duties of a pollution control agency under the recommended market design include the following: assignment of emissions allocations, recording of trades of emissions allocations, monitoring of emissions, and enforcement of emissions limits. Information on the contribution of emissions by source (i.e., stationary sources, rail operations, trucking, etc.) available from SIPs and air quality management plans can serve as the basis from which rigid caps and emissions allocation strategies can be developed.

Under the recommended emissions allocation trading scheme, the state would collect and certify locomotive emissions data from railroad operations in each district and disseminate these data to each air quality district. There are a number of methods for accomplishing this state function. This analysis, however, assumes that a simplified approach for estimating the contribution of locomotives to emissions in each district based on methodologies developed by the U.S. EPA in its proposed national locomotive rule, or that an alternative approach based on methodologies previously developed for the ARB, will be employed by California. If measures taken by a given railroad increase the railroad's contribution to emissions in a given district to levels that exceed the prescribed allocation, the railroad must either 1) reduce emissions from the other sources that it operates within the district, 2) obtain additional allocations from another railroad operating in the given district, or 3) obtain emissions allocations from another source (e.g., a stationary source located in the district). Conversely, if a railroad institutes measures that decrease its contribution to emissions in a particular district to levels below its prescribed allocation, the railroad would be able to trade surplus allocations to other railroads or sources.

In sum, emissions allocation trading is the preferred option. The following attributes of emissions allocation trading exemplify its inherent advantages over ERC trading and emissions averaging.

- Emissions allocation trading affords the greatest economic benefit since it provides the largest trading universe (i.e., it provides the greatest opportunity to reduce costs associated with NO_x emissions control).
- Emissions allocation trading preserves the emissions cap, thereby maintaining the desired level of environmental protection.
- Emissions allocation trading results in the lowest transactions costs, thereby maximizing the level of market participation.

- Emissions allocation trading will provide railroads with the easiest method for reducing cost burdens associated with the implementation of rigid, declining statewide emissions caps.

However, to maximize the potential benefits of emissions allocation trading, it is necessary to establish emissions trading systems in all jurisdictions of the state where there is likely to be a demand for emissions allocations, and to ensure that, at least with respect to railroads, emissions allocation programs across jurisdictions operate in a uniform manner. An example highlights the importance of a comprehensive, uniform trading system. Suppose that a railroad over-controls the emissions from a locomotive that moves across several jurisdictions in the state, with the attendant goal of being able to sell or use the surplus reductions under a trading scheme. The associated emissions reductions will occur in each jurisdiction that is traversed by the specific locomotive, and to receive benefit for 100 percent of its surplus emissions, the railroad would have to complete emissions trades in each jurisdiction. If it cannot find trading partners in some jurisdictions, then the cost per ton of the emissions reduction surpluses it does trade will be greater than the cost per ton of those that are not traded. For instance, if it costs $100,000 to reduce the locomotive's emissions by 25 tons/year, the yearly cost of the emissions reduction is $4,000/ton. If only 80 percent of those emissions can be traded because the rest are emitted in a region where there is no demand for emissions allocations, the cost of producing the 20 tons/year of tradable emissions is $5,000 per ton/year. Therefore, implementing a trading scheme that maximizes the opportunity for trades provides significant economic benefits to market participants. However, even when comprehensive and uniform schemes are developed there will still be the added burden of identifying trading partners in each jurisdiction. State and local emissions clearing houses will ease this burden.

7.5 Conclusions

This analysis has developed and described three economic incentive programs for use in conjunction with rigid, declining statewide caps on locomotive emissions. The proposed method for setting the caps takes account of each region's environmental needs and emissions reduction priorities. Emissions data collection was assigned to the state to reduce the number of agencies the railroads must deal with. The method for calculating emissions is yet to be determined, but could be based on current methodologies adopted by the ARB.

The recommended market design, emissions allocation trading, adds little administrative burden to that prevailing under a statewide cap. It provides railroads with the opportunity to minimize compliance costs associated with an emissions cap by allowing for the purchase (sale) of emissions allocations from (to) any other emissions source participating in local emissions markets while concurrently ensuring that emissions levels will not exceed the cap. The only major cost associated with the recommended emissions allocation trading market is the cost of identifying trading partners. This cost can be minimized by ensuring that as many sources as possible participate in emissions markets and by establishing information clearing houses.

Other market designs do not have the same attributes of emissions allocation trading. ERC trading adds a costly step that inhibits market participation (i.e., certifying a proposed ERC increases transaction costs). Emissions averaging does not result with significant economic benefits nor does it ensure adherence to the statewide emissions cap.

Appendix A

Statement of Methodology

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Memorandum

To: Members of the Steering Committee

From: Jack Faucett Associates, Inc. (M. Fischer, S. Ostria, E. Van De Verg)

Subject: ARB study entitled *Assessment of the Effects of Proposed Locomotive Regulations on Goods Transport Modes and Locomotive Emissions*, Statement of Methodologies

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The purpose of this memorandum is to present the proposed methodology for conducting the various tasks of the study. The study is divided into two general tasks. Task 1, ***Goods Transport***, basically involves the analysis of the effects of emissions regulations on mode diversion and emissions. It includes three subtasks: Task 1A, *Intermodal Shift Analyses*, Task 1B, *Emissions Assessments*, and Task 1C, *Emissions Comparisons*. Task 2, ***Market Development***, involves the design of an emissions credit trading program in which the railroad industry can be active. This task includes two subtasks: Task 2A, *Marketability Review* and Task 2B, *Market Design*. The Steering Committee is asked to please review our proposed approaches and comment accordingly by no later than April 4, 1994.

Task 1A — Intermodal Shift Analyses

The principal objective of the study of the economic impacts of proposed locomotive emission regulations in California is to determine how increased costs of rail freight transportation due to emission regulations would impact freight movement patterns in the state. Ultimately, impacts on the amount of cargo shipped through California, the modal choice for these shipments, and the relative emissions characteristics of each mode are the significant issues which must be addressed in the study. In order to address the objectives of the study, the following issues are the most important:

- the extent to which increased rail costs or decreased levels of service would cause modal diversion from rail to other modes (primarily trucking);
- the extent to which increased rail costs or decreased level of service would cause diversion of international trade from California ports to other West Coast ports;

- the extent to which increased rail costs could change intermodal shipment patterns by displacing truck-rail transfer points to locations out of state; and
- the extent to which increased rail costs could cause substitution of non-transport factors for transportation.

The last issue is linked directly to the cross-price elasticities of demand for transportation services with respect to other factor inputs. Many of these substitution possibilities are long-term phenomena, especially location decisions and the use of equipment capital, which are outside the scope of this study. Changes in the makeup of intermodal moves, while potentially significant, are difficult to capture in existing models and data bases and must therefore be handled through ad hoc methods outside of the modeling framework. While port diversion could potentially be handled in a port traffic model, this not the principal focus of the study and will be discussed qualitatively rather than in a modeling framework. Thus, the primary focus of the study is on modal diversion impacts. Modal diversion consequences of locomotive emission regulations are critical to this analysis, especially if parallel regulations on trucking are not implemented, since diversion will result in an increase in trucking emissions which could more than offset the decrease in rail emissions anticipated to result from regulation.

In developing the approach for the intermodal shift analysis, JFA's objective was to identify an appropriate modal diversion analysis methodology with the ability to analyze the effects of changes in key variables on mode choice (e.g., the relative transport cost of rail as compared to other modes). In addition, in order to limit bias in the diversion analysis, the methodology needs to include model parameters which reflect data relevant to California shipment characteristics in the base year (1987) and forecast year (2010). Finally, the methodology needs to employ data which is readily available given the limited resources of the study.

JFA conducted a detailed review of the literature to identify previous modal diversion analyses and mode choice models with relevance to the current study. Both aggregate and disaggregate mode choice models were reviewed. In a disaggregate model, changes in costs and service characteristics determine whether a sample of shipments will move by rail or by truck. Once the mode split for the sample has been determined (typically employing probability models), suitable expansion factors can be applied to determine modal diversion for the universe of shipments which were sampled. Given the lack of good disaggregate models, a number of researchers have developed techniques for modeling mode choice which utilize more aggregate data sets. Typically, these models use aggregate data on total commodity flows and mode shares for industries, sectors, and/or regions. Data is often available disaggregated by commodity group but not necessarily by origin-destination pair. The results of JFA's literature search is contained in a draft chapter for Task 1A of this project (see Section 1.2 of the draft Task 1A chapter).

The literature review raised several important issues which were considered in the selection of a modal diversion analysis methodology. First, while disaggregate models are generally preferred for mode choice analysis, they require very detailed data bases which are generally not available in the public domain. The last comprehensive survey of shipments conducted at the national level was the 1977 Commodity Transportation Survey (CTS). This survey did not include shipments from all economic sectors and all modes. In addition to the type of data contained in the CTS, disaggregate models also require detailed information on logistics costs and service characteristics which are only available in proprietary data bases. Aggregate models, on the other hand, use aggregate data on commodity flows which is available in the public domain for most modes. We believe that aggregate models are both appropriate and sufficient for the modal diversion analysis which will be conducted in this study.

Unfortunately, aggregate models estimated to-date suffer from some of the same data deficiencies mentioned above for disaggregate models. The main short-coming is that most of these models are estimated with 1977 U.S. or foreign data. Re-estimating these models with current freight flow data would be costly and outside the scope of this project.

As a result, JFA selected the modal diversion algorithms from the California Energy Commission's (CEC) Freight Energy Demand Model (CALFED) to conduct the modal diversion analysis. CALFED was developed in 1983 for the CEC by JFA. The model incorporates an aggregate modal diversion analysis methodology which calculates changes in rail market share as a function of rail-truck relative costs for each commodity group and a set of regional origin-destination pairs. CALFED offers several important advantages over other alternative choices. CALFED is the only model that we reviewed which is estimated specifically with California shipment data. It also provides O-D and commodity detail, and it implicitly incorporates length of haul and shipment size effects.

