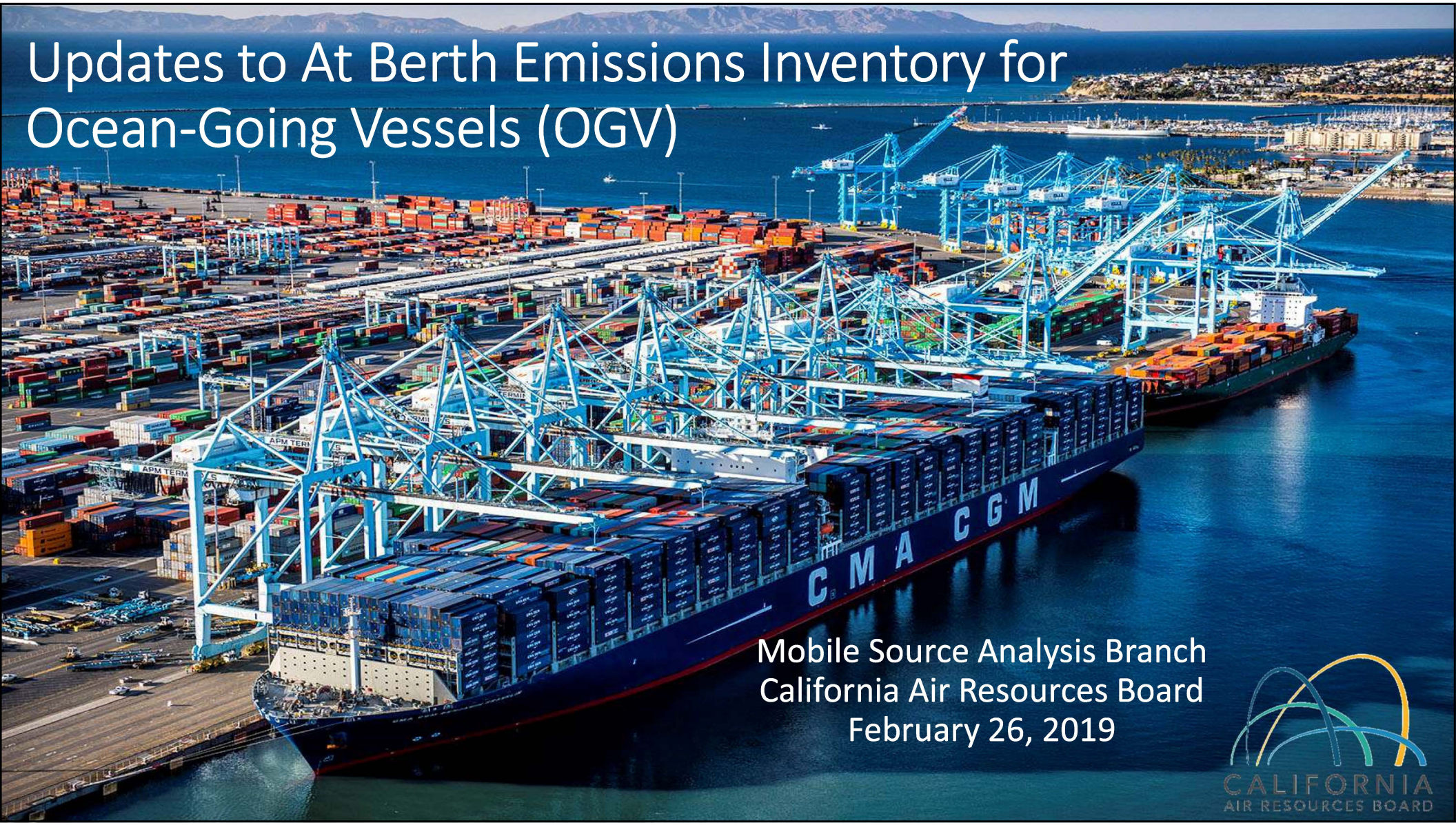
Updates to At Berth Emissions Inventory for Ocean-Going Vessels (OGV)



Mobile Source Analysis Branch
California Air Resources Board
February 26, 2019

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Ocean-Going Vessel Inventory: Outline

- Introduction & Background
- Inventory Methodology
- Base Year Inputs
- Growth and Forecasting
- Shorepower
- Emission Factors
- Emissions and Results

For a copy of this presentation;
https://www.arb.ca.gov/msei/ordiesel/feb19ogvinv.pdf

Introduction

Current inventory focused on at berth emissions for health risk assessment

Ocean-going vessels covered by this inventory are;

- Over 400 feet, 10,000 tons, large engine displacement
- Visit CA port or marine terminal complex (MTC) at least once
- Significant source of emissions around the ports and coastal shipping lanes

Background

- Updated activity growth rates
- Used in or to corroborate 2014, 2016, 2018 SIP updates

2011 OGV Model
Released: May 2011

2014 OGV Model
Released: September 2013

2018/2019 OGV Model
Next (TODAY'S WORKSHOP)

- Updates to the model accounting for the 2008 economic recession
- Used for 2011 CARB fuel rule amendments and the 2012 State Implementation Plan (SIP) updates

- Used to support CARB's 2018 Health Risk Assessment (HRA) at specific California ports
- Used to support regulatory development efforts
- Will be used in future (2020+) SIP planning

Updates include:

- Improvements to vessel visit data
- Emissions factors
- Information on vessel compliance with CARB's At Berth Regulation
- Growth rates

Vessel Categories

- Vessels are grouped by category / function
- Containers and tankers further grouped by vessel size (1000s of TEUs (containers) / gross tonnage of tanker)
- Engines grouped by main (propulsion), auxiliary (provide electric power), and boilers (heat, pumping, producing inert gas)
- At berth emissions include auxiliary engine and boiler emissions, not main engines

Vessel Types
Auto
Bulk Cargo
Container
Cruise
General Cargo
Reefers
Ro-Ro
Tankers

Data Sources

- Vessel visits and vessel information
  - IHS-Markit data and
  - South Coast Marine Exchange
- Growth rates
  - Freight Analysis Framework (FAF)
  - Mercator Report for Ports of LA/LB
- Marine engine tier forecast
  - San Pedro Bay Clean Air Action Plan: Delayed expected introduction of Tier 3 marine engines to 2030 -2040, based on a study of Ports of LA/LB,
- Effective power (load factor)
  - Data from the vessel boarding program (VBP) in the Ports of LA/LB
- Shorepower time or emissions reduction
  - ARB Enforcement Division audit data

Method Overview

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Base Year (2016)

1. Base Year Vessel Visits
   (Vessel type, size, port, model year, length of visit)
2. Determine Effective Power of Engines
3. Determine Engine Tier/Emission Factor Based on Model Year
4. Determine Reduction in Engine Activity Time from Current and Proposed Regulatory Programs

Forecast (2017 – 2050)

5. Growth Forecast based on Port of Visit
6. Determine Future Reduction from Regulatory Programs
7. Estimate Future Year Engine Tier Introduction Dates

Summary: Emissions Calculation (1)

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- Emissions are calculated for each engine, for each vessel visit

Emissions per Visit = Activity (hours) x Effective Power x Emission Factor (g/kW-hr)

Base Emissions Inventory = Sum of Emissions Per Visit

- Existing regulatory program reductions (i.e., reduction in activity or reduction in emissions) are applied to aggregated vessel visits

Summary: Emissions Calculation (2)

The inputs to each vessel visit calculation will differ due to the following:

- **Activity**: Time the engine or boiler is running (hours)
  - Visit hours reported for each individual vessel visit
- **Effective Power**: average power output for an engine (kW) by:
  - Vessel Type
  - Vessel Size
- **Emission factor** (grams of pollutant/kW-hr):
  - Engine Tier
  - Fuel type
  - Source type (e.g., boiler, auxiliary)
  - Pollutants (NOx, PM, PM10, PM2.5, Diesel PM, CH4, N2O, NH3, ROG, CO, SOx, HC, CO2, TOG)

Summary: Emission Calculation (3)

- **Forecasting** – Future years will add a growth factor to the calculation, specific to:
    - Vessel type
    - Port
    - Vessel size
- Forecasting can change the emission factors used based on:
    - Engine age
    - Engine tier introduction date

Base Year Inputs

OGV Base Year Inputs –Vessel Visits

- Sources
  - 2016 IHS-Markit at berth times for California
  - 2016 South Coast Marine Exchange arrival and departure data
- Information used for emissions calculation
  - Vessel IMO number (for identifying vessel characteristics)
  - Port of call
    - Berth at port (if provided)
  - In port mode (only reflecting at berth emissions)
  - Length of visit

Number of Visits by Port and Vessel Type (Calendar Year 2016)

