Appendix A.10
Air Quality Analysis Methodology

List of Acronyms

bhp-hr/gal	Brake Horsepower-Hour per Gallon
CARB	California Air Resources Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSRP	California State Rail Plan
EMFAC	Emission Factors
g/bhp-hr	Grams per Brake Horsepower-Hour
GHG	Greenhouse Gas
NOx	Oxides of Nitrogen
PM_{10}	Large Respirable Particles
$PM_{2.5}$	Fine Particles
ROG	Reactive Organic Gases
USEPA	U.S. Environmental Protection Agency
VMT	Vehicle Miles of Travel

This memorandum presents the consultant team's proposed methodology for passenger and freight rail system air quality (greenhouse gas (GHG) and criteria pollutants) analysis for the 2018 California State Rail Plan (CSRP). This effort will analyze changes in on-road motor vehicle and locomotive emissions resulting from passenger and freight rail service and infrastructure modifications. The team will present the air quality analysis results as part of CSRP Section 4.4: Program Effects.

The analysis will replicate the 2013 CSRP's on-road motor vehicle emissions analysis. A new addition to the 2018 CSRP, locomotive emissions, will be derived from locomotive hours of operation, coupled with weighted emission rates that reflect a distribution of engine certification tiers and notch power settings. We will coordinate with the California Air Resources Board (CARB) to develop the specifics of those distributions for consistency with their ongoing locomotive inventory updates. After describing the scope of the analysis and the schema for reporting results, analysis methodology specifics for on-road emissions and locomotives will be discussed.

We will supplement these quantitative projections of emission changes with summary information regarding current rail-related emissions from CARB's Draft Technology Assessment: Freight Locomotives (April 2016). CSRP Chapter 6 will also reference and briefly discuss recent CARB documents and technology proposals that may influence air quality analysis in future CSRP updates.

1.0 Analysis Scope

Six Pollutants will be included in the air quality analysis:

- Carbon dioxide (CO_2);
- Reactive Organic Gases (ROG);
- Oxides of Nitrogen (NO_2);
- Carbon Monoxide (CO);
- Large Respirable Particles (PM_{10}); and
- Fine Particles ($PM_{2.5}$).

Emission changes will be calculated for 2022, 2027, 2040; and 2050[1] analysis years

[1] 2050 analysis will be done qualitatively, based on extrapolation of 2040 results.

On-road emission reduction benefits will only consider passenger vehicles. The consultant team assumes rail investments will not affect cargo amounts moving by commercial truck. From a programmatic perspective, we assume cargo suitable for freight rail transport will divert to an alternate port or business rather than change transportation modes.

The consultant team anticipates presenting passenger rail emission changes by the following geographic groups:

- Southern California (counties south of the Tehachapi Mountains);
- Central California (including the Bay Area, San Jaquan Valley, and Sacramento Region);
- Other California counties.

We also anticipate disaggregating freight rail emission into two groups representing Class 1 railroads and all other freight rail operators.

Table 1.1 provides a mockup of what we anticipate the results table will include. Emission reduction benefits from on-road passenger vehicles, passenger rail, and freight rail are combined to report the anticipated benefits accrued by each rail network element.

2.0 On-Road Emissions

The consultant team will base no-action on-road emission inventories for criteria pollutants on default results from the Emission Factors (EMFAC) 2014 emissions model. On-road GHG forecasts will be based on the fuel consumption projections produced by EMFAC 2014[2]. We will forecast on-road emission reduction benefits attributable to the 2018 CSRP using projected changes in VMT to scale emissions from the no-action alternative.

- The team will derive passenger vehicle VMT changes by air basin following the procedures outlined in Methodology Memorandum #5 (*Passenger Rail Ridership and Revenue Forecasting Process*). The passenger rail forecasts will identify VMT changes and to allocate those changes to the passenger rail network elements described in the prior section.

[2] Note that the California GHG inventory does not currently extend to 2050. GHG forecasts will be based on EMFAC 2014 fuel consumption and standardized emission rates per gallon of fuel used.

Table 1.1: Proposed Annual Statewide Emission Reduction Reporting Format

No-Action Emissions (Tons/Year)			Emission Reduction for 2018 California State Rail Plan Resulting From Changes in Locomotive and On-Road Vehicle Activity (Tons/Year)					
Year	On-Road	Rail	S California Passenger Service	N California Passenger Service	Other Passenger Service	Class 1 Railroads	Other Freight Rail Service	Total Change
Carbon Dioxide (CO_2)								
2022								
2027								
2040								
Reactive Organic Gases (ROG)								
2022								
2027								
2040								
Oxides of Nitrogen (NO_x)								
2022								
2027								
2040								
Carbon Monoxide								
2022								
2027								
2040								
Large Respirable Particles (PM_{10})								
2022								
2027								
2040								
Fine Particles ($PM_{2.5}$)								
2022								
2027								
2040								

- The passenger vehicle VMT changes will be used to scale emissions for the light-duty auto, light duty truck 1, light duty truck 2, medium duty vehicle, and motorcycle vehicle classes.

