Final Memorandum

Clearing the Air:
Would Shoreside Power Reduce Air Pollution Emissions from Cruise Ships calling on the Port of Charleston, SC?

Prepared by:

James J. Corbett, PhD, PE
Bryan Comer
Energy and Environmental Research Associates, LLC
2 Babcock Farms Lane
Pittsford, NY 14534

Prepared for:

Southern Environmental Law Center
43 Broad St., Suite 300
Charleston, SC 29401

September 9, 2013

Abstract

Cruise ships can contribute to local and regional air pollution by using their on-board engines to generate power for the vessel while docked in port. One alternative to using on-board engines is shore power. Shore power allows marine vessels, including cruise ships, to plug into the electric grid to power lights, air conditioning, refrigeration, and other ancillary equipment while at berth in port. This memo compares estimated emissions from cruise vessels while docked at the Port of Charleston, SC when using on-board engines as opposed to shore power for the following pollutants: carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2). We find that the use of shore power would greatly reduce air pollution from these ships. Specifically, in 2013 shore power would reduce CO by 92%, NO_x by 98%, PM_{10} up to 59%, $PM_{2.5}$ up to 66%, SO_2 up to 73%, and CO_2 by 26%. Emissions reductions would be expected to be even greater in 2019 after the local power company reduces its use of coal for electricity generation. Reducing air pollution by switching to shore power could provide health benefits for the near-port community.

1. Introduction

Air emissions from commercial marine vessels, including cruise ships, can have deleterious effects on air quality and negatively impact communities near ports. While docked in port, cruise ships generate the electricity they need by either operating on-board engines or accessing electricity by plugging into shoreside power connections at the dock, if available. Marine engines combusting petroleum fuels emit air pollutants that may lead to, or exacerbate, health problems like asthma, bronchitis, and lung cancer. Engine combustion produces harmful byproducts including carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM), and sulfur dioxide (SO_2) in addition to greenhouse gases like carbon dioxide (CO_2). Shoreside electrical connections can substitute for on-board generation of power while the ship is docked. Electricity supplied to the ship would come from the local utility's power generation portfolio, which might include renewable and non-renewable sources. Shore power can avoid idling of marine engines, reduce on-board fuel consumption, and eliminate engine-combustion emissions while the vessel is docked. Many cruise lines have begun to use shore power to reduce emissions.

Carnival, the world's largest cruise firm, operates 100 ships under 10 brands like Princess Cruises and Holland America. One of these ships is the Carnival Fantasy. The Carnival Fantasy is 855 feet long and holds over 2000 passengers.[1] The electricity demand of a cruise ship is considerable, in many cases several times that of a container vessel. Carnival Corporation states in its 2008 environmental management report that shore power installations at ports "allow ships that have been configured [to accept shore power] to use shore power provided by land-based power plants. This allows those Carnival ships to shut down their engines and avoid air emissions while moored in these ports. These land-based power plants use environmental technologies not yet available to ships that enable them to produce power with less environmental impact and take advantage of sustainable resources, such as hydroelectric power."[2] In their 2009 Corporate Sustainability Summary (updated 2011), the company states that "Carnival has taken the lead in the cruise industry in developing shore power for cruise ships in Juneau, Alaska; Seattle, Washington; and Vancouver, British Columbia. Carnival is engaged in planning shore power in several other United States and European ports and participates in a working group that is establishing international standards for shore power."[3]

---

[1] http://www.carnival.com/cruise-ships/carnival-fantasy.aspx

[2] *Environmental Management Report: Fiscal Year 2008.* Carnival Corporation & PLC. See p. 19 at http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9NzkyMHxDaGlsZElEPS0xfFR5cGU9Mw==&t=1

[3] *Corporate Sustainability Summary 2009: Updated 29 April 2011*. Carnival Corporation & PLC. See p. 37 at http://phx.corporate-ir.net/External.File?item=UGFyZW50SUQ9OTE1NjV8Q2hpbGRJRD0tMXxUeXBlPTM=&t=1

However, in some cases, there is resistance to installing shore power. For instance, in the "Frequently Asked Questions" section of the South Carolina State Ports Authority's (SCSPA) website detailing upgrades to the Union Pier Cruise Terminal at the Port of Charleston, the SCSPA states the following in direct response to a question about the potential for air quality benefits from shore power:

> "On March 26, the IMO designated a 230-mile area around the U.S. coast as an Emission Control Area (ECA), dramatically reducing ship-related emissions and eliminating the need to consider shore power. The EPA estimates this move reduces sulfur content in fuel by 98% – cuts particulate matter by 85%, and NOx by 80%. The new standards go into effect in 2011, with implementations in 2012 and 2015."[4]

This explanation is misleading and partly incorrect. Sulfur and PM emissions from ships calling on the port will decrease under new international maritime pollution standards, especially in 2015, due to increasingly stringent fuel sulfur limits. However, NO_x emissions will most assuredly not be reduced by 80%. New NO_x emissions standards only apply to marine engines installed on vessels built on or after January 1, 2011 (Tier II standards) or January 1, 2016 (Tier III standards). Tier II standards achieve 20% NO_x reductions compared to Tier I standards.[5] Tier III standards achieve 80% NO_x reductions compared to Tier I standards and apply to ships operating in ECAs.[6] Therefore, a cruise ship that calls on the port after 2011 could potentially have 20% lower NO_x emissions if it were newly built; 80% reductions could only be realized after 2016, provided the vessel was constructed on or after January 1, 2016. Moreover, it is necessary to compare emissions that would arise from electricity generation for shore power to emissions from the ship while at berth in order to determine if environmental (and human health) benefits are likely to occur. Without quantifying the emission reductions offered by shore power, claiming that shore power is unnecessary and would not produce environmental benefits is misguided.