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Port	Auto	Bulk	Container	Cruise	General	Reefer	Ro-Ro	Tanker	Grand Total
Avon	-	1	-	-	-	-	-	69	70
Benicia	126	11	-	-	-	-	-	88	225
Crockett	-	14	-	-	3	-	-	-	17
Eureka	-	6	-	-	-	-	-	-	6
Hueneme	262	-	68	-	3	52	-	12	397
Long Beach	186	199	948	258	28	1	2	443	2,065
Los Angeles	83	89	1,291	118	47	17	24	236	1,905
Martinez	-	-	-	-	-	-	-	161	161
Oakland	-	19	1,711	-	-	-	1	-	1,731
Oleum	-	-	-	-	-	-	-	78	78
Redwood City	-	55	-	-	-	-	-	-	55
Richmond	110	72	-	-	-	-	-	409	591
Sacramento	-	18	-	-	12	-	-	1	31
San Diego	251	6	62	73	21	-	6	16	435
San Francisco	6	58	92	79	3	-	1	70	309
Selby	-	-	-	-	-	-	-	31	31
Stockton	-	107	-	-	40	-	-	69	216
Grand Total	1,024	655	4,172	528	157	70	34	1,683	8,323

Vessel Visit Length

- Vessel visit length is specified for each vessel visit by Marine Exchange and/or AIS data (IHS-Markit data)

- The auxiliary engines and boilers are both assumed to be active over the vessel visit
  - Effective power uses average engine power over length of a vessel visit

2016 Average Length of Vessel Visits (hours)

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Port	Auto	Bulk	Container	Cruise	General	Reefer	Ro-Ro	Tanker
Avon	-	1	-	-	-	-	-	53
Benicia	22	278	-	-	-	-	-	24
Crockett	-	225	-	-	229	-	-	-
Eureka	-	130	-	-	-	-	-	-
Hueneme	15	-	35	-	132	68	-	53
Long Beach	14	54	62	13	43	6	300	38
Los Angeles	22	73	54	12	63	35	34	44
Martinez	-	-	-	-	-	-	-	49
Oakland	-	124	24	-	-	-	300	-
Oleum	-	-	-	-	-	-	-	49
Redwood City	-	41	-	-	-	-	-	-
Richmond	19	77	-	-	-	-	-	40
Sacramento	-	76	-	-	164	-	-	1
San Diego	25	56	54	13	43	-	32	173
San Francisco	29	7	7	24	1	-	0	5
Selby	-	-	-	-	-	-	-	42
Stockton	-	107	-	-	40	-	-	69

Engine Effective Power

- Effective power is combination of maximum power and the average load factor
  - Based on the Starcrest's Vessel Boarding Program (referred to as load factor)
  - Weighted average between the Ports of LA and LB and used for all other ports
- For Auxiliary engines and boilers only (not main engines)

Engine Effective Power – Auxiliary Engines

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- Container (size bin)

Size Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18
kW	709	1036	597	1153	1007	988	2326	951	973	1122	1500	1945	990	1500	1000	1000

- Tanker

Vessel Type	Seawaymax	Panamax	Aframax	Suezmax	VLCC	ULCC
kW	784	654	724	2509	1171	1171

- Other Vessel Types

Vessel Type	Auto	Bulk	Bulk - Self Discharging	Cruise	General	Misc	Reefer	Ro-Ro
kW	1159	190	179	5620	661	228	900	711

Engine Effective Power – Auxiliary Boilers

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- Container (size bin)

Size Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18
kW	273	361	420	477	579	615	623	668	677	581	790	790	612	612	647	647

- Tanker

Vessel Type	Seawaymax	Panamax	Aframax	Suezmax	VLCC	ULCC
kW	2586	3421	5030	5843	6000	6000

- Other Vessel Types

Vessel Type	Auto	Bulk	Bulk - Self Discharging	Cruise	General	Misc	Reefer	Ro-Ro
kW	314	125	132	612	160	96	304	259

Effective Engine Power: Tankers

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⚠ **Upcoming inventory improvement**: Split effective power for tanker with steam-powered pumps based on on-loading vs off-loading product

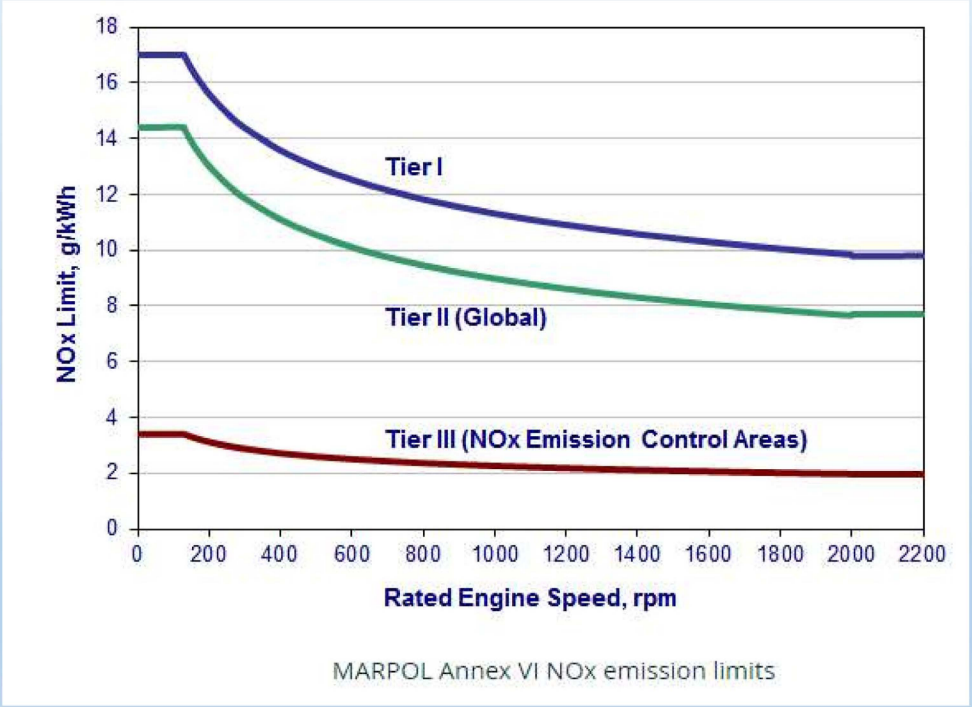
- Effective power for on-loading is ~800 to 900 kW per boiler
- Effective power for off-loading is 2,500 to 6,000 kW per boiler depending on vessel size

Currently reviewing available data for receiving vs off-loading product times and activity

Marine Engine Tier

- Marine engine standards divided into three engine Tiers
- Engine tiers based on keel laid date of vessel (not engine model year)
- Engine tiers are focused on NOx emissions reductions
- Significant NOx reductions with Tier 3 marine engine standards

IMO NOx Standards for Cat. 3 Marine Engines



MARPOL Annex VI NOx emission limits

Forecasting and Growth

Tier and Age Distribution Forecasting

- Tier introduction / arrival dates for California ports based on a study by Starcrest for Ports of LA/LB
- Tier 3 marine engines are not expected until 2030 to 2040 (Starcrest, 2017)
  - Significant increase in keels laid prior to Tier 3 standard
  - Incorporates delay in California receiving visits from newer vessels compared to Asia / Europe

Age Distribution Forecasting

- Age distribution held static from base year
- Model year and engine tier change over time, **but average age and age distribution stay constant**
- Attrition or turnover model not used due to lack of captive fleet that would follow turnover curve

Example

Assume that 2016 data shows a specific vessel visit with keel laid of 1995 then:

- Forecast year of 2017 would show that vessel visit with keel laid year of 1996
- Forecast year of 2018 would show that vessel visit with keel laid year of 1997

Activity Growth

- Growth is based on:
  - Freight Analysis Framework (FAF)
  - Mercator forecast for Ports of LA/LB
  - Port specific data for Port of Hueneme

- Growth factors are specific to:
  a) Vessel type
  b) Port
  c) Vessel size
  d) Forecast year

Activity Growth Factors: FAF Version 4.3.1

- Based on 2016 FAF database
  - Developed by Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA)
  - FAF forecasts cargo movements in tons
  - Forecasts are specific to regions and commodity groups

FAF #	California Port	FAF Region
8	**Avalon/Catalina**	Los Angeles CA CSA
8	**POLA**	Los Angeles CA CSA
8	**POLB**	Los Angeles CA CSA
8	**LA-LB**	Los Angeles CA CSA
11	**POak**	San Francisco CA CSA
9	**POSD**	San Diego CA CSA
11	**POSF**	San Francisco CA CSA
10	**Stockton**	Sacramento CA-NV CSA
10	**Sacramento**	Sacramento CA-NV CSA
11	**Richmond**	San Francisco CA CSA
11	**Carquinez**	San Francisco CA CSA
8	**El Segundo**	Los Angeles CA CSA
12	**Humboldt**	Remainder of CA
12	**Monterey**	Remainder of CA
8	**Hueneme**	Los Angeles CA CSA
12	**Redwood**	San Francisco CA CSA

FAF Activity Growth

- Growth rates vary slightly over time between 2016 and 2050, but are fairly close to the averages shown here