In CALFED, 10 commodity classes are identified as competitive traffic, with rail and truck modes able to compete for a share of the transportation market. The ten commodity classes include agricultural commodities, construction and mining, timber and lumber, and all manufacturing commodities. The change in the rail share of transport (in ton-miles) is calculated for each commodity and O-D region combination. The O-D regions include intrastate freight, Arizona, Nevada and Utah, Oregon and Idaho, Washington and Montana, and the remaining 40 contiguous states. For each commodity/O-D region combination, the change in rail share is computed by multiplying a modal sensitivity to the cost of service parameter for each commodity by the change in the rail cost advantage per ton-mile for transport of each commodity to or from each O-D region. This product is adjusted by taking into account the previous year's rail share. Thus, commodity traffic for a particular O-D region which was evenly split between rail and truck in the previous year appears to the model as highly competitive, and the modal sensitivity to cost of service parameter and the change in relative cost advantage of rail tend to dominate the modal share equation. In cases in which one mode was dominant in the previous year, modal costs and sensitivities to changes in these costs are a less significant determinant of mode choice. The modal sensitivity to cost of service parameter for each commodity group is calculated taking into account the distribution of all shipments in California by length of haul and the cost of rail service as a function of length of haul.[1] The data used to determine the distribution of shipments by length of haul was developed from the 1977 CTS. The data used to determine the cost of rail service as a function of length of haul was obtained from the 1977

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[1] *California Freight Energy Demand Model*, Jack Faucett Associates, prepared for the California Energy Commission, Sacramento, CA, June 1983.

ICC Carload Waybill Sample.

In order to implement the modal diversion methodology from CALFED several additional pieces of information are necessary. First, it is important to have a forecast of modal shares (in ton-miles) for each commodity group in each O-D region. Second, it is necessary to have a forecast of modal costs of service for each commodity group in each O-D region. These two forecasts will be based on the latest available economic data and economic forecasts for California and up-to-date modal cost data obtained from the 1990 ICC Carload Waybill Sample (revenue per ton-mile data for rail) and from a 1990 working paper on truck costs prepared by JFA for the Federal Highway Administration.[2] In the analysis of modal diversion effects associated with locomotive emission regulations, rail costs will be adjusted to take account of the effects of emission control technologies using data drawn primarily from *Controlling Locomotive Emissions in California: Technology, Cost-Effectiveness, and Regulatory Strategy* by Engine, Fuel, and Emissions Engineering, Inc. (October 1993). To the extent that there is some controversy surrounding the cost estimates for emissions reduction strategies contained in the EF&EE report, JFA proposes to conduct sensitivity analyses using a range of costs for each emission reduction technology, assuming that alternative cost data acceptable to the ARB can be obtained from industry sources. While the data used to calculate the modal sensitivity to cost of service parameters used in CALFED is drawn from 1977 sources, the use of more up-to-date data on modal shares and modal costs of service should provide more accurate estimates of modal diversion which reflect current goods movement patterns in California.

In light of the foregoing discussion, there are some clear advantages of the CALFED model for application in this study. These include:

- it is based on actual California shipment data;
- modal cost sensitivities are developed by commodity group and thus reflect the unique commodity characteristics which would favor one mode over another irrespective of modal costs (e.g., commodity value, use rate, shelf life, etc.);
- modal diversion is calculated for O-D pairs which reflects the actual production and consumption patterns of California economic regions and trade relationships with the rest of the nation; and
- it uses aggregate shipment data which is the only data readily available without additional survey work.

There are two principal disadvantages of CALFED. First, the modal cost sensitivity parameters are estimated using 1977 data. Given changes in the regulatory environment facing trucking and rail, the change in commodity characteristics, and the changes in rail and truck pricing practices, the use of the 1977 modal cost sensitivity parameters is likely to bias the results of the analysis

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[2] Jack Faucett Associates, "The Effect of Size and Weight Limits on Truck Costs: Working Paper," prepared for the U.S. Department of Transportation, Federal Highway Administration, Washington, DC, June 1990.

to some extent. We believe that CALFED may have a tendency to slightly underestimate diversion. Second, CALFED only incorporates modal costs as the sole explanatory variable for modal diversion. To the extent that emission regulations impact other level of service variables, this could be a shortcoming. However, we believe that the principal effect of locomotive emission regulations which will impact mode choice is to raise rail costs. Thus, this last shortcoming of CALFED may be of limited significance for the current study.

The only other model identified in the literature review with any potential for overcoming the above-mentioned shortcomings was the AAR's Intermodal Competition Model (ICM). The ICM is a proprietary disaggregate model which has been maintained with data revisions over the last 15 years. When JFA approached AAR about using the ICM in this study, we were told that the model is not available for use by outside contractors and that the AAR would be unable to make the model available for use in this study. While the two models (CALFED and ICM) have very different theoretical approaches, we believe that the results which would be obtained using these models may not be too dissimilar. During a previous truck size and weight study for the Federal Highway Administration, JFA compared cross-elasticities of rail ton-miles with respect to trucking costs calculated from CALFED with results from ICM runs. These cross-elasticities show the percentage change in rail ton-miles which would result from a given change in trucking costs. In this comparison it was shown that for scenarios involving across the board reductions in rail-competitive trucking costs, cross elasticities computed with CALFED were less than 33% lower than those obtained with ICM. While the effects to be examined in this study are associated with increases in rail costs rather than decreases in trucking costs, we believe that the cross-elasticity comparisons made for the truck size and weight study provide an indication of how changes in the relative costs of rail vs. trucking might affect modal diversion calculations that are conducted with each model. These comparisons lead us to believe analyses conducted with CALFED should provide a good "ballpark" estimate of modal diversion effects as compared to ICM.

As stated above, in order to use CALFED, JFA will need to develop a reasonable estimate of baseline and forecasted modal shares in the absence of any regulations. Our approach to developing baseline commodity flows and modal shares is described in detail in Section 1.5 of the Task 1A draft chapter. In summary, base year economic data will be used to develop estimates of production and consumption of each commodity in each region. Data from the ICC Carload Waybill Sample, the Corps of Engineers Waterborne Commerce Statistics, and Census data for air cargo will be used to determine baseline flows for these modes. The residual production and consumption in each region will then be used to develop trucking flows among the regions (this is necessary due to the lack of good data on trucking flows available from public sources). Trucking flows will be developed using gravity model techniques. Forecasts of production and consumption by region will be developed from OBERS projections and other economic forecasts for the state as appropriate. Flows will be developed among the regions using a Frater model. Initially these flows will be allocated to modes using the base year modal shares. These will be adjusted for diversion which would have taken place in the absence of regulations by using the CALFED modal diversion algorithms and the modal cost data developed by JFA for the truck size and weight study described above.

Task 1B - Emissions Assessment

The underlying objective of this subtask is to develop a methodology that can be employed to evaluate the emission repercussions of modal shifts. Diversion will directly influence both truck and rail emissions in the state. From the perspective of railroad operations, diversion away from rail may change the number of trains that operate in the state at any given point in time, the average horsepower of the consist, the average trailing tons of the train, duty cycles, and other emission parameters. Moreover, changes in activity that result from diversion probably will not be evenly distributed across all locomotive types, nor across all segments or corridors. Similarly, significant levels of diversion from rail to truck may increase the number of trucks operating in the state and/or the average cargo weight per truck. Changes in any of these parameters will alter the emission profiles of these goods transport modes.

In addition to the effects of changes in relative activity on emissions, emission control regulations will change the emission factors of locomotives and trucks. For example, regulations that require the conversion of locomotives to LNG will directly impact the emission rate of a consist or train. Therefore, it is important to account for both the emission consequences of modal diversion and the emission consequences of control regulations when constructing emission forecasts under dynamic scenarios.

In order to answer the underlying question of how will freight mode-specific emissions change as a result of regulations and diversion, the following preliminary steps must be performed.

- First, a base year emissions inventory must be gathered for each freight mode. These base year inventories will be the basis from which changes in emissions will be calculated.
- Second, the reliability of the base year emission inventories must be assessed, and if necessary the base year inventories must be adjusted to account for inherent biases.
- Third, emission factors must be altered to reflect emission control strategies.
- Fourth, a methodology to assess the impacts of diversion on emissions by mode must be developed.

The base year for this study will be 1987 since emission inventories have been developed by ARB for that year. The base year inventories will be drawn from a variety of sources (see briefing package for JFA's Progress Meeting with ARB, February 16, 1994, page 17). For truck emissions, ARB's *Emission Inventory, 1987* (Emission Inventory Branch, March 1990) will be used. To be useful for this study, truck emission inventories presented in this ARB publication will need to be adjusted. Adjustments are needed because ARB's vehicle classification scheme includes all vehicles above 8,501 GVW as heavy-duty. This implies that ARB's HDV emission inventories include emissions from non-freight vehicles (such as passenger trucks and buses) and from vehicles that do not compete with rail (such as urban delivery trucks and trash trucks). Since the focus of this study will be on comparing emissions from line-haul freight modes, from a freight transport perspective the current inventories for heavy-duty vehicles published by ARB overstate the truck contribution. HDV emissions should only reflect those trucks that directly compete with rail (line-haul combination trucks). In order to perform these adjustments, JFA has contacted ARB's emissions inventory branch for guidance. They have agreed to provide us with revised inventories that only reflect the heavy-heavy duty component of the HDV fleet. Heavy-heavy is the classification for vehicles above 33,000 GVW. Although an adjustment based on this classification helps to resolve the problem, bias will still remain since line-haul combination trucks typically scale at 60,000 GVW and above.

Base year locomotive emissions will be drawn from ARB's *Locomotive Emissions Study* (Booz●Allen & Hamilton, March 1991). The inventories presented in this report are the official ARB estimates and, thus, should be the basis for this study. In any event, Booz●Allen's throttle notch analysis probably results in the most representative emission estimates given available data.

Base year inventories for the other goods transport modes, air and water, have been collected and are reported in the accompanying briefing package. However, the focus of the analysis in this study will be on truck and rail emissions.

The recalculation of emission factors to reflect regulatory initiatives will be conducted from data provided by the ARB, from data available in the Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) report entitled *Controlling Locomotive Emissions in California*, and from data provided in Booz●Allen & Hamilton's report to ARB entitled *Locomotive Emissions Study* (including appendix and addendum).

ARB's Emissions Inventory Branch will provide emission factors for heavy-heavy duty vehicles. HDV emission factors will be provided on a grams/mile basis. Preliminary data has been provided that demonstrates the potential impacts of various regulatory programs to control heavy-duty vehicle (HDV) emissions. For example, the ARB has estimated the emission reductions due to cleaner diesel fuels to be as follows:

	NO_x	PM
Pre MY 91 Vehicles	7%	25%
MY 91 to 93 Vehicles	10%	45%

For the purpose of this study, one approach may be to adjust the base year emission factors for HDVs by percentage reductions estimated for the various regulatory initiatives that will be considered.