This project evaluates whether using shore power at the Union Pier Cruise Terminal at the Port of Charleston, S.C., could reduce air pollution emissions from the Carnival Fantasy. Specifically, we estimate and compare emissions from shore power to emissions from the Carnival Fantasy (i.e. "vessel power") while moored in port. Emissions are estimated for CO, NO_x, $PM_{2.5}$, PM_{10}, SO_2, and CO_2 assuming that the electricity used for shore power would be supplied by South Carolina Electric and Gas (SCE&G) and vessel power would be provided by the Carnival Fantasy's on-board engines. Annual in-port emissions associated with hotelling of the Carnival Fantasy are estimated for 2013 and 2015. Shore power and vessel power assumptions for each scenario are explained below.

2013 Scenario:

i. Shore power
   a. Electricity is supplied by SCE&G assuming they use the same fuel mix as they did in 2011 (48% coal; 28% natural gas; 19% nuclear; 3% hydro; 2% biomass)[7]

ii. Vessel power
   a. Electricity is generated by on-board engines assuming 1% sulfur (S) fuel (maximum allowable S content in ECAs in 2013)
   b. Electricity is generated by on-board engines assuming 0.5% S fuel[8]

---

[4] *Frequently Asked Questions*. SCSPA. http://www.scspa.com/UnionPierPlan/faq.html#a8

[5] Tier I standards apply to marine engines installed on vessels constructed on or after January 1, 2000.

[6] See p. 4 of the EPA fact sheet on the North American Emissions Control Area for a concise summary of the impacts of new marine vessel fuel sulfur and NO_x standards: http://www.epa.gov/otaq/regs/nonroad/marine/ci/420f10015.pdf

[7] *2012 Environmental Sustainability Report.* SCANA. 2012. See p. 4 at http://www.scana.com/NR/rdonlyres/A8A5F326-5E16-4DD6-B6DC-F3EA6172ADFC/0/ESR_2012.pdf

2015 Scenario

i. Shore power
   a. Electricity is supplied by SCE&G assuming they use the fuel mix as they did in 2011 (48% coal; 28% natural gas; 19% nuclear; 3% hydro; 2% biomass)
ii. Vessel power
   a. Electricity is generated by on-board engines assuming 0.1% S fuel (2015 ECA compliant)

Emissions are also estimated for a future scenario: the "2019 Scenario." This scenario assumes that SCE&G's energy portfolio shifts away from coal and toward more natural gas and nuclear. We also evaluate how emissions would change if a larger cruise ship were to call on the port. Shore power and vessel power assumptions for the 2019 scenario are explained below.

2019 Scenario

i. Shore power
   a. Electricity is supplied by SCE&G assuming they produce one-third of their energy using coal, one-third using natural gas, and one-third using nuclear (or other non-emitting sources)[9]
ii. Vessel power
   a. Electricity is generated by on-board engines from a 2000 passenger cruise ship (like the Carnival Fantasy) operating on 0.1% S fuel
   b. Electricity is generated by on-board engines from a 3500 passenger cruise ship (like the Carnival Dream) operating on 0.1% S fuel

2. Methodology

This section briefly describes the methodology used to calculate vessel power and shore power emissions for the 2013 and 2015 Scenarios as well as the 2019 Scenario.

2.1 2013 and 2015 Scenarios

2.1.1 Carnival Fantasy Emissions

Emissions from the Carnival Fantasy were estimated by applying methodologies similar to those used by the California Air Resources Board (CARB)[10] and the US Environmental Protection Agency (EPA).[11] In general, to estimate annual cruise ship emissions one needs to know the total installed power of the on-board engines, the proportion of that installed power used for auxiliary power while at berth (i.e., the hotelling load factor), the annual number of port calls, and the average time at berth; these inputs are found in Table 1. Once the total amount of energy (kWh) used by the cruise ship each year is determined, one can estimate total annual air emissions for each pollutant by applying the emissions factors (g/kWh) found in Table 2.

---

[8] While the ECA requires marine fuels to contain at most 1% S, we believe that the sulfur content of fuel used in cruise ships calling on the Port of Charleston is probably closer to 0.5%. Using a lower S assumption for marine fuels yields a more conservative estimate of vessel emissions for SO_2 and PM.

[9] A recent SCE&G press release suggests that by the end of 2018, the generation mix will be closer to one-third coal, one-third natural gas, and one-third nuclear. See: http://www.sceg.com/en/news-room/current-news/sceg-accelerates-plans-to-retire-canadys-station.htm

[10] *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf

[11] *Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter: Technical Support Document*. US EPA. 2009. http://www.epa.gov/nonroad/marine/ci/420r09007.pdf

Our assumptions can be compared with those used in other reports estimating cruise ship emissions. We believe that a memorandum by Trinity Consultants titled *Historical, Current and Future Criteria Pollutant Emissions at Union Pier Terminal* has underestimated air pollution emissions from cruise ships calling on Port of Charleston by nearly 75% as a direct result of incorrect assumptions. The Trinity memo correctly assumes that the hotelling load factor is 16% (the same assumption we make in Table 1). However, they incorrectly apply this load factor to what they call "hotelling power" (which they assume is 11,000 kW) instead of total installed power. Thus, they assume that cruise ships calling on the port use 1,760 kW while at berth. We estimate that the Carnival Fantasy uses 6,758 kW at berth (42,240 kW installed power * 0.16). Therefore, we believe that the Trinity Consultants memorandum underestimates air pollution emissions from cruise ships during hotelling by almost 75%. As an example, Trinity Consultants claims that 64 cruise ship calls, spending an average of 10 hours at berth, yielded 1.29 metric tons (1.43 short tons) of CO in 2010; we estimate this activity would result in 4.76 metric tons of CO.

