CALIFORNIA
AIR RESOURCES BOARD

2020 Locomotive Emissions Inventory

Air Quality Planning & Science Division

Public Workshop

September 3, 2020

What is an emission inventory?

- An emission inventory represents *total emissions* from an equipment category (i.e. locomotives, ships, trucks, etc.)
- Emission inventories are generally based on total *activity* or *fuel usage*
  - ✓ *Equipment age* is very important, as newer equipment are generally cleaner
- Emission inventories help determine sources for statewide air quality issues, and informs the need for, and effectiveness, of different emission reduction strategies.

California's rail system is vital to the freight network, yet it also contributes a significant portion of the state's emissions at railyards and regionally.

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Locomotive Types

California's locomotive emission inventory is composed of **4 categories**:

1. **Line-haul**
   - Categorized as Class I freight rail, operated in California by BNSF and UP
2. **Switcher**
   - Move railcars in or around rail yards, limited to those operated at BNSF and UP railyards
3. **Short line**
   - Categorized as Class III rail
   - Local and regional railroads haul freight and provide switching, but report lower revenue than Class I, and operate over a small network. (Class III switching is captured here, not w/ Switcher)
4. **Passenger**
   - Commuter, intercity and interstate passenger rail lines

Note

- COVID19 has had and will have impacts on freight movement and passenger rail activity
- CARB is collecting and reviewing monthly data to determine and reflect impacts for 2020 and beyond

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Line-haul locomotive emission inventory

Data Sources

Inventory Variable	Data Source
Population	South Coast MOU Data from 2010 to 2018
Activity (Megawatt Hrs)	Provided by UP and BNSF for 2018
Location/Distribution	Provided by UP and BNSF for 2018
Age and/or Tier Distribution	Both South Coast MOU data and those provided for non-SC regions by UP and BNSF for 2018
Emission Factors	US EPA Locomotive Emission Factors
Growth	Primarily Freight Analysis Framework (comparison with other sources)

Background information

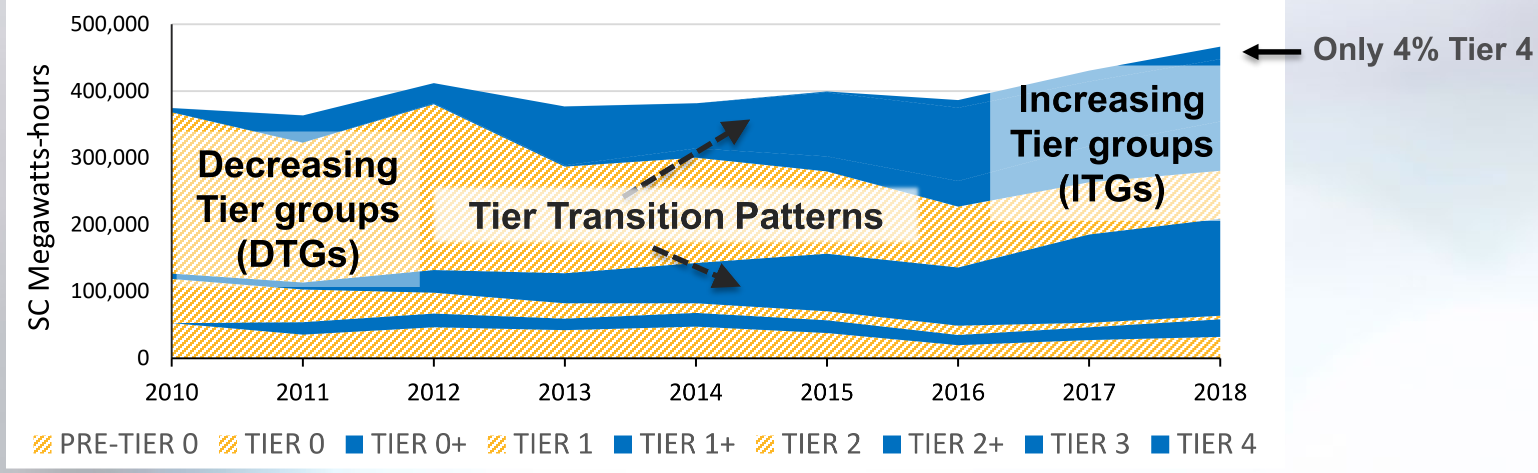
Tier	NOx (g/bhp-hr)	PM10 (g/bhp-hr)
Pre-Tier 0	**13.0**	**0.32**
Tier 0	8.6	0.32
Tier 0+	7.2	0.20
Tier 1	6.7	0.32
Tier 1+	6.7	0.20
Tier 2	4.95	0.18
Tier 2+	4.95	0.08
Tier 3	4.95	0.08
Tier 4	**1.0**	**0.015**

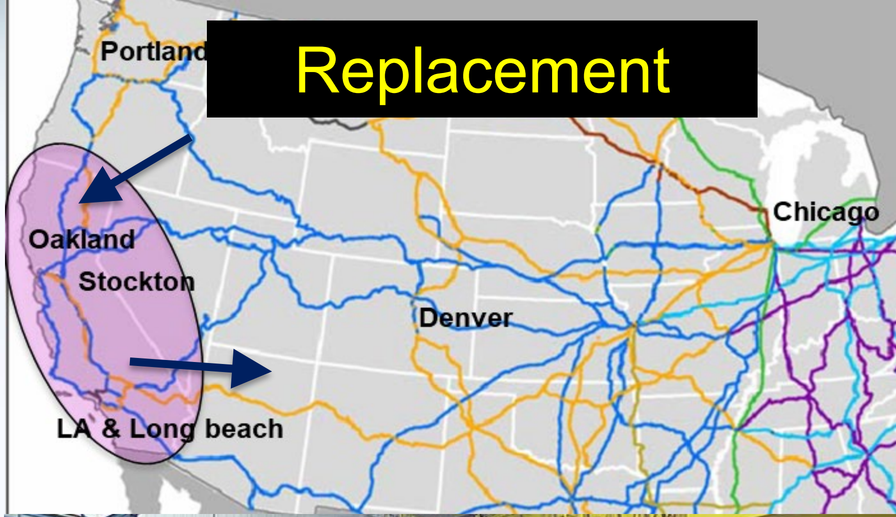
- Importance of Engine Tiers
  - Standards for new engines got progressively cleaner over time
  - Tier 4 engines achieve NOx reductions of 93%, PM reductions of 95% when compared to an uncontrolled engine
- Tier 0+ / 1+ / 2 + mean remanufactured* engines

**Remanufacturing is a process to increase the life of the locomotive. Through this process, locomotives are disassembled to the frame and their components are replaced as needed.*

Modeling Concept

- Work / energy (MWhrs)-based emissions inventory
- Primary goals are
  1) Understanding current Tier mix, and which Tiers are being retired vs. Tier groups that are increasing
  2) Using this to project future Tier mix based on last decade of rail visits and remanufacturing behavior.
     - ➢ Engines are not only replaced but remanufactured to different Tier standards → MWhrs flows across different Tiers





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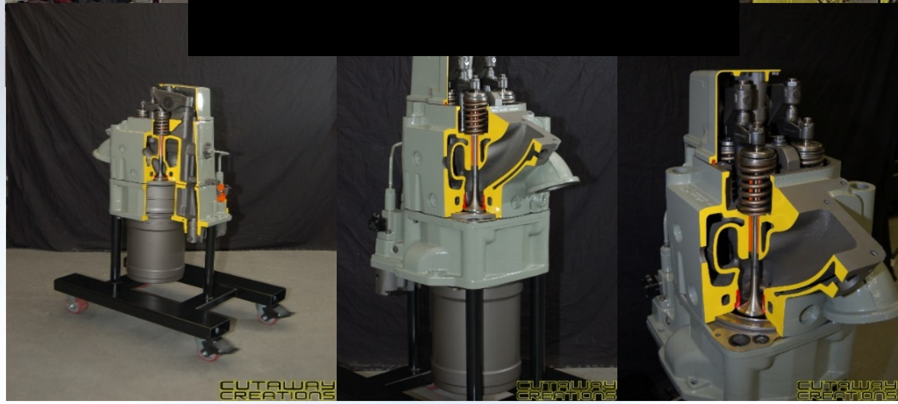


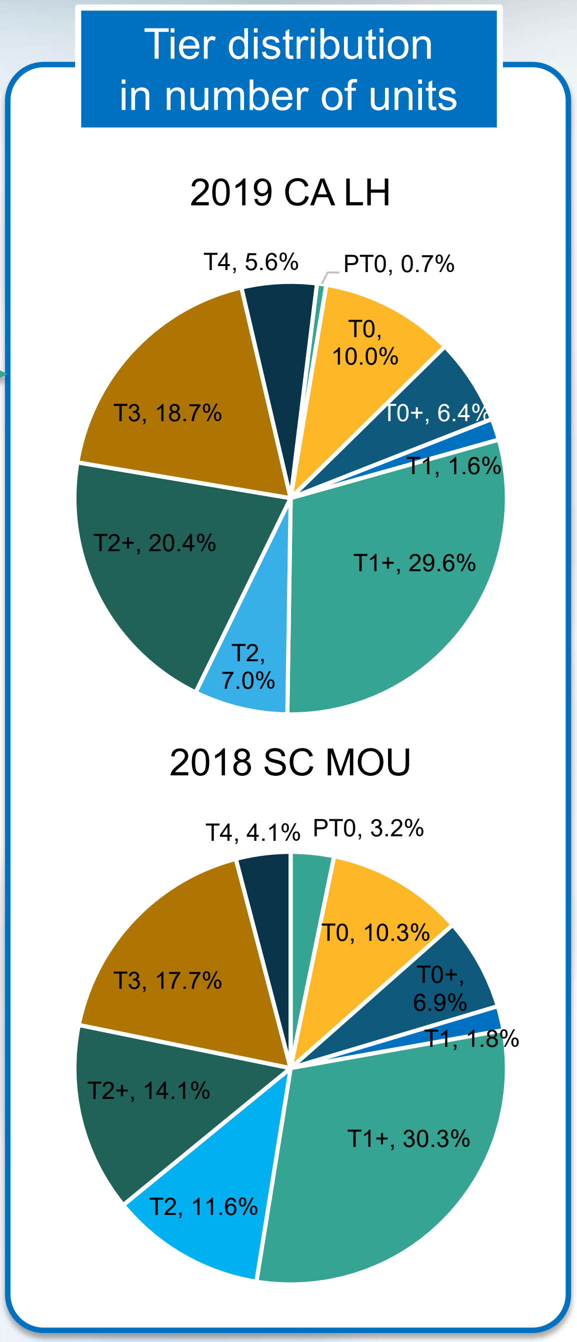
Rebuilding process: https://www.assemblymag.com/articles/94429-ge-stays-on-track-by-rebuilding-locomotives

Current and Historical Data & Trends

Data	Year	Used For
'98 South Coast MOU Reporting Data	2010-2018	Understanding Activity & Workload by Engine Tier
Ever-Visited South Coast Population	2015-2018	Looking at Remanufacturing Behavior & Tier Transition Pattern (can monitor locomotives by tracking number, observe remanufactures)

❖ Additional factors;

- ✓ Tier 4 locomotive purchases have been steadily decreasing since the standards went into effect in 2015, with no 2019 Tier 4 locomotive purchases as of May 31, 2019
- ✓ Tier 0 and Tier 1 locomotives might be parked and can be pulled back into service



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Combing Growth, Tier Transition and Retirement into Forecasting Steps

STEP 1

Increasing & Decreasing Tier groups based on Tier Transition Patterns

STEP 2

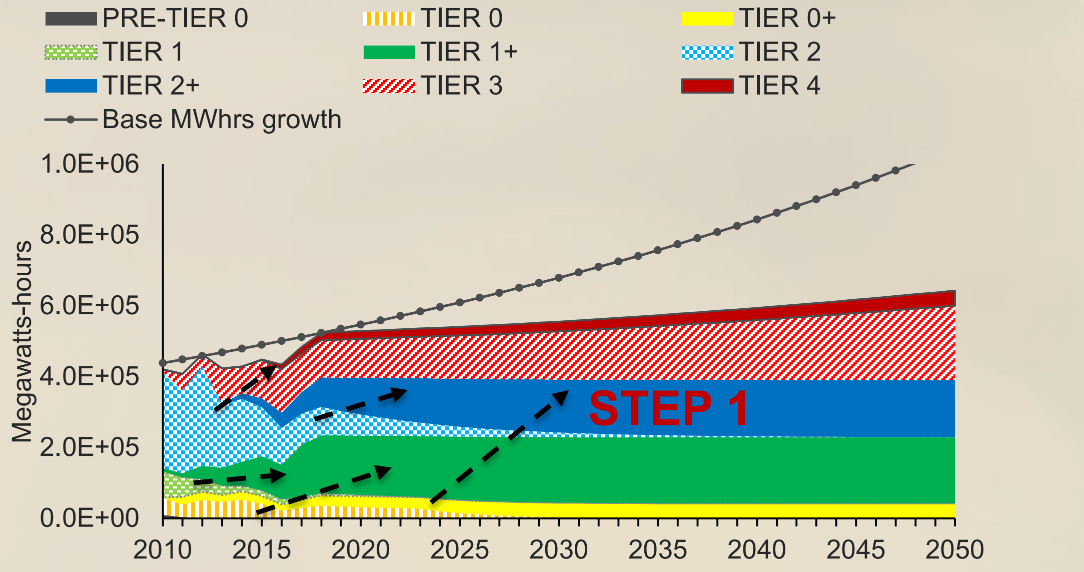
Retiring of units after several remanufacture cycles (i.e., limit on total service life)

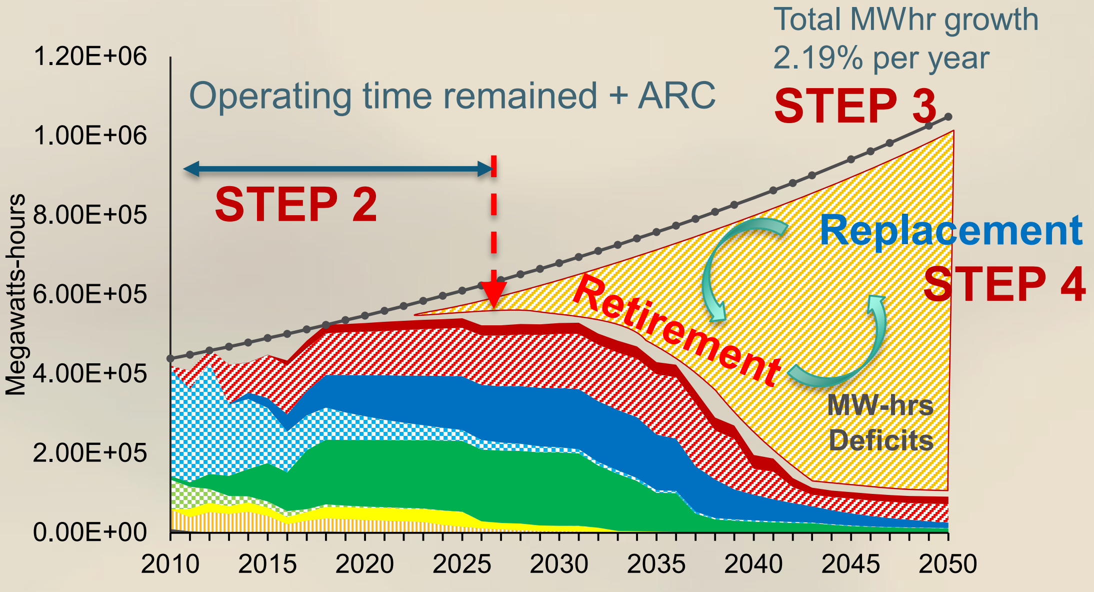
STEP 3

Baseline MWhrs growth due to increased freight movement (2.19% YOY)

STEP 4

Determine Tier of Locomotives that will backfill retirements and growth needs
(Potential for many parked Tier 0+ /1+ units brought back into service to fill gap)





ARC: Average Reman. Cycle

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Forecasting Steps – BAU scenario

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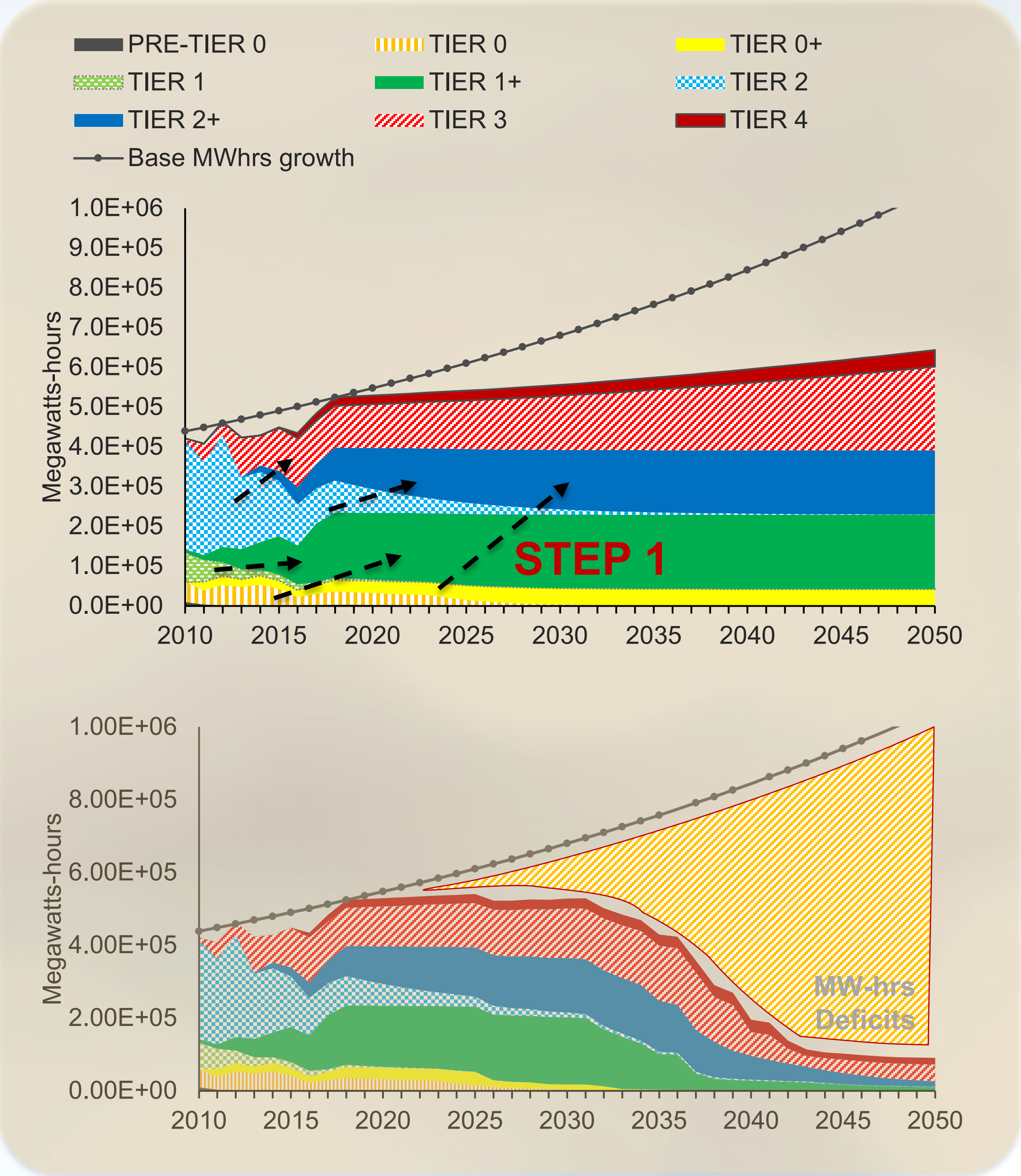