Region	Vessel Type	Average Annual Growth (percent)
Los Angeles	Auto	2.8
Los Angeles	Bulk cargo	3.2
Los Angeles	Container	4.5
Los Angeles	General cargo	4.9
Los Angeles	Reefer	4.1
Los Angeles	Ro-Ro	4.9
Los Angeles	Tanker	1.5
Rest of California	Bulk cargo	4.0
Rest of California	Container	4.8
Rest of California	General cargo	4.1
San Diego	Auto	2.6
San Diego	Bulk cargo	0.3
San Diego	Container	3.8
San Diego	General cargo	4.2
San Diego	Reefer	4.8
San Diego	Ro-Ro	4.8
San Diego	Tanker	4.3
San Francisco	Auto	2.7
San Francisco	Bulk cargo	2.1
San Francisco	Container	4.6
San Francisco	General cargo	5.1
San Francisco	Reefer	4.1
San Francisco	Ro-Ro	4.8
San Francisco	Tanker	1.1

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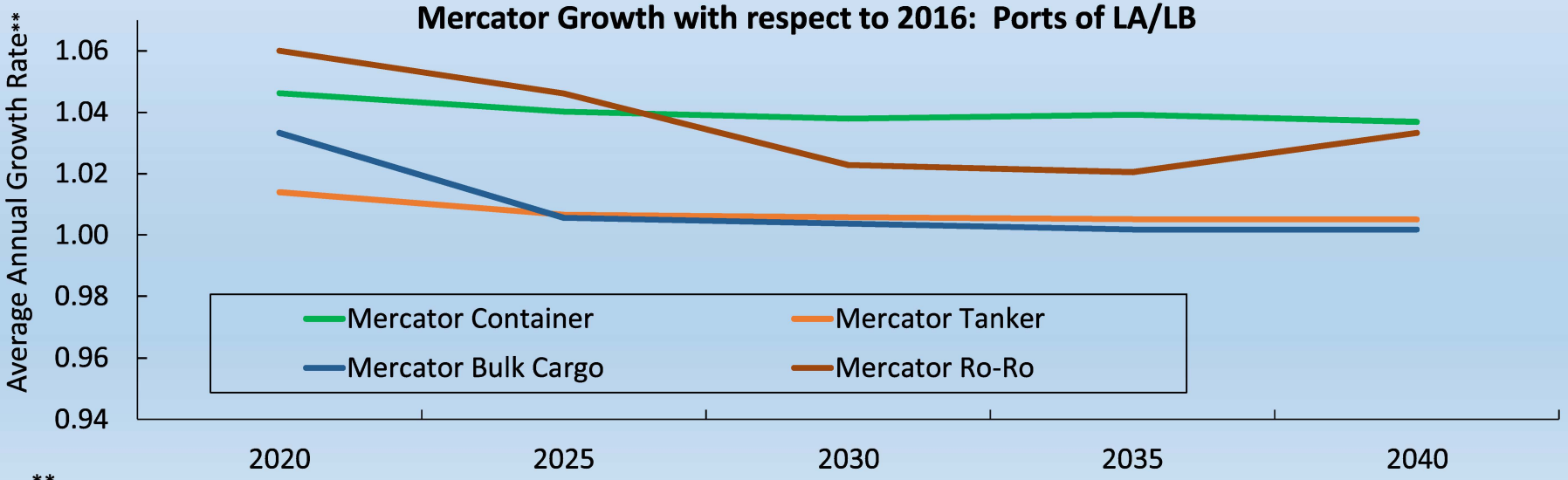
Growth Factors: Ports of LA/LB

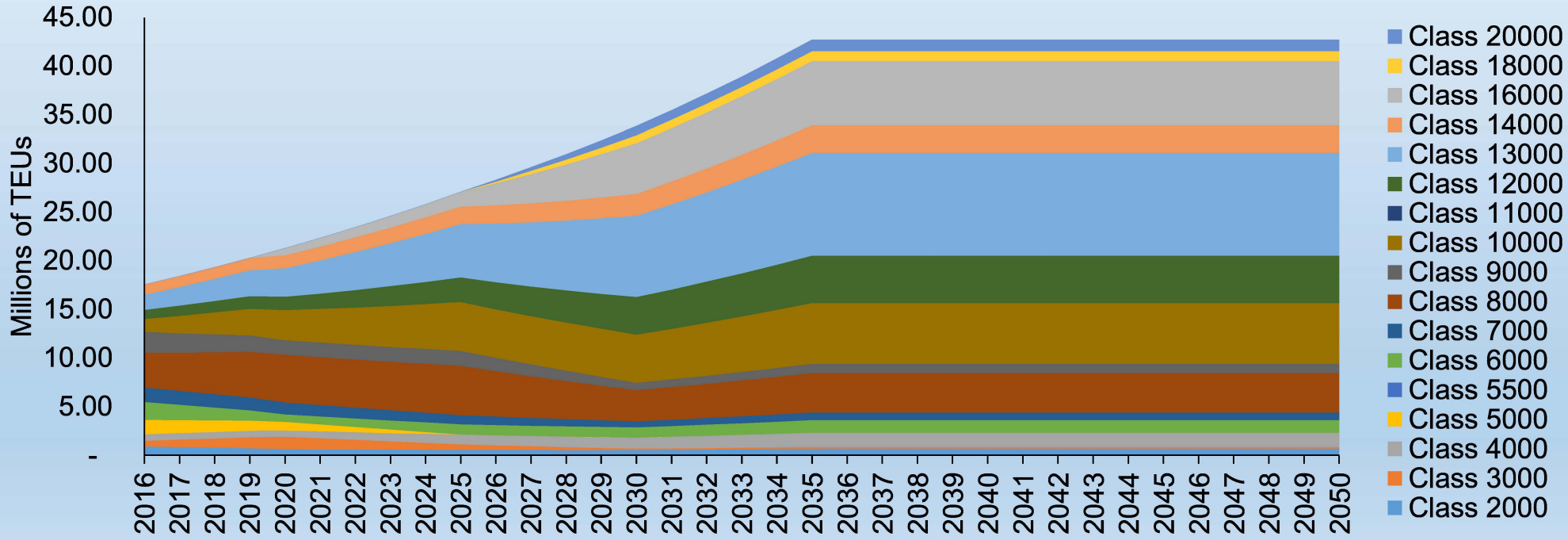
- Mercator and Oxford Economics created a growth forecast specific to Ports of LA/LB (specific to both ports, not regional)
- Capacity limit of the port included in the growth rate analysis (2035)
- Comparison with FAF growth rates show less than 3% overall difference in total activity by 2030 regardless of which rate is used



** *For example, 1.02 means 2% annual growth*

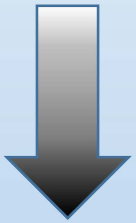
Growth Factor: Vessel Sizes at Ports of LA/LB

- Container vessel sizes expected to increase over time based on Mercator analysis
- Efficiency gain in terms of kWHr per TEU delivered



Shorepower / Current At-Berth Regulation

- The existing At-Berth Regulation requires applicable vessel visits to spend percent of vessel visits on shorepower (or alternatives) with the following phase-in schedule:

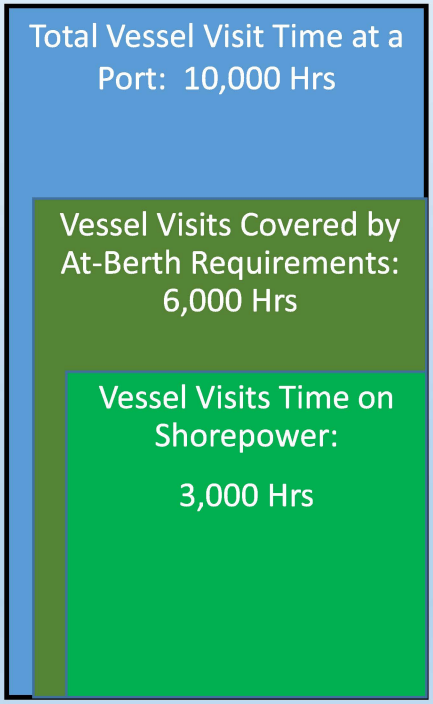


50% in 2014
70% in 2017
80% in 2020

- The OGV model utilizes data from enforcement audits and real world information on time at berth to model the impact of the existing regulation

Shorepower (or Alternatives) Example: Not Real Data

2014 Regulatory Requirements
50% of Applicable Time on Shorepower



2020 Regulatory Requirements
80% of Applicable Time on Shorepower

For draft regulatory concepts, see page 37 of https://www.arb.ca.gov/msei/ordiesel/draft2019ogvinv.pdf

Vessel Visits - Length - Effective Power - Engine Tier - Growth - Shorepower - Emission Factor

At Berth Updates Needed to Achieve Added Health Benefits

- Additional vessel categories and boilers (for certain tankers)
- Controls at more ports and marine terminals
- Use an approved compliance strategy for each visit
  - Shore power or technologies with a CARB Executive Order
- Draft implementation schedule (Aug 2018 concept)
  - Containers/Reefers/Cruise in 2021
  - Ro-Ro/Auto carriers in 2025
  - Tankers in 2025 and 2031
- Future strategies might also include onboard controls and cleaner vessels
- Opacity standards at berth and at anchor

