UCR College of Engineering- Center for Environmental Research & Technology

Vessel Speed Reduction Lowers Emissions

Research funded by US EPA and California Air Resources Board

Protecting Blue Whales and Blue Skies
Community Forum

Wednesday, September 10, 2014 3-5 PM

Cabrillo Pavilion Arts Center, 1118 E. Cabrillo Blvd

Santa Barbra, CA 93103

UCR | College of Engineering- Center for Environmental Research & Technology

Discussion Topics

Photo: (John Calambokidis / Cascadia Research)

Greenhouse Gas and Criteria Emission Benefits through Reduction of Vessel Speed at Sea

(Khan et. al. *Environ. Sci. Technol.* 2012, 46, 12600-12607)

UCR Marine Experience

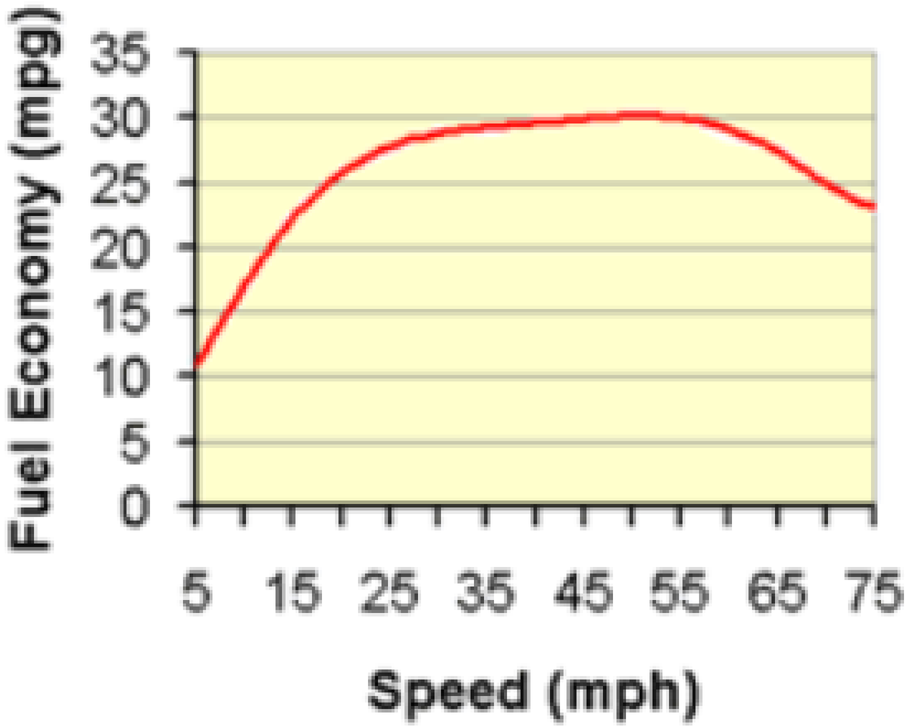
Ocean Going Vessels: main engines
- Feb 04 Container Ship I
- Oct 06 Container Ship IV
- Feb 07 Oil tanker
- July 07 Container Ship I
- Sept 07 Container Ship IV
- Sept 08 Container Ship IV
- Jun 09 Container Ship IV
- Aug 09 Container Ship IV
- Apr 10 Container Ship V
- Sept 10 Container Ship VI (Tier1)

Ocean Going Vessels: auxiliary engines
- Feb 04 Container Ship I
- May 05 Container Ship II
- July 05 Container Ship II
- Oct 05 Container Ship II
- Dec 05 Container Ship II
- Dec 05 Container Ship III
- Mar 06 Container Ship II
- Oct 06 Container Ship IV
- Nov 06 RORO
- Feb 07 Oil tanker
- Apr 10 Container Ship V

Ocean Going Vessels: auxiliary boiler
- Feb 07 Oil tanker
- Sept 07 Container ship IV

Harbor Craft: main & auxiliary engines
- Mar 06 Ferry exhaust control
- Jun 06 Shuttle: Biodiesel
- Aug 06 Activity studies
- Sept 06 Dredger: engine control
- Oct 06 Dredger: exhaust control
- Oct 08 Workboat: T2 & biodiesel
- Feb 09 Ferry: T2 & biodiesel –
- Sept 09 AZ Shuttle: T2 & biodiesel
- Oct 10 First hybrid tug
- Sept 11 Great Lakes vessel + algal fuel
- Dec 11 Retrofit tug