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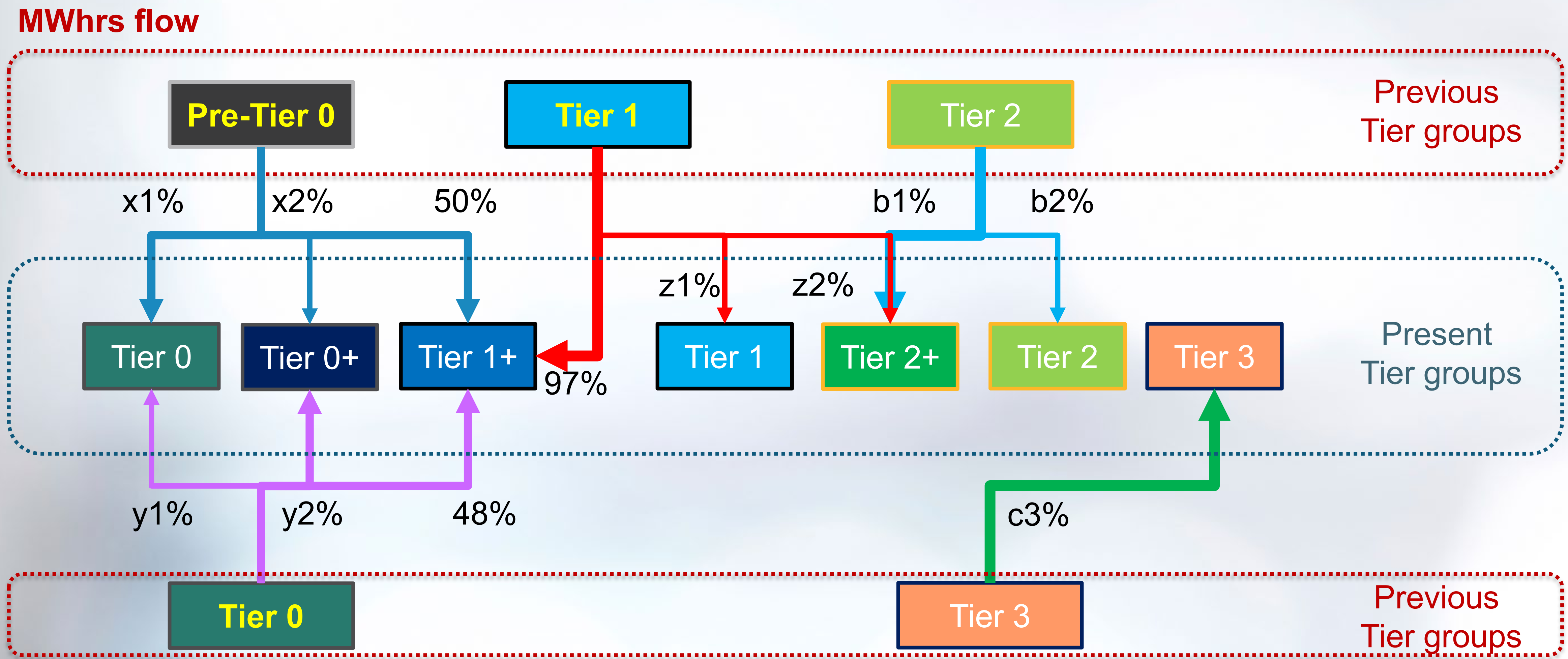
Step 1: Calculation of incremental MWhrs of Increasing Tier Groups by using Tier Transition Patterns



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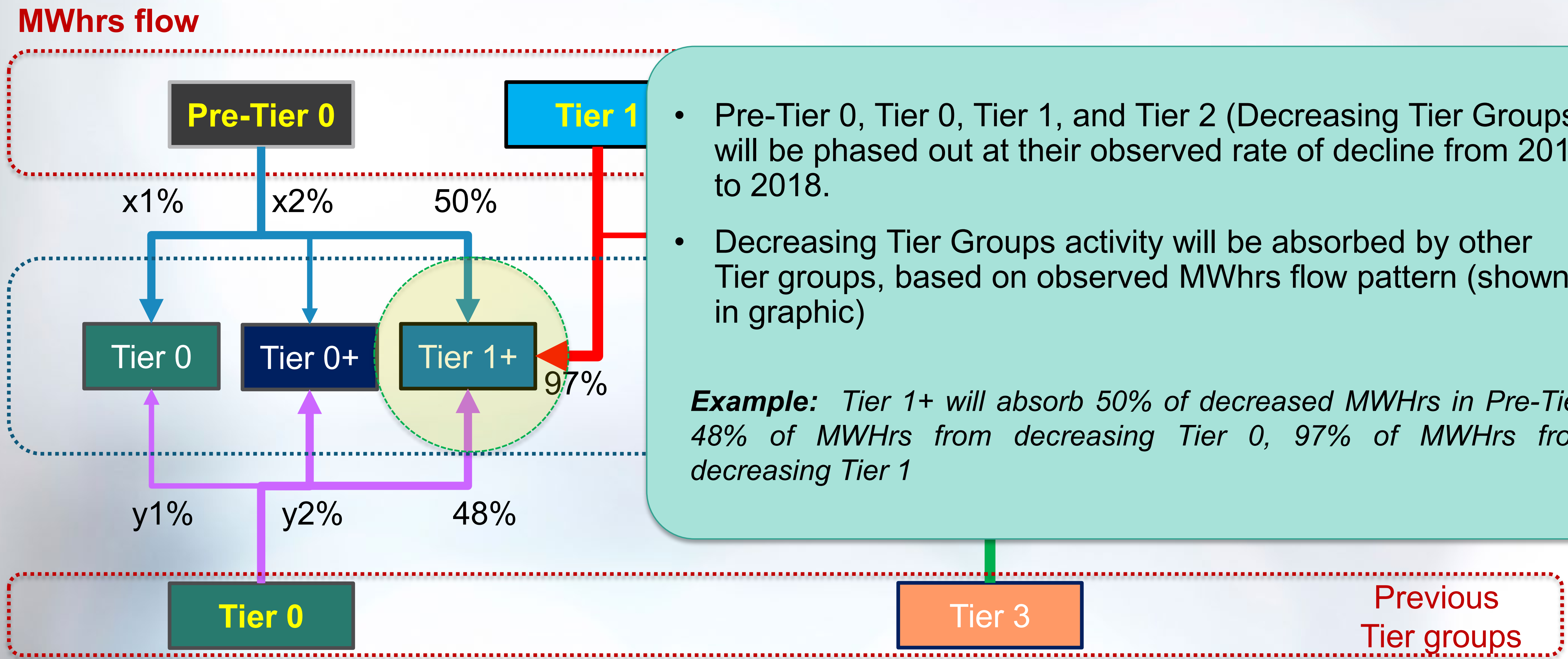

- Pre-Tier 0, Tier 0, Tier 1, and Tier 2 (Decreasing Tier Groups) will be phased out at their observed rate of decline from 2010 to 2018.
- Decreasing Tier Groups activity will be absorbed by other Tier groups, based on observed MWhrs flow pattern (shown in graphic)

Example: *Tier 1+ will absorb 50% of decreased MWHrs in Pre-Tier, 48% of MWHrs from decreasing Tier 0, 97% of MWHrs from decreasing Tier 1*

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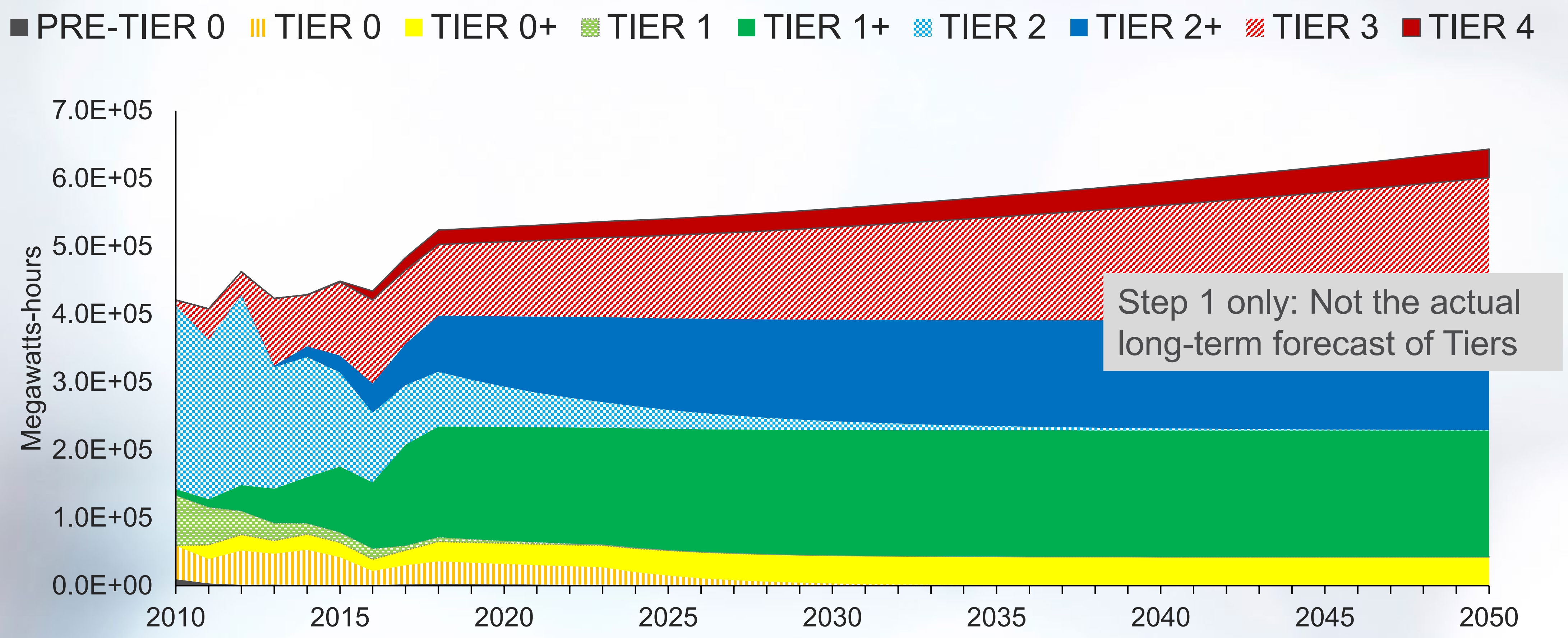
Step 1: Results of Tier Transition Only



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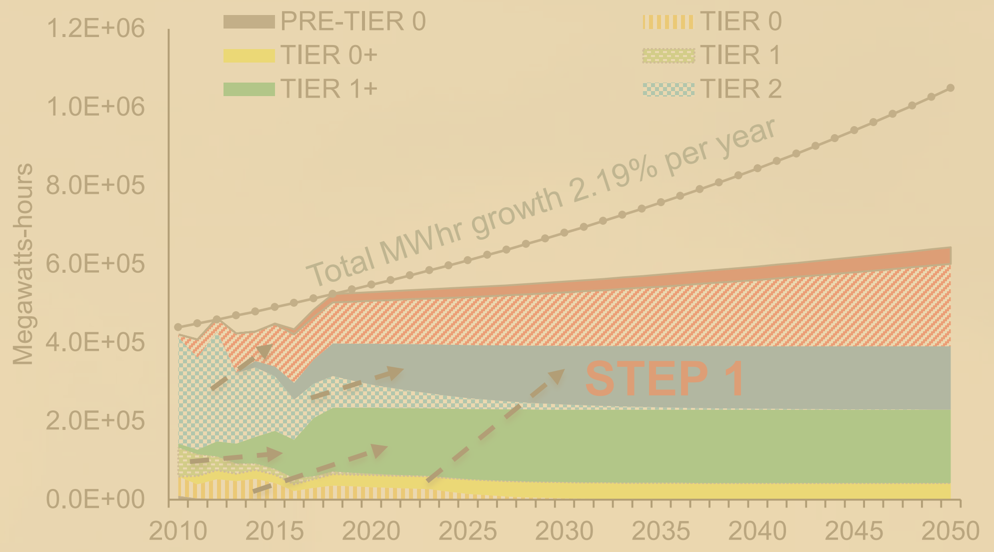

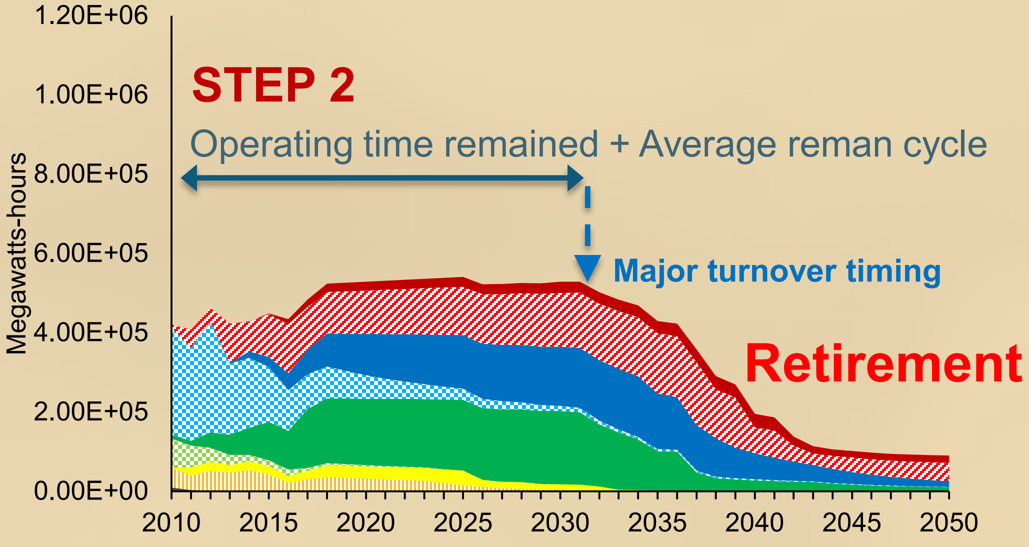

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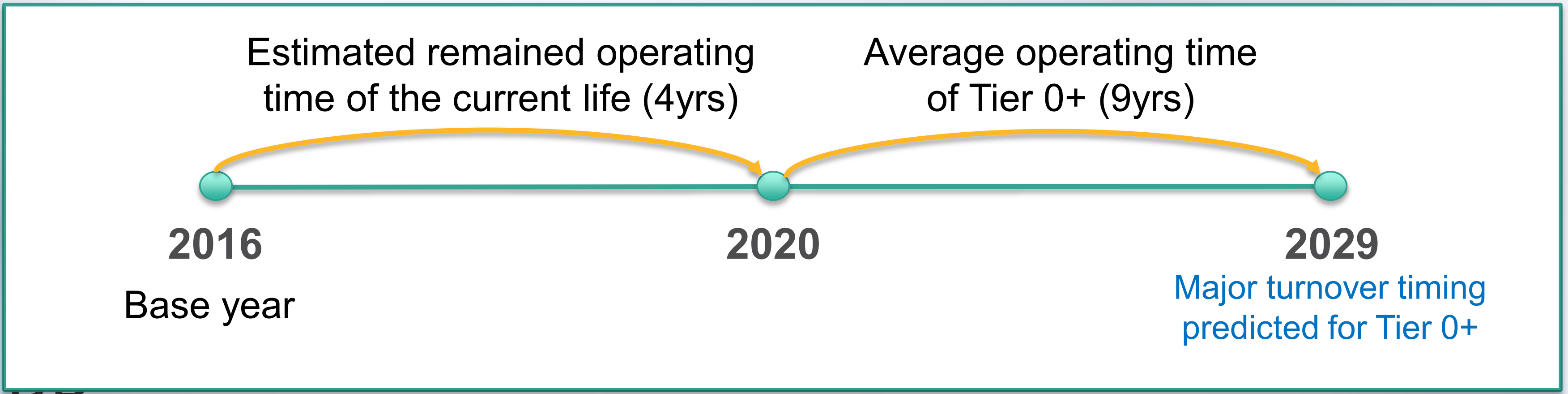
Step 2: Major Turnover Year per Tier (Retirement)