Vessel Visits - Length - Effective Power - Engine Tier - Growth - Shorepower - Emission Factor

Draft Implementation Timelines (Aug 2018 Concept)

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Vessel Category	Implementation Dates*		
	2021	2025	2031
Remaining Container, Reefer, Cruise	✓		
Ro-Ro/Auto carrier		✓	
Tanker (plus boilers for steam powered pumps)		✓ Intermediate level	✓

* *CARB Approved Controls Required*

Vessel Visits - Length - Effective Power - Engine Tier - Growth - Shorepower - Emission Factor

Emission Control Factor Assumptions (Aug 2018 Concept)

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Control Strategy	NOx	Diesel PM, PM_{10}, $PM_{2.5}$
Shore Power	100%	100%
Intermediate Tanker Concept	50%	50%
Capture and Control	85%	85%

Vessel Visits - Length - Effective Power - Engine Tier - Growth - Shorepower - Emission Factor

Emission Factors

- PM and NOx emission factors updated based on U.S. EPA and IMO research and reports
  - PM emission factors reduced from previous emissions inventories based on updated test data
- Emission factors vary by pollutant, operating mode, engine type, fuel type, and fuel sulfur content

At Berth Emission Factor

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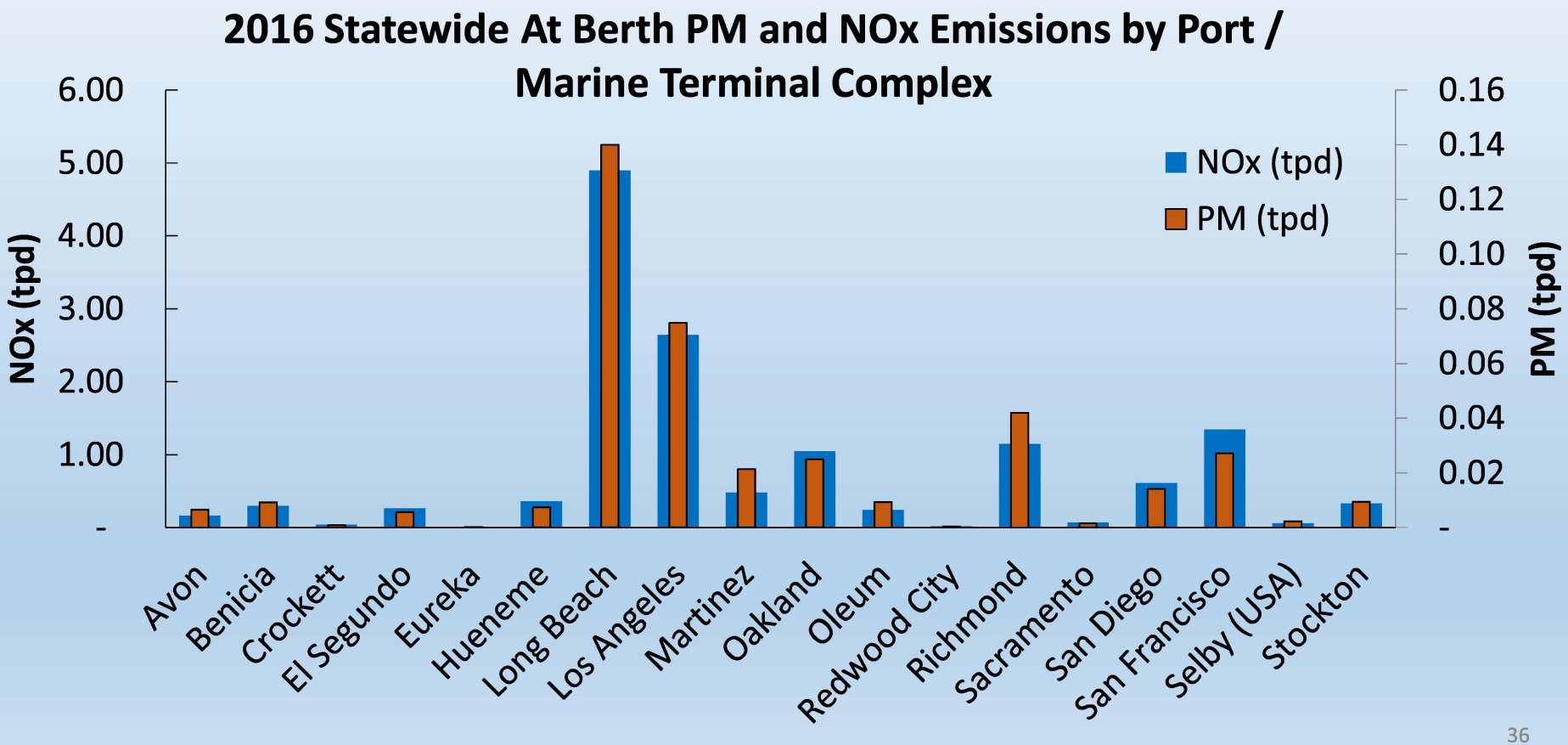
Engine type	Fuel type	Fuel Sulfur content (%)	Tier ID	Emission Factor (g/kw hr)			
				NOx	PM 10	PM 2.5	CO2
Auxiliary	Distillate	0.1	0	13.8	0.182	0.168	676
			1	12.2			
			2	10.5			
			3	2.6			
		0.3	0	13.8	0.25	0.23	
			1	12.2			
			2	10.5			
			3	2.6			
		1	0	13.8	0.489	0.45	
			1	12.2			
			2	10.5			
			3	2.6			
	residual	2.7	0	14.7	1.436	1.321	707
			1	13			
			2	11.2			
			3	2.309			
Boiler	Distillate	0.1	N/A	1.995	0.164	0.151	934
		0.3					
		1			0.589	0.542	
	residual	2.7		2.1	1.465	1.348	950

Vessel Visits - Length - Effective Power - Engine Tier - Growth - Shorepower - Emission Factor