To verify that our assumptions would yield realistic results, we used our assumptions to calculate emissions from cruise ships calling on the Union Pier Terminal in 2011 and compared those results to the 2011 South Carolina Ports emissions inventory conducted by Moffat & Nichol.[12] Assuming the same number of port calls and average time at berth (88 calls; 12.3 hrs/call), our results closely match those of Moffat & Nichol for CO and NO_x. For CO, we estimate that 2011 cruise activity would generate 8.87 tons compared to 8.85 tons in the Moffat & Nichol report; for NO_x we estimate 112 tons compared to 108 tons.[13] Moffat & Nichol estimate higher PM and SO_2 emissions than what we would, but this appears to reflect their assumption that cruise vessels in 2011 were operating on residual oil (RO) instead of marine diesel oil (MDO). To comply with ECA fuel sulfur limits, cruise ships would have to operate on lower sulfur fuel beginning in July 2010, requiring a shift to MDO or some other distillate fuel, so we question the accuracy of PM and SO_2 emissions from cruise vessels in the Moffat & Nichol report. Nevertheless, because our results track well with the South Carolina Ports emissions inventory for CO and NO_x, we believe that our estimates for annual emissions from the Carnival Fantasy will be reasonable.

Table 1. Assumptions for Carnival Fantasy vessel characteristics and activity.

Description	Value	Units
Installed power[14]	42,240	kW
Hotelling load factor[15]	0.16	hotelling power/installed power
Hotelling power	6,758	kW
Port calls per year[16]	68	port calls/yr
Hours per call[17]	10	hr
Hours per year	680	hr/yr
Annual power consumption at berth	4,595,712	kWh

[12] *South Carolina Ports 2011 Air Emissions Inventory Update.* Moffatt & Nichol. 2013. http://www.pledgeforgrowth.com/documents/2011_Air_Emissions_Inventory_Update.pdf
[13] See on-terminal hotel emissions for Union Pier in Table 7-2 on p. 52 of *South Carolina Ports 2011 Air Emissions Inventory Update.* Moffatt & Nichol. 2013. http://www.pledgeforgrowth.com/documents/2011_Air_Emissions_Inventory_Update.pdf.
[14] http://www.cruiseships.xtreemhost.com/Ships%20A%20to%20C/Carnival%20Fantasy.htm
[15] Table II-5 on p. D-14 of *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf
[16] Table 2-1 on p. 27 of *South Carolina Ports 2011 Air Emissions Inventory Update.* Moffatt & Nichol. 2013. http://www.pledgeforgrowth.com/documents/2011_Air_Emissions_Inventory_Update.pdf.
[17] ibid.

Table 2. Emissions factors (g/kWh) used to calculate Carnival Fantasy emissions.

	2013 (1% S fuel)[18]	2013 (0.5% S fuel)[19]	2015 (0.1% S fuel)[20]
CO	1.10	1.10	1.10
NO_x	13.9	13.9	13.9
PM_{10}	0.49	0.38	0.25
$PM_{2.5}$	0.45	0.35	0.23
SO_2	4.24	2.12	0.42
CO_2	690	690	690

2.1.2 SCE&G Emissions

Net energy generation data for SCE&G power plants from the US Energy Information Administration (EIA), coupled with annual facility-wide emissions data obtained from the South Carolina Department of Health and Environmental Control (SCDHEC), were used to calculate emissions factors for CO, NO_x, PM_{10}, $PM_{2.5}$, SO_2, and CO_2 for 2011 (the most recent year for which quality-assured emissions data are available) as shown in Table 3. These emissions factors were used in combination with the Carnival Fantasy activity assumptions above (Table 1) to determine what the annual emissions would be if shore power were used (i.e., we multiply annual power consumption at berth by the emissions factors in Table 3). It should be noted that at the end of 2012 SCE&G retired one of three coal-fired generating units at the Canadys station; the other two coal-fired units will be retired by the end of 2013.[21] Therefore, in 2013 and 2015 (when the 0.1% S limit for marine fuels takes effect) there will likely be decreases in the emissions rates of some pollutants, especially SO_2 and PM, from the SCE&G portfolio. Using SCE&G's 2011 generation mix helps ensure that the emissions reduction benefits of shore power are not overestimated.

---

[18] Source for CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_2 is Table 2-10 on p. 35 of *South Carolina Ports 2011 Air Emissions Inventory Update.* Moffatt & Nichol. 2013. http://www.pledgeforgrowth.com/documents/2011_Air_Emissions_Inventory_Update.pdf. Source for CO_2 is Table II-08 on p. D-16 of *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf

[19] Source for CO, NO_x, PM_{10}, $PM_{2.5}$, and CO_2 is Table II-08 on p. D-16 of *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. SO_2 was calculated using equation 2-3 on p. 2-10 of *Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter: Technical Support Document*. US EPA. 2009. http://www.epa.gov/nonroad/marine/ci/420r09007.pdf

[20] ibid.