- 25 years of total service life (years)
  - Data from 2010 to 2018 shows a significant drop in population and activity at 25 years of age
  - Not guaranteed to continue, reality is maintaining locomotives past a certain age carries increased cost, balanced against increased cost of Tier 4 engines
- 2016 (Base year) + Remaining useful life + future remanufacturing period = Major turnover timing (Retiring year of the locomotives)
  - Remaining useful life = Average service life – Average age in 2016
  - Future remanufacturing period: 9~12 years depending on Tier

Tier	Major Turnover Timing
Pre-Tier 0	2029
Tier 0	2029
Tier 0+	2029
Tier 1	2029
Tier 1+	2032
Tier 2	2031
Tier 2+	2033
Tier 3	2035
Tier 4	2039

Example: Major Turnover Year of Tier 0+

- Average reman cycle (Average service life) of Tier 0+: 9 years
  - Average age of Tier 0+: 5 years
  - Remained operating time: 4 years
- Avg total service life of Tier 0+: 18 years
  - Likely to be remanned earlier than the average total service life
  - Remained service lifespan: 13 years (18yrs – 5yrs)
- # of Reman likely: Average of 1.44 time (=13 yrs / 9 yrs of ARC)



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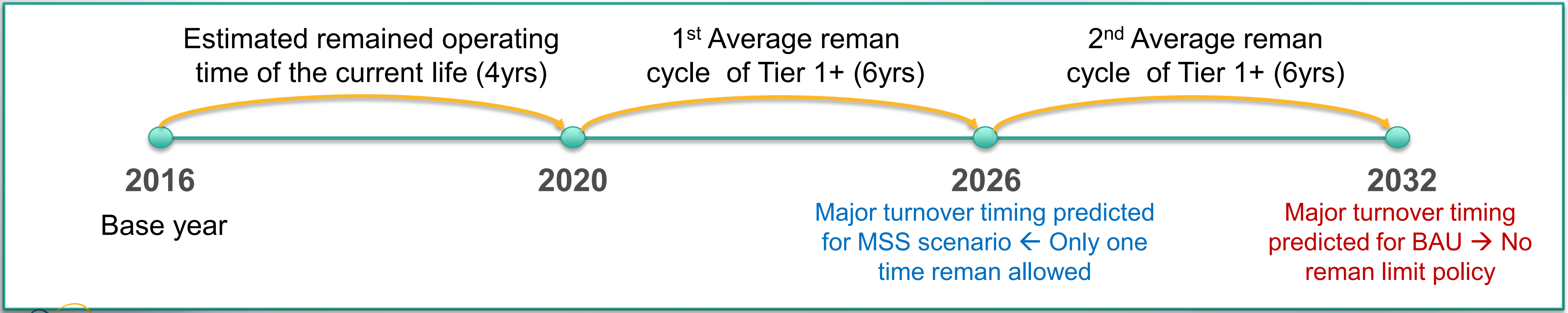
Example: Major Turnover Year of Tier 1+

- Average reman cycle (Average service life) of Tier 1+: 6 years
  - Average age of Tier 1+: 2 years
  - Remained operating time: 4 years
- Avg total service life of Tier 1+: 25 years
  - Remained service lifespan: 23 years (25yrs – 2yrs of avg. age)
- # of Reman available: At least twice, reman up to 3.83 times (=23 yrs / 6 yrs of ARC)



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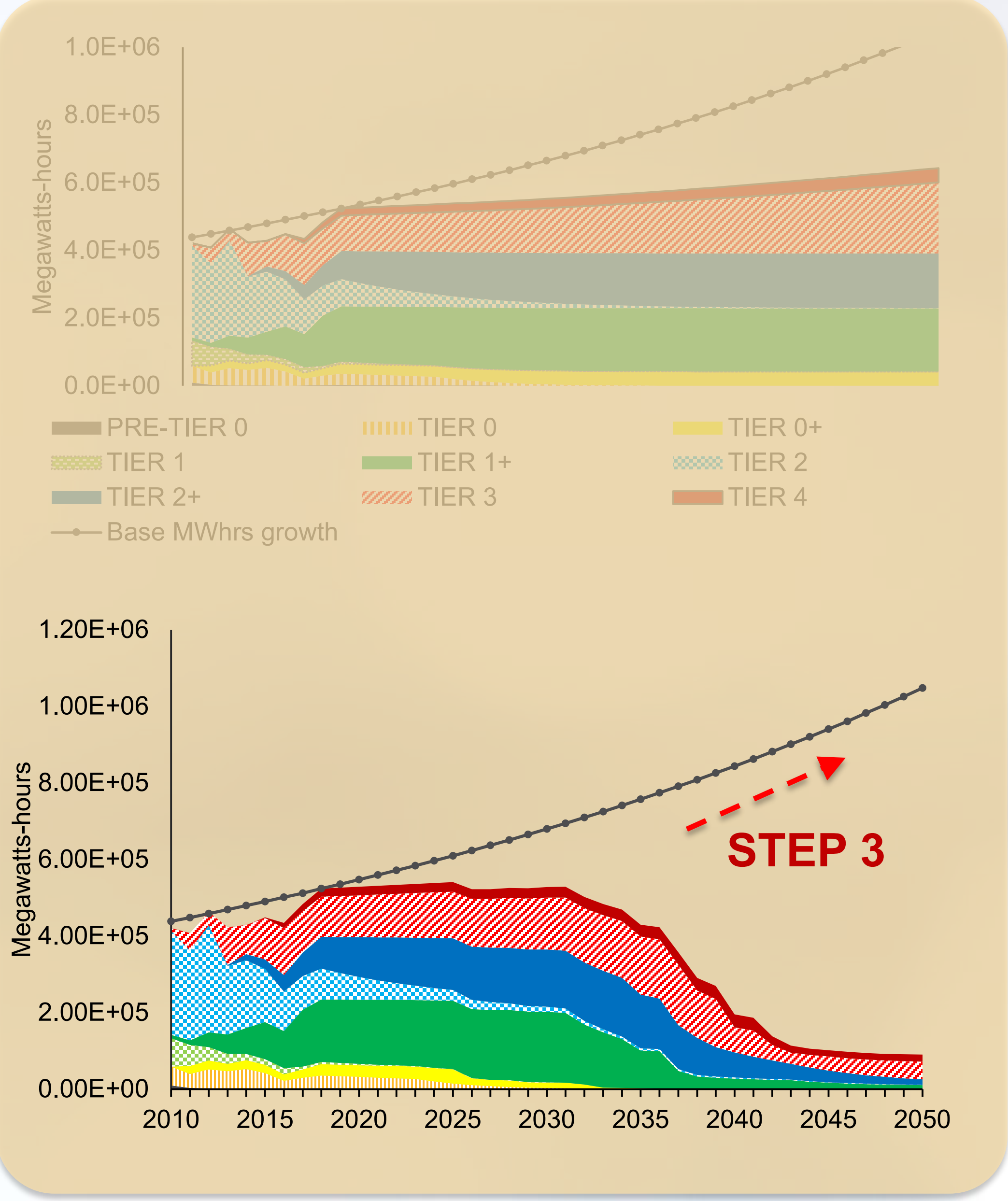

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Step 3: Baseline Activity Growth Rate of Total MWhrs

- Base activity growth rate is based on the relationship between the freight movement growth rates at different time points.
- MWhrs forecast to grow at fixed rate, 2.19%

Data sources	Time frame	AVG
Total Distillate Sales/Deliveries to Railroad Consumers (Thousand Gallons) [1]	2013 – 2018	1.82%
CA State Rail Plan: Compound annual growth rates for carload service [2]	2013 – 2040	1.70%
CA State Rail Plan: Compound annual growth rates for intermodal service [3]	2013 – 2040	2.90%
ATA 2012 Rail Volume Forecast: Rail Carload & Intermodal Freight [4]	2012 – 2023	1.42%
2019 The Budget and Economic Outlook: GDP (Billions of dollars) [5]	2013 - 2018	4.70%
Rail growth used for SCAG Regional Transportation Planning [6]	2012 - 2040	3.30%
Class I Rail Freight Fuel Consumption and Travel (million gallons) [7]	2010 – 2012	1.51%
Seasonally-adjusted Rail Freight Intermodal Traffic [7](BTS & AAR)	2010 - 2018	3.17%
Port of Long beach container counts (TEUs) [8]	2010 – 2019	2.20%
Port of LA container counts (TEUs) [9]	2010 – 2019	2.00%

[1]U.S. Energy Information Administration, Sales of Distillate Fuel Oil by End Use
[2]California State Rail Plan, https://dot.ca.gov/programs/rail-and-mass-transportation/california-state-rail-plan
[3]California State Rail Plan, https://dot.ca.gov/programs/rail-and-mass-transportation/california-state-rail-plan
[4] American Trucking Associations, http://www.azttca.org/pdf/ATA-Freight-Forecast.pdf
[5]The Budget and Economic Outlook: 2019 to 2029 of Congressional budget office (CBO), https://www.cbo.gov/system/files/2019-03/54918-Outlook-3.pdf
[6]2012-2035 Regional Transportation Plan (RTP) of the Southern California Association of Governments, http://rtpscs.scag.ca.gov/Pages/2012-2035-RTP-SCS.aspx
[7] Bureau of transportation statistics: Class I Rail Freight Fuel Consumption and Travel, https://www.bts.gov/content/class-i-rail-freight-fuel-consumption-and-travel
[8] Port of Long Beach latest statistics, https://www.polb.com/business/port-statistics/#latest-statistics
[9] Port of LA container statistics, https://www.portoflosangeles.org/business/statistics/container-statistics

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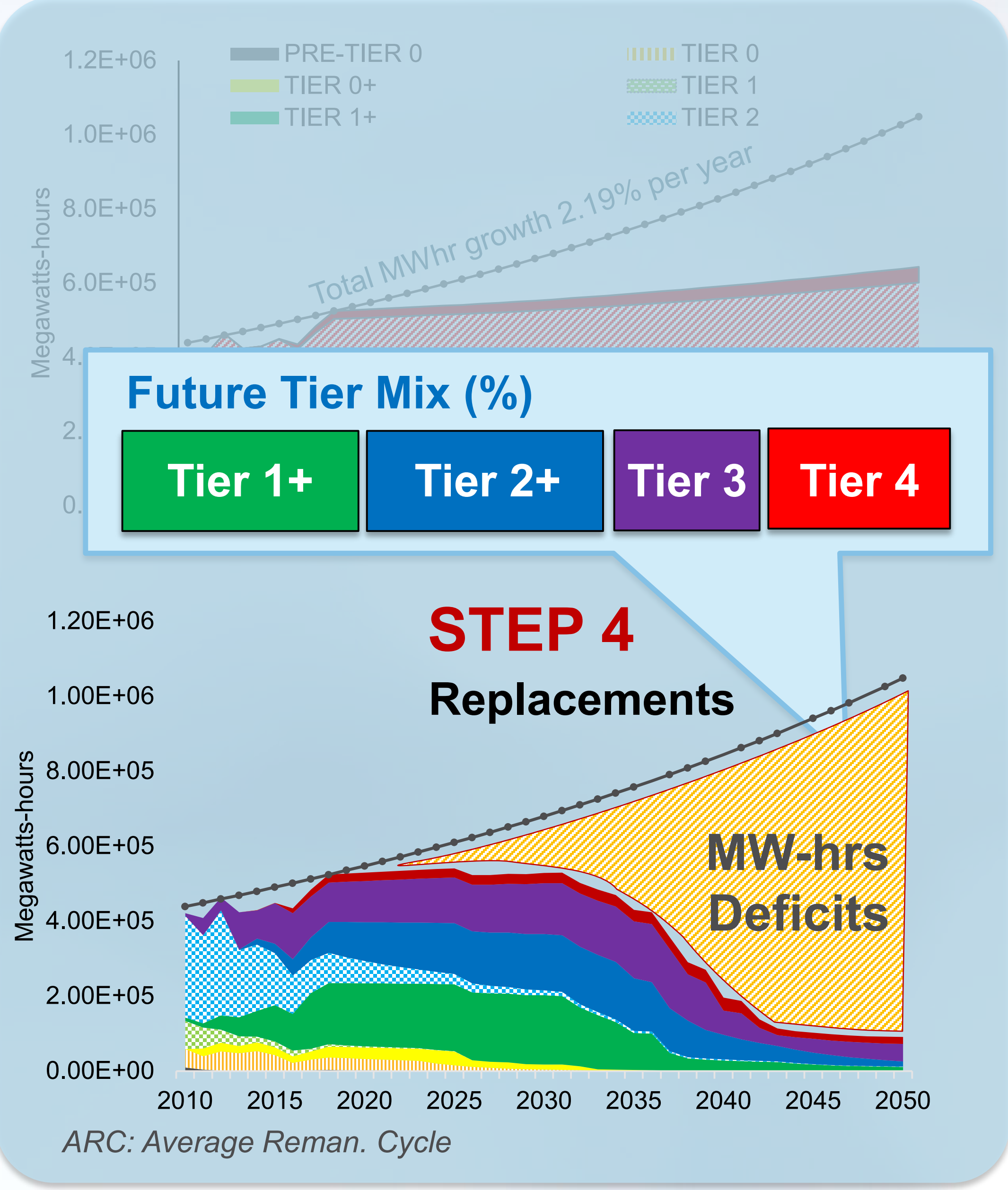

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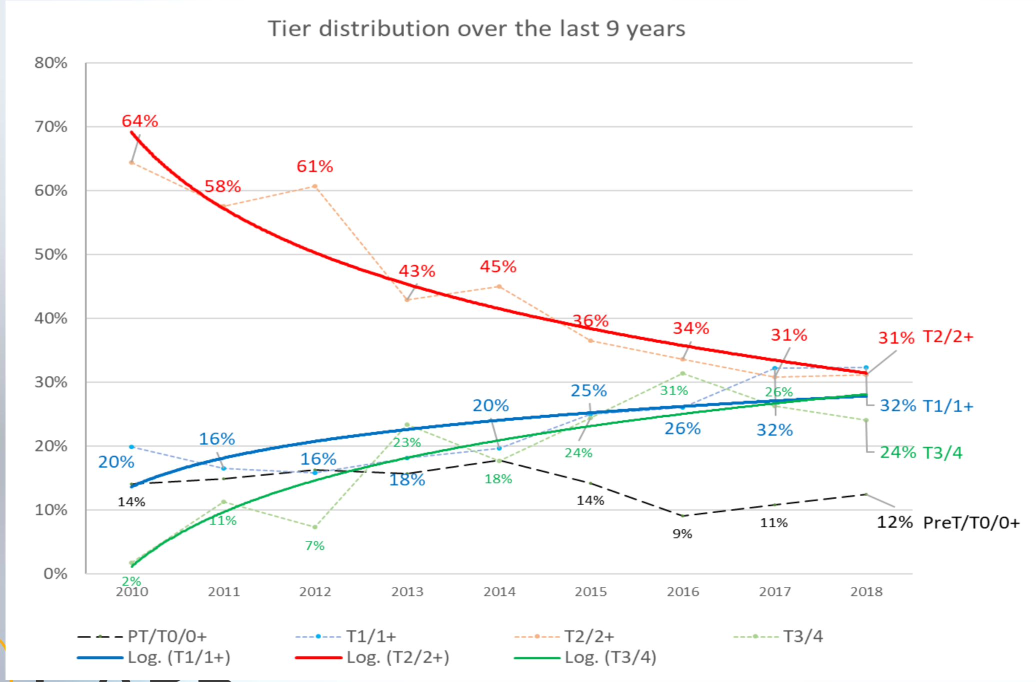
Market growth and Tier replacement

- Locomotive units will gradually be scrapped, parked, or converted to switchers (useful life is not infinite, even for increasing Tier groups)
- In most models, replacements would be new equipment, however (1) ongoing changes in purchasing habits, (2) lack of current or planned Tier 3 or 4 purchases, (3) parking large amounts of older locomotives that may be used again suggest that **future replacements will primarily be Tier 1+ or Tier 2+** with only moderate Tier 3 and Tier 4 purchases



Tier	Workload share (%) for the past 9 years
Tier 1/1+	30%
Tier 2/2+	30%
Tier 3/4	25%
Tier PT0/T0/0+	15%

Step 4: Replacement

Step 4. Distribution of MWhrs deficits to target tier groups

Tier Allocation of Replacement in Business-as-Usual scenario

Tier	Workload share (%) for the past 9 years
Tier 1/1+	30%
Tier 2/2+	30%
Tier 3/4	25%
Tier PT0/T0/0+	15%

Tier	Percent of Deficit MWHrs	
	Until 2030	CY 2050
Tier 1+	35%	0%
Tier 2+	35%	0%
Tier 3	15%	10%
Tier 4	15%	90%

CY	T1+	T2+	T3	T4
until2030	0.350	0.350	0.150	0.150
2031	0.350	0.350	0.150	0.150
2032	0.332	0.332	0.147	0.189
2033	0.313	0.313	0.145	0.229
2034	0.295	0.295	0.142	0.268
2035	0.276	0.276	0.139	0.308
2036	0.258	0.258	0.137	0.347
2037	0.239	0.239	0.134	0.387
2038	0.221	0.221	0.132	0.426
2039	0.203	0.203	0.129	0.466
2040	0.184	0.184	0.126	0.505
2041	0.166	0.166	0.124	0.545
2042	0.147	0.147	0.121	0.584
2043	0.129	0.129	0.118	0.624
2044	0.111	0.111	0.116	0.663
2045	0.092	0.092	0.113	0.703
2046	0.074	0.074	0.111	0.742
2047	0.055	0.055	0.108	0.782
2048	0.037	0.037	0.105	0.821
2049	0.018	0.018	0.103	0.861
2050	0.000	0.000	0.100	0.900

- The focus on T1+ / T2+ is based on current trends where T4 purchases are at or near zero
- MWHrs for Tier 1+/2+ are the primary increasing Tier groups
- Parked locomotives present an opportunity to be pulled back into service, would allow T4 to be phased in instead of purchased in huge quantities (which is unlikely based on current trends)