- Urban bus emissions will be scaled to reflect connecting bus service changes that are part of the 2018 CSRP, such as Amtrak Thruway buses.

This approach assumes that trip-end emissions scale proportionately to VMT, which is reasonable in this situation where VMT result mostly from mode shifts. Trip-end emissions include vehicle start emissions and evaporative emissions from the hot soaks after shutting off the engine. Diurnal and resting loss evaporative emissions will not be included in scaling of passenger vehicle emissions because, for purposes of this study, the regional passenger vehicle fleet's size is assumed to remain unchanged with the CSRP Vision Scenario.

3.0 Locomotive Emissions

3.1 Approach

The consultant team will forecast no-action locomotive emissions and projected locomotive emissions changes similarly to the on-road emissions, and consistent with CARB locomotive emissions inventory estimates. No action forecasts will be based the current locomotive emission inventory, extrapolated by a growth factor tied to projected locomotive activity. Control factors will be applied to account for the emission reduction benefits of electrification and for the reduction in criteria pollutants attributable to the uptake of Tier 4 locomotives by class 1 railroads and passenger services. We will apply emission rates from The Climate Registry[3] to forecast GHG emissions associated with increased electricity production for electrified portions of the system; we will scale the national emission rates to reflect implementation of California's Renewables Portfolio Standard. Criteria pollutant emissions associated with electricity generation will not be forecasts as additional electrical generation capacity is assumed to be located outside of the MTC region.

3.2 Locomotive Activity

The no action alternative will reflect locomotive activity levels consistent with the 2018 CSRP freight rail forecasts and assumed 2017 passenger rail services. The operating plans specified in the CSRP passenger rail forecasts and the projected activity levels on Class 1 and short line

[3] See for example: http://theclimateregistry.org/wp-content/uploads/2015/01/2013-Climate-Registry-Default-Emissions-Factors.pdf

railroads will inform the changes to locomotive hours of operation. Differences between the no action alternative and 2018 CSRP Vision Scenario will account for any changes in locomotive fleet or overall activity levels.

In general, duty cycles will be assumed to remain unchanged between analysis years and scenarios. However, benefits of some types of infrastructure investment, such as targeted capacity improvements to relieve congestion may be accounted for "off-model", potentially utilizing duty cycle, or similar, data.

3.3 Locomotive Emission Rates

Diesel locomotive engine power, and thus emissions, is controlled by "notched" throttles. Locomotive idling, braking, and movement occur by placing the throttle in one of several available notches, which in turn influence emissions. U.S. Environmental Protection Agency (USEPA) published default duty cycles (Table 3.1) in 1998 for different locomotive types[4]. We will use California-specific locomotive duty cycles data should they be reasonably available from CARB or industry stakeholders.

As part of U.C. Berkeley's Rail Economic Study being led by Mark Hansen, he has agreed to work with CARB to review proprietary CARB data that includes locomotive duty cycles. Dr. Hansen's team will identify if regional variation in duty cycles can be derived, and provide updated locomotive duty cycles where appropriate.

The consultant team will base traction engine emission rates on USEPA estimates[5], which are not identical to the locomotive citification levels. There can be significant variability in in-use emission rates depending on ambient conditions, the locomotive age, and deterioration of the emission controls. The USEPA emission rates are shown in Tables 3.2 and 3.3.

Use of these emission rates requires that each throttle notch's power level be known. We will use default assumptions derived from USEPA data[6], and augmented with California specific data to the extent that it is reasonably available from CARB or industry participants.

[4] USEPA (1998) Locomotive Emission Standards regulatory support document, EPA-420-R-98-101.
[5] USEPA (2009) Emission Factors for Locomotives, EPA-420-F-09-025. April 2009.
[6] USEPA (1998) Locomotive Emission Standards regulatory support document, EPA-420-R-98-101.