In any event, to forecast HDV emissions under diversion, we will need to convert the adjusted emission factors to a grams/revenue ton-mile basis. We will employ California specific information from the 1987 Truck Inventory and Use Survey (TIUS) on average payload or cargo weight to achieve this objective. The following equation reflects the general relationship that will allow for this conversion:

$$\text{grams/mile} \times 1/\text{revenue ton} = \text{grams/revenue ton-mile}$$

The forecast of truck emissions under diversity then becomes a simple exercise since the modal diversion model will provide forecasts on total revenue ton-miles by mode. Moreover, we will be able to distinguish between diversion effects and impacts attributable to increased activity irrespective of mode shifts.

The process for locomotives is more involved. We have reviewed the approaches that were used by EF&EE and Booz•Allen to estimate locomotive emissions. This review has identified key issues that ultimately constrain the level of accuracy that will be imbedded in our analysis. First, the EF&EE report contains some limitations that may not be possible to overcome. The most important of these is the lack of tons/year emission reduction estimates for **all** the locomotives that are expected to be operating across California in the future. EF&EE restricts their emission reduction analyses to a select number of locomotive types. Yet, as was mentioned in the February 16, 1994 workshop, the penetration of more efficient locomotives has been evident for years, and there is no reason to suspect that this will not continue. Therefore, limiting the analysis to older models may create bias in the results. However, we do not have emission reduction estimates for all the locomotives that likely are to be operating in California in the year 2010 (our proposed forecast year).

Booz•Allen & Hamilton recognizes the need to change the mix of locomotives in the fleet for its forecast of emissions. They change the mix by assuming a constant percentage increase in the penetration of newer, more efficient models. However, Booz•Allen's report does not provide emission forecasts under an emissions control regulatory scenario. So, it is not possible to use their estimates.

As a result of these constraints, we have developed an approach that relies on data from both reports and that makes various necessary simplifying assumptions. (It is important to keep in mind the scope of this project and the budget, approximately $84,000 for the entire project, that we have to work with in evaluating this approach and in providing comments and alternative methods.) Our proposed approach basically employs the more aggregate emissions calculation process that was used by EF&EE. It is centered on the assumption that locomotive-hours will scale **proportionally** to changes in revenue ton-miles. We will forecast locomotive emissions by calculating the sum of the following products:

- the adjusted notch-specific average NO_x emission factors for each locomotive type that is expected to be in-use in the forecast year;
- the notch-specific average duty cycles by type of service found in the EF&EE report; and
- the annual number of locomotive-hours by locomotive type and type of service adjusted to reflect diversion, growth in activity, and/or the penetration of newer,

more efficient locomotives as suggested by the Booz•Allen study.

For the locomotive types that are included in the EF&EE report, we plan to adjust the notch-specific NO_x emission factors by the EF&EE tons/year emission reduction estimates (in percentage terms) to derive the emission factors for the regulatory scenarios that will be considered in this study. For those locomotives not included in the EF&EE report, we plan to adjust the emission factors presented in the Booz•Allen report by the EF&EE's average notch-specific emission reduction percentages. These notch-specific emission reductions will be averaged across all locomotive types included in the EF&EE report by type of service. We realize that this is not an accurate approach, but there currently does not exist another alternative that is within the scope and budget of this study. We are, however, open to suggestions from the Steering Committee, and we urge the Committee to provide us with alternatives.

The average notch-specific duty cycles used by EF&EE will be directly incorporated into this emissions forecasting approach. Given the lack of readily available information on the types and degrees of operational effects that can arise as a result of diversion (such as changes in average horsepower, average trailing tons, etc.), we are forced to make the simplifying assumption that duty cycles will not change in the future as a result of increased activity and/or diversion. For those locomotives not included in the EF&EE report, we will use the duty cycles presented in the Booz•Allen report. Therefore, we will be accounting for differences in duty cycles between older locomotives and newer, more efficient models.

The annual number of locomotive-hours by locomotive type and type of service will be proportionally scaled to reflect growth in revenue ton-miles without diversion and changes in revenue ton-miles that result from diversion. We will also alter the mix of locomotive-hours to reflect Booz•Allen's estimates of the penetration rates attributable to the newer locomotive models. The proportionality approach implies that if our diversion model estimates a 10% decrease in rail revenue ton-miles from a particular regulatory initiative, then the locomotive-hours for all locomotive types will be reduced by that 10%. We recognize that changes in activity levels are not likely to be distributed proportionally across all locomotive types. However, we do not expect this to create significant bias, especially when considered at the aggregate level. The magnitude of the bias is, therefore, expected to be small.

In this manner, we will forecast locomotive emissions that account for both changes in emission factors resulting from regulation and changes in activity that result from diversion and/or growth.

Task 1C — Emissions Comparison

The underlying objective of this subtask is to estimate the changes in relative emissions that result from regulatory initiatives to control emissions from the freight transport modes, especially trucks and rail. Therefore, the implementation of the methodologies that are outlined above for subtasks 1A and 1B will occur under this subtask.

Before this implementation takes place, however, we will need to conduct various preliminary analyses related to emission control regulations and strategies. Specifically, a prerequisite to the implementation process is the development of the regulatory scenarios to be included in this study for both locomotives and line-haul trucks and the estimation of changes in freight rates (rail and truck) for each scenario. The rate changes will drive the degree of diversion that is calculated by the CALFED model and ultimately the emission effects. As a result, the first activities that will be conducted under this subtask will be to evaluate proposed emission control regulations for each mode and define the regulatory bundles that will be analyzed. Second, for each regulatory strategy in a bundle, the estimated emission reductions must be identified. These reductions can then be used to adjust the emission factors. Finally, for each regulatory bundle, associated costs must be calculated and spread to the California portion of freight movements.

JFA has begun the review of the regulatory initiatives that are being considered by ARB for trucks and locomotives. There are a number of initiatives on the table for heavy-duty vehicles operating in California. These are outlined in the accompanying briefing package on pages 26 through 27. The costs associated with various HDV emission control strategies are also outlined in the briefing package. We are currently investigating approaches to translating these costs to a program level and eventually to a freight rate change level. For locomotives, we will select from the proposed strategies that EF&EE has outlined in their report. Similarly, the costs attributable to the programs specified by EF&EE are outlined in detailed in that report. Costs are provided at the program level and must also be translated to the freight rate change level. We are currently investigating approaches to conduct this translation and are open to suggestion by the Steering Committee. A special concern is the distribution of program level costs to the California portions of hauls.

Once we have defined the regulatory bundles for the analysis, the corresponding emission impacts, and the freight rate impacts, we will implement the methodologies discussed under subtasks 1A and 1B.

Task 2A — Marketability Review

JFA is reviewing the literature relevant to the marketing of emission allowances and other closely related economic incentives including emission reduction credits, emissions averaging, and declining emission caps. JFA's review covers three types of information:

- Documents and reports prepared by or for ARB.
- Papers appearing in the economics literature on emissions trading.
- Regulations prepared by federal, state, and local governmental agencies. These regulations include the federal implementation plan (FIP) prepared by the U.S. EPA for the Sacramento, Ventura, and South Coast air basins; U.S. EPA's Economic Incentive Programs Rule; U.S. EPA's conformance rules; the mobile to stationary source emission reduction credit trading program prepared by SMAQMD; and the RECLAIM program prepared by SCAQMD.

ARB Memoranda and Consultant Reports

To identify the issues of concern to ARB, JFA reviewed ARB memoranda and consultant reports on the control of locomotive exhaust emissions. ARB's deliberations show steady movement towards a rational plan for emission trading of NO_x from locomotives.[3] The ARB has recognized the need for and benefits of:

- a flexible cap on NO_x emissions from locomotives in each air district that may be applied in each air basin's State Implementation Plan (SIP) or Federal Implementation Plan (FIP) — the cap would adjust based on changes in activity;
- trading of intra-basin emission limits between various operations within individual railroads and between railroads;
- a mechanism to allow for the growth of rail traffic; and
- the consideration of the potential impact on truck and marine emissions when developing a regulatory strategy for locomotive emissions.

In addition, ARB has entertained the possibility of extending trading beyond locomotive emissions to include other transportation emissions and stationary source emissions. Complicating ARB's considerations are: the intersecting roles of air quality management districts, which must develop SIPs; the ARB, which is developing regulations for NO_x reductions from locomotives; the U.S. EPA, which is developing emission trading and is preparing FIPs for several AQMDs in California; and the preemption by the U.S. Clean Air Act Amendments of 1990, which place the authority for setting standards for emissions from new locomotives with the U.S. EPA.

These documents raised the following three issues:

- how to accommodate economic growth, given that locomotive emissions are capped;
- how to diminish the tendency of stringent regulations on locomotives, or caps on locomotive emissions, to increase the share of shipments by truck; and
- how to integrate the roles of the ARB in developing an emission trading system

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[3] ARB Mailout No. 91-34. *Notice of Public Meeting to Consider Approval of the Final Report of the Locomotive Emission Advisory Committee Regarding the Feasibility and Cost-Effectiveness of Controlling Emissions from Locomotives Operated in California.* August 1991; ARB Mailout No. 91-36 *Notice of Public Meeting to Consider a Regulatory Plan for the Control of Locomotive Exhaust Emissions.* August 1991; ARB Mailout No. 92-55. *Regulatory Measures to Control Locomotive Exhaust Emissions in the State of California.* December 1992; ARB Mailout No. 93-48. *Notice of Public Meeting to Consider a Report to the Legislature on Emission Reductions from Locomotives Operating in California.* November 1993.

with the roles of the air quality management districts and U.S. EPA.

Economic Literature

The economic literature does not directly address trading of NO_x emissions from locomotives. However, the following relevant issues were identified:

- how differential environmental regulations (for example, differences in treatment of rail emissions and truck emissions) can distort the regulatory outcome, possibly leading to emissions increases rather than decreases;
- how to ensure that long-term markets for NO_x emissions are sufficiently efficient and free of risk that government will change the rules to support major decisions affecting capital investments by the railroads;
- how to keep transactions costs at a level that supports frequent spot market and short-term market transactions; and
- widespread concern among economists that the degree of uncertainty in the operation of trading programs will not support costly long-term investment programs.

Recent Regulatory Developments

New regulations, rules, and guidelines are currently being prepared and other recently developed regulatory programs are breaking new ground. These regulatory materials raise numerous issues related to emissions trading and propose new forms of emissions trading. Therefore, it is vital that JFA keep abreast of the issues raised in these documents.