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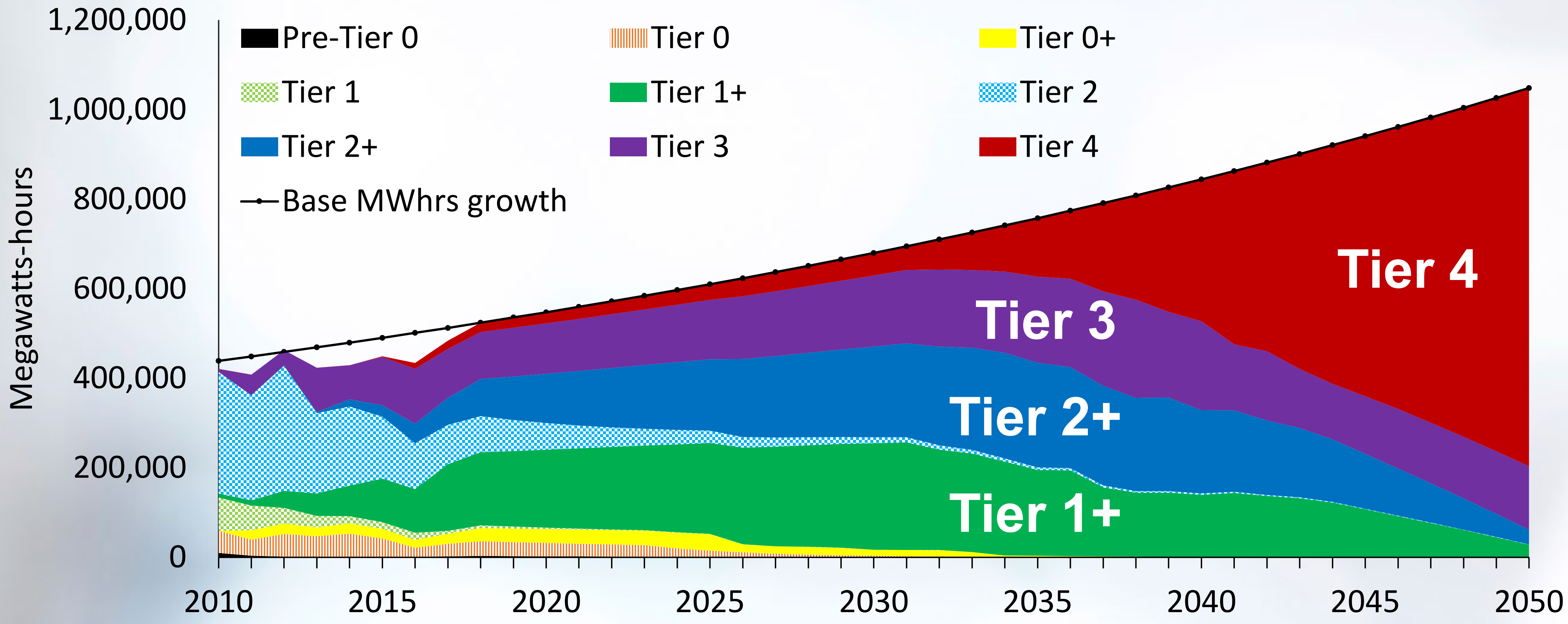
BAU (Business-As-Usual) Scenario

- **BAU scenario Tier distribution**



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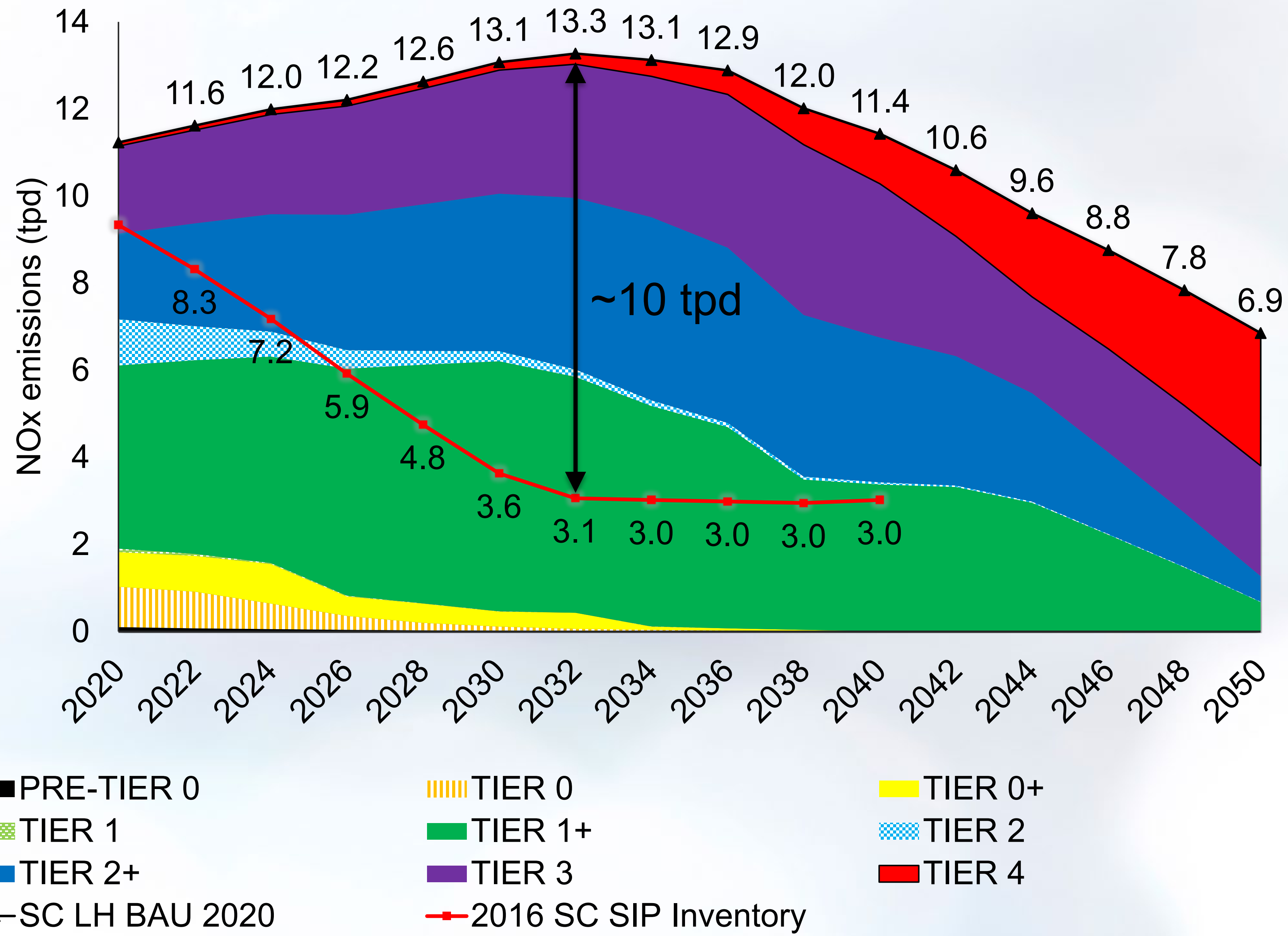
South Coast

NOX Emission Result

(BAU scenario)



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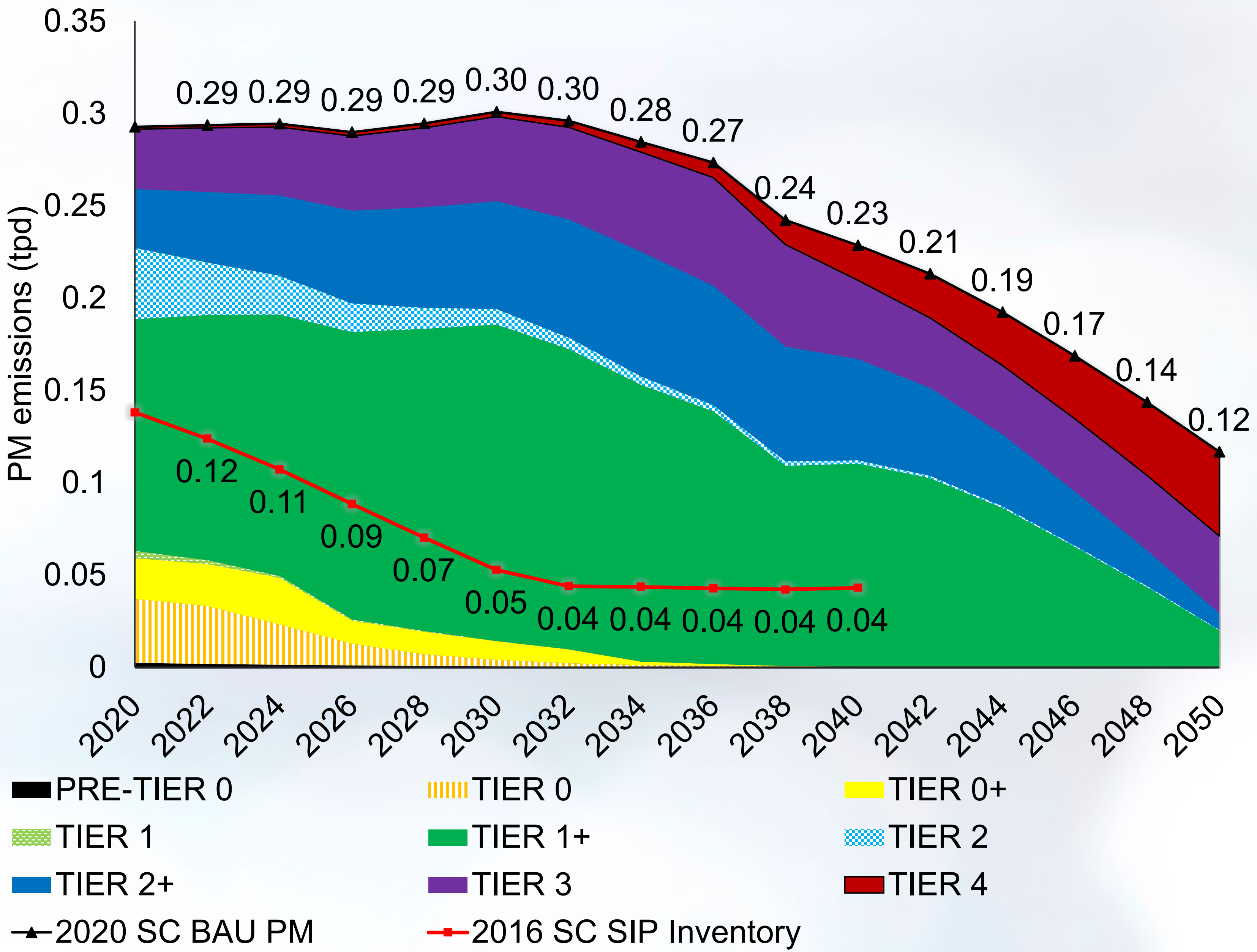
South Coast

PM Emission Result

(BAU scenario)



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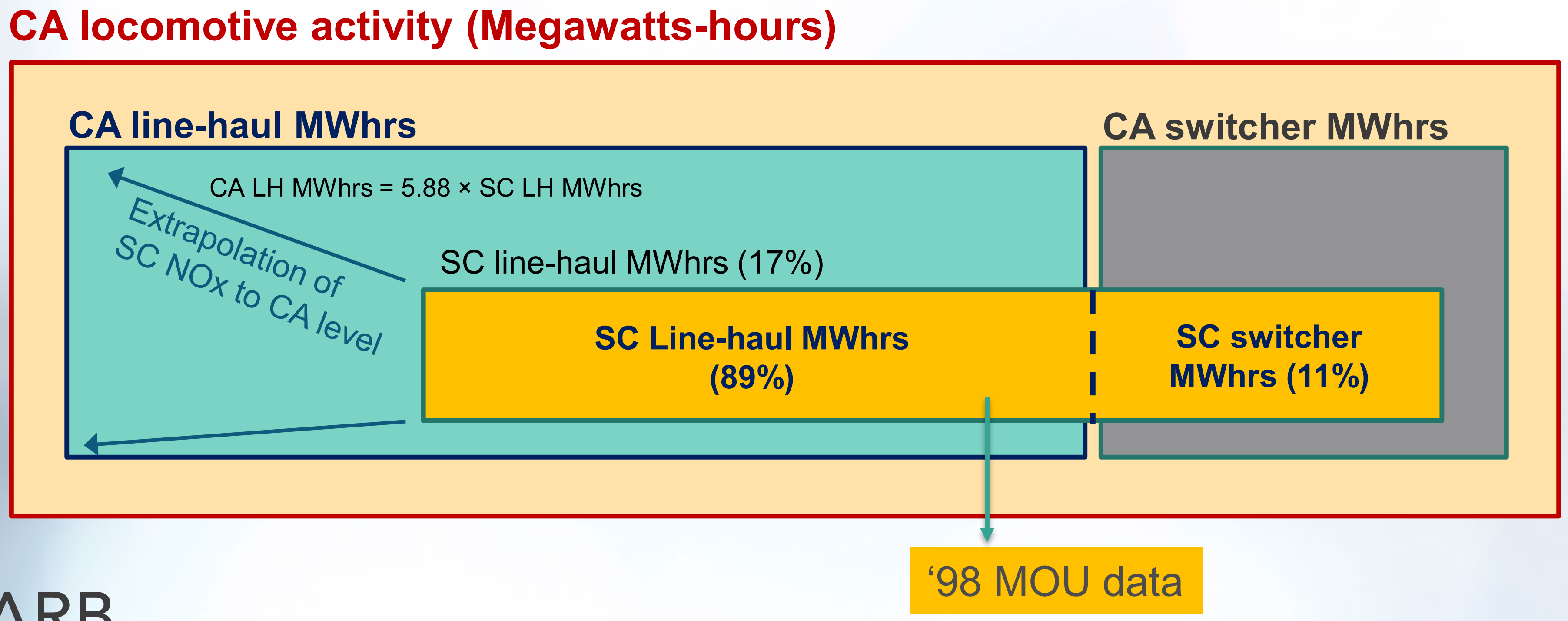
Scaling up South Coast MWhrs to CA MWhrs

- MOU data only covers locomotive activities in the South Coast Air Basin area, and it also include switcher activity.
- The model had to separate switchers' impact from the MOU data and scale up SC line-haul MWhrs to the CA level.
- CA GTM data, OFFROAD2017, 2016 SIP, and switcher emission inventory

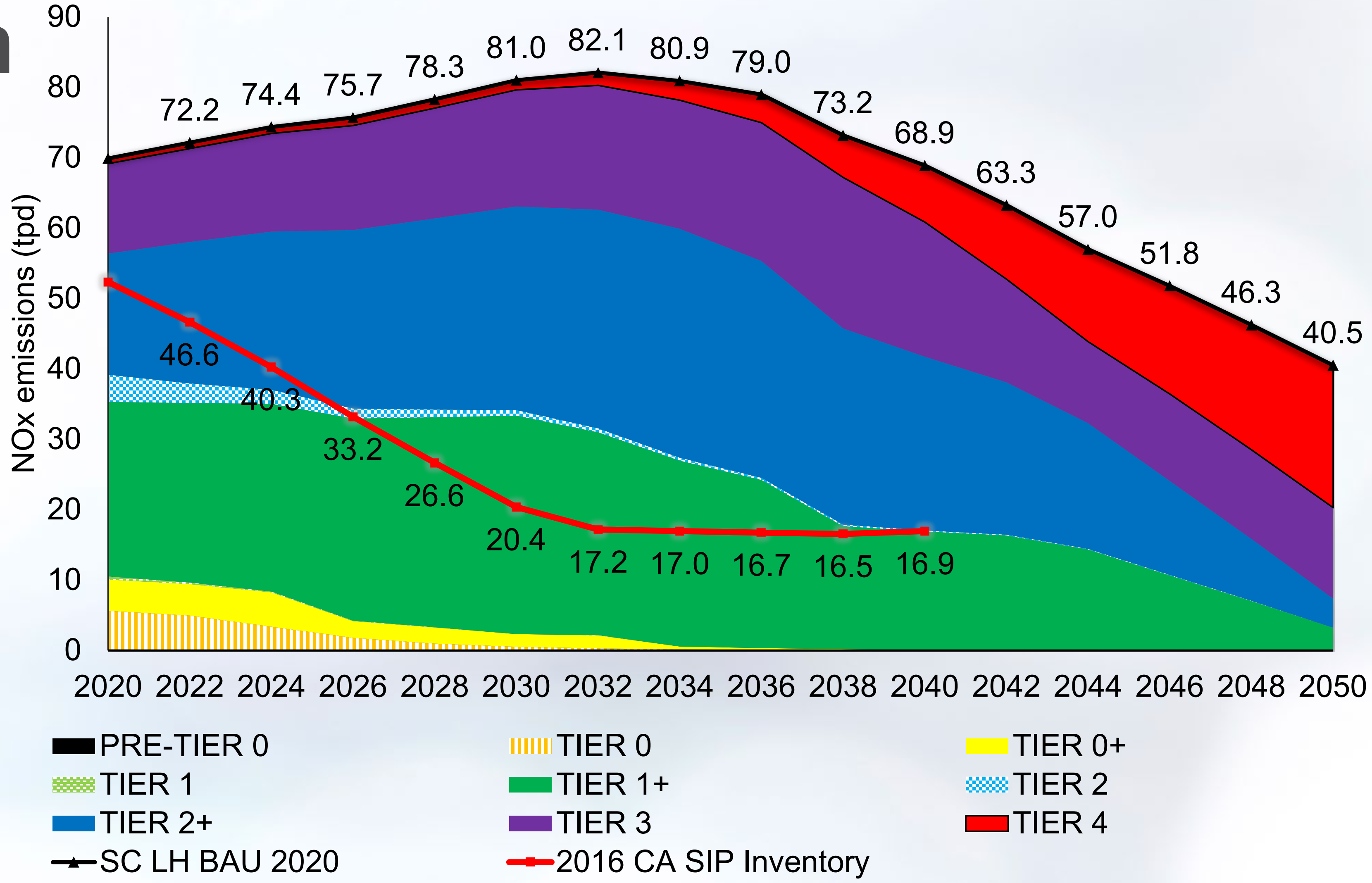


Statewide

NOX Emission Result

(BAU scenario)

NOx Emission Factor (US EPA , 2009)	
Tier	g/bhp-hr
Pre-Tier 0	13
Tier 0	8.6
Tier 0+	7.2
Tier 1	6.7
Tier 1+	6.7
Tier 2	4.95
Tier 2+	4.95
Tier 3	4.95
Tier 4	1.0



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Switcher Rail Yard emission inventory

What Data Did UP/BNSF Supply?