Table 3.1 USEPA Estimated Locomotive Duty Cycles

Throttle Notch	Line-Haul	Passenger	Switch
Idle	38%	47.4%	59.8%
Dynamic Brake	12.5%	6.2%	0%
1	6.5%	7%	12.4%
2	6.5%	5.1%	12.3%
3	5.2%	5.7%	5.8%
4	4.4%	4.7%	3.6%
5	3.8%	4%	3.6%
6	3.9%	2.9%	1.5%
7	3.0%	1.4%	0.2%
8	16.2%	15.6%	0.8%

Table 3.2 USEPA Line-Haul Freight and Passenger Locomotive Emission Factors

Emissions Standard	Manufacture Year	PM_{10} (g/bhp-hr)	$PM_{2.5}$ (g/bhp-hr)	ROG (g/bhp-hr)	NO_x (g/bhp-hr)	CO (g/bhp-hr)
Uncontrolled	Pre 1973	0.32	0.310	0.48	13.00	1.28
Tier 0	1973-2001	0.32	0.310	0.48	8.60	1.28
Tier 0+	2008+	0.20	0.194	0.30	7.20	1.28
Tier 1	2002-2004	0.32	0.310	0.47	6.70	1.28
Tier 1+	2008+	0.20	0.194	0.29	6.70	1.28
Tier 2	2005	0.18	0.175	0.26	4.95	1.28
Tier 2+ & Tier 3	2008 + & 2012-14	0.08	0.078	0.13	4.95	1.28
Tier 4	2015+	0.015	0.015	0.04	1.00	1.28

Table 3.3 USEPA Switcher Locomotive Emission Factors

Emissions Standard	Manufacture Year	PM_{10} (g/bhp-hr)	$PM_{2.5}$ (g/bhp-hr)	ROG (g/bhp-hr)	NO_x (g/bhp-hr)	CO (g/bhp-hr)
Uncontrolled	Pre 1973	0.44	0.427	1.01	17.40	1.83
Tier 0	1973-2001	0.44	0.223	1.01	12.60	1.83
Tier 0+	2008+	0.23	0.417	0.57	10.60	1.83
Tier 1	2002-2004	0.43	0.223	1.01	9.90	1.83
Tier 1+	2008+	0.23	0.184	0.57	9.90	1.83
Tier 2	2005	0.19	0.107	0.51	7.30	1.83
Tier 2+ & Tier 3	2008 + & 2012-14	0.11	0.078	0.26	7.30	1.83
Tier 4	2015+	0.08	0.015	0.26	4.50	1.83

We will forecast CO2 emissions based on fuel consumption, which will be determined from the following brake horsepower-hour per gallon (bhp-hr/gal) conversion factors[7]:

- Large line-haul and Passenger: 20.8 bhp-hr/gal;
- Small line-haul: 18.2 bhp-hr/gal; and
- Switching: 15.2 bhp-hr/gal.

4.0 Locomotive Fleet Distribution by Tier

CARB has published Class 1 locomotive fleet data in the South Coast Air Basin (Table 4.1)[8]. The Bureau of Transportation Statistics (BTS) publishes similar American Association of Railroads national locomotive fleet data (Table 4.2)[9]. We will combine data from these two tables with

[7] USEPA (2009) Emission Factors for Locomotives, EPA-420-F-09-025. April 2009.
[8] CARB (2015) 1998 Locomotive NOx Fleet Average Emissions Agreement in the South Coast Air Basin, http://www.arb.ca.gov/railyard/1998agree/1998agree.htm.
[9] "Association of American Railroads, Railroad Facts (Washington, DC: Annual Issues) p. 52 and similar pages in earlier editions" as cited by BTS:

locomotive survival rates to forecast future year tier distributions analysis. We will use an average of national and South Coast fleet data for areas outside of the South Coast Air Basin.

Mark Hansen has agreed to coordinate with CARB to develop the existing distribution of Locomotive certification tiers through their Rail Economic Study, which is a companion and supporting effort to the CSRP. Dr. Hansen's team will work with the South Coast and BTS data, plus proprietary data held by CARB to develop these distributions for the major elements of the rail system for which emissions will be reported. T. Kear Transportation Planning and Management will estimate how those distributions change over time using survival rate data published by USEPA.

Table 4.1 South Coast Class 1 Locomotive Fleet in 2014

Tier	Number of Locomotives	Megawatt-Hours (MWhrs)	%MWhrs by Tier Level
BNSF Railway			
Uncontrolled	78	220	0.1%
Tier 0	372	9,459	4.7%
Tier 1	1,128	50,382	25.3%
Tier 2	1,145	107,503	53.9%
Tier 3	576	31,832	16.0%
Total	3,299	199,396	100.0%
Union Pacific Railroad			
Uncontrolled	82	624	0.3%
Tier 0	2,699	62,605	29.4%
Tier 1	1,805	30,671	14.4%
Tier 2	1,758	78,119	36.7%
Tier 3	636	32,040	15.1%
Tier 4	2	78	0.0%
ULEL	61	8,476	4.0%
Total	7,043	212,613	100.0%

http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_32.html.