DRAFT Emissions Results: NOx and PM

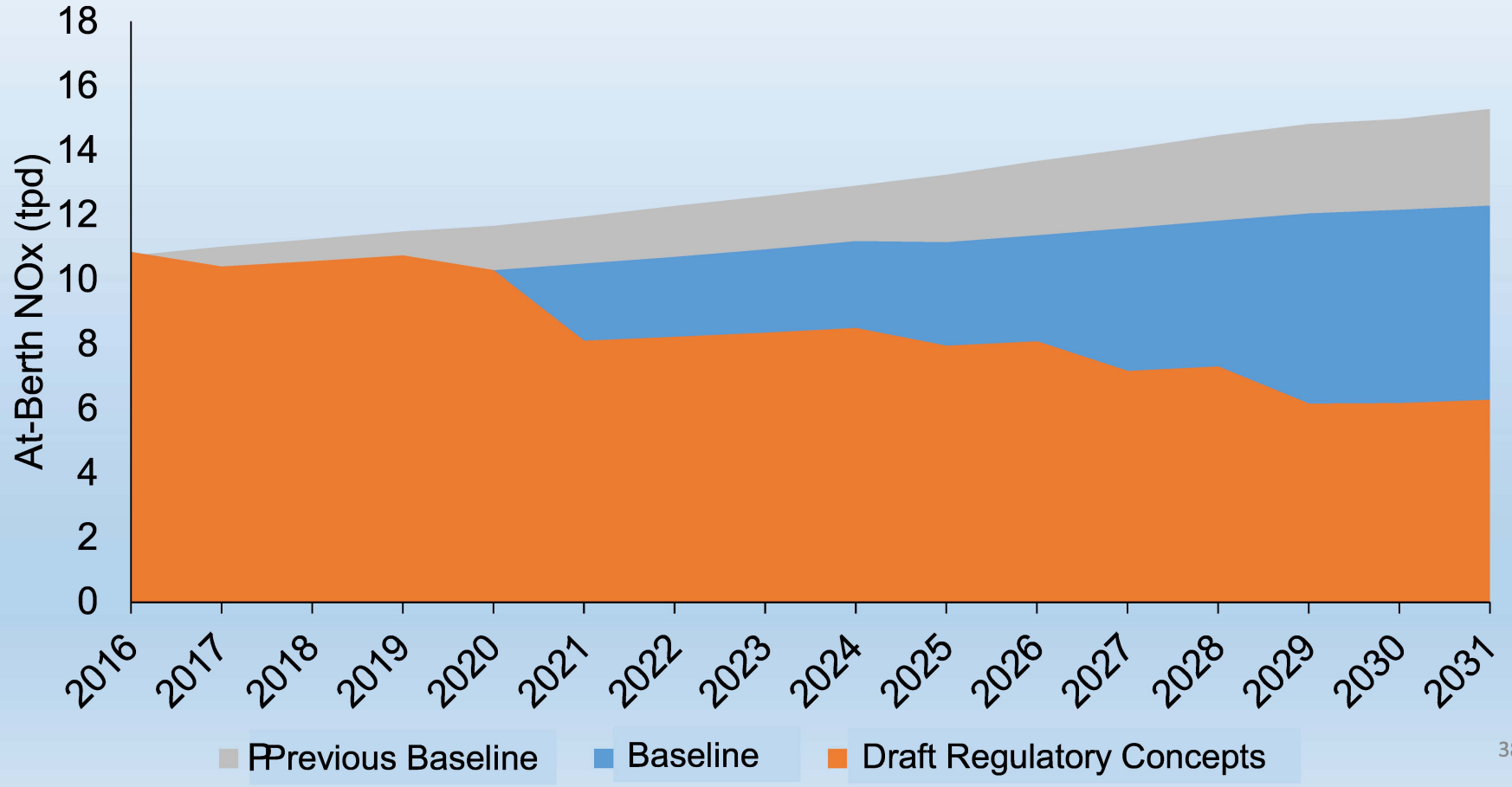


Emissions and Results

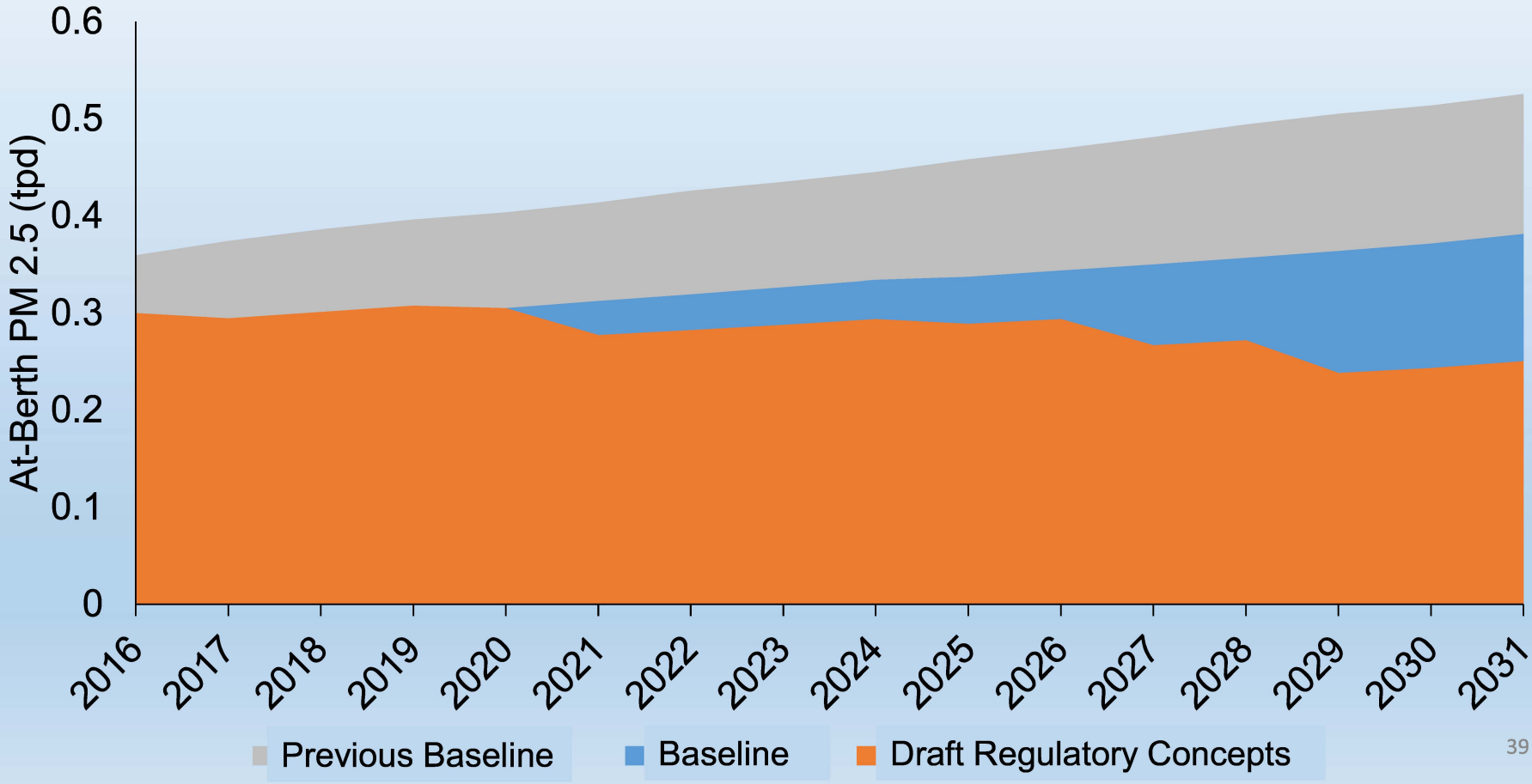
Three scenarios are assessed:

1. Previous Baseline – 2014 OGV Inventory accounting for existing At-Berth Regulation
2. Baseline – 2019 OGV Inventory accounting for existing At-Berth Regulation
3. Draft regulatory concepts – 2019 OGV inventory with draft regulatory concepts