CEA submitted data on behalf of UP/BNSF in 2019

1. Combined statewide tier distribution for both companies

2. Number of full-time-equivalent (FTE) engines per railyard

- FTE = number of engines operating $= \dfrac{\#\ engines\ \times activity\ (hr/yr)}{24\ hr/day \times 365\ day/yr}$
- On average, a yard locomotive consumes 82,490 gal/yr (Source: U.S. EPA)
- Fuel (annual gal/yard) = (# FTE per yard) × (82,490 gal/yr)

Calculations based on general assumptions

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Model Assumptions

CEA Assumptions

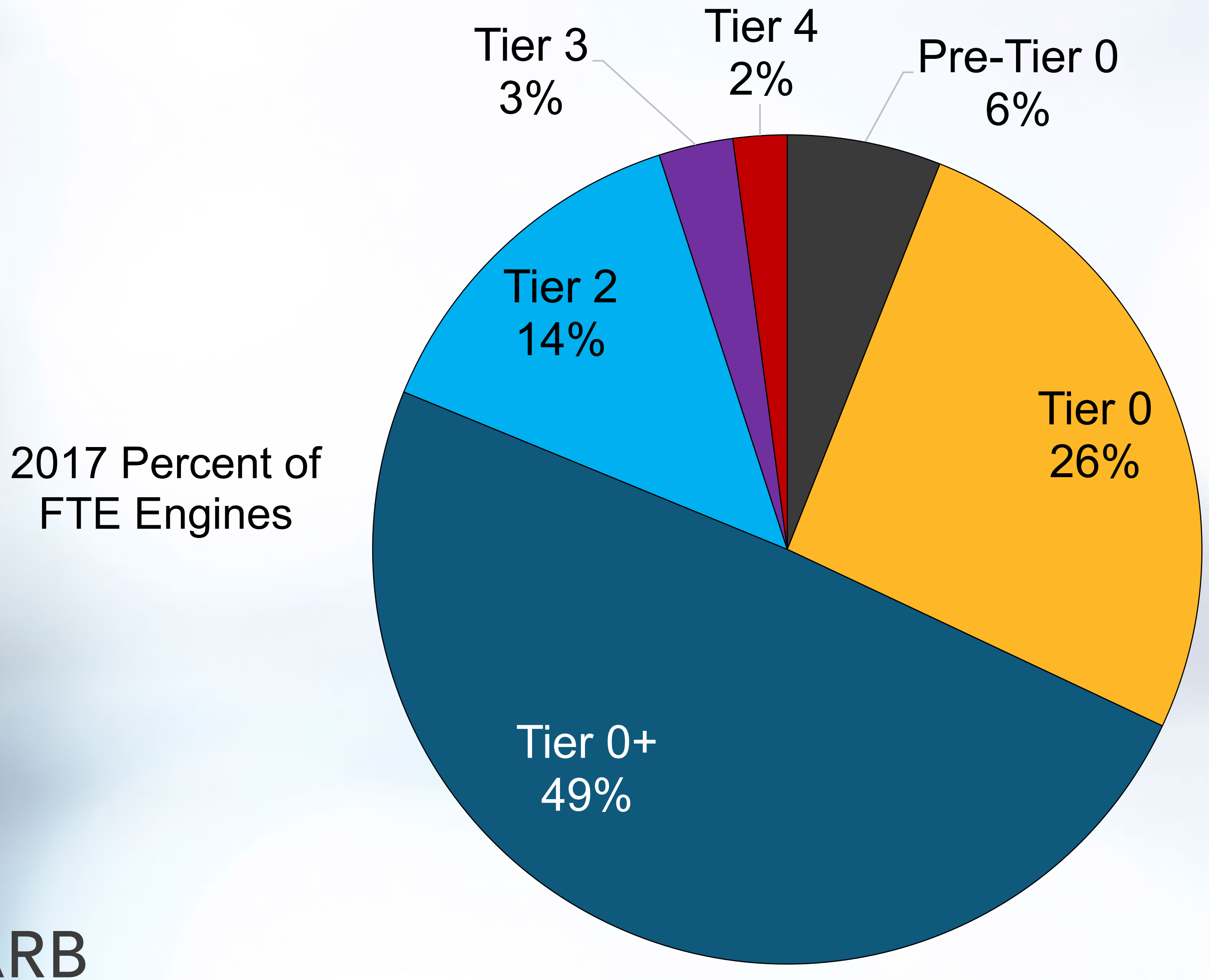
- Tier distribution applied equally to all yards
- CEA assumes fuel consumption according to U.S. EPA conversion rate

CARB Assumptions

- Calendar Year 2017 data
- 2.19% fuel growth rate matches freight growth assumptions in the new line haul Inventory
- No forced turnover or engine purchases/trades, except phase-out of Pre-Tier 0 in 2030

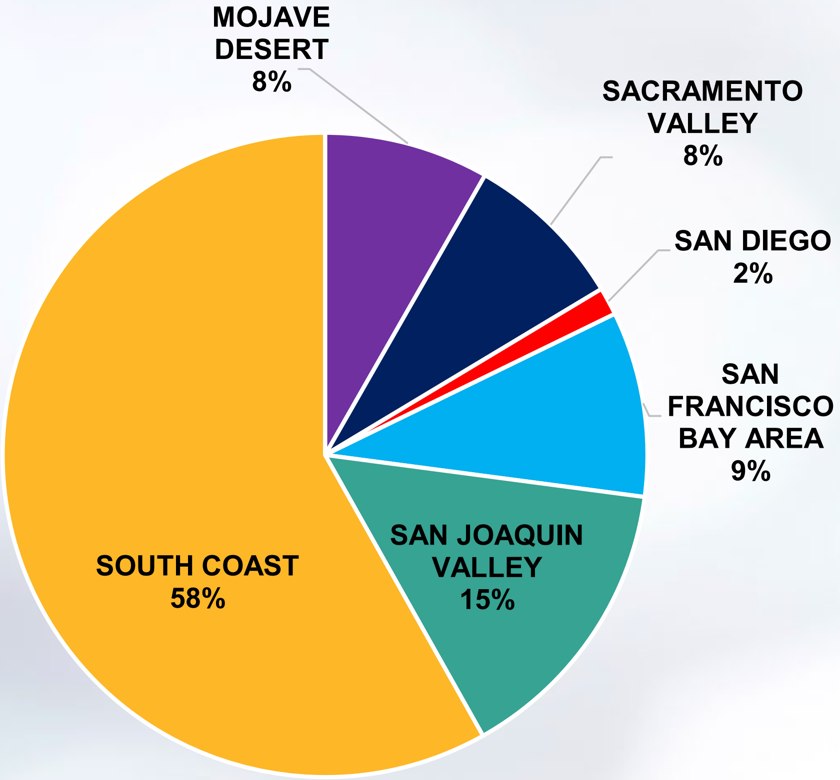
** Lack of turnover is supported by a study of South Coast locomotives between 2010 and 2018, and their observed turnover practices

Base Year Statewide Tier Distribution



Base Year FTE and Fuel by Air Basin

Air Basin	Number of yards (BNSF:UP)	Number of FTE	Annual Fuel (gallons)	Percent of Fuel
Mojave Desert	1:0	8.17	674,161	8%
Sacramento Valley	0:3	8.04	662,782	8%
San Diego	1:0	1.38	114,040	1%
San Francisco Bay Area	1:5	9.19	758,823	9%
San Joaquin Valley	4:3	14.61	1,204,789	15%
South Coast	5:5	57.51	4,743,834	58%



2017 Percent Fuel

Annual Fuel = FTE x 82,490 gal/yr

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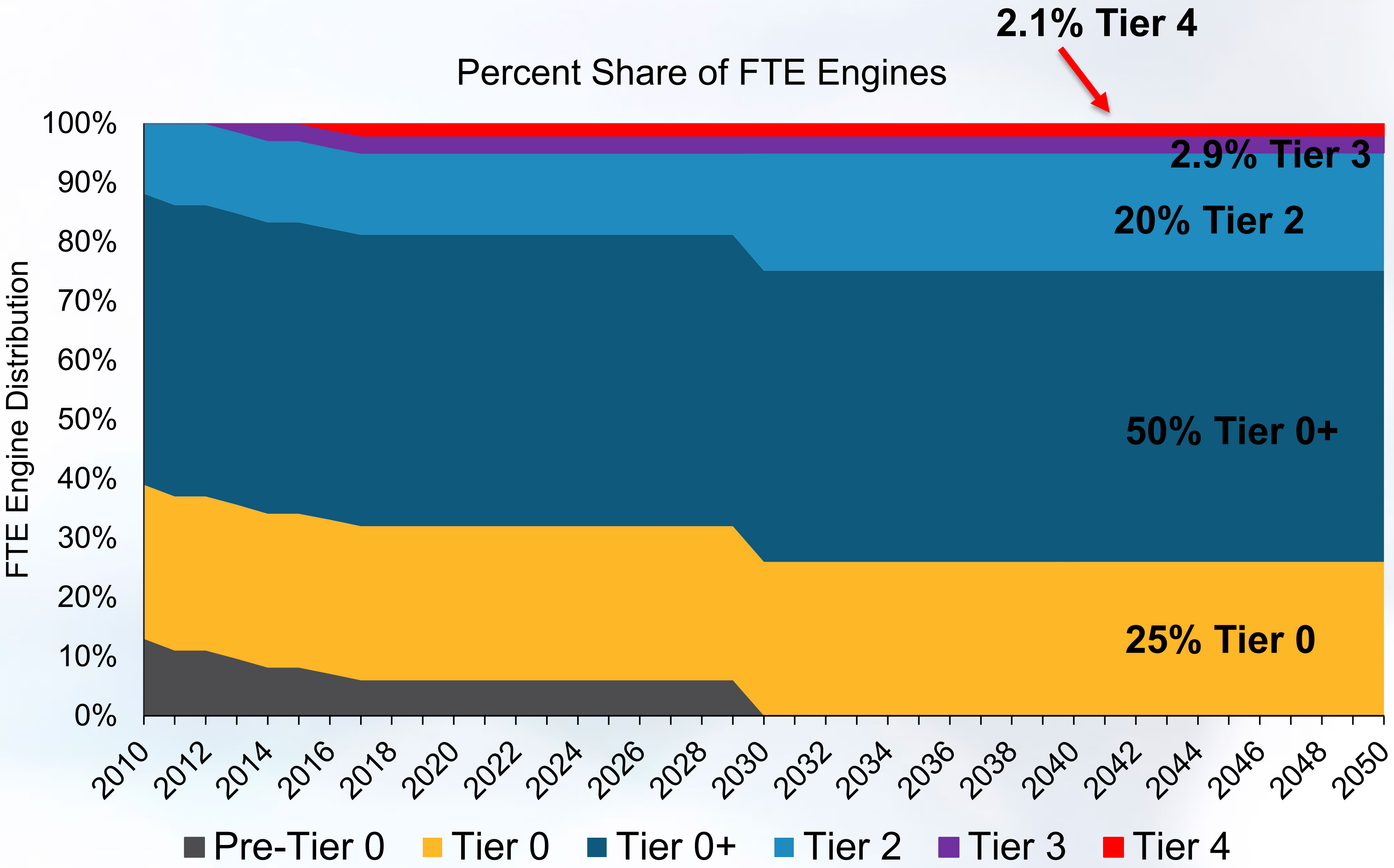
Statewide FTE Population by Tier

Tier	Turnover Notes
Pre-Tier 0	in 2030, replace with Tier 2
Tier 0	before 2000, all to Pre-Tier 0
Tier 0+	before 2001, all to Pre-Tier 0
Tier 2	before 2005, all to Pre-Tier 0
Tier 3	before 2013, all to Pre-Tier 0
Tier 4	before 2016, all to Pre-Tier 0



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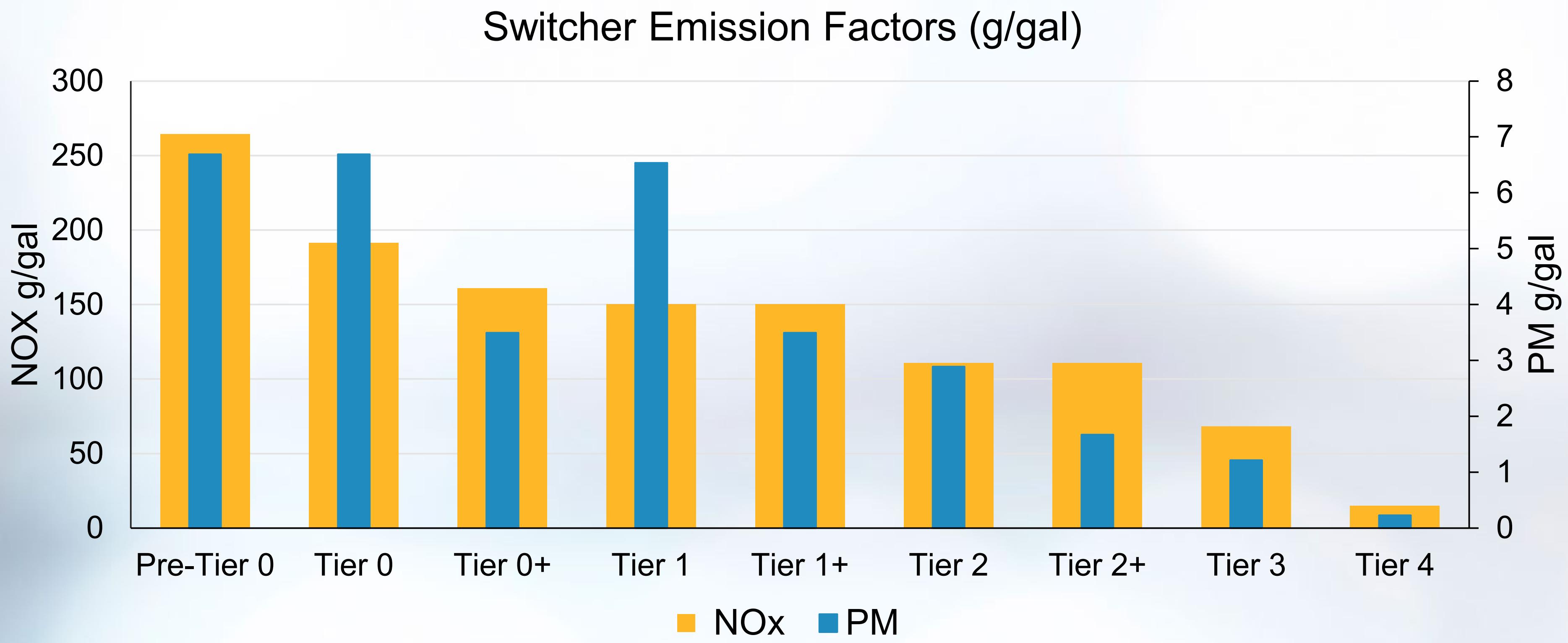
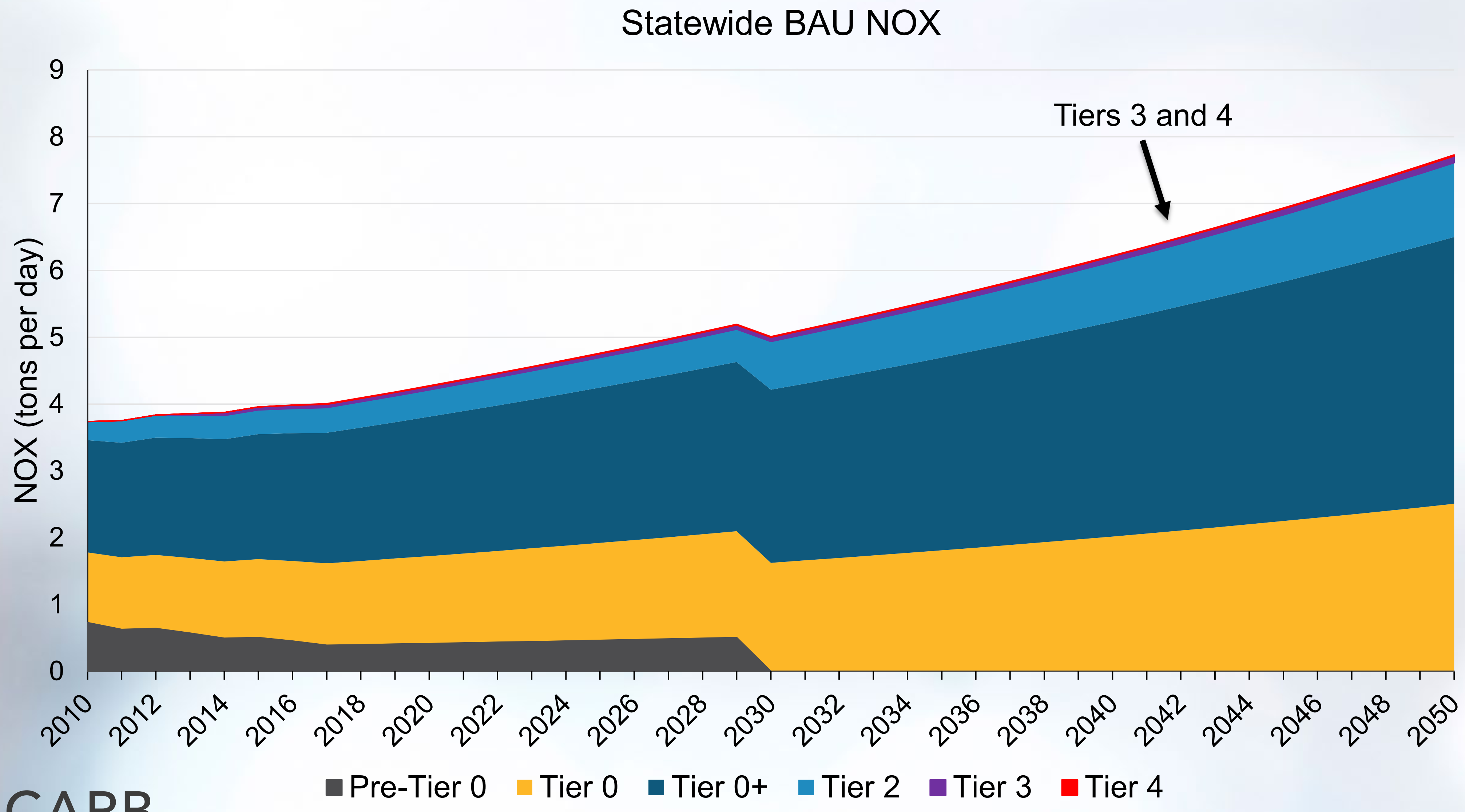
Switch Emission Factors