[21] *SCE&G Accelerates Plans to Retire Coal-fired Canadys Station*. SCE&G. 2013. http://www.sceg.com/en/news-room/current-news/sceg-accelerates-plans-to-retire-canadys-station.htm

Table 3. Data used to calculate emissions factors for shore power from SCE&G for 2013 and 2015 Scenarios

Facility Name	Net Generation (MWh)	CO (MT)	NO_x (MT)	PM_{10} (MT)	$PM_{2.5}$ (MT)	SO_2 (MT)	CO_2 (MT)
Canadys Steam	1,558,389	883.33	2,409.91	2,070.54	1,639.68	14,180.75	1,386,546
Coit GT	870	0.28	4.92	0.05	0.05	0.12	1,045
Cope Station	2,459,909	94.96	956.24	536.26	425.90	1,428.92	2,038,986
Hagood	55,604	38.95	37.02	1.40	1.40	0.68	38,287
Hardeeville	11	0.01	0.38	0.00	0.00	0.00	64
Jasper County Generating Facility	5,549,564	34.69	138.48	113.09	113.09	10.31	1,955,072
McMeekin	1,204,643	152.41	1,638.15	525.12	515.25	6,548.88	1,033,022
Parr	51,659	0.55	7.72	0.09	0.09	0.18	1,717
Urquhart	2,186,990	547.99	753.73	589.02	421.50	4,279.52	1,163,511
Wateree	3,973,744	383.58	1,970.64	1,156.82	707.04	3,523.06	3,874,183
Williams	2,742,673	239.59	1,400.17	505.95	301.76	550.60	2,429,011
Neal Shoals (Hydro)	11,169	0.00	0.00	0.00	0.00	0.00	0.00
Stevens Creek (Hydro)	53,984	0.00	0.00	0.00	0.00	0.00	0.00
Saluda (Hydro)	41,426	0.00	0.00	0.00	0.00	0.00	0.00
Fairfield Pumped Storage (Hydro)	(229,744)	0.00	0.00	0.00	0.00	0.00	0.00
V C Summer (Nuclear)	7,426,232	0.00	0.00	0.00	0.00	0.00	0.00
Total	27,087,123	2,376	9,317	5,498	4,125	30,523	13,921,444
Emissions factor (g/kWh)[a]		**0.088**	**0.344**	**0.152**	**0.203**	**1.13**	**514**

[a] To calculate emissions factor for each pollutant in grams per kilowatt hour (g/kWh), multiply the total emissions of each pollutant by 10^6 to convert from metric tons (MT) to grams (g); then, multiply net generation by 10^3 to convert from megawatt hours (MWh) to kilowatt hours (kWh); finally, divide total emissions (g) by total net generation (kWh).

2.2 2019 Scenario

2.2.1 Cruise Ship Emissions – Bigger Ships in 2019?

The Carnival Fantasy is the oldest ship in the Carnival fleet and entered into service in 1990.[22] The Carnival Fantasy holds a little more than 2000 passengers; whereas, newer ships like the Carnival Dream can hold over 3,500.[23] The relocation and upgrades of the cruise terminal at the Port of Charleston's Union Pier may permit larger cruise ships to call on the port. A larger ship with larger engines may yield more in-port emissions during hotelling. For the 2019 Scenario, we compare shore power emissions to Carnival Fantasy emissions as well as a larger cruise ship: the Carnival Dream. Operating characteristics and assumed annual activity for the Carnival Fantasy are the same as they were in the 2013 and 2015 Scenarios; operating characteristics and assumed annual activity (i.e., port calls per year and hours per call) for the Carnival Dream are found in Table 4. This analysis leaves unchanged the time-in-port and number-of-port-call inputs applied to the Carnival Fantasy, essentially assuming the larger vessel would not require more dockside time. This affords easier comparison with vessel emission characteristics and may provide a conservative (low) estimate for a larger vessel's dockside emissions. Emissions factors used to calculate emissions from the Carnival Fantasy and the Carnival Dream are shown in Table 5.

Table 4. Assumptions for Carnival Dream vessel characteristics and activity.

Description	Value	Units
Installed power[24]	63,335	kW
Hotelling load factor[25]	0.16	hotelling power/installed power
Hotelling power	10,134	kW
Port calls per year[26]	68	port calls/yr
Hours per call[27]	10	hr
Hours per year	680	hr/yr
Annual power consumption at berth	6,890,848	kWh

[22] *Carnival Fantasy Cruise Ship.* Fritscher, L. USA Today. http://traveltips.usatoday.com/carnival-fantasy-cruise-ship-17589.html
[23] ibid.
[24] *Carnival Dream Fact Sheet.* Note: 84,833 hp = 63,335 kW. http://carnival-news.com/2013/01/17/fact-sheet-carnival-dream-2/
[25] Table II-5 on p. D-14 of *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. http://www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf
[26] We assume that the Carnival Dream would call on the port as often as the Carnival Fantasy does.
[27] We assume that the Carnival Dream would spend the same average time hotelling as the Carnival Fantasy.

Table 5. Emissions factors (g/kWh) used to calculate Carnival Fantasy and Carnival Dream emissions.