For example, the U.S. EPA signed off on the FIP for the Sacramento, Ventura, and South Coast regions on February 15, 1994. The FIP includes comments directly applicable to the trading of locomotive emissions, such as:

- emission averaging of locomotive emissions in the South Coast region;
- emission limits on freshly manufactured locomotives;
- a standard for remanufactured engines — average 8 g/hp-hr or less;
- emission limits on all heavy duty trucks registered in California;
- restricted access to California for heavy duty trucks not certified to meet California standards; and

- a one month averaging time for sources involved in emissions trading as compared to the one year averaging time envisioned in RECLAIM.

In addition, the U.S. EPA obtained a delay until March 15, 1994 for releasing its Economic Incentive Programs Rule. The reason for the delay is to consider whether too much of the benefits of trading are going to industry. This leads us to believe that the new rule will have features such as high offset ratios that work against emission trading similar to the emission trading guidelines published in the mid-1980s.

The U.S. EPA's conformance rules place a requirement on SIP developers and transportation planners to maintain the emission budgets they use in their SIP demonstrations. This may imply that truck and rail emissions are already capped and that SIP planners will have to closely consider how projections of truck emissions are affected by regulations on locomotive emissions.

At the state level, the SMAQMD has implemented a mobile to stationary credit trading program and will soon implement a mobile to mobile program. Under this program, mobile credit values determined using ARB guidance and credits established on a vehicle-by-vehicle basis. The program requires enactment of fleet rules for effectiveness — or an active spot market. Moreover, the SMAQMD is currently investigating the incorporation of locomotives by focusing on passenger trains.

In addition, the SCAQMD's RECLAIM program provides some relevant background on emission credit programs in California. Literature on the program describes their NO_x trading program for stationary sources and discusses general rules for allowing emission trades. An example of the level of detail required in the measurement of emissions to be traded is also provided. Although SCAQMD's program establishes NO_x trading for stationary sources, RECLAIM offers a possible vehicle for trades between stationary and mobile sources. It will be necessary to consider how any locomotive emission trading program can be incorporated with RECLAIM.

Discussion of Key Issues

Based on the documents discussed above, JFA has identified five key issues that must be resolved in order to design a declining cap on locomotive emissions.

1) Whether or not to Place a Flexible Cap on Locomotive NO_x Emissions — Because trucks and trains are such close substitutes, capping emissions from trains but not from trucks could aggravate the emissions problem. The problem is to identify the conditions under which capping locomotive emissions is part of a cost-effective program for reducing NO_x emissions.

2) Ensuring the Viability of Long-term Markets — In order to encourage railroads to make long term investments based on emissions trading transactions, the durability and stability of the trading system must be guaranteed.

3) Reducing Transactions Costs — High transactions costs will limit the use of emissions trading. Ways of keeping the transactions costs of an emissions trading system need to be investigated.

4) Averaging Times and Other Technical Issues — The FIP suggests that averaging times for sources involved in emissions trading be one month rather than one year as specified in RECLAIM. The pros and cons of this and other technical issues must be considered.

5) Overlapping Jurisdictions — The U.S. EPA, ARB, and local AQMDs are all involved in regulating locomotive emissions. In addition to the potential for conflicting regulations, there are already conflicting time tables. The emission trading systems to be considered should be adaptable to these circumstances.

JFA is in the process of finalizing a draft chapter for this subtask that will review and analyze these issues and adapt them to the setting of locomotive emissions in California.

Task 2B: Market Design

Once the underlying issues have been characterized, JFA will develop emission trading schemes. The underlying objective is to identify specific emission trading programs applicable to NO_x emissions from locomotives in California. The approach employed by JFA includes the following steps. First, in consultation with ARB, JFA will develop options for defining each element of the emission trading system. These elements include the trading goal, the trading universe, the emission baseline, the unit of trade, and the trading rule. Second, JFA will define, describe, and assess three internally consistent trading systems and prepare recommendations.

We envision that the systems we will suggest will include the following central feature: declining caps on NO_x emissions from locomotives, line-haul trucks, and major stationary sources, with emission trading allowed among all three types of sources. The ARB will enact the cap on locomotive emissions, but it must address concerns that truck emissions do not increase as a result. As an example, some local AQMDs have already placed declining caps on major stationary sources of NO_x. But we believe that placing a flexible cap on truck emissions will be much more difficult (conformity rules seem to require that it be done, however).

Other features of the systems that we envision include:

- a system of "dated" emission allocations showing each firm's allocation of NO_x emissions by year for the next twenty years, including clear rules as to how emission allocations beyond that time frame will be determined;
- an allowance for the trade of any number of emissions allocations in any year (current or future), where a trade becomes valid as soon as it is duly submitted to ARB;

- a criterion that no increases in total NO_x emissions in any air shed occur as the basis of ARB's administration of emissions trading; and

- a rule that no extra emission reduction be required to make up for uncertainty in the measurement of locomotive emissions.

Appendix B

Mileage Estimates From BEA Area to State Border by Interstate Route

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

REDDING

Origin/Destination	Interstate						Total
	I5	I8	I10	I15	I40	I80	
Alabama	672	168	0	0	0	0	840
Alaska	117	0	0	0	0	0	117
Arizona	442	0	0	0	277	0	719
Arkansas	442	0	0	0	277	0	719
Colorado	163	0	0	0	0	133	296
Connecticut	163	0	0	0	0	133	296
Delaware	163	0	0	0	0	133	296
District of Columbia	163	0	0	0	0	133	296
Florida	672	168	0	0	0	0	840
Georgia	442	0	0	0	277	0	719
Hawaii	0	0	0	0	0	0	0
Idaho	163	0	0	0	0	133	296
Illinois	163	0	0	0	0	133	296
Indiana	163	0	0	0	0	133	296
Iowa	163	0	0	0	0	133	296
Kansas	163	0	0	0	0	133	296
Kentucky	442	0	0	0	277	0	719
Louisiana	672	168	0	0	0	0	840
Maine	163	0	0	0	0	133	296
Maryland	163	0	0	0	0	133	296
Massachusetts	163	0	0	0	0	133	296
Michigan	163	0	0	0	0	133	296
Minnesota	163	0	0	0	0	133	296
Mississippi	672	168	0	0	0	0	840
Missouri	163	0	0	0	0	133	296
Montana	163	0	0	0	0	133	296
Nebraska	163	0	0	0	0	133	296
Nevada	163	0	0	0	0	133	296
New Hampshire	163	0	0	0	0	133	296
New Jersey	163	0	0	0	0	133	296
New Mexico	442	0	0	0	277	0	719
New York	163	0	0	0	0	133	296
North Carolina	442	0	0	0	277	0	719
North Dakota	163	0	0	0	0	133	296
Ohio	163	0	0	0	0	133	296
Oklahoma	442	0	0	0	277	0	719
Oregon	117	0	0	0	0	0	117
Pennsylvania	163	0	0	0	0	133	296
Rhode Island	163	0	0	0	0	133	296
South Carolina	442	0	0	0	277	0	719
South Dakota	163	0	0	0	0	133	296
Tennessee	442	0	0	0	277	0	719
Texas	672	168	0	0	0	0	840
Utah	163	0	0	0	0	133	296
Vermont	163	0	0	0	0	133	296
Virginia	163	0	0	0	0	133	296
Washington	117	0	0	0	0	0	117
West Virginia	163	0	0	0	0	133	296
Wisconsin	163	0	0	0	0	133	296
Wyoming	163	0	0	0	0	133	296

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

EUREKA

Origin/Destination	Interstate I5	I8	I10	I15	I40	I80	Total
Alabama	672	168	0	0	0	0	840
Alaska	117	0	0	0	0	0	117
Arizona	442	0	0	0	277	0	719
Arkansas	442	0	0	0	277	0	719
Colorado	163	0	0	0	0	133	296
Connecticut	163	0	0	0	0	133	296
Delaware	163	0	0	0	0	133	296
District of Columbia	163	0	0	0	0	133	296
Florida	672	168	0	0	0	0	840
Georgia	442	0	0	0	277	0	719
Hawaii	0	0	0	0	0	0	0
Idaho	163	0	0	0	0	133	296
Illinois	163	0	0	0	0	133	296
Indiana	163	0	0	0	0	133	296
Iowa	163	0	0	0	0	133	296
Kansas	163	0	0	0	0	133	296
Kentucky	442	0	0	0	277	0	719
Louisiana	672	168	0	0	0	0	840
Maine	163	0	0	0	0	133	296
Maryland	163	0	0	0	0	133	296
Massachusetts	163	0	0	0	0	133	296
Michigan	163	0	0	0	0	133	296
Minnesota	163	0	0	0	0	133	296
Mississippi	672	168	0	0	0	0	840
Missouri	163	0	0	0	0	133	296
Montana	163	0	0	0	0	133	296
Nebraska	163	0	0	0	0	133	296
Nevada	163	0	0	0	0	133	296
New Hampshire	163	0	0	0	0	133	296
New Jersey	163	0	0	0	0	133	296
New Mexico	442	0	0	0	277	0	719
New York	163	0	0	0	0	133	296
North Carolina	442	0	0	0	277	0	719
North Dakota	163	0	0	0	0	133	296
Ohio	163	0	0	0	0	133	296
Oklahoma	442	0	0	0	277	0	719
Oregon	117	0	0	0	0	0	117
Pennsylvania	163	0	0	0	0	133	296
Rhode Island	163	0	0	0	0	133	296
South Carolina	442	0	0	0	277	0	719
South Dakota	163	0	0	0	0	133	296
Tennessee	442	0	0	0	277	0	719
Texas	672	168	0	0	0	0	840
Utah	163	0	0	0	0	133	296
Vermont	163	0	0	0	0	133	296
Virginia	163	0	0	0	0	133	296
Washington	117	0	0	0	0	0	117
West Virginia	163	0	0	0	0	133	296
Wisconsin	163	0	0	0	0	133	296
Wyoming	163	0	0	0	0	133	296