Switch Emission Factors (g/bhp-hr) x Conversion Factor (bhp-hr/gal) = Emissions Factor (g/gal)



https://nepis.epa.gov/Exe/ZyPDF.cgi/P100500B.PDF?Dockey=P100500B.PDF

Switcher Statewide NOx



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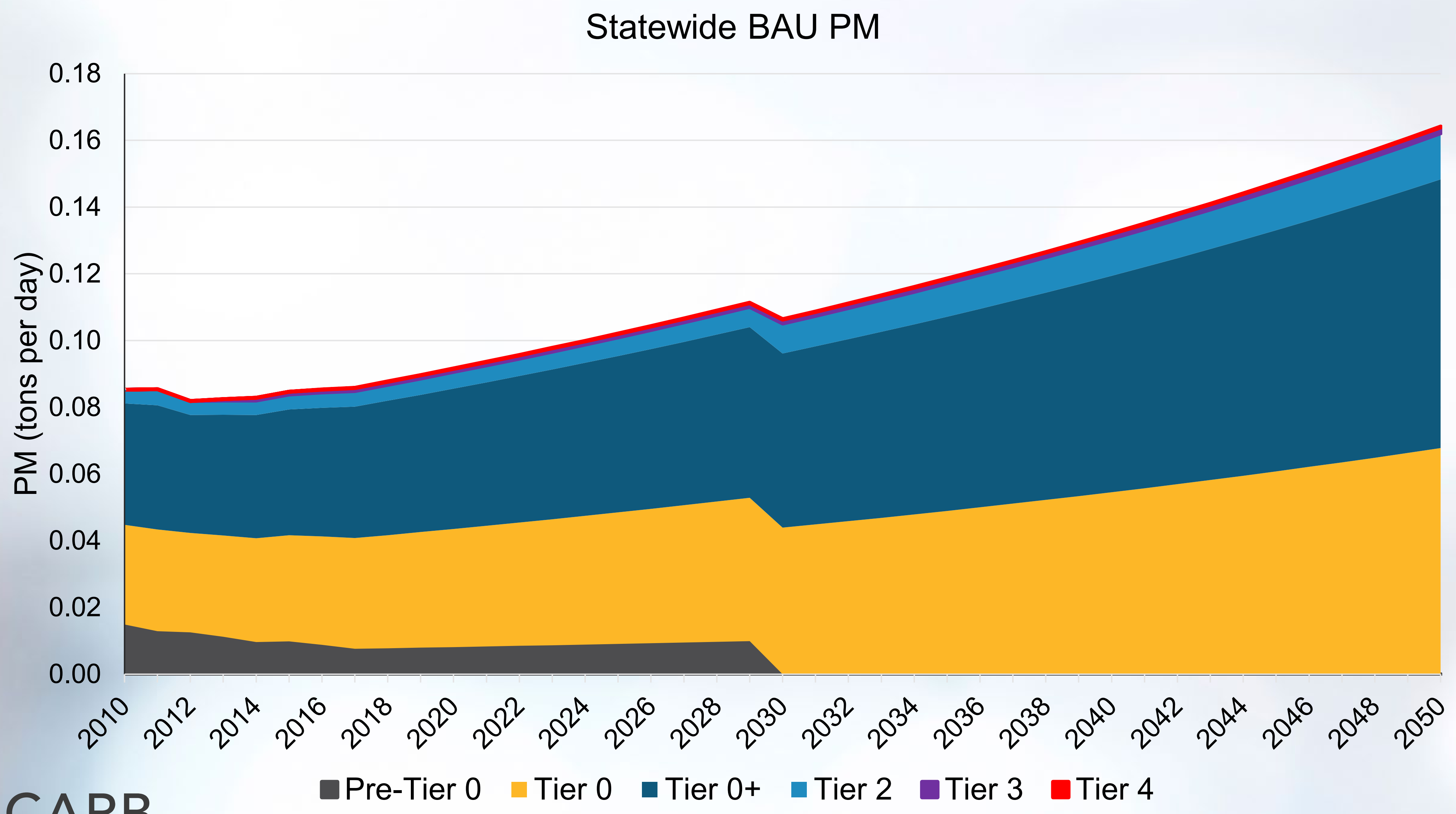
Switcher Statewide PM



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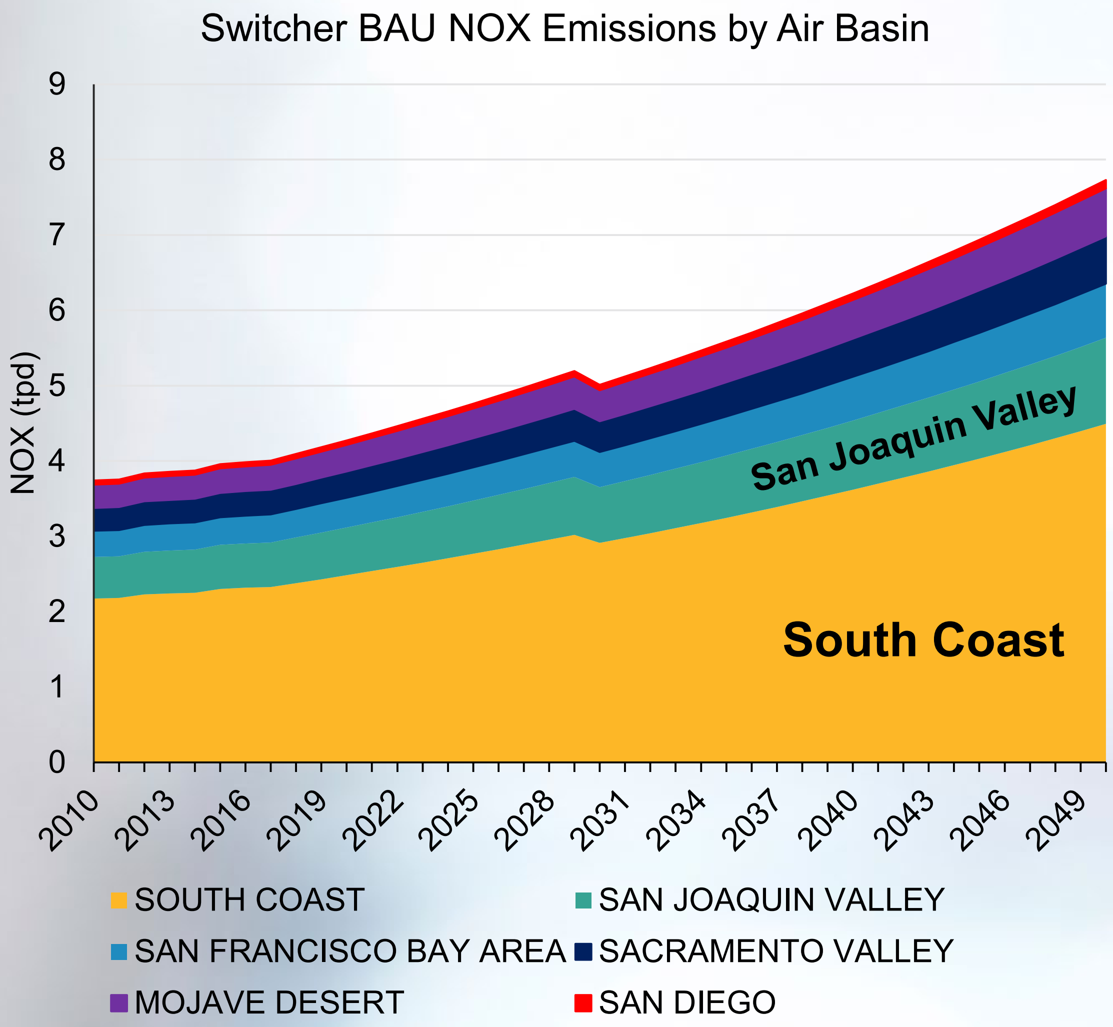
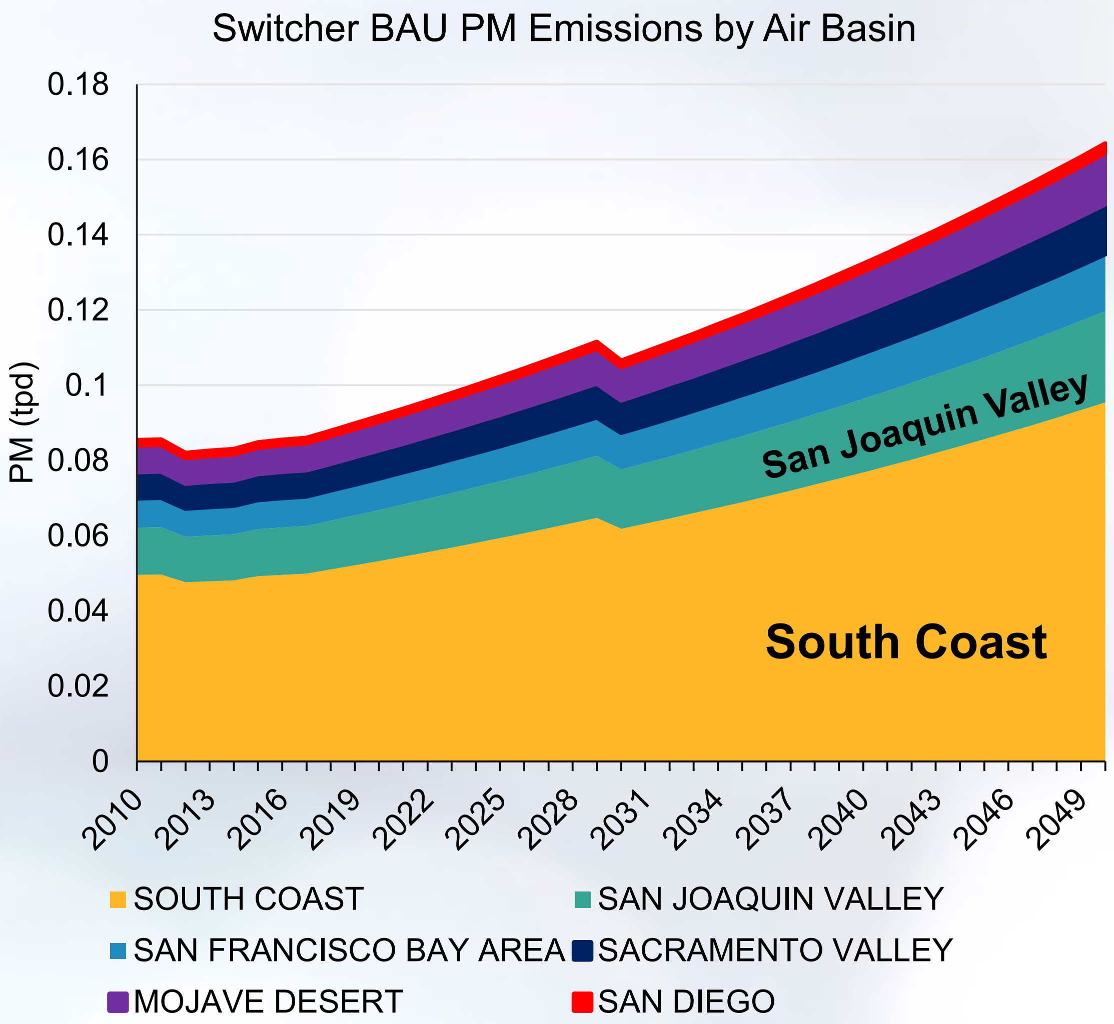
Air Basin Emissions





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Short Line Rail emission inventory

Short Line Rail Emission Inventory

What is Short Line Rail?

- Local or regional rail lines that haul freight and provide switching (Class 3)
- Lower revenue than line haul (Class I)
- No reporting obligations

Short Line Rail Summary

Rail companies voluntarily submitted data in 2017

- 25 rail companies – Commercial, switching, and recreational rail lines

Data

- Locomotive model year, tier, and horsepower
- Fuel consumption data is for 2015

Growth

- Assumed to be constant – no available future plans

Turnover

- Assumed no turnover – companies do not make long-range business plans
- Average age is 43 years old

(Engines have been bought, sold, leased, and traded over and over again)

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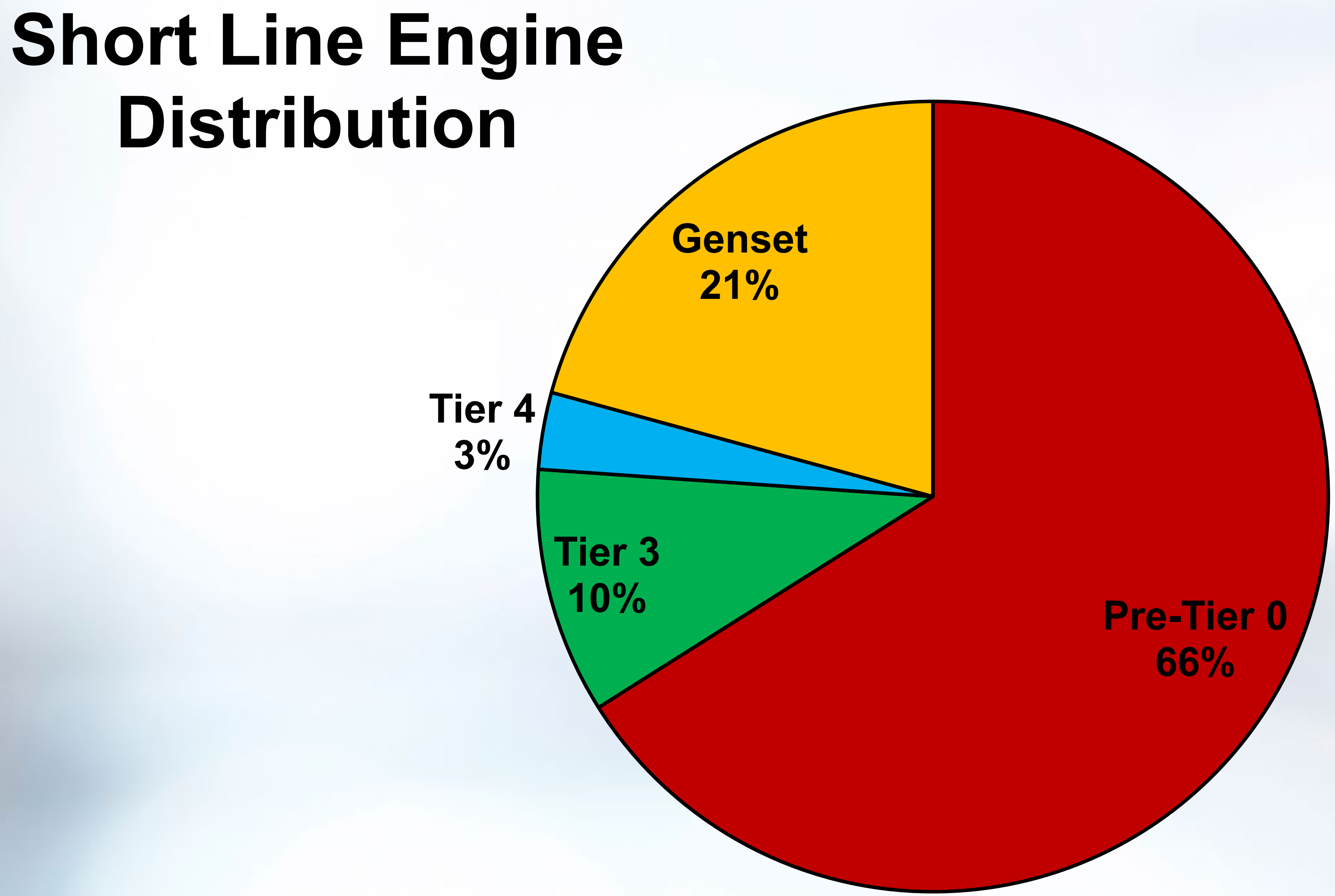
Short Line Tier Distribution