Table 4.2 BTS Class 1 National Fleet Data

Year Built[a]	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total	18,835	18,344	18,004	18,161	18,505	18,812	19,269	19,684	20,261	20,256	20,028	19,745	20,506
<1970	5,117	4,353	4,038	3,766	3,535	[b]	[b]	[b]	[b]	[b]	[f]	[f]	[f]
1970-74	3,852	3,617	3,384	3,248	3,184	6,048[c]	5,783[c]	5,529[c]	5,565[c]	5196[c]	[f]	[f]	[f]
1975-79	4,432	4,375	4,292	4,352	4,275	4,254	4,274	4,219	4,116	4,000	8,541[g]	7,862[g]	7,133[g]
1980-84	2,837	2,826	2,784	2,730	2,625	2,754	2,735	2,728	2,723	2,581	2,411	2,153	1,790
1985-89	1,989	1,985	1,970	1,968	1,971	1,890	1,866	1,829	1,830	1,779	1,775	1,672	1,807
1990	608	605	604	604	599	2,965[d]	2,959[d]	2,958[d]	2,736[d]	2,688[d]	2,648[d]	2,667[d]	2,702[d]
1991		583	595	595	594	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1992			337	340	339	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1993				558	602	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1994					781	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1995						901	945	983	953	951	973	4,020[h]	4,582[h]
1996							707	696	708	706	697	[i]	[i]
1997								742	741	743	745	[i]	[i]
1998									889	890	890	[i]	[i]
1999										722	713	[i]	[i]
2000											635	691	987
2001												680	810
2002													695
2003													
2004													
2005													
2006													

Year Built[a]	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
2007													
2008													
2009													
2010													
2011													
2012													
2013													

Table Notes

a: Disregards year of rebuilding.
b: Included in 1970-74 category.
c: Includes all locomotives built before 1975.
d: Includes locomotives built between 1990-94.
e: Included in 1990 category.
f: Included in 1975-79 category.
g: Includes all locomotives built before 1980.
h: Includes locomotives built between 1995-99.
i: Included in 1995 category.
j: Included in 1980-84 category.
K : Includes all locomotives built before 1985.
l: Includes locomotives built between 2000-04.
m: Included in 2000 category.
n: Included in 1990 category.
o: Includes all locomotives built before 1990.
p: Includes locomotives built between 2005-09.
q: Included in 2005 category.

Table 4.3 BTS Class 1 National Fleet Data (continued)

Year Built[a]	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Total	20,774	22,015	22,779	23,732	24,143	24,003	24,045	23,893	24,250	24,707	25,033
<1970	[f]	[f]	[j]	[j]	[j]	[j]	[j]	[n]	[n]	[n]	[n]
1970-74	[f]	[f]	[j]	[j]	[j]	[j]	[j]	[n]	[n]	[n]	[N]
1975-79	6,889[g]	7,056[g]	[j]	[j]	[j]	[j]	[j]	[n]	[n]	[n]	[n]
1980-84	1,655	1,585	8,705[k]	8,237[k]	7,907[k]	7,297[k]	7,054[k]	[n]	[n]	[n]	[n]
1985-89	1,791	1,799	1,786	1,735	1,695	1,604	1,558	8,420[o]	8,304[o]	8,145[o]	7,901[o]
1990	2,700[d]	2,715[d]	2,783[d]	2,740[d]	2,718[d]	2,494[d]	2,464[d]	2,384[d]	2,365[d]	2,368[d]	2,363[d]
1991	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1992	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1993	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1994	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]	[e]
1995	4,673[h]	4,672[h]	4,348[h]	4,535[h]	4,300[h]	4,146[h]	4,173[h]	4,467[h]	4,461[h]	4,411[h]	4,382[h]
1996	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]
1997	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]
1998	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]
1999	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]	[i]
2000	863	863	[l]4,350	[l]4,673	[l]4,618	[l]4,777	[l]4,650	[l]4,265	[l]4,268	[l]4,262	[l]4,258
2001	891	891	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
2002	725	722	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
2003	587	591	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
2004		1,121	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]	[m]
2005			807	881	876	876	875	[p]4,098	[p]4,091	[p]4,087	[p]4,039
2006				931	1,097	1,145	1,122	[q]	[q]	[q]	[q]

Year Built[a]	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
2007					932	907	911	q	q	q	q
2008						757	777	q	q	q	q
2009							461	q	q	q	q
2010								259	256	256	253
2011									503	498	495
2012										683	693
2013											649

Table Notes

a: Disregards year of rebuilding.
b: Included in 1970-74 category.
c: Includes all locomotives built before 1975.
d: Includes locomotives built between 1990-94.
e: Included in 1990 category.
f: Included in 1975-79 category.
g: Includes all locomotives built before 1980.
h: Includes locomotives built between 1995-99.
i: Included in 1995 category.
j: Included in 1980-84 category.
K: Includes all locomotives built before 1985.
l: Includes locomotives built between 2000-04.
m: Included in 2000 category.
n: Included in 1990 category.
o: Includes all locomotives built before 1990.
p: Includes locomotives built between 2005-09.
q: Included in 2005 category.