Fuel Economy Decreases at High Speed



- How much?
  - 3% @ 60mph
  - 17% @ 70mph
  - 28% @ 80mph

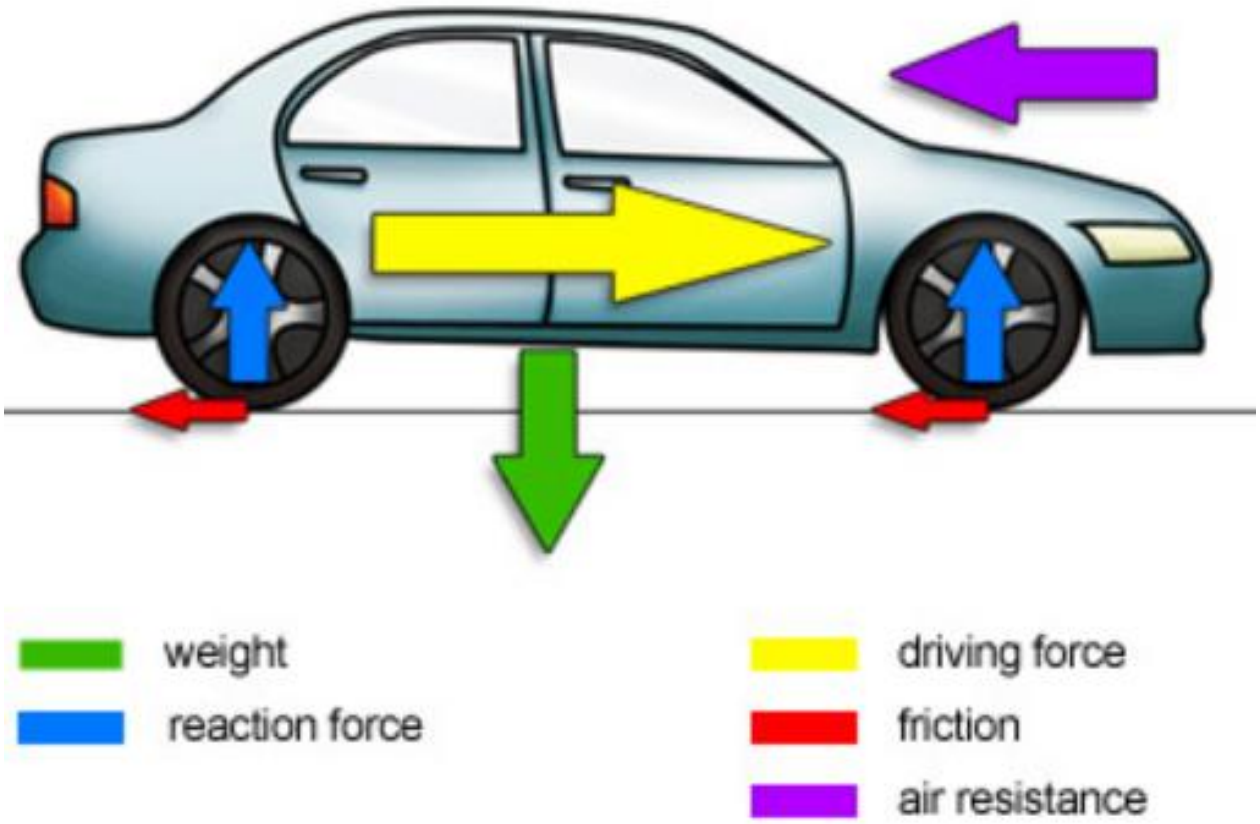
Ref. US Dept of Energy

UCR College of Engineering- Center for Environmental Research & Technology

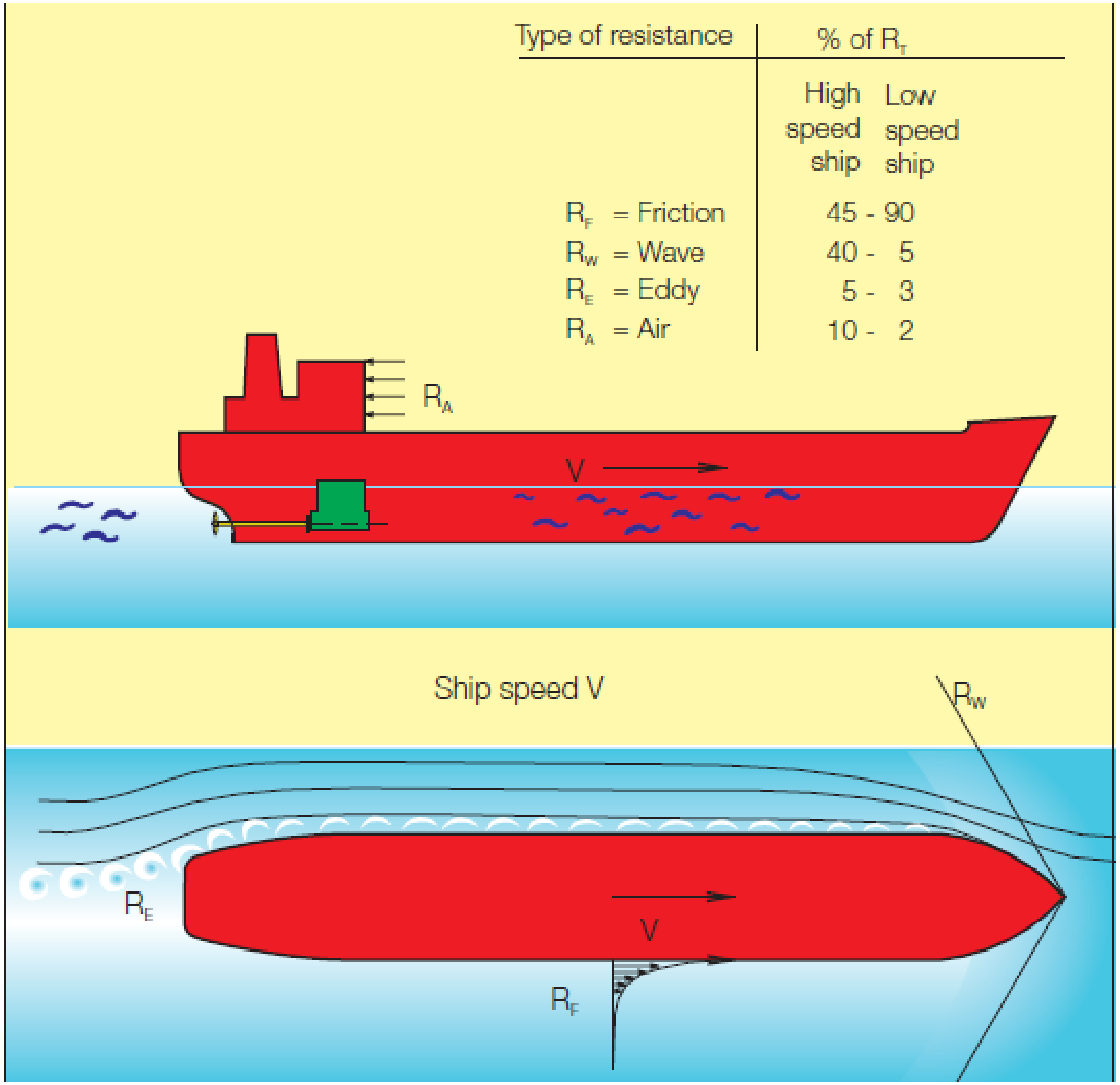
Consumer Report on Faster Speeds

Make & model	55 mph	65 mph	75 mph
Acura TSX 2.4-liter 4-cyl.	39.9 mpg	35.5 mpg	30.7 mpg
Honda Insight 1.3-liter 4-cyl.	51.9	44.8	36.5