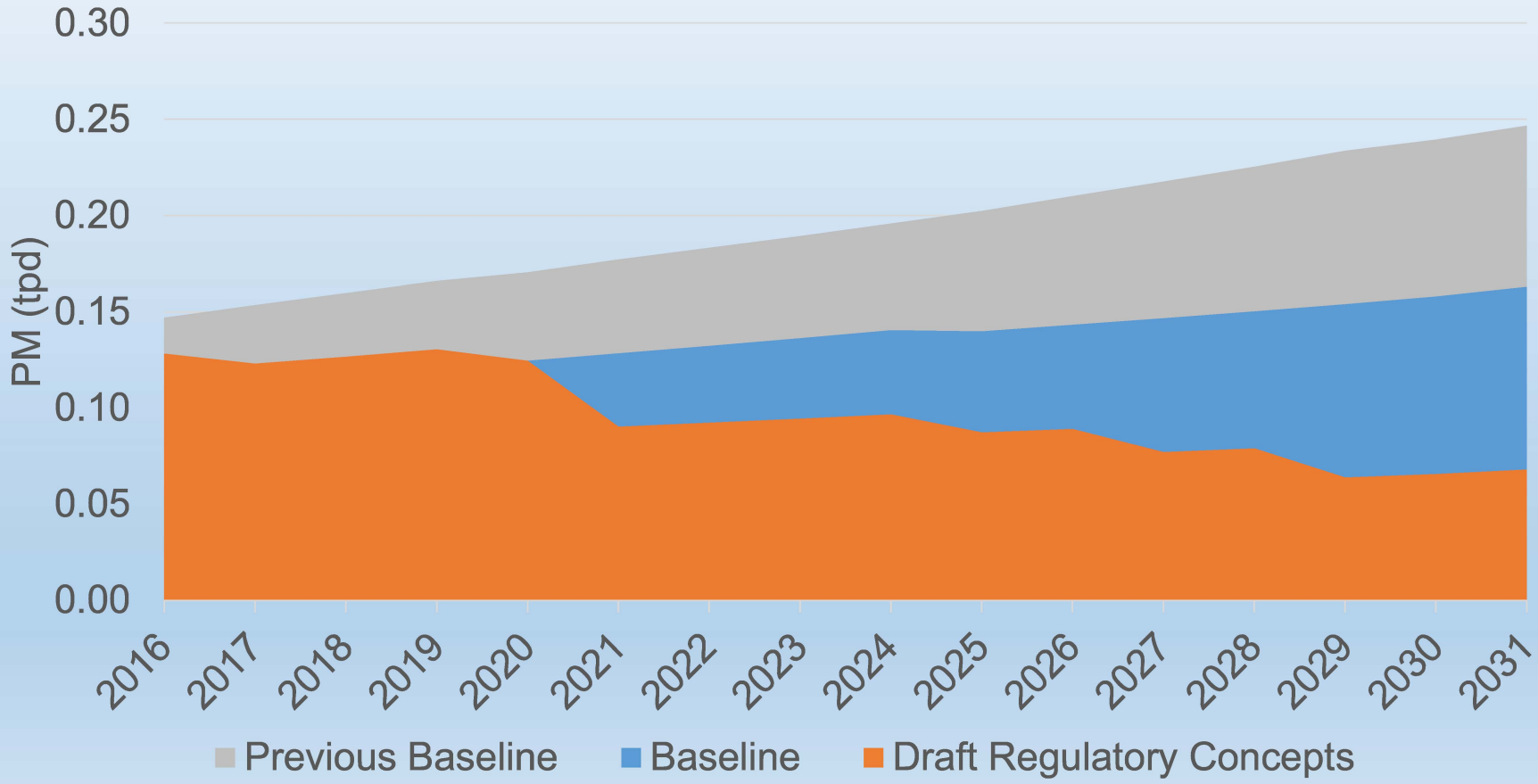
DRAFT Statewide At-Berth NOx Emissions



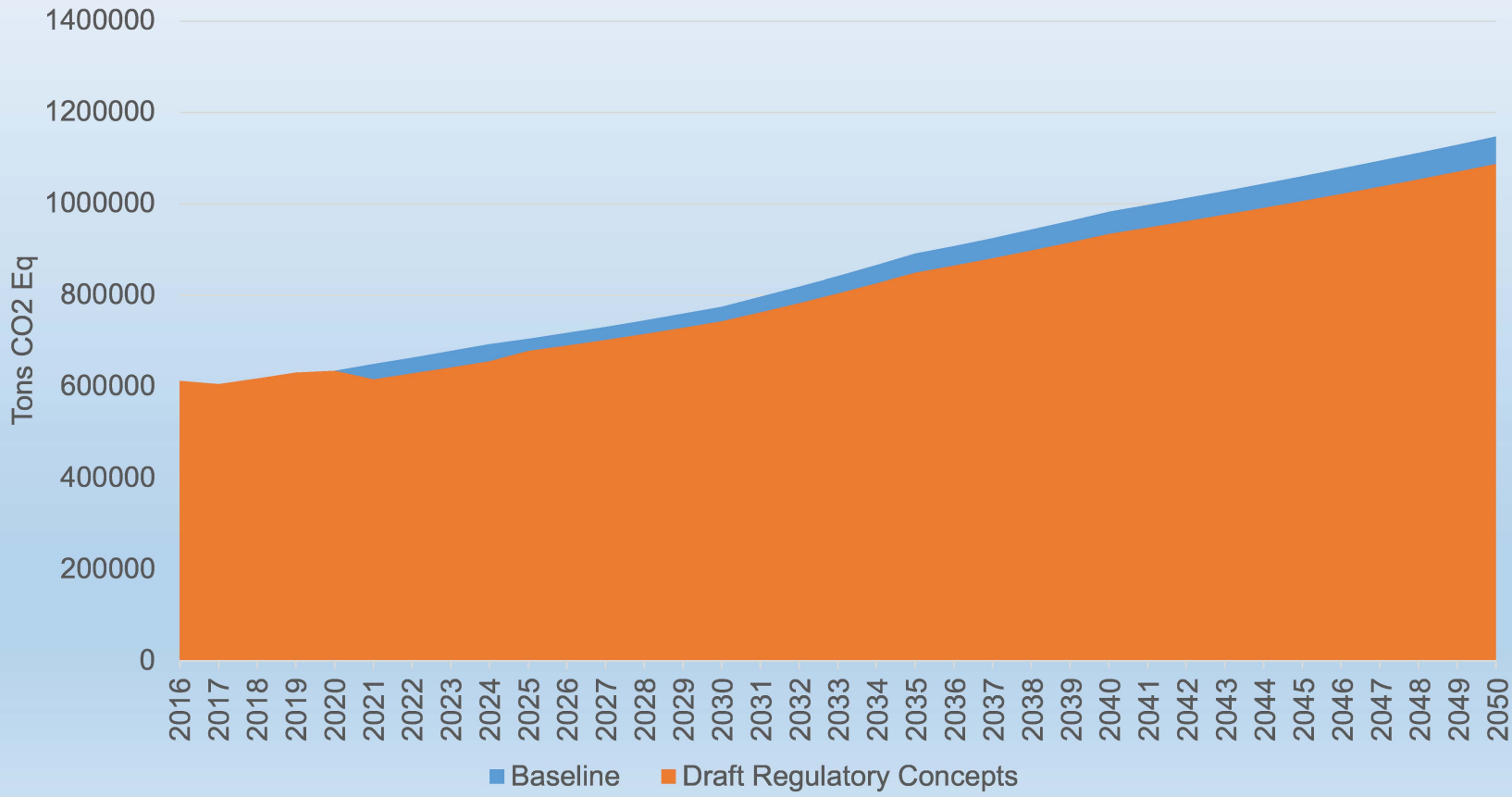
DRAFT Statewide At-Berth PM2.5 Emissions
(Auxiliary and Boiler PM2.5)



DRAFT Statewide At-Berth Diesel PM Emissions
(Auxiliary PM10)



DRAFT Statewide At-Berth CO2 Emissions (with Grid Emissions included)



Online Information

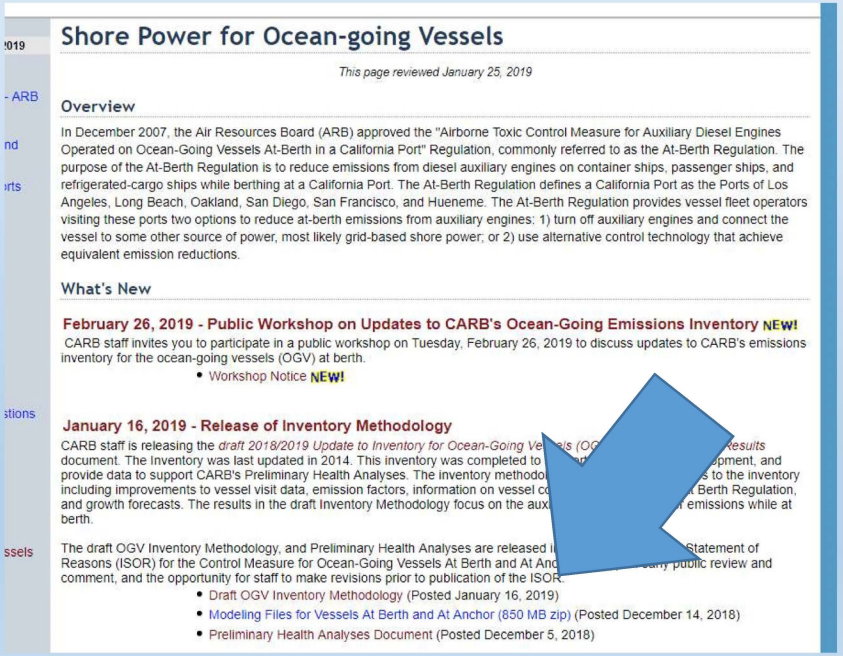
https://www.arb.ca.gov/ports/shorepower/shorepower.htm

Available online

-Draft At Berth Inventory Methodology Documentation

-Preliminary Health Risk Assessment

New: Draft OGV At Berth Inventory Model



Shore Power for Ocean-going Vessels

This page reviewed January 25, 2019

Overview

In December 2007, the Air Resources Board (ARB) approved the "Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port" Regulation, commonly referred to as the At-Berth Regulation. The purpose of the At-Berth Regulation is to reduce emissions from diesel auxiliary engines on container ships, passenger ships, and refrigerated-cargo ships while berthing at a California Port. The At-Berth Regulation defines a California Port as the Ports of Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme. The At-Berth Regulation provides vessel fleet operators visiting these ports two options to reduce at-berth emissions from auxiliary engines: 1) turn off auxiliary engines and connect the vessel to some other source of power, most likely grid-based shore power; or 2) use alternative control technology that achieve equivalent emission reductions.

What's New

February 26, 2019 - Public Workshop on Updates to CARB's Ocean-Going Emissions Inventory NEW!

CARB staff invites you to participate in a public workshop on Tuesday, February 26, 2019 to discuss updates to CARB's emissions inventory for the ocean-going vessels (OGV) at berth.

- Workshop Notice **NEW!**

January 16, 2019 - Release of Inventory Methodology

CARB staff is releasing the *draft 2018/2019 Update to Inventory for Ocean-Going Ve…ls (OG… …Results* document. The Inventory was last updated in 2014. This inventory was completed to … …pment, and provide data to support CARB's Preliminary Health Analyses. The inventory methodo… …s to the inventory including improvements to vessel visit data, emission factors, information on vessel co… …Berth Regulation, and growth forecasts. The results in the draft Inventory Methodology focus on the aux… …emissions while at berth.

The draft OGV Inventory Methodology, and Preliminary Health Analyses are released i… …Statement of Reasons (ISOR) for the Control Measure for Ocean-Going Vessels At Berth and At Anc… …public review and comment, and the opportunity for staff to make revisions prior to publication of the ISOR.