	0.1% S fuel[28]
CO	1.10
NO_x	13.9
PM_{10}	0.25
$PM_{2.5}$	0.23
SO_2	0.42
CO_2	690

2.2.2 SCE&G Emissions – Cleaner Energy Portfolio in 2019

SCE&G is planning to shift their electricity generation portfolio away from coal and toward natural gas and nuclear by the end of 2018. In 2011, SCE&G's generation mix was mainly coal (48%), followed by natural gas (28%), and nuclear (19%); the rest was hydro (3%) or biomass combustion (2%).[29] A recent SCE&G press release suggests that by the end of 2018, the generation mix will be closer to one-third coal, one-third natural gas, and one-third nuclear.[30] In fact, SCE&G retired one coal-fired unit at their Canadys plant at the end of 2012; they plan on retiring the other two by the end of 2013.[31] Three additional coal-fired units will be retired by the end of 2018 (Urquhart Unit 3 and McMeekin Units 1 and 2).[32] These six coal-fired generating units are the oldest[33] and most polluting in the SCE&G portfolio. Our analysis reveals that in 2011 the Canadys and McMeekin plants were responsible for 68% of SO_2 emissions and 52% of $PM_{2.5}$ emissions while representing only 10% of SCE&G electricity generation. Shifting away from coal will considerably reduce emissions from the SCE&G electricity generation portfolio, particularly for SO_2 and PM.

In order to estimate emissions factors for shore power in 2019, we assumed that the one-third of total electricity generated from coal was produced by the Wateree power plant. After the coal-fired units at Canadys, McMeekin, and Urquhart close, the Wateree plant will be the "dirtiest" remaining coal-fired power plant. For example, in 2011 the Canadys plant produced approximately 9,000 g of SO_2 per MWh, followed by McMeekin (~5,400 g/MWh) and Urquhart (~2,000 g/MWh); Wateree produced almost 900 g/MWh of SO_2. While it is unlikely that Wateree will handle all of the coal electricity generation duties in 2019, other SCE&G coal-fired power plants produce fewer emissions per MWh. Thus, we have selected Wateree to ensure that we do not underestimate shore power emissions, particularly for SO_2 and PM. For the one-third of electricity generated by natural gas, we assumed that this electricity was generated by the Jasper plant. This plant produced 20% of

---

[28] Source for CO, NO_x, PM_{10}, $PM_{2.5}$, and CO_2 is Table II-08 on p. D-16 of *Emissions Estimation Methodology for Ocean-Going Vessels*. CARB. 2011. SO_2 was calculated using equation 2-3 on p. 2-10 of *Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter: Technical Support Document*. US EPA. 2009. http://www.epa.gov/nonroad/marine/ci/420r09007.pdf

[29] *2012 Environmental Sustainability Report.* SCANA. 2012. See p. 4 at http://www.scana.com/NR/rdonlyres/A8A5F326-5E16-4DD6-B6DC-F3EA6172ADFC/0/ESR_2012.pdf

[30] *SCE&G Accelerates Plans to Retire Coal-fired Canadys Station*. SCE&G. 2013. http://www.sceg.com/en/news-room/current-news/sceg-accelerates-plans-to-retire-canadys-station.htm

[31] ibid.

[32] *SCE&G Announces Plans to Retire a Portion of its Coal-fired Generation*. SCE&G. 2012. http://www.sceg.com/en/news-room/current-news/sceg-announces-plans-to-retire-a-portion-of-its-coal-fired-generation.htm

[33] *2012 Environmental Sustainability Report.* SCANA. 2012. See p. 6 at http://www.scana.com/NR/rdonlyres/A8A5F326-5E16-4DD6-B6DC-F3EA6172ADFC/0/ESR_2012.pdf

total electricity in 2011 (the most of any natural gas plant by far); we think it is reasonable to assume that this plant will generate most of the natural gas electricity in 2019. The rest of the electricity will be produced by non-emitting[34] technologies (mostly nuclear). Given these assumptions, the emissions factors for electricity produced by SCE&G in the 2019 Scenario are presented in Table 6.

Table 6. Shore power emissions factors for 2019 Scenario.

Pollutant	Emissions Factor (g/kWh)
CO	0.034
NO_x	0.174
PM_{10}	0.104
$PM_{2.5}$	0.066
SO_2	0.300
CO_2	442

3. Results

3.1 2013 and 2015 Scenarios

Our estimates for emissions generated by the Carnival Fantasy while at berth (hotelling) compared with shore power, assuming 68 port calls per year and an average of 10 hours per call, are found in Table 7.

Table 7. Potential annual emissions (metric tons) generated by the Carnival Fantasy while at berth using shore power compared with on-board engines operating on 1%, 0.5%, and 0.1% sulfur fuel, respectively.

	Shore Power	2013 (1% S fuel)	2013 (0.5% S fuel)	2015 (0.1% S fuel)
CO	0.40	5.06	5.06	5.06
NO_x	1.58	63.9	63.9	63.9
PM_{10}	0.93	2.25	1.75	1.15
$PM_{2.5}$	0.70	2.07	1.61	1.06
SO_2	5.18	19.5	9.75	1.95
CO_2	2,362	3,171	3,171	3,171

Results indicate that:

1. Shore power would reduce CO emissions by 92% in 2013 and in 2015 (Figure 1a)
2. Shore power would reduce NO_x emissions by nearly 98% in 2013 and in 2015 (Figure 1b)
3. Shore power would reduce PM_{10} emissions 46%-59% in 2013 and 19% in 2015 (Figure 1c)
4. Shore power would reduce $PM_{2.5}$ emissions by 56%-66% in 2013 and 34% in 2015 (Figure 1d)
5. Shore power would reduce SO_2 emissions by 47%-73% in 2013; however SO_2 emissions from shore power would be greater than vessel power in 2015 (Figure 2a).
6. Shore power would reduce CO_2 emissions by 26% in 2013 and in 2015 (Figure 2b)

[34] Non-emitting at the point of electricity generation; like most electricity generating technologies (e.g., coal and natural gas), there are emissions associated with resource extraction and transportation.