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

SAN FRANCISCO

Origin/Destination	Interstate I5	I8	I10	I15	I40	I80	Total
Alabama	387	0	228	0	0	0	615
Alaska	335	0	0	0	0	0	335
Arizona	284	0	0	0	277	0	561
Arkansas	284	0	0	0	277	0	561
Colorado	0	0	0	0	0	226	226
Connecticut	0	0	0	0	0	226	226
Delaware	0	0	0	0	0	226	226
District of Columbia	0	0	0	0	0	226	226
Florida	387	0	228	0	0	0	615
Georgia	284	0	0	0	277	0	561
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	226	226
Illinois	0	0	0	0	0	226	226
Indiana	0	0	0	0	0	226	226
Iowa	0	0	0	0	0	226	226
Kansas	0	0	0	0	0	226	226
Kentucky	0	0	0	0	0	226	226
Louisiana	387	0	228	0	0	0	615
Maine	0	0	0	0	0	226	226
Maryland	0	0	0	0	0	226	226
Massachusetts	0	0	0	0	0	226	226
Michigan	0	0	0	0	0	226	226
Minnesota	0	0	0	0	0	226	226
Mississippi	387	0	228	0	0	0	615
Missouri	0	0	0	0	0	226	226
Montana	0	0	0	0	0	226	226
Nebraska	0	0	0	0	0	226	226
Nevada	0	0	0	0	0	226	226
New Hampshire	0	0	0	0	0	226	226
New Jersey	0	0	0	0	0	226	226
New Mexico	284	0	0	0	277	0	561
New York	0	0	0	0	0	226	226
North Carolina	284	0	0	0	277	0	561
North Dakota	0	0	0	0	0	226	226
Ohio	0	0	0	0	0	226	226
Oklahoma	284	0	0	0	277	0	561
Oregon	335	0	0	0	0	0	335
Pennsylvania	0	0	0	0	0	226	226
Rhode Island	0	0	0	0	0	226	226
South Carolina	284	0	0	0	277	0	561
South Dakota	0	0	0	0	0	226	226
Tennessee	284	0	0	0	277	0	561
Texas	387	0	228	0	0	0	615
Utah	0	0	0	0	0	226	226
Vermont	0	0	0	0	0	226	226
Virginia	0	0	0	0	0	226	226
Washington	335	0	0	0	0	0	335
West Virginia	0	0	0	0	0	226	226
Wisconsin	0	0	0	0	0	226	226
Wyoming	0	0	0	0	0	226	226

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

SACRAMENTO

	Interstate						
Origin/Destination	I5	I8	I10	I15	I40	I80	Total
Alabama	387	0	228	0	0	0	615
Alaska	335	0	0	0	0	0	335
Arizona	284	0	0	0	277	0	561
Arkansas	284	0	0	0	277	0	561
Colorado	0	0	0	0	0	226	226
Connecticut	0	0	0	0	0	226	226
Delaware	0	0	0	0	0	226	226
District of Columbia	0	0	0	0	0	226	226
Florida	387	0	228	0	0	0	615
Georgia	284	0	0	0	277	0	561
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	226	226
Illinois	0	0	0	0	0	226	226
Indiana	0	0	0	0	0	226	226
Iowa	0	0	0	0	0	226	226
Kansas	0	0	0	0	0	226	226
Kentucky	0	0	0	0	0	226	226
Louisiana	387	0	228	0	0	0	615
Maine	0	0	0	0	0	226	226
Maryland	0	0	0	0	0	226	226
Massachusetts	0	0	0	0	0	226	226
Michigan	0	0	0	0	0	226	226
Minnesota	0	0	0	0	0	226	226
Mississippi	387	0	228	0	0	0	615
Missouri	0	0	0	0	0	226	226
Montana	0	0	0	0	0	226	226
Nebraska	0	0	0	0	0	226	226
Nevada	0	0	0	0	0	226	226
New Hampshire	0	0	0	0	0	226	226
New Jersey	0	0	0	0	0	226	226
New Mexico	284	0	0	0	277	0	561
New York	0	0	0	0	0	226	226
North Carolina	284	0	0	0	277	0	561
North Dakota	0	0	0	0	0	226	226
Ohio	0	0	0	0	0	226	226
Oklahoma	284	0	0	0	277	0	561
Oregon	335	0	0	0	0	0	335
Pennsylvania	0	0	0	0	0	226	226
Rhode Island	0	0	0	0	0	226	226
South Carolina	284	0	0	0	277	0	561
South Dakota	0	0	0	0	0	226	226
Tennessee	284	0	0	0	277	0	561
Texas	387	0	228	0	0	0	615
Utah	0	0	0	0	0	226	226
Vermont	0	0	0	0	0	226	226
Virginia	0	0	0	0	0	226	226
Washington	335	0	0	0	0	0	335
West Virginia	0	0	0	0	0	226	226
Wisconsin	0	0	0	0	0	226	226
Wyoming	0	0	0	0	0	226	226

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

STOCKTON

Origin/Destination	Interstate						
	I5	I8	I10	I15	I40	I80	Total
Alabama	387	0	228	0	0	0	615
Alaska	335	0	0	0	0	0	335
Arizona	284	0	0	0	277	0	561
Arkansas	284	0	0	0	277	0	561
Colorado	0	0	0	0	0	226	226
Connecticut	0	0	0	0	0	226	226
Delaware	0	0	0	0	0	226	226
District of Columbia	0	0	0	0	0	226	226
Florida	387	0	228	0	0	0	615
Georgia	284	0	0	0	277	0	561
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	226	226
Illinois	0	0	0	0	0	226	226
Indiana	0	0	0	0	0	226	226
Iowa	0	0	0	0	0	226	226
Kansas	0	0	0	0	0	226	226
Kentucky	0	0	0	0	0	226	226
Louisiana	387	0	228	0	0	0	615
Maine	0	0	0	0	0	226	226
Maryland	0	0	0	0	0	226	226
Massachusetts	0	0	0	0	0	226	226
Michigan	0	0	0	0	0	226	226
Minnesota	0	0	0	0	0	226	226
Mississippi	387	0	228	0	0	0	615
Missouri	0	0	0	0	0	226	226
Montana	0	0	0	0	0	226	226
Nebraska	0	0	0	0	0	226	226
Nevada	0	0	0	0	0	226	226
New Hampshire	0	0	0	0	0	226	226
New Jersey	0	0	0	0	0	226	226
New Mexico	284	0	0	0	277	0	561
New York	0	0	0	0	0	226	226
North Carolina	284	0	0	0	277	0	561
North Dakota	0	0	0	0	0	226	226
Ohio	0	0	0	0	0	226	226
Oklahoma	284	0	0	0	277	0	561
Oregon	335	0	0	0	0	0	335
Pennsylvania	0	0	0	0	0	226	226
Rhode Island	0	0	0	0	0	226	226
South Carolina	284	0	0	0	277	0	561
South Dakota	0	0	0	0	0	226	226
Tennessee	284	0	0	0	277	0	561
Texas	387	0	228	0	0	0	615
Utah	0	0	0	0	0	226	226
Vermont	0	0	0	0	0	226	226
Virginia	0	0	0	0	0	226	226
Washington	335	0	0	0	0	0	335
West Virginia	0	0	0	0	0	226	226
Wisconsin	0	0	0	0	0	226	226
Wyoming	0	0	0	0	0	226	226

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

FRESNO

	Interstate						
Origin/Destination	I5	I8	I10	I15	I40	I80	Total
Alabama	387	0	228	0	0	0	615
Alaska	335	0	0	0	0	0	335
Arizona	284	0	0	0	277	0	561
Arkansas	284	0	0	0	277	0	561
Colorado	0	0	0	0	0	226	226
Connecticut	0	0	0	0	0	226	226
Delaware	0	0	0	0	0	226	226
District of Columbia	0	0	0	0	0	226	226
Florida	387	0	228	0	0	0	615
Georgia	284	0	0	0	277	0	561
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	0	0	226	226
Illinois	0	0	0	0	0	226	226
Indiana	0	0	0	0	0	226	226
Iowa	0	0	0	0	0	226	226
Kansas	0	0	0	0	0	226	226
Kentucky	0	0	0	0	0	226	226
Louisiana	387	0	228	0	0	0	615
Maine	0	0	0	0	0	226	226
Maryland	0	0	0	0	0	226	226
Massachusetts	0	0	0	0	0	226	226
Michigan	0	0	0	0	0	226	226
Minnesota	0	0	0	0	0	226	226
Mississippi	387	0	228	0	0	0	615
Missouri	0	0	0	0	0	226	226
Montana	0	0	0	0	0	226	226
Nebraska	0	0	0	0	0	226	226
Nevada	0	0	0	0	0	226	226
New Hampshire	0	0	0	0	0	226	226
New Jersey	0	0	0	0	0	226	226
New Mexico	284	0	0	0	277	0	561
New York	0	0	0	0	0	226	226
North Carolina	284	0	0	0	277	0	561
North Dakota	0	0	0	0	0	226	226
Ohio	0	0	0	0	0	226	226
Oklahoma	284	0	0	0	277	0	561
Oregon	335	0	0	0	0	0	335
Pennsylvania	0	0	0	0	0	226	226
Rhode Island	0	0	0	0	0	226	226
South Carolina	284	0	0	0	277	0	561
South Dakota	0	0	0	0	0	226	226
Tennessee	284	0	0	0	277	0	561
Texas	387	0	228	0	0	0	615
Utah	0	0	0	0	0	226	226
Vermont	0	0	0	0	0	226	226
Virginia	0	0	0	0	0	226	226
Washington	335	0	0	0	0	0	335
West Virginia	0	0	0	0	0	226	226
Wisconsin	0	0	0	0	0	226	226
Wyoming	0	0	0	0	0	226	226

