COASTAL CONSERVATION LEAGUE

How Do Cruise Emissions and Truck Emissions Stack Up?

The goal: conversion of sulfur dioxide (SO2) emissions from a cruise ship, the Carnival Fantasy[1], from a 10-hour idling period at berth into equivalent number of long-haul trucks idling for 10 hours.

Background: Katie Zimmerman of the Coastal Conservation League (CCL) initially consulted with John Kaltenstein of Friends of the Earth (FOE) and his contacts at the California Air Resources Board (CARB) to calculate the full numbers, and then submitted those calculations to the U.S. Environmental Protection Agency (EPA) for fact-checking. The EPA reviewed and conducted a different calculation, which yielded more conservative numbers. CCL has chosen to use the EPA's calculations in order to be as conservative as possible.

Cruise ship portion of the equation:

Solveig Irvine[2] of the EPA used the following equation[3] to calculate the "hotelling" emissions for the cruise ship.

$$Emissions_{hotel[aux]} = (calls) \times (P_{[aux]}) \times (hrs/\,call_{hotel}) \times (LF_{hotel[aux]}) \times (EF_{[aux]}) \times (10^{-6}\,tonnes/\,g)$$

---

[1] The Coastal Conservation League made a good-faith effort to determine the exact type of fuel burned by the Carnival Fantasy while in Charleston's port, and was repeatedly denied that information. Therefore, we made some basic assumptions about the fuel type, and calculated based on a standard sulfur composition, as well as cleaner fuels required by new regulation.

[2] Solveig A. Irvine
Chemical Engineer, Assessment and Standards Division
U.S. Environmental Protection Agency
2000 Traverwood Drive
Ann Arbor, MI 48105-2498, USA
w. 734-214-4154
f. 734-214-4050
irvine.solveig@epa.gov

[3] Equation 3-20: Hotelling Mode Emissions for Auxiliary Engines, page 3-13.
U.S. Environmental Protection Agency Office of Transportation and Air Quality's Assessment and Standards Division. (2009 December). *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines* (EPA-420-R-09-019). Retrieved from http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf

Where:

$Emissions_{hotel[aux]}$ = Metric tonnes emitted from auxiliary engines in hotelling mode

Calls = Round-trip visits (i.e., one entrance and one clearance is considered a call)

$P_{[aux]}$ = Total auxiliary engine power, in kilowatts

$Hrs/call_{hotel}$ = Hours per call for hotelling mode

$LF_{hotel\ [aux]}$ = Load factor for auxiliary engines in hotelling mode, unitless (these vary by ship type and activity mode)

$EF_{[aux]}$ = Emission factor for auxiliary engines for the pollutant of interest, in g/kW-hr (these vary as a function of engine type and fuel used, rather than activity mode)

10^{-6} = Conversion factor from grams to metric tonnes (left this off as the comparable emissions are in grams)

For the engine load factors and engine power values, used the values listed[4] in the reference document for auxiliary engines, 0.64 and 11,000 kW respectively. To calculate the EFs for the varying sulfur levels, used the reference document[5].

$$SO_2\ EF = BSFC \times 2 \times 0.97753 \times \text{Fuel Sulfur Fraction}$$

Irvine used a brake specific fuel consumption of 210 g/kW-hrs, per the reference document[6] and the three sulfur levels listed in Zimmerman's analysis[7] to obtain the three EF for SO_2.

---

[4] Table 3-3: Auxiliary Engine Power Ratios, page 3-22. Table 3-4: Auxiliary Engine Load Factor Assumptions, page 3-23.
U.S. Environmental Protection Agency Office of Transportation and Air Quality's Assessment and Standards Division. (2009 December). *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines* (EPA-420-R-09-019). Retrieved from http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf

[5] Equation 3-22: Calculation of SO2 Emission Factors, g/kWh, page 3-25.
U.S. Environmental Protection Agency Office of Transportation and Air Quality's Assessment and Standards Division. (2009 December). *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines* (EPA-420-R-09-019). Retrieved from http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf

[6] Used for medium speed engines, page 3-25.
U.S. Environmental Protection Agency Office of Transportation and Air Quality's Assessment and Standards Division. (2009 December). *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Category 3 Marine Diesel Engines* (EPA-420-R-09-019). Retrieved from http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09019.pdf

SO_2 EF HFO (@2.7%S) = 210 g/kW-hr x 2 x 0.97753 x 0.027
=11.09 g/kW-hr

SO_2 EF @0.1%S = 210 g/kW-hr x 2 x 0.97753 x 0.001
= 0.41 g/kW-hr

SO_2 EF @0.5%S = 210 g/kW-hr x 2 x 0.97753 x 0.005
= 2.05 g/kW-hr

Using the cited 10 hours in port, Irvine obtained this mass of SO_2 for each of the three fuel sulfur levels for an average cruise ship at berth.

Fuel sulfur level	Grams of SO2 at berth for 10 hrs
Heavy Fuel Oil (HFO) 2.7%	780,397
0.5%[8]	144,518
0.1%[9]	28,904

Truck portion of the equation:
Originally, Zimmerman attempted to calculate the equivalent in long-haul truck miles, which Irvine provided. Then CCL decided to investigate the more equivalent ratio of cruise idling to truck idling. Irvine's assistance proved useful here as well, as another EPA staff member, Prashanth Guruaja[10] assisted.