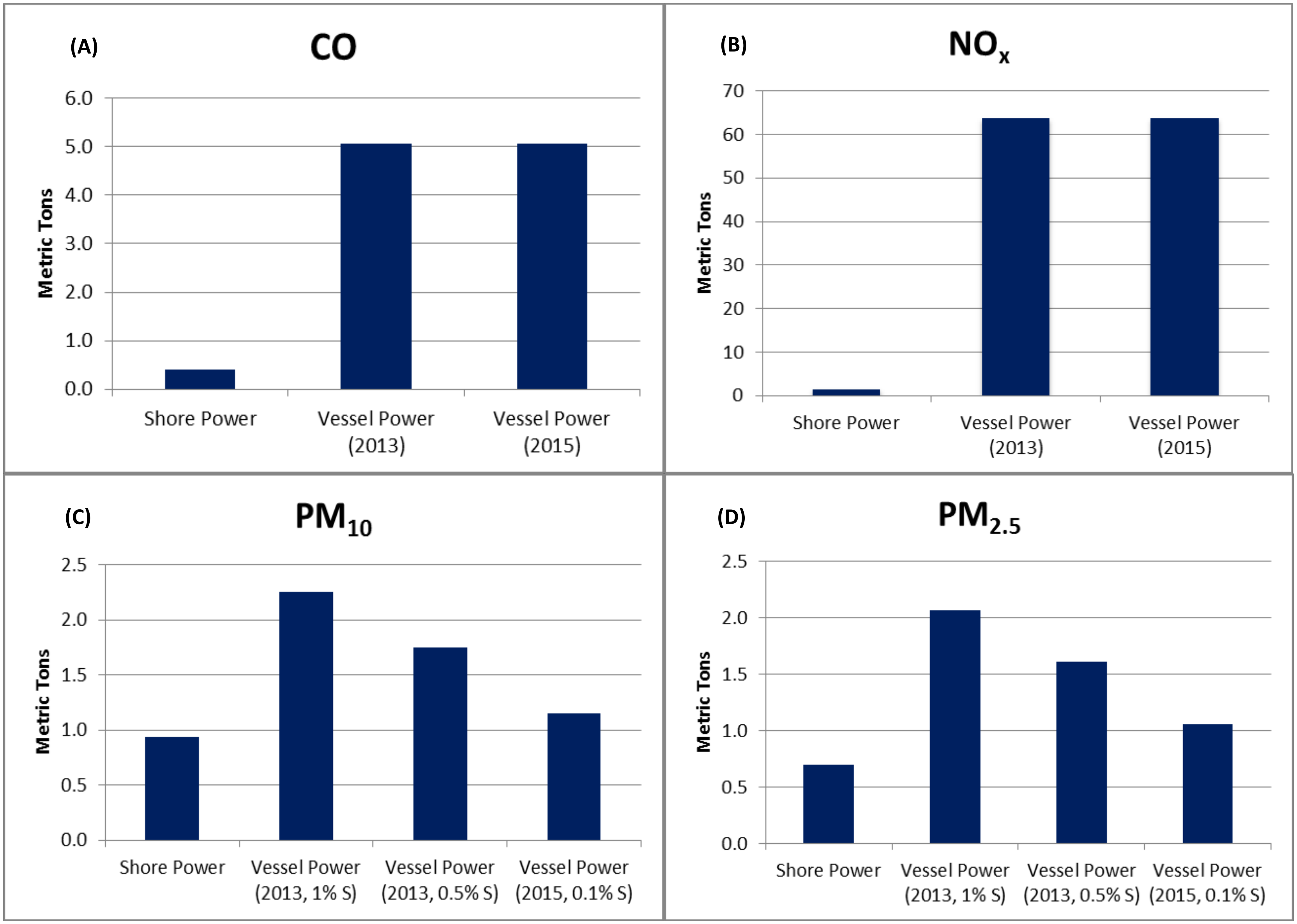

Figure 1. Shore power reduces CO, NO_x, PM_{10}, and $PM_{2.5}$ emissions in 2013 and 2015.