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

LOS ANGELES

Origin/Destination	Interstate I5	I8	I10	I15	I40	I80	Total
Alabama	0	0	238	0	0	0	238
Alaska	660	0	0	0	0	0	660
Arizona	0	0	238	0	0	0	238
Arkansas	0	0	0	0	285	0	285
Colorado	0	0	0	237	0	0	237
Connecticut	0	0	0	0	285	0	285
Delaware	0	0	0	0	285	0	285
District of Columbia	0	0	0	0	285	0	285
Florida	0	0	238	0	0	0	238
Georgia	0	0	238	0	0	0	238
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	237	0	0	237
Illinois	0	0	0	0	285	0	285
Indiana	0	0	0	0	285	0	285
Iowa	0	0	0	237	0	0	237
Kansas	0	0	0	0	285	0	285
Kentucky	0	0	0	0	285	0	285
Louisiana	0	0	238	0	0	0	238
Maine	0	0	0	0	285	0	285
Maryland	0	0	0	0	285	0	285
Massachusetts	0	0	0	0	285	0	285
Michigan	0	0	0	0	285	0	285
Minnesota	0	0	0	237	0	0	237
Mississippi	0	0	238	0	0	0	238
Missouri	0	0	0	0	285	0	285
Montana	0	0	0	237	0	0	237
Nebraska	0	0	0	237	0	0	237
Nevada	0	0	0	237	0	0	237
New Hampshire	0	0	0	0	285	0	285
New Jersey	0	0	0	0	285	0	285
New Mexico	0	0	0	0	285	0	285
New York	0	0	0	0	285	0	285
North Carolina	0	0	0	0	285	0	285
North Dakota	0	0	0	237	0	0	237
Ohio	0	0	0	0	285	0	285
Oklahoma	0	0	0	0	285	0	285
Oregon	660	0	0	0	0	0	660
Pennsylvania	0	0	0	0	285	0	285
Rhode Island	0	0	0	0	285	0	285
South Carolina	0	0	0	0	285	0	285
South Dakota	0	0	0	237	0	0	237
Tennessee	0	0	0	0	285	0	285
Texas	0	0	238	0	0	0	238
Utah	0	0	0	237	0	0	237
Vermont	0	0	0	0	285	0	285
Virginia	0	0	0	0	285	0	285
Washington	660	0	0	0	0	0	660
West Virginia	0	0	0	0	285	0	285
Wisconsin	0	0	0	237	0	0	237
Wyoming	0	0	0	237	0	0	237

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

SAN DIEGO

Origin/Destination	Interstate I5	I8	I10	I15	I40	I80	Total
Alabama	0	168	0	0	0	0	168
Alaska	789	0	0	0	0	0	789
Arizona	0	168	0	0	0	0	168
Arkansas	0	168	0	0	0	0	168
Colorado	0	0	0	339	0	0	339
Connecticut	0	0	0	339	0	0	339
Delaware	0	0	0	339	0	0	339
District of Columbia	0	0	0	339	0	0	339
Florida	0	168	0	0	0	0	168
Georgia	0	168	0	0	0	0	168
Hawaii	0	0	0	0	0	0	0
Idaho	0	0	0	339	0	0	339
Illinois	0	0	0	339	0	0	339
Indiana	0	0	0	339	0	0	339
Iowa	0	0	0	339	0	0	339
Kansas	0	0	0	339	0	0	339
Kentucky	0	168	0	0	0	0	168
Louisiana	0	168	0	0	0	0	168
Maine	0	0	0	339	0	0	339
Maryland	0	0	0	339	0	0	339
Massachusetts	0	0	0	339	0	0	339
Michigan	0	0	0	339	0	0	339
Minnesota	0	0	0	339	0	0	339
Mississippi	0	168	0	0	0	0	168
Missouri	0	0	0	339	0	0	339
Montana	0	0	0	339	0	0	339
Nebraska	0	0	0	339	0	0	339
Nevada	0	0	0	339	0	0	339
New Hampshire	0	0	0	339	0	0	339
New Jersey	0	0	0	339	0	0	339
New Mexico	0	168	0	0	0	0	168
New York	0	0	0	339	0	0	339
North Carolina	0	168	0	0	0	0	168
North Dakota	0	0	0	339	0	0	339
Ohio	0	0	0	339	0	0	339
Oklahoma	0	168	0	0	0	0	168
Oregon	789	0	0	0	0	0	789
Pennsylvania	0	0	0	339	0	0	339
Rhode Island	0	0	0	339	0	0	339
South Carolina	0	168	0	0	0	0	168
South Dakota	0	0	0	339	0	0	339
Tennessee	0	168	0	0	0	0	168
Texas	0	168	0	0	0	0	168
Utah	0	0	0	339	0	0	339
Vermont	0	0	0	339	0	0	339
Virginia	0	0	0	339	0	0	339
Washington	789	0	0	0	0	0	789
West Virginia	0	168	0	0	0	0	168
Wisconsin	0	0	0	339	0	0	339
Wyoming	0	0	0	339	0	0	339

APPENDIX B
Highway Mileage Estimates Between California BEA Areas

	Redding	Eureka	San Francisco	Sacramento	Stockton	Fresno	Los Angeles	San Diego
Redding	68	154	215	163	214	327	545	672
Eureka	154	40	281	298	332	462	680	807
San Francisco	215	281	81	95	82	183	387	514
Sacramento	163	298	95	75	51	164	382	509
Stockton	214	332	82	51	68	124	335	459
Fresno	327	462	183	164	124	80	211	336
Los Angeles	545	680	387	382	335	211	95	124
San Diego	672	807	514	509	459	336	124	80

Appendix C

Average Mileage Estimates From BEA Area to State Border for Interstate Rail Movements

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

REDDING

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	181	0	0	0	181
Alaska	150	0	0	0	0	150
Arizona	0	0	0	800	0	800
Arkansas	0	181	0	0	0	181
Colorado	0	181	0	0	0	181
Connecticut	0	181	0	0	0	181
Delaware	0	181	0	0	0	181
District of Columbia	0	181	0	0	0	181
Florida	0	181	0	0	0	181
Georgia	0	181	0	0	0	181
Hawaii	0	0	0	0	0	0
Idaho	151	0	0	0	0	151
Illinois	0	181	0	0	0	181
Indiana	0	181	0	0	0	181
Iowa	0	181	0	0	0	181
Kansas	0	181	0	0	0	181
Kentucky	0	181	0	0	0	181
Louisiana	0	181	0	0	0	181
Maine	0	181	0	0	0	181
Maryland	0	181	0	0	0	181
Massachusetts	0	181	0	0	0	181
Michigan	0	181	0	0	0	181
Minnesota	0	181	0	0	0	181
Mississippi	0	181	0	0	0	181
Missouri	0	181	0	0	0	181
Montana	150	0	0	0	0	150
Nebraska	0	181	0	0	0	181
Nevada	0	181	0	0	0	181
New Hampshire	0	181	0	0	0	181
New Jersey	0	181	0	0	0	181
New Mexico	0	0	0	800	0	800
New York	0	181	0	0	0	181
North Carolina	0	181	0	0	0	181
North Dakota	0	181	0	0	0	181
Ohio	0	181	0	0	0	181
Oklahoma	0	181	0	0	0	181
Oregon	150	0	0	0	0	150
Pennsylvania	0	181	0	0	0	181
Rhode Island	0	181	0	0	0	181
South Carolina	0	181	0	0	0	181
South Dakota	0	181	0	0	0	181
Tennessee	0	181	0	0	0	181
Texas	0	181	0	0	0	181
Utah	0	181	0	0	0	181
Vermont	0	181	0	0	0	181
Virginia	0	181	0	0	0	181
Washington	150	0	0	0	0	150
West Virginia	0	181	0	0	0	181
Wisconsin	0	181	0	0	0	181
Wyoming	0	181	0	0	0	181

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

EUREKA

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	870	0	0	870
Alaska	445	0	0	0	0	445
Arizona	0	0	870	0	0	870
Arkansas	0	0	870	0	0	870
Colorado	0	490	0	0	0	490
Connecticut	0	490	0	0	0	490
Delaware	0	490	0	0	0	490
District of Columbia	0	490	0	0	0	490
Florida	0	0	870	0	0	870
Georgia	0	0	870	0	0	870
Hawaii	0	0	0	0	0	0
Idaho	445	0	0	0	0	445
Illinois	0	490	0	0	0	490
Indiana	0	490	0	0	0	490
Iowa	0	490	0	0	0	490
Kansas	0	490	0	0	0	490
Kentucky	0	490	0	0	0	490
Louisiana	0	0	870	0	0	870
Maine	0	490	0	0	0	490
Maryland	0	490	0	0	0	490
Massachusetts	0	490	0	0	0	490
Michigan	0	490	0	0	0	490
Minnesota	0	490	0	0	0	490
Mississippi	0	0	870	0	0	870
Missouri	0	490	0	0	0	490
Montana	445	0	0	0	0	445
Nebraska	0	490	0	0	0	490
Nevada	0	490	0	0	0	490
New Hampshire	0	490	0	0	0	490
New Jersey	0	490	0	0	0	490
New Mexico	0	0	870	0	0	870
New York	0	490	0	0	0	490
North Carolina	0		870	0	0	870
North Dakota	0	490	0	0	0	490
Ohio	0	490	0	0	0	490
Oklahoma	0	0	870	0	0	870
Oregon	445	0	0	0	0	445
Pennsylvania	0	490	0	0	0	490
Rhode Island	0	490	0	0	0	490
South Carolina	0	0	870	0	0	870
South Dakota	0	490	0	0	0	490
Tennessee	0	0	870	0	0	870
Texas	0	0	870	0	0	870
Utah	0	490	0	0	0	490
Vermont	0	490	0	0	0	490
Virginia	0	490	0	0	0	490
Washington	445	0	0	0	0	445
West Virginia	0	490	0	0	0	490
Wisconsin	0	490	0	0	0	490
Wyoming	0	490	0	0	0	490

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

SAN FRANCISCO

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	636	0	0	636
Alaska	400	0	0	0	0	400
Arizona	0	0	636	0	0	636
Arkansas	0	0	636	0	0	636
Colorado	0	282	0	0	0	282
Connecticut	0	282	0	0	0	282
Delaware	0	282	0	0	0	282
District of Columbia	0	282	0	0	0	282
Florida	0	0	636	0	0	636
Georgia	0	0	636	0	0	636
Hawaii	0	0	0	0	0	0
Idaho	0	282	0	0	0	282
Illinois	0	282	0	0	0	282
Indiana	0	282	0	0	0	282
Iowa	0	282	0	0	0	282
Kansas	0	282	0	0	0	282
Kentucky	0	282	0	0	0	282
Louisiana	0	0	636	0	0	636
Maine	0	282	0	0	0	282
Maryland	0	282	0	0	0	282
Massachusetts	0	282	0	0	0	282
Michigan	0	282	0	0	0	282
Minnesota	0	282	0	0	0	282
Mississippi	0	0	636	0	0	636
Missouri	0	282	0	0	0	282
Montana	0	282	0	0	0	282
Nebraska	0	282	0	0	0	282
Nevada	0	282	0	0	0	282
New Hampshire	0	282	0	0	0	282
New Jersey	0	282	0	0	0	282
New Mexico	0	0	636	0	0	636
New York	0	282	0	0	0	282
North Carolina	0	0	636	0	0	636
North Dakota	0	282	0	0	0	282
Ohio	0	282	0	0	0	282
Oklahoma	0	0	636	0	0	636
Oregon	400	0	0	0	0	400
Pennsylvania	0	282	0	0	0	282
Rhode Island	0	282	0	0	0	282
South Carolina	0	0	636	0	0	636
South Dakota	0	282	0	0	0	282
Tennessee	0	0	636	0	0	636
Texas	0	0	636	0	0	636
Utah	0	282	0	0	0	282
Vermont	0	282	0	0	0	282
Virginia	0	282	0	0	0	282
Washington	400	0	0	0	0	400
West Virginia	0	282	0	0	0	282
Wisconsin	0	282	0	0	0	282
Wyoming	0	282	0	0	0	282