- Draft OGV Inventory Methodology (Posted January 16, 2019)
- Modeling Files for Vessels At Berth and At Anchor (850 MB zip) (Posted December 14, 2018)
- Preliminary Health Analyses Document (Posted December 5, 2018)

CONTACTS

- Questions, comments and feedback are encouraged and welcome
- To address comments and reflect any changes, please submit comments and any supporting data by **March 26, 2019**
- Off-Road Emissions Inventory Team is available at:

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Additional Slide(s)

Tier 3 Introduction

- Containerships (by size bin)

Size Bin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Year Start	2030	2040	2030			2040	2030	2040		2032	2037					2030		2037	2030	2040

- Tankers

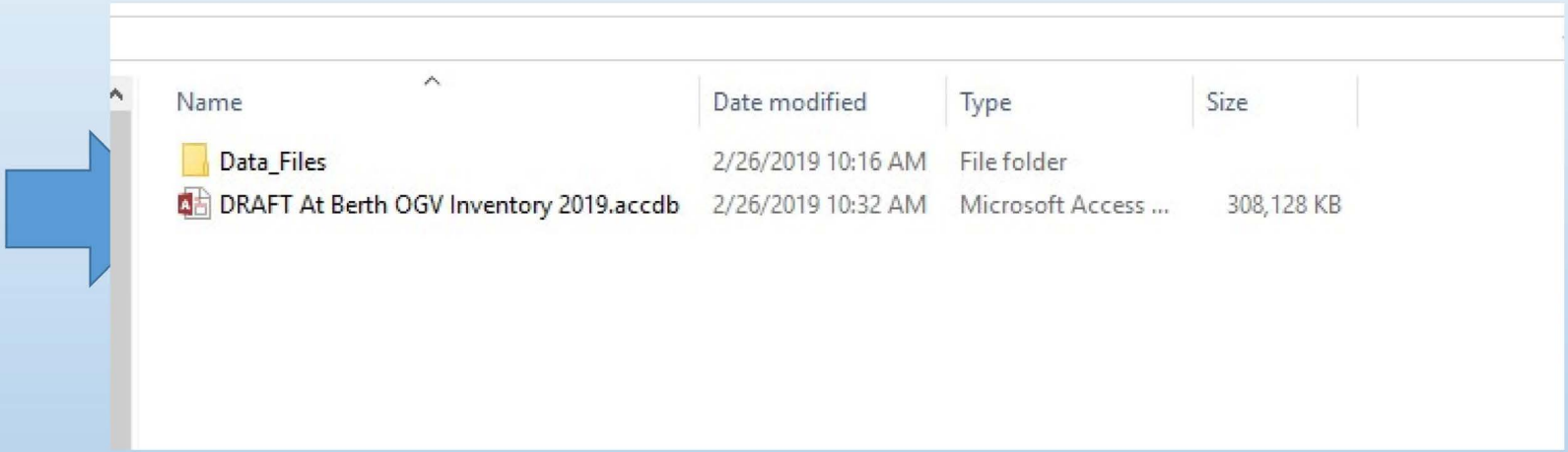
Size Bin	Seawaymax	Panamax	Aframax	Suezmax	VLCC	ULCC
Year Start	2030					

- Other vessel types

Size Bin	Auto	Bulk	Cruise	General	Reefer	Ro-Ro	Tanker
Year Start	2037	2040	2026	2030			