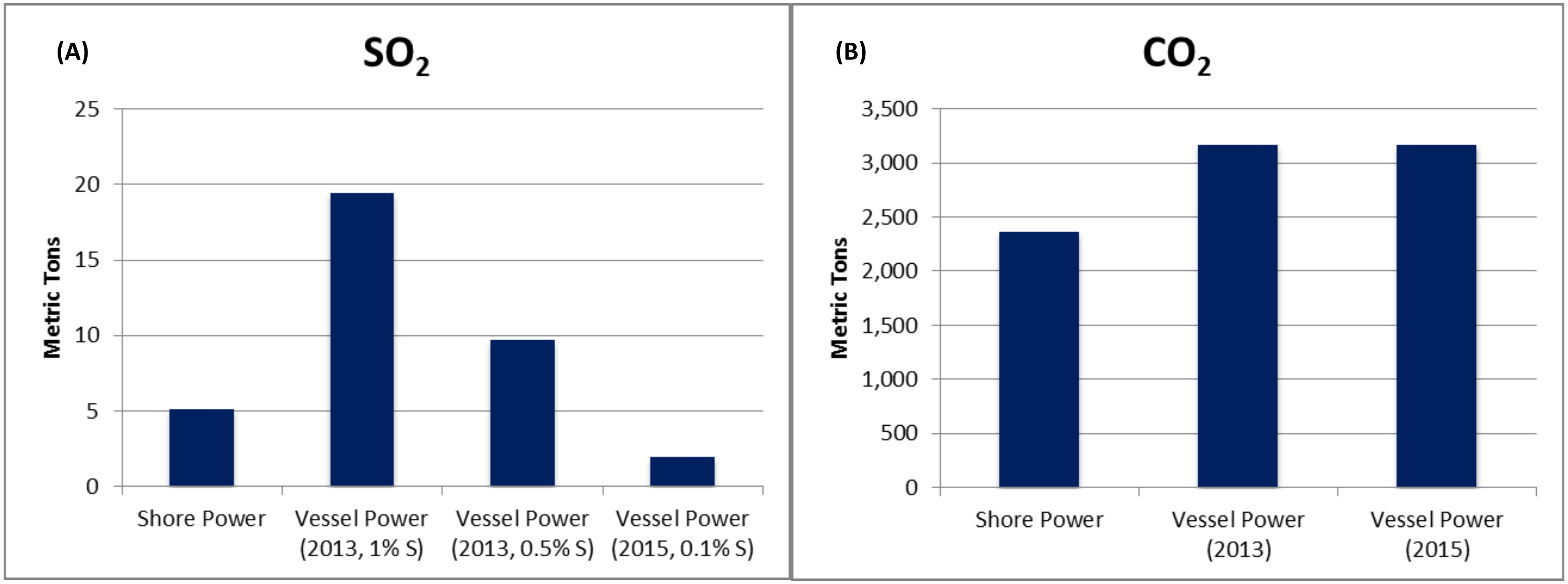

Figure 2. Shore power reduces SO_2 in 2013 but not 2015, and shore power reduces CO_2 emissions in 2013 and 2015.

3.2 2019 Scenario

In 2019 SCE&G's energy portfolio will produce fewer air emissions per MWh due to a shift away from coal toward natural gas and nuclear. Shore power could be especially beneficial if larger ships begin calling on the port in the future. Our estimates for emissions generated by a 2000 passenger cruise ship (Carnival Fantasy) and a 3500 passenger cruise ship (Carnival Dream) while at berth (hotelling) compared with shore power, assuming 68 port calls per year and an average of 10 hours per call, are found in Table 8.

Table 8. Potential annual emissions (metric tons) generated by a 2000 passenger cruise ship (Carnival Fantasy) and a 3500 passenger cruise ship (Carnival Dream) while at berth using shore power compared with using on-board engines operating on 0.1% sulfur fuel.

	2000 Passenger		**3500 Passenger**	
	Shore Power	Vessel Power	Shore Power	Vessel Power
CO	0.16	5.06	0.24	7.58
NO_x	0.80	68.3	1.20	95.8
PM_{10}	0.48	1.15	0.72	1.72
$PM_{2.5}$	0.30	1.06	0.46	1.58
SO_2	1.36	1.95	2.04	2.92
CO_2	2,033	3,171	3,049	4,755

Results indicate that:

1. Larger cruise ships would produce more emissions of all pollutants (Figure 3 and Figure 4)
2. Shore power would reduce CO emissions by 97% in 2019 (Figure 3a)
3. Shore power would reduce NO_x emissions by nearly 99% in 2019 (Figure 3b)
4. Shore power would reduce PM_{10} emissions by 58% in 2019 (Figure 3c)
5. Shore power would reduce $PM_{2.5}$ emissions by 71% in 2019 (Figure 3d)
6. Shore power would reduce SO_2 emissions by 30% in 2019 (Figure 4a)
7. Shore power would reduce CO_2 emissions by 36% in 2019 (Figure 4b)