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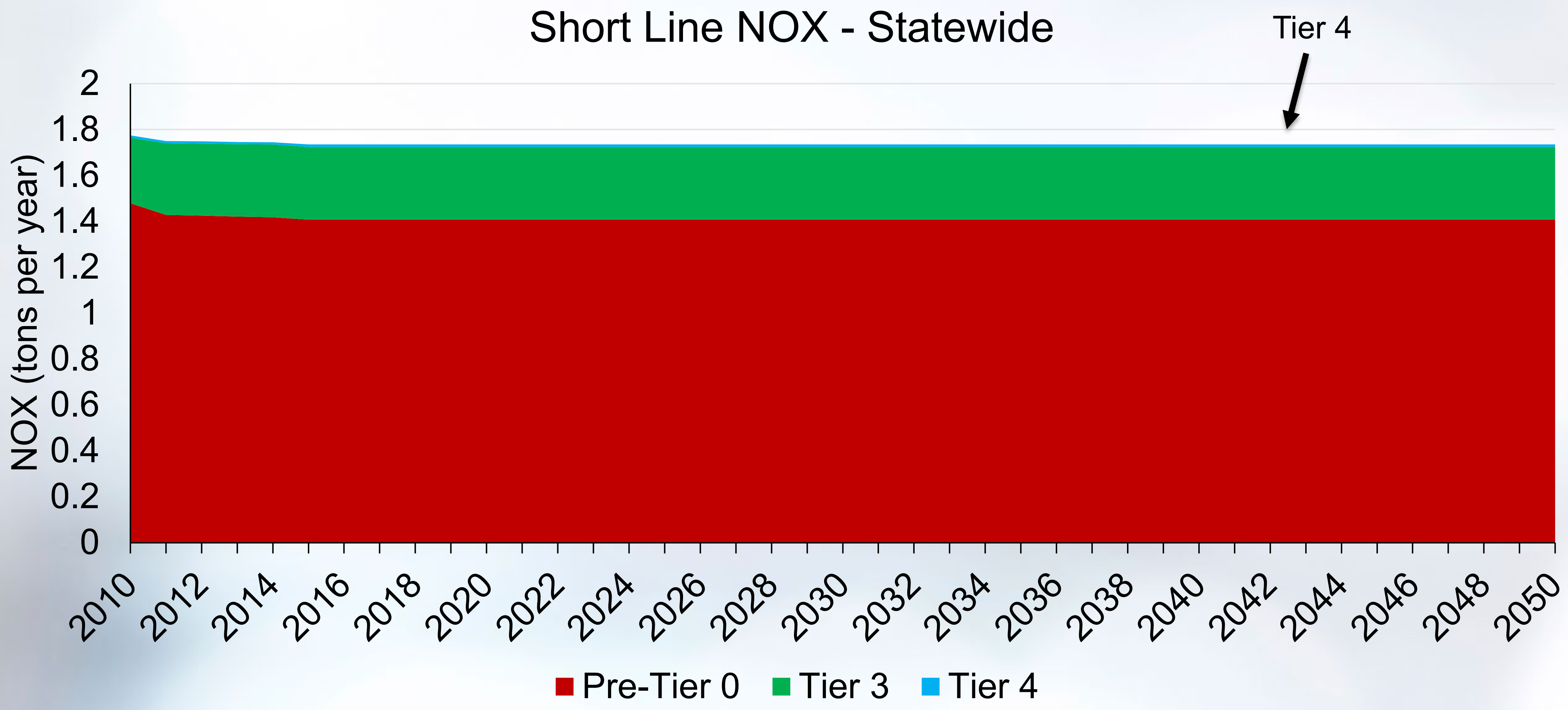
Short Line Statewide NOx



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Passenger Rail emission inventory

Passenger Rail Emission Inventory

Passenger Rail

- Commuter, intercity and interstate passenger rail operating within the state of California.

History

- Commuter rail is relatively newer in California, with service beginning in 1991
- Amtrak intercity and interstate lines are significantly older.

Passenger Rail Summary

Rail companies voluntarily submitted data

- Base Year 2017
- Six rail companies

Data

- Locomotive model year, tier, and horsepower
- Fuel Consumption

Fuel

- Fuel consumption is averaged over several years, by rail company (data provided fuel per engine)
- Fuel growth is assumed to be constant – no plans for additional routes or other operational changes

Turnover

- Turnover based on individual rail company’s plans

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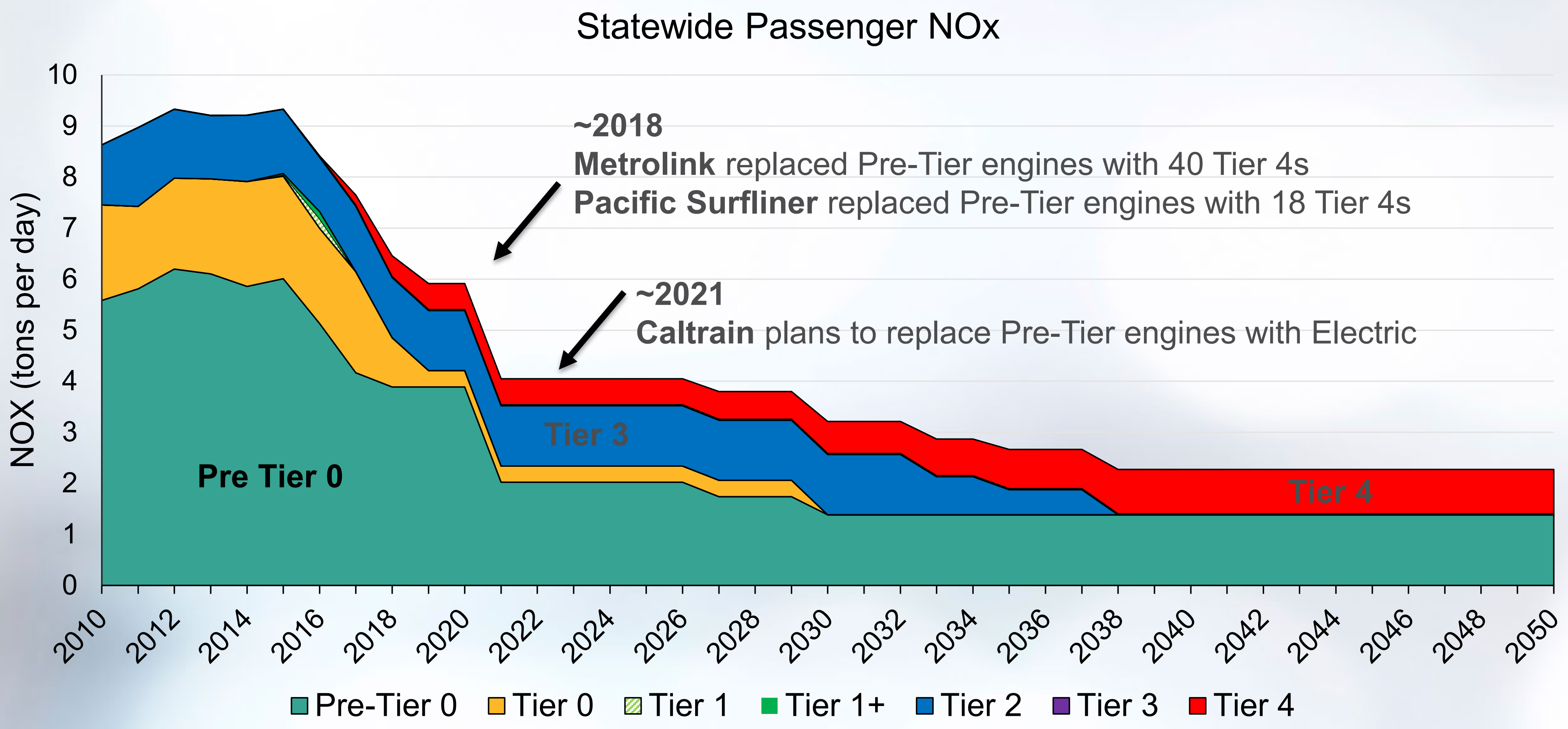
Passenger Rail Statewide NOx



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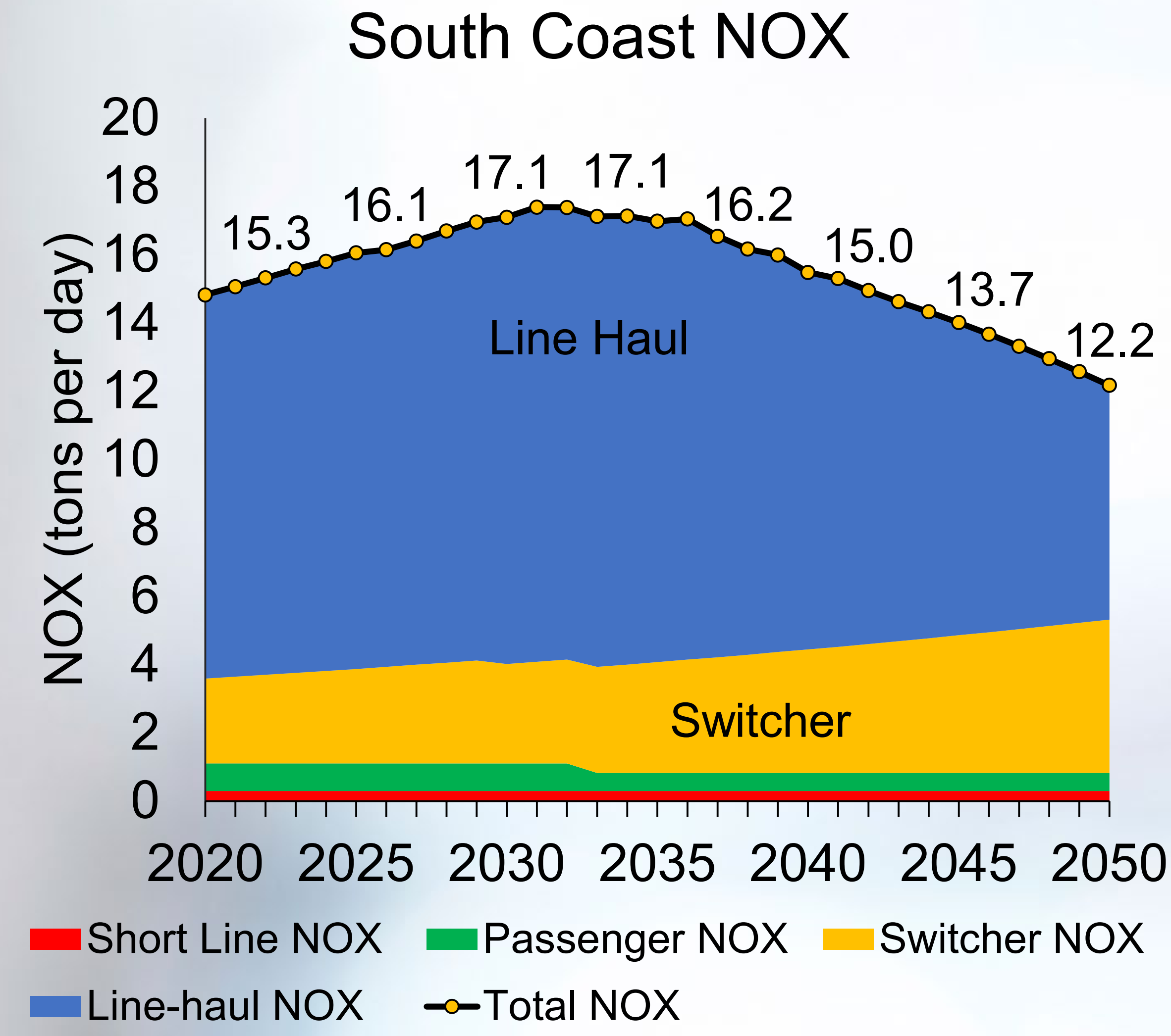
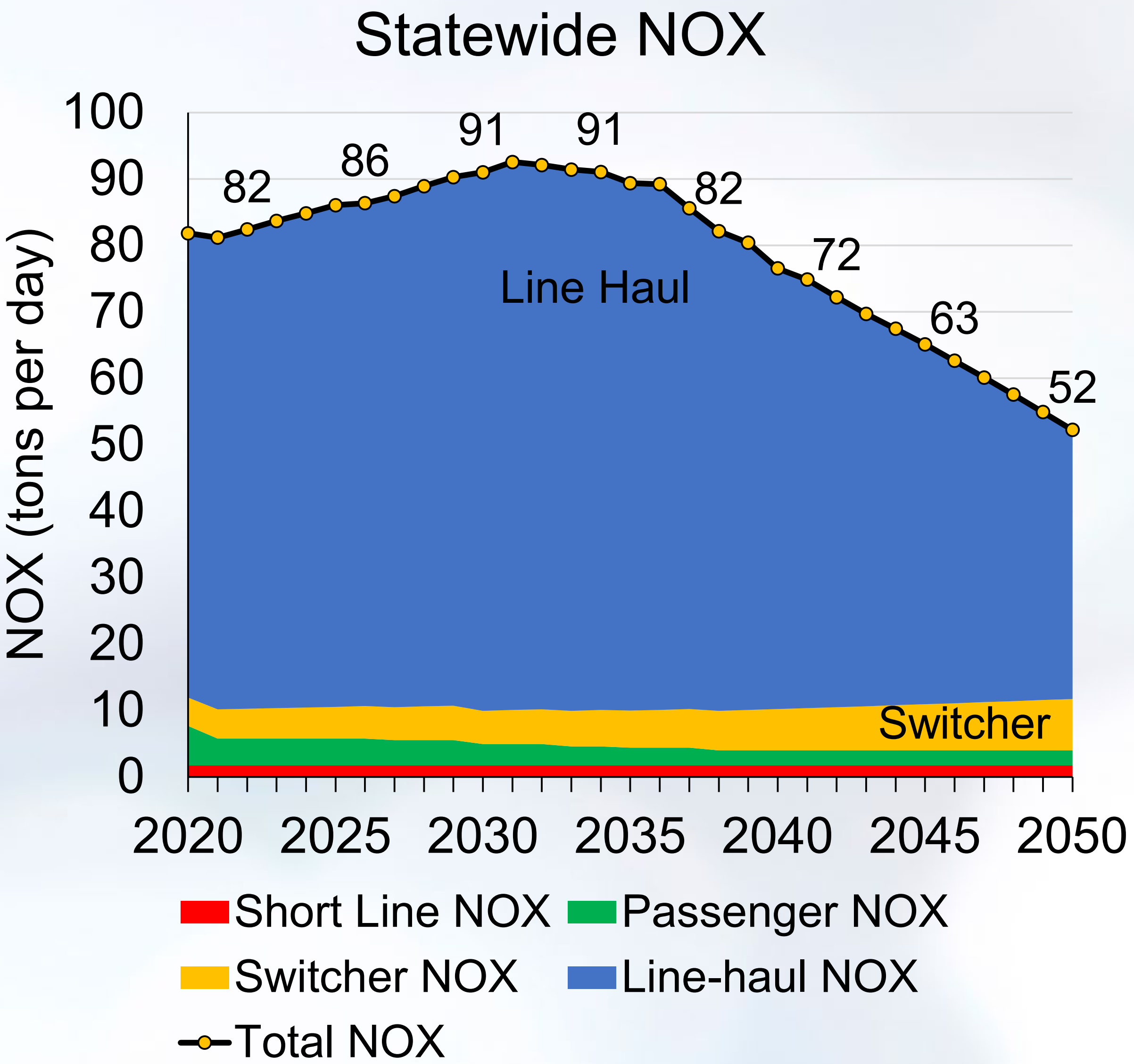
Total Locomotive NOx Emissions Inventory and Mobile Source Strategies (MSS)

Locomotive NOx Emissions





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2020 Mobile Source Strategy (MSS)

- MSS considers technology mixes for mobile source sector that are needed to meet mid-term air quality goals and mid-century climate goals
- MSS scenarios are developed to illustrate the extent of transformation needed to achieve the clean air goals
- Extensive additional work would be needed to translate these scenarios into measures
- Additional information can be found at: https://ww2.arb.ca.gov/resources/documents/2020-mobile-source-strategy

Line Haul Scenarios Considered

Scenarios	Average Reman Cycle (ARC)	MWhrs deficit allocation (Unit replacement of RRs) (T1+ : T2+ : T3 : T4)	Note
BAU	No reman limit policy	- Until 2030 40% : 40% : 10% : 10% - Until 2050 0% : 0% : 10% : 90%	• Tier 1+ and Tier 2+ will be the majority by 2030 which is the predicted major turnover timing of the locomotives in the CA operation. • Tier 4 (possibly including T5) will take over the workload of its predecessors.
MSS	Twice-remanned units are not operated in CA operations	0% : 0% : 0% : 100%	• Tier 5 adoption scenario - All old Tiers except for Tier 4 are almost phased out by 2035 - MWhrs of Tier 5 increases from 2028 to 2050 at 35% per year. → 100% of activity share by 2050

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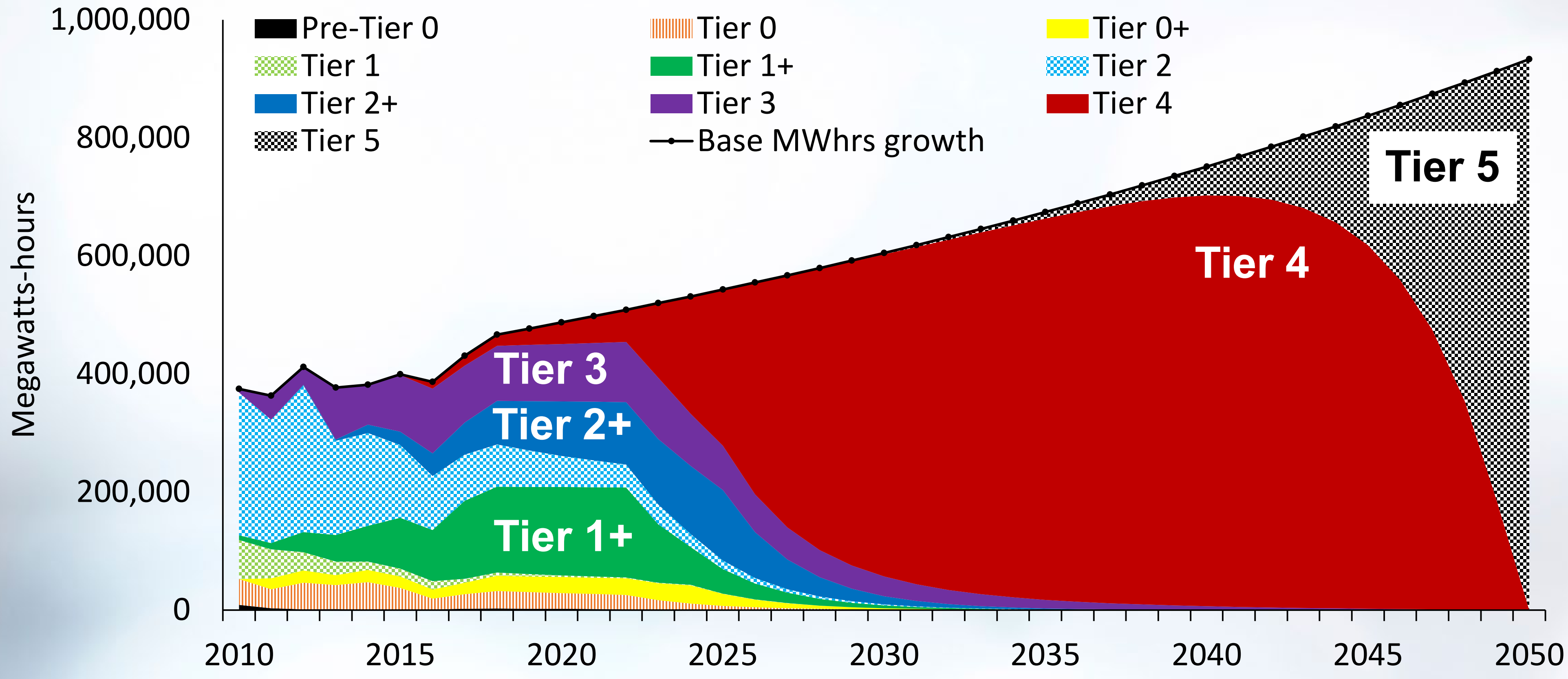
MSS (Mobile Source Strategy) Scenario