---

[7] .1%, .5%, and heavy fuel oil sulfur contents

[8] From Table 1: International Ship Engine and Fuel Standards (MARPOL Annex VI). This fuel may be required for ships by 2020 worldwide, depending on fuel availability study results in 2018.
U.S. Environmental Protection Agency webpage on Nonroad Engines, Equipment, and Vehicles. (2010 March). *Designation of North American Emission Control Area to Reduce Emissions from Ships: Regulatory Announcement* (EPA-420-F-10-015). Retrieved from http://www.epa.gov/nonroad/marine/ci/420f10015.htm#3

[9] Table 1: International Ship Engine and Fuel Standards (MARPOL Annex VI). This fuel will be the required for ships by year 2015 while in the North American Emissions Control Area.
U.S. Environmental Protection Agency webpage on Nonroad Engines, Equipment, and Vehicles. (2010 March). *Designation of North American Emission Control Area to Reduce Emissions from Ships: Regulatory Announcement* (EPA-420-F-10-015). Retrieved from http://www.epa.gov/nonroad/marine/ci/420f10015.htm#3

[10] Prashanth Gururaja
U.S. Environmental Protection Agency
Office of Transportation & Air Quality
2000 Traverwood Dr.
Ann Arbor, MI 48105
734.214.4771

Gururaja calculated the following:

During extended idle, according to our modeling, we estimate that heavy-duty engines consume 0.89 gallons of diesel fuel per hour, as opposed to 0.2 gallons per hour for auxiliary power units (APUs). That number indirectly comes from MOVES, EPA's vehicle emissions inventory model. Since SO2 emissions are generally proportional the amount of fuel burned, we can approximate the SO2 rate from engines by proportioning the SO2 rate Solveig provided[11] with the ratio of these fuel rates. That is,

SO2 rate from engines = (0.89 gallons per hour from engine/0.2 gallons per hour from APU) x (0.0188 grams SO2 per hour from APU)

= 0.084 grams SO2 per hour from engine

---

[11] Section 1.2: Heavy-Duty Truck Categories, page 1-6. For the truck analysis, Irvine took the average miles per gallon rating for a class 8 truck (6.1 mpg). Using the standard values for density and sulfur in diesel fuel, 7.1 lbs/gal and 15ppm (or 0.0015%) respectively, along with some conversion factors, the ratio of sulfur to sulfur dioxide, and an estimation of SO_2 conversion in the exhaust plume of 97.7%, Irvine came up with this value for the amount of SO_2 per gallon of diesel fuel:

$$g\ SO2 \Big/ gallon\ fuel = \frac{1{,}000\,g}{2.2\ lbs} * \frac{7.1\ lbs}{gal\ fuel} * 0.977 * 0.000015\ S * \frac{64\ SO2}{32\ S}$$

$$g\ SO_2 / gal\ fuel = 0.0946$$

$$\frac{\dfrac{0.0946\ g\ SO2}{1\ gal\ fuel}}{\dfrac{gal\ fuel}{6.1\ miles}} = 0.0156\ g\ \frac{SO2}{truck}\ mile$$

780,397 g $SO_{2\text{-vessel}}$ / 0.0156 g SO_2/$mile_{\text{-truck}}$ = 50,326,202 truck miles

144,518 g $SO_{2\text{-vessel}}$ / 0.0156 g SO_2/$mile_{\text{-truck}}$ = 9,319,667 truck miles

28,904 g $SO_{2\text{-vessel}}$ / 0.0156 g SO_2/$mile_{\text{-truck}}$ = 1,863,933 truck miles

U.S. Environmental Protection Agency Office of Transportation and Air Quality and U.S. Department of Transportation National Highway Traffic Safety Administration. (2011 August). *Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium-and Heavy-Duty Engines and Vehicles Regulatory Impact Analysis* (EPA-420-R-11-901). Retrieved from http://www.epa.gov/oms/climate/documents/420r11901.pdf

Overall Comparison:
(0.084 grams SO2 per hour per truck) x (10 hours)=0.84 grams SO2 per ten hours per truck

Then the formula becomes

Grams SO2 per cruise ship idling at berth for ten hours / grams SO2 per truck idling for ten hours = number of trucks idling per ten hours equivalent to a cruise ship idling per ten hours

Fuel sulfur level	Grams of SO2 at berth for 10 hrs	Number of trucks idling for 10 hrs equivalent
Heavy Fuel Oil (HFO) 2.7%	780,397	929,044
0.5%	144,518	172,045
0.1%	28,904	34,409.5

A visual way to understand the ratio of trucks to cruise ship is how many acres of the Charleston peninsula would be covered by the equivalent trucks to cruise. Zimmerman found that over 60% of long-haul trucks in the United States use box trailers, and the standard sizes are 53 feet long by 96 feet wide[12]. The cab/tractor averages 20 feet long, according to a basic google search.

Based on those numbers, the average long-haul trucks measures 620.5 square feet, which translates to 0.014 acres per truck. Multiply that acreage by the number of trucks based on previous calculations, and we get the following:

---

[12] Section 11.1.1: Trailer Types, page 11-2.
U.S. Environmental Protection Agency Office of Transportation and Air Quality and U.S. Department of Transportation National Highway Traffic Safety Administration. (2011 August). *Final Rulemaking to Establish Greenhouse Gas Emissions Standards and Fuel Efficiency Standards for Medium-and Heavy-Duty Engines and Vehicles Regulatory Impact Analysis* (EPA-420-R-11-901). Retrieved from http://www.epa.gov/oms/climate/documents/420r11901.pdf

Fuel sulfur level	Grams of SO2 at berth for 10 hrs	Number of trucks idling for 10 hrs equivalent	Number of acres those trucks would take up
Heavy Fuel Oil (HFO) 2.7%	780,397	929,044	13,007
0.5%	144,518	172,045	2,409
0.1%	28,904	34,409.5	482

Questions about this document can be directed to
CCL Project Manager Katie Zimmerman
katiez@scccl.org
(843) 725-1292