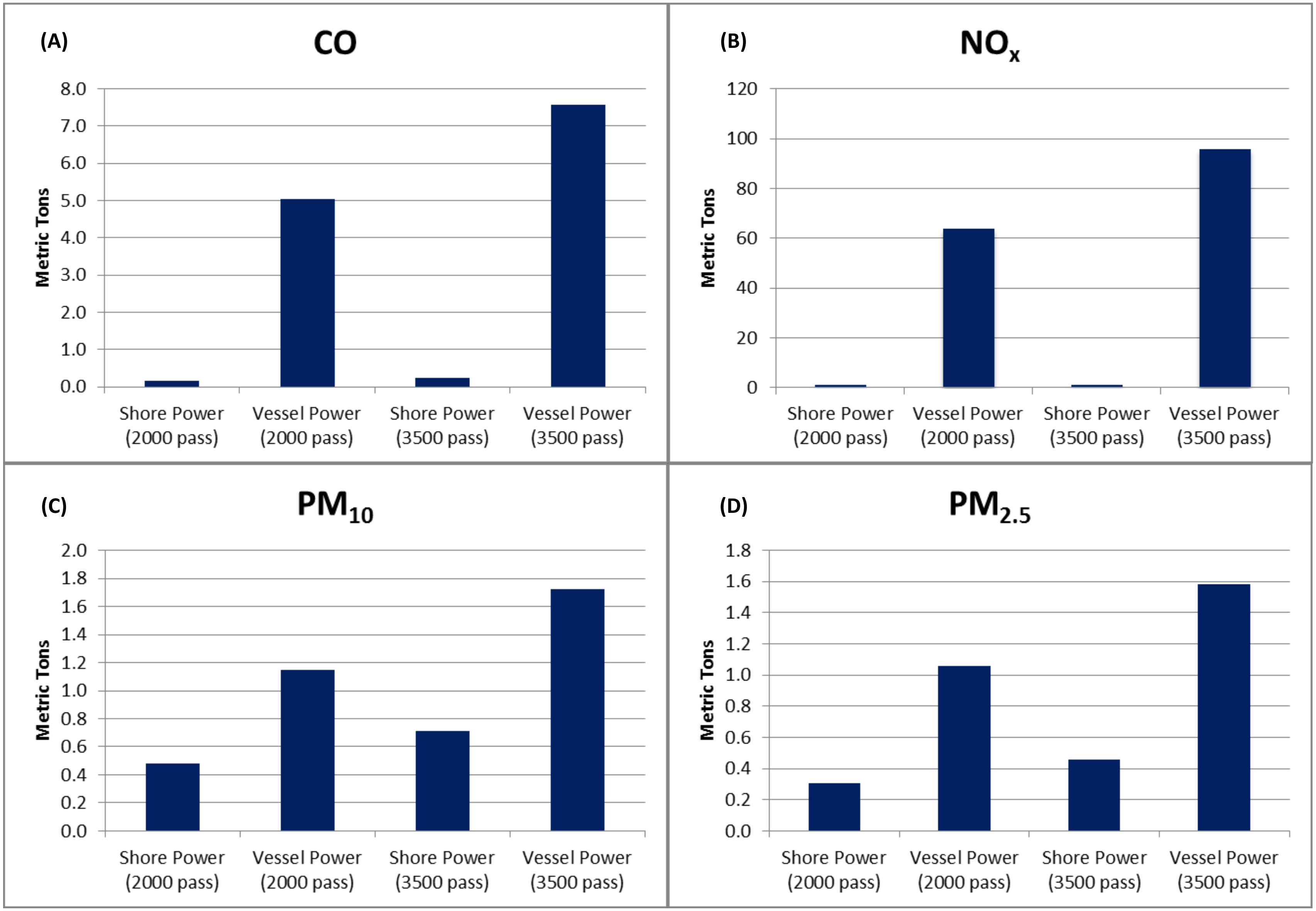

Figure 3. Shore power reduces CO, NO_x, PM_{10}, and $PM_{2.5}$ emissions in 2019; larger cruise ships would be expected to produce more emissions.

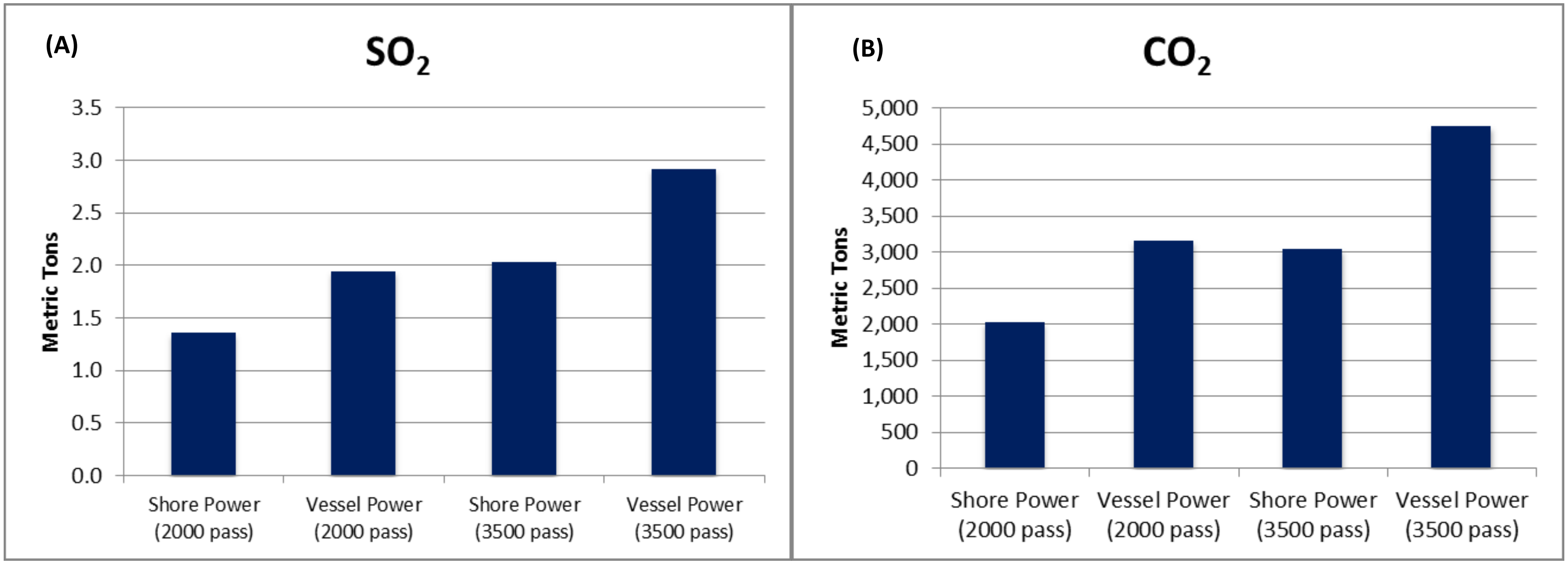

Figure 4. Shore power reduces SO_2 and CO_2 in 2019; larger cruise ships would be expected to produce more emissions