- **MSS scenario Tier distribution**



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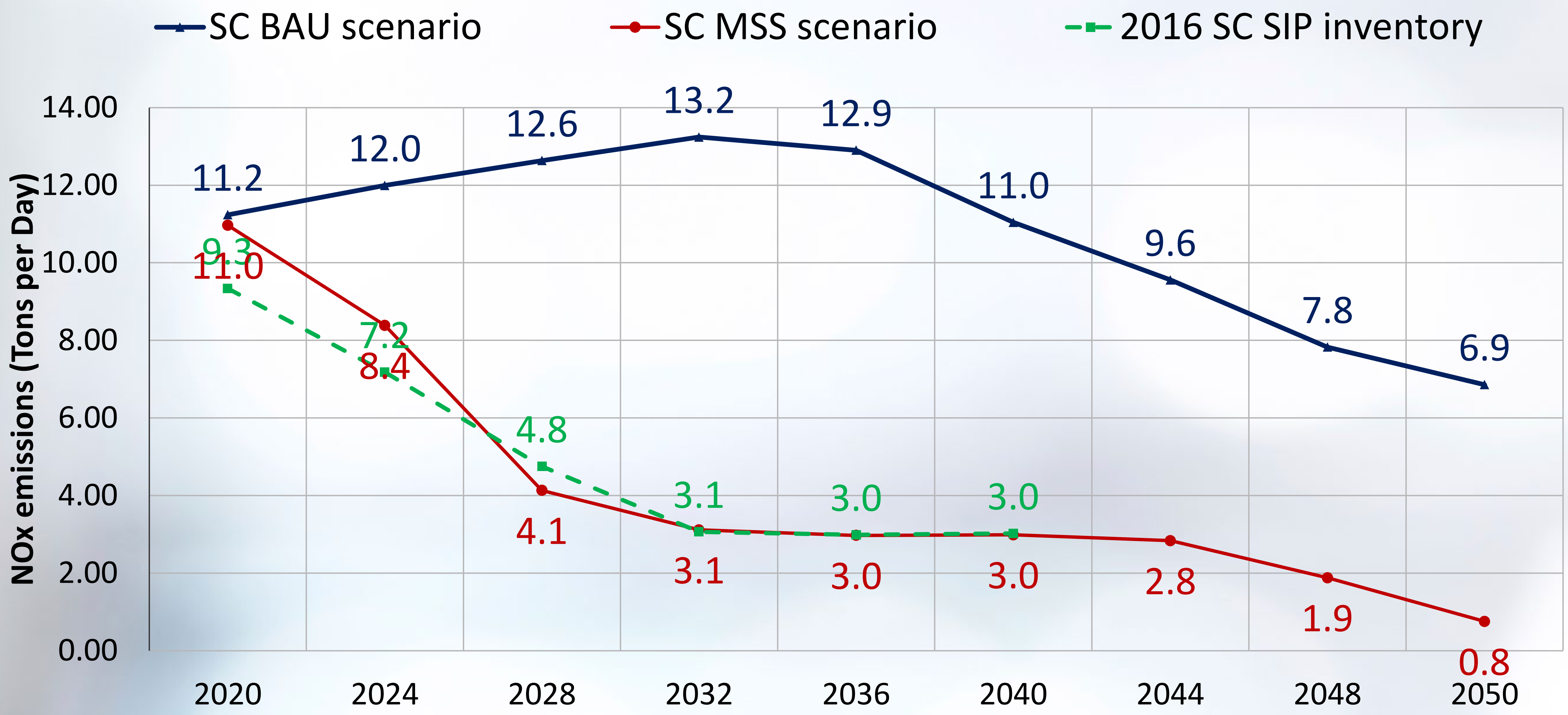
SC NOx emission projections



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Switcher Scenarios Considered

Scenarios	2017 Tier Mix (PTO:TO:T0+:T2:T3:T4)	2030 Tier Mix (PTO:TO:T0+:T2:T3:T4)	Notes
BAU	6% : 26% : 49% : 14% : 3% : 2%	0% : 26% : 49% : 20% : 3% : 2%	• No purchases/turnover • Turnover Pre-Tiers to Tier 2 in 2030.
Optimistic		0% : 0% : 0% : 95% : 3% : 2%	• Turnover all Pre-Tier, Tier 0, Tier 0+ turnover over to Tier 2 by 2030.
Aggressive		0% : 0% : 0% : 20% : 30% : 50%	• Turnover all Pre-Tier, Tier 0, Tier 0+ by 2030. • Only Tier 2, Tier 3, Tier 4, with primarily Tier 4.

*ARB is reviewing zero emission battery technology for switchers and planning to incorporate them in future MSS scenarios this year

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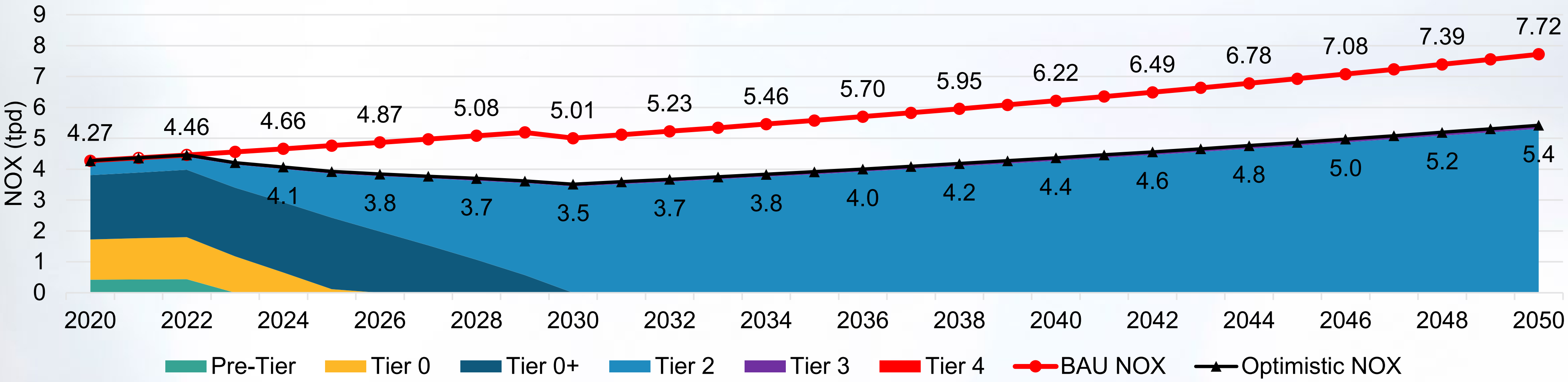
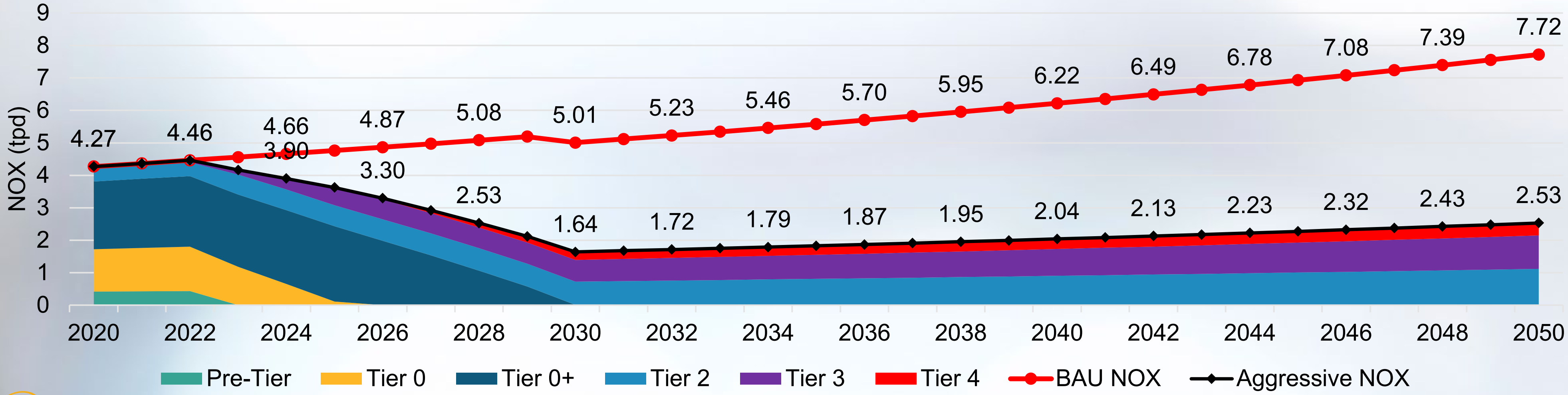
Scenarios: NOX

Switcher Scenario - Optimistic



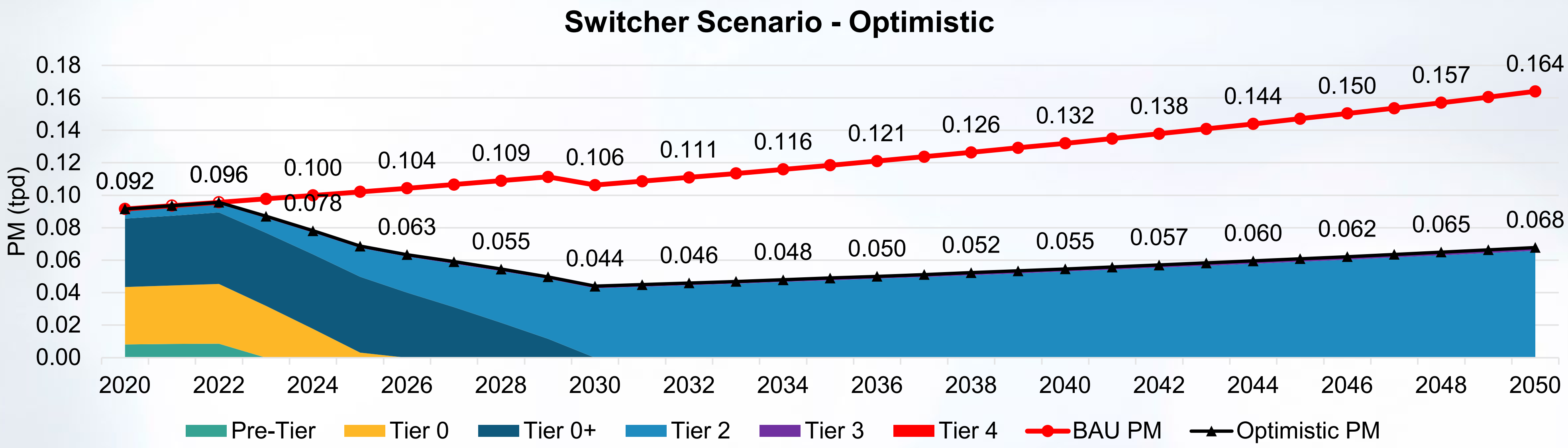
Pre-Tier	0%
Tier 0	0%
Tier 0+	0%
Tier 2	95%
Tier 3	3%
Tier 4	2%

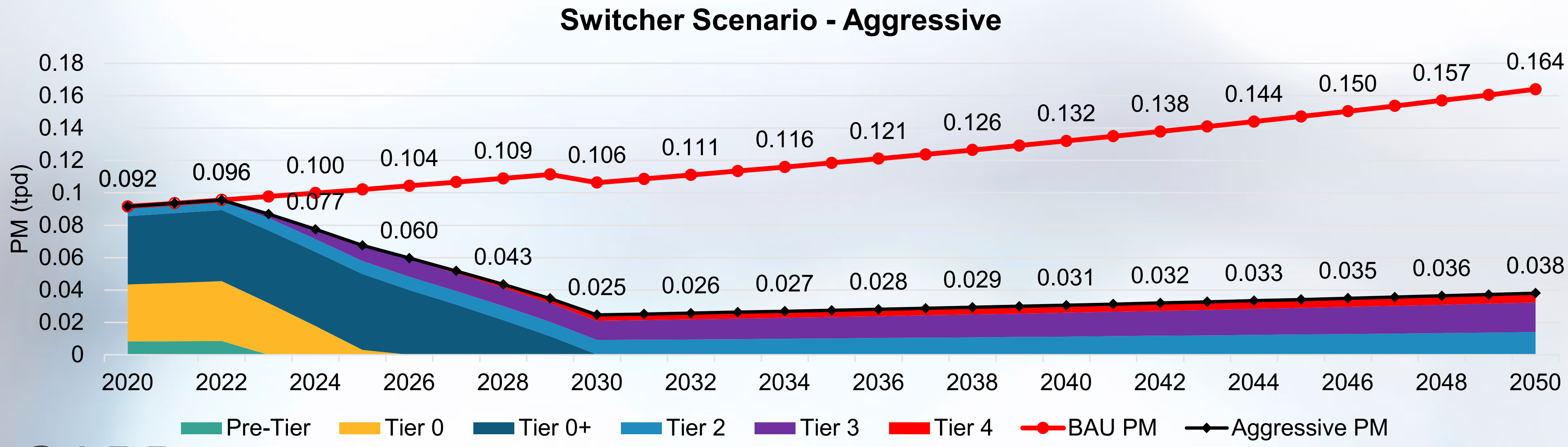
Switcher Scenario - Aggressive



Pre-Tier	0%
Tier 0	0%
Tier 0+	0%
Tier 2	20%
Tier 3	30%
Tier 4	50%

Scenarios: PM





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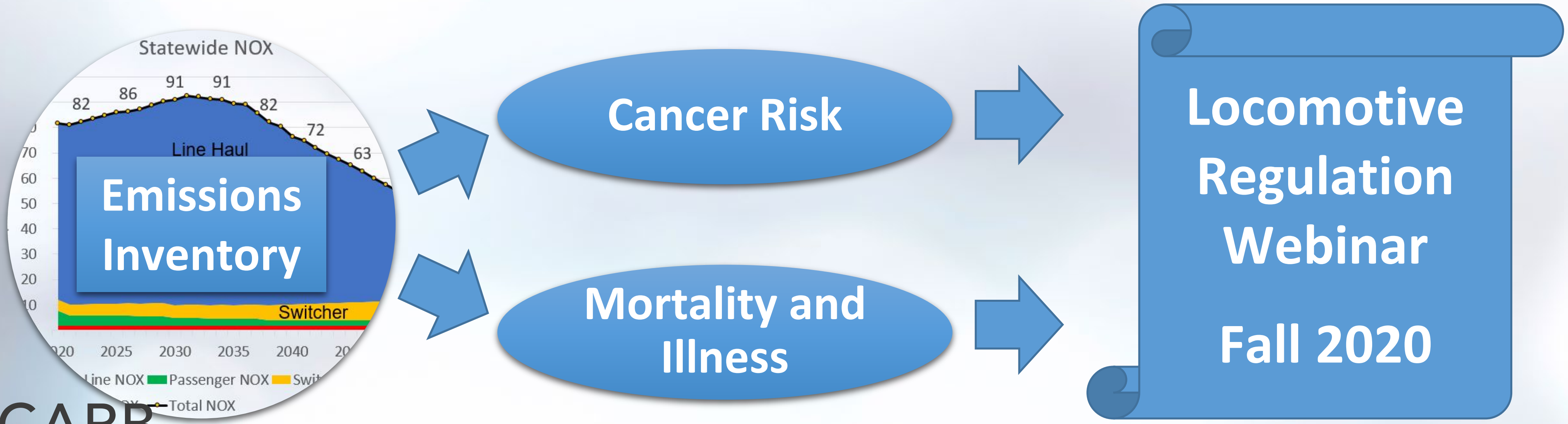
Emissions Inventory and Health Impact

Emissions Inventory and Health Impact

- Emissions inventory is significant part of health risk analyses.
- Cancer risk characterization near railyards
- Mortality and Illness from locomotive emissions
- Health Impacts from locomotive emissions will be updated during Fall Locomotive Regulation Webinar.



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Timeline

Public Workshop
September 2020
(Today)

Draft Inventory
mid-September 2020

Comments on inventory
October 1, 2020

Final Inventory
Late 2020

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Questions and Contacts

- Questions, comments and feedback are encouraged and welcome
- To address comments and reflect any changes, please submit comments and any supporting data by **October 1, 2020**

Health Risk and Regulatory Related Questions

Freight Hotline
freight@arb.ca.gov

Inventory or MSS Questions

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Thank you
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