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

SACRAMENTO

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	610	0	0	610
Alaska	333	0	0	0	0	333
Arizona	0	0	610	0	0	610
Arkansas	0	0	610	0	0	610
Colorado	0	205	0	0	0	205
Connecticut	0	205	0	0	0	205
Delaware	0	205	0	0	0	205
District of Columbia	0	205	0	0	0	205
Florida	0	0	610	0	0	610
Georgia	0	0	610	0	0	610
Hawaii	0	0	0	0	0	0
Idaho	0	205	0	0	0	205
Illinois	0	205	0	0	0	205
Indiana	0	205	0	0	0	205
Iowa	0	205	0	0	0	205
Kansas	0	205	0	0	0	205
Kentucky	0	205	0	0	0	205
Louisiana	0	0	610	0	0	610
Maine	0	205	0	0	0	205
Maryland	0	205	0	0	0	205
Massachusetts	0	205	0	0	0	205
Michigan	0	205	0	0	0	205
Minnesota	0	205	0	0	0	205
Mississippi	0	0	610	0	0	610
Missouri	0	205	0	0	0	205
Montana	0	205	0	0	0	205
Nebraska	0	205	0	0	0	205
Nevada	0	205	0	0	0	205
New Hampshire	0	205	0	0	0	205
New Jersey	0	205	0	0	0	205
New Mexico	0	0	610	0	0	610
New York	0	205	0	0	0	205
North Carolina	0	0	610	0	0	610
North Dakota	0	205	0	0	0	205
Ohio	0	205	0	0	0	205
Oklahoma	0	0	610	0	0	610
Oregon	333	0	0	0	0	333
Pennsylvania	0	205	0	0	0	205
Rhode Island	0	205	0	0	0	205
South Carolina	0	0	610	0	0	610
South Dakota	0	205	0	0	0	205
Tennessee	0	0	610	0	0	610
Texas	0	0	610	0	0	610
Utah	0	205	0	0	0	205
Vermont	0	205	0	0	0	205
Virginia	0	205	0	0	0	205
Washington	333	0	0	0	0	333
West Virginia	0	205	0	0	0	205
Wisconsin	0	205	0	0	0	205
Wyoming	0	205	0	0	0	205

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

STOCKTON

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	436	0	0	436
Alaska	570	0	0	0	0	570
Arizona	0	0	436	0	0	436
Arkansas	0	0	436	0	0	436
Colorado	0	350	0	0	0	350
Connecticut	0	350	0	0	0	350
Delaware	0	350	0	0	0	350
District of Columbia	0	350	0	0	0	350
Florida	0	0	436	0	0	436
Georgia	0	0	436	0	0	436
Hawaii	0	0	0	0	0	0
Idaho	0	350	0	0	0	350
Illinois	0	350	0	0	0	350
Indiana	0	350	0	0	0	350
Iowa	0	350	0	0	0	350
Kansas	0	350	0	0	0	350
Kentucky	0	350	0	0	0	350
Louisiana	0	0	436	0	0	436
Maine	0	350	0	0	0	350
Maryland	0	350	0	0	0	350
Massachusetts	0	350	0	0	0	350
Michigan	0	350	0	0	0	350
Minnesota	0	350	0	0	0	350
Mississippi	0	0	436	0	0	436
Missouri	0	350	0	0	0	350
Montana	0	350	0	0	0	350
Nebraska	0	350	0	0	0	350
Nevada	0	350	0	0	0	350
New Hampshire	0	350	0	0	0	350
New Jersey	0	350	0	0	0	350
New Mexico	0	0	436	0	0	436
New York	0	350	0	0	0	350
North Carolina	0	0	436	0	0	436
North Dakota	0	350	0	0	0	350
Ohio	0	350	0	0	0	350
Oklahoma	0	0	436	0	0	436
Oregon	570	0	0	0	0	570
Pennsylvania	0	350	0	0	0	350
Rhode Island	0	350	0	0	0	350
South Carolina	0	0	436	0	0	436
South Dakota	0	350	0	0	0	350
Tennessee	0	0	436	0	0	436
Texas	0	0	436	0	0	436
Utah	0	350	0	0	0	350
Vermont	0	350	0	0	0	350
Virginia	0	350	0	0	0	350
Washington	570	0	0	0	0	570
West Virginia	0	350	0	0	0	350
Wisconsin	0	350	0	0	0	350
Wyoming	0	350	0	0	0	350

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

FRESNO

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	436	0	0	436
Alaska	570	0	0	0	0	570
Arizona	0	0	436	0	0	436
Arkansas	0	0	436	0	0	436
Colorado	0	350	0	0	0	350
Connecticut	0	350	0	0	0	350
Delaware	0	350	0	0	0	350
District of Columbia	0	350	0	0	0	350
Florida	0	0	436	0	0	436
Georgia	0	0	436	0	0	436
Hawaii	0	0	0	0	0	0
Idaho	0	350	0	0	0	350
Illinois	0	350	0	0	0	350
Indiana	0	350	0	0	0	350
Iowa	0	350	0	0	0	350
Kansas	0	350	0	0	0	350
Kentucky	0	350	0	0	0	350
Louisiana	0	0	436	0	0	436
Maine	0	350	0	0	0	350
Maryland	0	350	0	0	0	350
Massachusetts	0	350	0	0	0	350
Michigan	0	350	0	0	0	350
Minnesota	0	350	0	0	0	350
Mississippi	0	0	436	0	0	436
Missouri	0	350	0	0	0	350
Montana	0	350	0	0	0	350
Nebraska	0	350	0	0	0	350
Nevada	0	350	0	0	0	350
New Hampshire	0	350	0	0	0	350
New Jersey	0	350	0	0	0	350
New Mexico	0	0	436	0	0	436
New York	0	350	0	0	0	350
North Carolina	0	0	436	0	0	436
North Dakota	0	350	0	0	0	350
Ohio	0	350	0	0	0	350
Oklahoma	0	0	436	0	0	436
Oregon	570	0	0	0	0	570
Pennsylvania	0	350	0	0	0	350
Rhode Island	0	350	0	0	0	350
South Carolina	0	0	436	0	0	436
South Dakota	0	350	0	0	0	350
Tennessee	0	0	436	0	0	436
Texas	0	0	436	0	0	436
Utah	0	350	0	0	0	350
Vermont	0	350	0	0	0	350
Virginia	0	350	0	0	0	350
Washington	570	0	0	0	0	570
West Virginia	0	350	0	0	0	350
Wisconsin	0	350	0	0	0	350
Wyoming	0	350	0	0	0	350

APPENDIX C
Average Mileage From BEA Area to State Border for Interstate Rail Movements

LOS ANGELES

Origin/Destination	Entry/Exit Route Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	329	0	0	329
Alaska	834	0	0	0	0	834
Arizona	0	0	329	0	0	329
Arkansas	0	0	329	0	0	329
Colorado	0	0	0	0	303	303
Connecticut	0	0	329	0	0	329
Delaware	0	0	329	0	0	329
District of Columbia	0	0	329	0	0	329
Florida	0	0	0	0	271	271
Georgia	0	0	329	0	0	329
Hawaii	0	0	0	0	0	0
Idaho	0	0	0	0	303	303
Illinois	0	0	329	0	0	329
Indiana	0	0	329	0	0	329
Iowa	0	0	329	0	0	329
Kansas	0	0	329	0	0	329
Kentucky	0	0	329	0	0	329
Louisiana	0	0	329	0	0	329
Maine	0	0	329	0	0	329
Maryland	0	0	329	0	0	329
Massachusetts	0	0	329	0	0	329
Michigan	0	0	329	0	0	329
Minnesota	0	0	329	0	0	329
Mississippi	0	0	329	0	0	329
Missouri	0	0	329	0	0	329
Montana	0	0	0	0	303	303
Nebraska	0	0	0	0	303	303
Nevada	0	0	0	0	303	303
New Hampshire	0	0	329	0	0	329
New Jersey	0	0	329	0	0	329
New Mexico	0	0	329	0	0	329
New York	0	0	329	0	0	329
North Carolina	0	0	329	0	0	329
North Dakota	0	0	0	0	303	303
Ohio	0	0	329	0	0	329
Oklahoma	0	0	329	0	0	329
Oregon	834	0	0	0	0	834
Pennsylvania	0	0	329	0	0	329
Rhode Island	0	0	329	0	0	329
South Carolina	0	0	329	0	0	329
South Dakota	0	0	0	0	303	303
Tennessee	0	0	329	0	0	329
Texas	0	0	329	0	0	329
Utah	0	0	0	0	303	303
Vermont	0	0	329	0	0	329
Virginia	0	0	329	0	0	329
Washington	834	0	0	0	0	834
West Virginia	0	0	329	0	0	329
Wisconsin	0	0	329	0	0	329
Wyoming	0	0	0	0	303	303