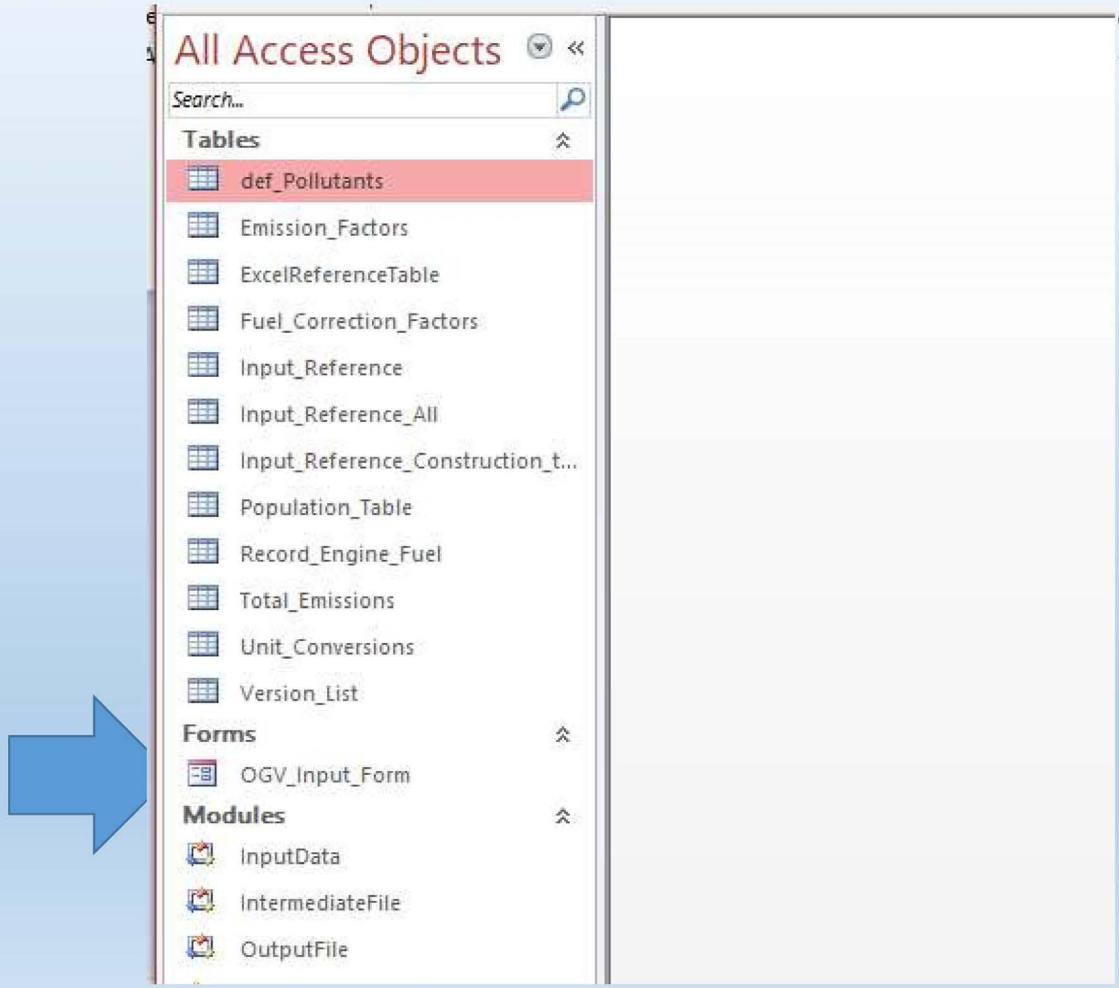
Model Demo

1. Open Model File



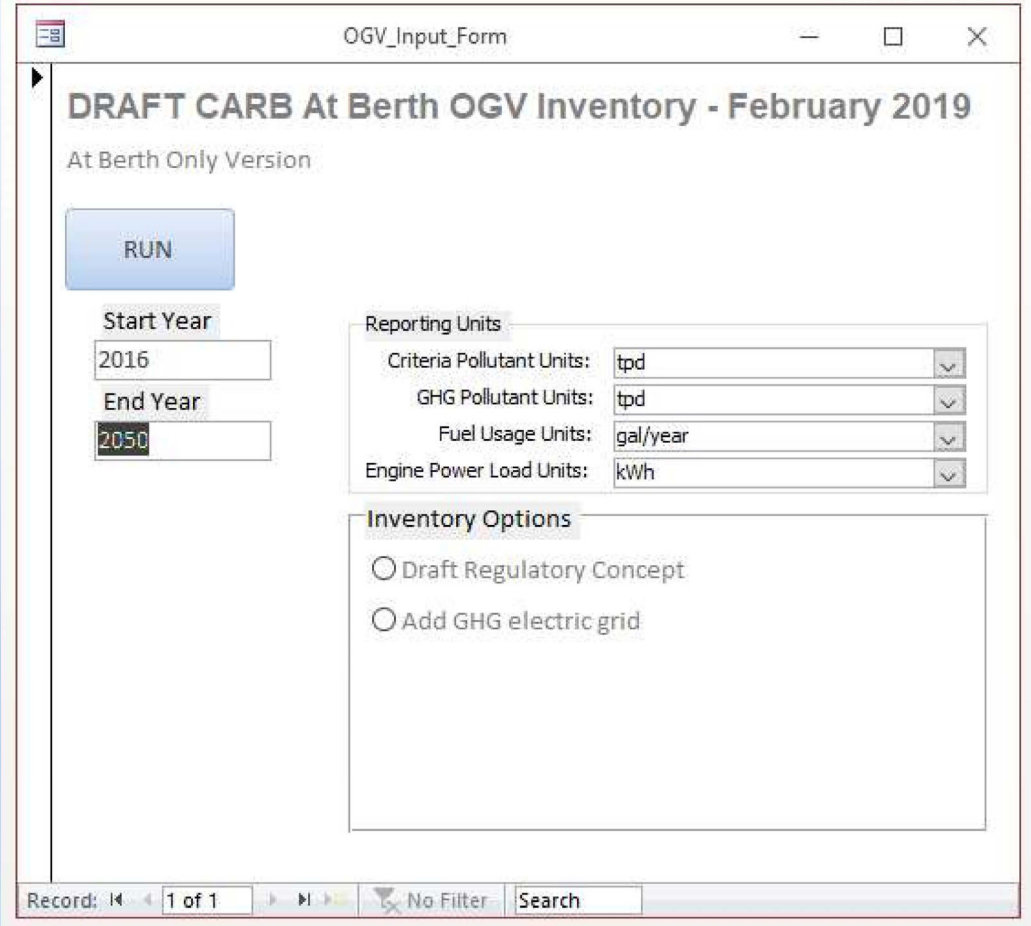
2. Open Form

- Enable Content if needed
- Click on OGV_Input_Form



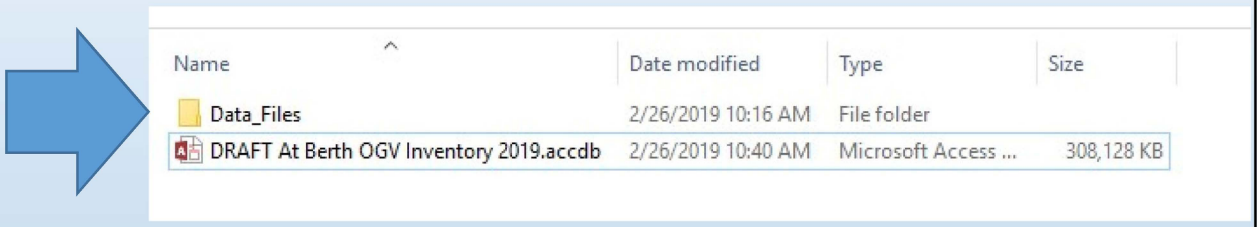
3. Select Options

- Years to run (more years means longer runtime)
- Units for pollutants
- Baseline or Draft Regulatory Concepts
- Hit “Run”

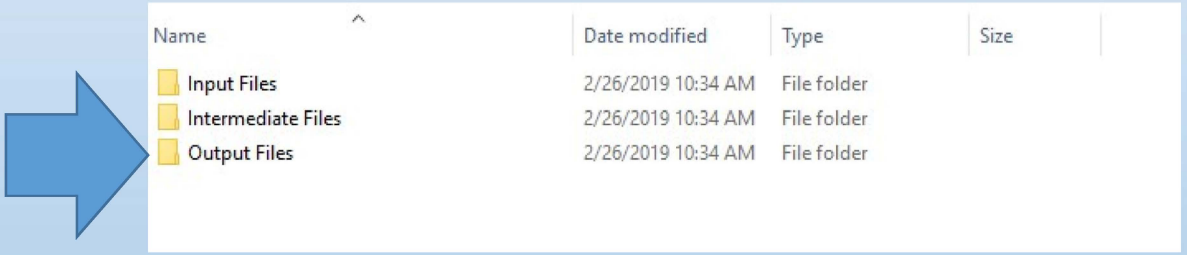


4. Output Files

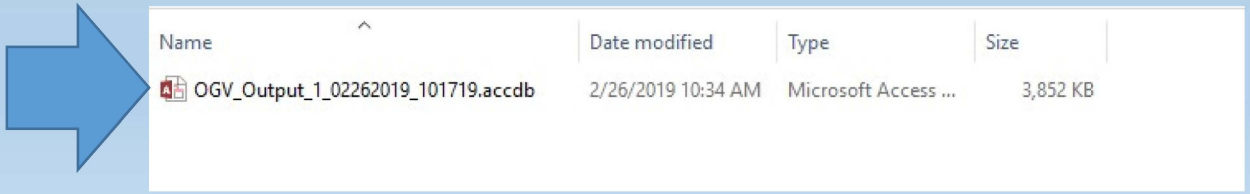
- Go back to containing folder
- Open “Data_Files”



- Open “Output Files”

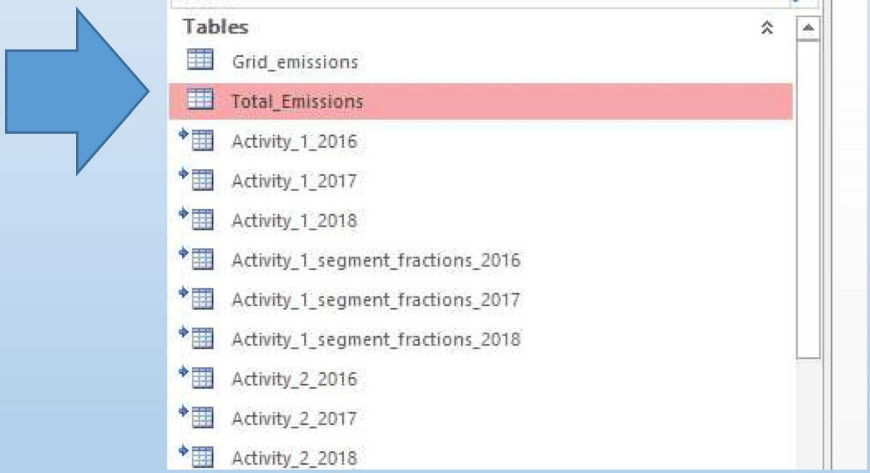


- Output file will be new Access database



5. Output Table

- For overall output, select
  "Total_Emissions"



6. Output Details

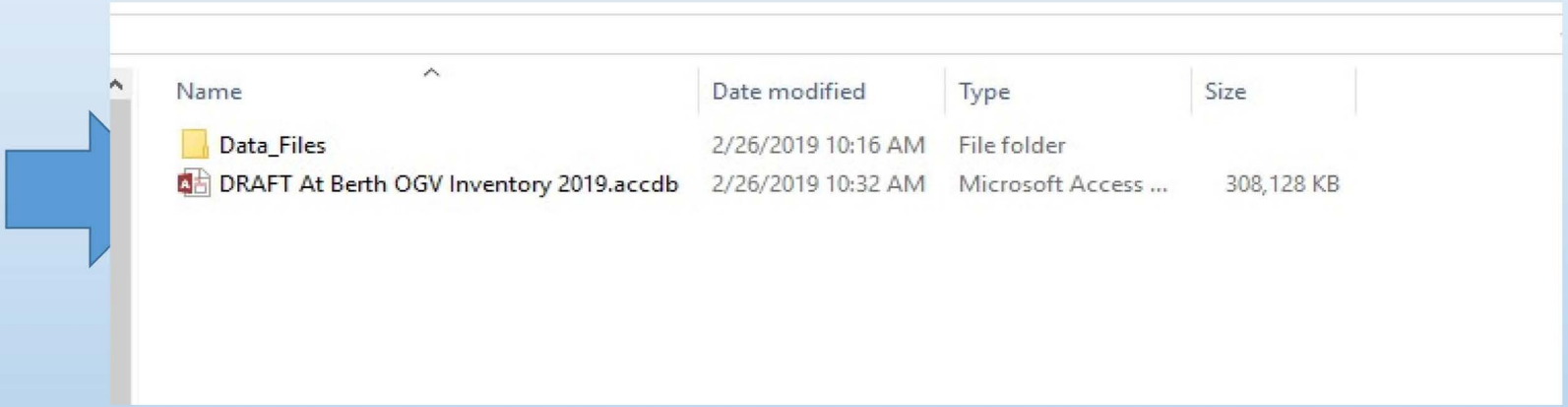
- "Total Emissions" has info by vessel visit (activity averaged currently) and emissions

grid_emission_factors

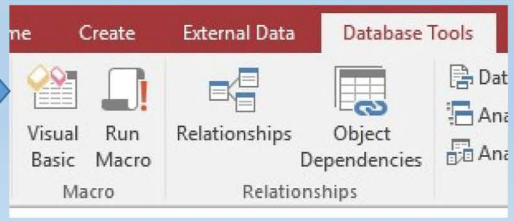
Arrival_Port	Mode	Model_Year	Calendar_Ye	vessel_type	vessel_subt	size_bin	tier_ID	runtime_hours	NOx_tpd	Fuel Used_g
San Francisco	At-Berth	1973	2016	3	4	1	0	1	0.000029548284	6221212121212
San Francisco	At-Berth	1973	2016	3	4	1	0	1	##########	##########
San Francisco	At-Berth	1978	2016	3	4	1	0	0.5	##########	##########
San Francisco	At-Berth	1978	2016	3	4	1	0	0.5	##########	##########

7. Code

- Back in containing folder, open main database



- Under Database Tools, Visual Basic



8. Primary code

- In modules, under OGV folder is primary code (somewhat lengthy)

```
'strCategory = DLookup("Category", "def_Polluntants", "Po

Select Case strCategory
    Case "Criteria"
       strCurrentUnit = strCriteriaUnit
        strsql = "UPDATE " & strTableName & " SET [" & st
       timed_query strsql, "output"
    Case "GHG"
       strCurrentUnit = strGHGUnit
        strsql = "UPDATE " & strTableName & " SET [" & st
        timed_query strsql, "output"
    Case "Fuel"
       strCurrentUnit = strFuelUnit
       'proper dynamic query was causing the database to
       strsql = "UPDATE " & strTableName & " INNER JOIN d
       Debug.Print strsql
       timed_query strsql, "output"

       strsql = "UPDATE " & strTableName & " INNER JOIN d
```