APPENDIX C

Average Mileage From BEA Area to State Border for Interstate Rail Movements

SAN DIEGO

	Entry/Exit Route					
Origin/Destination	Klamath	Reno	Williams	Yuma	Las Vegas	Total
Alabama	0	0	0	311	0	311
Alaska	850	0	0	0	0	850
Arizona	0	0	0	311	0	311
Arkansas	0	0	0	311	0	311
Colorado	0	0	0	311	0	311
Connecticut	0	0	0	311	0	311
Delaware	0	0	0	311	0	311
District of Columbia	0	0	0	311	0	311
Florida	0	0	0	311	0	311
Georgia	0	0	0	311	0	311
Hawaii	0	0	0	0	0	0
Idaho	0	0	0	0	443	443
Illinois	0	0	0	311	0	311
Indiana	0	0	0	311	0	311
Iowa	0	0	0	311	0	311
Kansas	0	0	0	311	0	311
Kentucky	0	0	0	311	0	311
Louisiana	0	0	0	311	0	311
Maine	0	0	0	311	0	311
Maryland	0	0	0	311	0	311
Massachusetts	0	0	0	311	0	311
Michigan	0	0	0	311	0	311
Minnesota	0	0	0	311	0	311
Mississippi	0	0	0	311	0	311
Missouri	0	0	0	311	0	311
Montana	0	0	0	0	443	443
Nebraska	0	0	0	311	0	311
Nevada	0	0	0	0	443	443
New Hampshire	0	0	0	311	0	311
New Jersey	0	0	0	311	0	311
New Mexico	0	0	0	311	0	311
New York	0	0	0	311	0	311
North Carolina	0	0	0	311	0	311
North Dakota	0	0	0	311	0	311
Ohio	0	0	0	311	0	311
Oklahoma	0	0	0	311	0	311
Oregon	850	0	0	0	0	850
Pennsylvania	0	0	0	311	0	311
Rhode Island	0	0	0	311	0	311
South Carolina	0	0	0	311	0	311
South Dakota	0	0	0	311	0	311
Tennessee	0	0	0	311	0	311
Texas	0	0	0	311	0	311
Utah	0	0	0	0	443	443
Vermont	0	0	0	311	0	311
Virginia	0	0	0	311	0	311
Washington	850	0	0	0	0	850
West Virginia	0	0	0	311	0	311
Wisconsin	0	0	0	311	0	311
Wyoming	0	0	0	0	443	443

Appendix D

Annual NO_x Emissions Estimation Process by Locomotive Model

Emissions Summary for: GP60 Linehaul

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	22.9%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	6.1%	6.8	1.0	1.0	6.8	1.0	0.4	0.1	0.1	0.4	0.1
idle	39.7%	3.4	3.4	0.5	3.4	3.4	1.3	1.3	0.2	1.3	1.3
1	3.0%	10.2	10.2	1.5	10.2	10.2	0.3	0.3	0.0	0.3	0.3
2	3.2%	18.1	18.1	2.7	18.1	18.1	0.6	0.6	0.1	0.6	0.6
3	3.1%	32.8	4.9	4.9	32.8	4.9	1.0	0.2	0.2	1.0	0.2
4	3.9%	37.4	5.6	5.6	7.5	1.1	1.5	0.2	0.2	0.3	0.0
5	3.1%	43.6	6.5	6.5	4.4	0.7	1.4	0.2	0.2	0.1	0.0
6	2.9%	51.6	7.7	7.7	5.2	0.8	1.5	0.2	0.2	0.1	0.0
7	2.2%	74.7	11.2	11.2	7.5	1.1	1.6	0.2	0.2	0.2	0.0
8	9.9%	112.3	16.8	16.8	11.2	1.7	11.1	1.7	1.7	1.1	0.2
Weighted Average NOx Emissions (lb/hr)							20.7	5.0	3.1	5.5	2.7
Annual NOx Emissions (tons)					88% Availability		**79.9**	**19.3**	**12.0**	**21.3**	**10.5**

Emissions Summary for: B40-8 Linehaul

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	22.9%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	6.1%	3.2	0.5	0.5	3.2	0.5	0.2	0.0	0.0	0.2	0.0
idle	39.7%	0.7	0.7	0.1	0.7	0.7	0.3	0.3	0.0	0.3	0.3
1	3.0%	6.7	6.7	1.0	6.7	6.7	0.2	0.2	0.0	0.2	0.2
2	3.2%	13.2	13.2	2.0	13.2	13.2	0.4	0.4	0.1	0.4	0.4
3	3.1%	27.6	4.1	4.1	27.6	4.1	0.9	0.1	0.1	0.9	0.1
4	3.9%	46.1	6.9	6.9	9.2	1.4	1.8	0.3	0.3	0.4	0.1
5	3.1%	82.8	12.4	12.4	8.3	1.2	2.6	0.4	0.4	0.3	0.0
6	2.9%	76.7	11.5	11.5	7.7	1.2	2.2	0.3	0.3	0.2	0.0
7	2.2%	93.7	14.1	14.1	9.4	1.4	2.1	0.3	0.3	0.2	0.0
8	9.9%	105.6	15.8	15.8	10.6	1.6	10.5	1.6	1.6	1.0	0.2
Weighted Average NOx Emissions (lb/hr)							21.1	3.9	3.2	4.0	1.4
Annual NOx Emissions (tons)			88% Availability				**81.2**	**15.1**	**12.2**	**15.6**	**5.3**

Emissions Summary for: F40-PH Passenger

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	41.4%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	0.4%	10.0	1.5	1.5	10.0	1.5	0.0	0.0	0.0	0.0	0.0
idle	29.7%	19.2	19.2	2.9	19.2	19.2	5.7	5.7	0.9	5.7	5.7
1	0.0%	7.0	7.0	1.1	7.0	7.0	0.0	0.0	0.0	0.0	0.0
2	0.0%	14.0	14.0	2.1	14.0	14.0	0.0	0.0	0.0	0.0	0.0
3	6.2%	22.7	3.4	3.4	22.7	3.4	1.4	0.2	0.2	1.4	0.2
4	6.0%	31.0	4.7	4.7	6.2	0.9	1.9	0.3	0.3	0.4	0.1
5	4.0%	42.5	6.4	6.4	4.3	0.6	1.7	0.3	0.3	0.2	0.0
6	2.9%	54.8	8.2	8.2	5.5	0.8	1.6	0.2	0.2	0.2	0.0
7	1.1%	91.0	13.7	13.7	9.1	1.4	1.0	0.2	0.2	0.1	0.0
8	8.3%	108.1	16.2	16.2	10.8	1.6	9.0	1.3	1.3	0.9	0.1
Weighted Average NOx Emissions (lb/hr)							22.3	8.2	3.3	8.8	6.2
Annual NOx Emissions (tons)					88% Availability		**85.8**	**31.5**	**12.9**	**34.1**	**23.8**

Emissions Summary for: SD40-2 Linehaul

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	22.9%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	6.1%	8.4	1.3	1.3	8.4	1.3	0.5	0.1	0.1	0.5	0.1
idle	39.7%	3.1	3.1	0.5	3.1	3.1	1.2	1.2	0.2	1.2	1.2
1	3.0%	7.4	7.4	1.1	7.4	7.4	0.2	0.2	0.0	0.2	0.2
2	3.2%	10.7	10.7	1.6	10.7	10.7	0.3	0.3	0.1	0.3	0.3
3	3.1%	18.3	2.7	2.7	18.3	2.7	0.6	0.1	0.1	0.6	0.1
4	3.9%	23.7	3.6	3.6	4.7	0.7	0.9	0.1	0.1	0.2	0.0
5	3.1%	34.5	5.2	5.2	3.5	0.5	1.1	0.2	0.2	0.1	0.0
6	2.9%	43.0	6.5	6.5	4.3	0.6	1.2	0.2	0.2	0.1	0.0
7	2.2%	63.7	9.6	9.6	6.4	1.0	1.4	0.2	0.2	0.1	0.0
8	9.9%	76.2	11.4	11.4	7.6	1.1	7.5	1.1	1.1	0.8	0.1
Weighted Average NOx Emissions (lb/hr)							15.1	3.8	2.3	4.2	2.2
Annual NOx Emissions (tons)				88% Availability			**58.1**	**14.6**	**8.7**	**16.1**	**8.3**

Emissions Summary for: SD40-2 Local

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-Si	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	35.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	1.2%	8.4	1.3	1.3	8.4	1.3	0.1	0.0	0.0	0.1	0.0
idle	47.1%	3.1	3.1	0.5	3.1	3.1	1.5	1.5	0.2	1.5	1.5
1	2.9%	7.4	7.4	1.1	7.4	7.4	0.2	0.2	0.0	0.2	0.2
2	2.7%	10.7	10.7	1.6	10.7	10.7	0.3	0.3	0.0	0.3	0.3
3	2.6%	18.3	2.7	2.7	18.3	2.7	0.5	0.1	0.1	0.5	0.1
4	2.2%	23.7	3.6	3.6	4.7	0.7	0.5	0.1	0.1	0.1	0.0
5	1.4%	34.5	5.2	5.2	3.5	0.5	0.5	0.1	0.1	0.0	0.0
6	1.1%	43.0	6.5	6.5	4.3	0.6	0.5	0.1	0.1	0.0	0.0
7	1.0%	63.7	9.6	9.6	6.4	1.0	0.6	0.1	0.1	0.1	0.0
8	2.1%	76.2	11.4	11.4	7.6	1.1	1.6	0.2	0.2	0.2	0.0
Weighted Average NOx Emissions (lb/hr)							6.3	2.6	0.9	3.0	2.1
Annual NOx Emissions (tons)				88% Availability			**24.1**	**10.0**	**3.6**	**11.4**	**8.1**

Emissions Summary for: GP38-2 Yard/Switch

Throttle Notch	Percent Time in Notch	NOx Emissions in Notch (lb/hr)					Weighted NOx Emissions in Notch (lb/hr)				
		Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR	Baseline	Dual-Fuel	LNG-SI	SCR	DF+SCR
off	31.7%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
brake	0.0%	6.2	0.9	0.9	6.2	0.9	0.0	0.0	0.0	0.0	0.0
idle	55.4%	2.8	2.8	0.4	2.8	2.8	1.5	1.5	0.2	1.5	1.5
1	3.2%	4.0	4.0	0.6	4.0	4.0	0.1	0.1	0.0	0.1	0.1
2	3.2%	9.6	9.6	1.4	9.6	9.6	0.3	0.3	0.0	0.3	0.3
3	2.2%	17.9	2.7	2.7	17.9	2.7	0.4	0.1	0.1	0.4	0.1
4	2.2%	27.4	4.1	4.1	5.5	0.8	0.6	0.1	0.1	0.1	0.0
5	0.8%	37.4	5.6	5.6	3.7	0.6	0.3	0.0	0.0	0.0	0.0
6	0.4%	51.2	7.7	7.7	5.1	0.8	0.2	0.0	0.0	0.0	0.0
7	0.0%	65.3	9.8	9.8	6.5	1.0	0.0	0.0	0.0	0.0	0.0
8	0.9%	76.6	11.5	11.5	7.7	1.1	0.7	0.1	0.1	0.1	0.0
Weighted Average NOx Emissions (lb/hr)							4.1	2.3	0.6	2.6	2.1
Annual NOx Emissions (tons)					88% Availability		**16.0**	**8.8**	**2.4**	**10.0**	**7.9**