Lexus RX350 3.5-liter V6	30.9	27.4	23.0
Mercury Mountaineer 4.6-liter V8	23.8	21.2	17.8
Toyota Camry 2.5-liter 4-cyl.	40.3	34.9	29.8
Toyota RAV4 2.5 liter 4-cyl.	34.6	29.3	25.9
Toyota Yaris 1.5-liter 4-cyl.	42.5	37.9	34.0

Forces on a Vehicle



Forces on a Ship



Reference: Appendix E from MANN B&W Technical Report, *Basic Principles of Ship Propulsion*

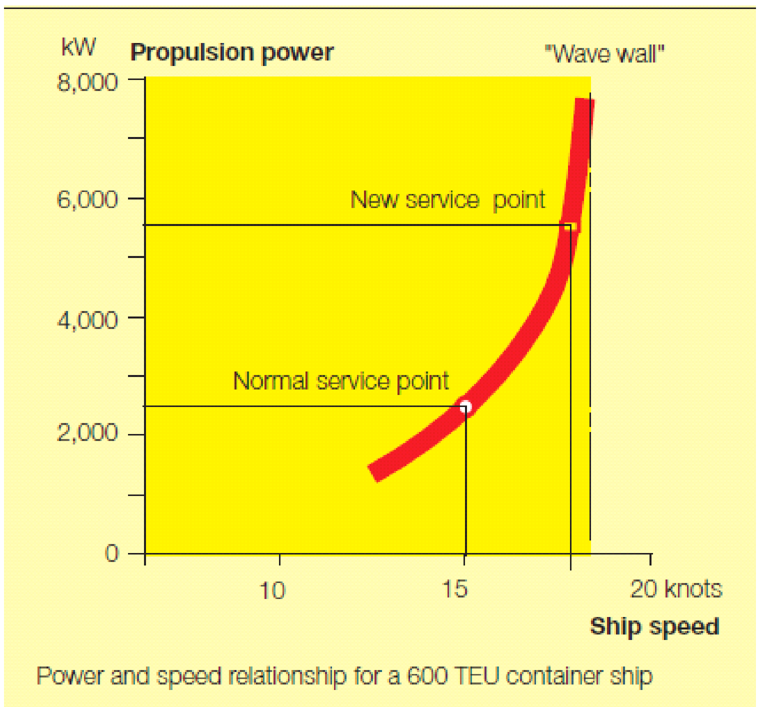
Ship Emission Measurement Project

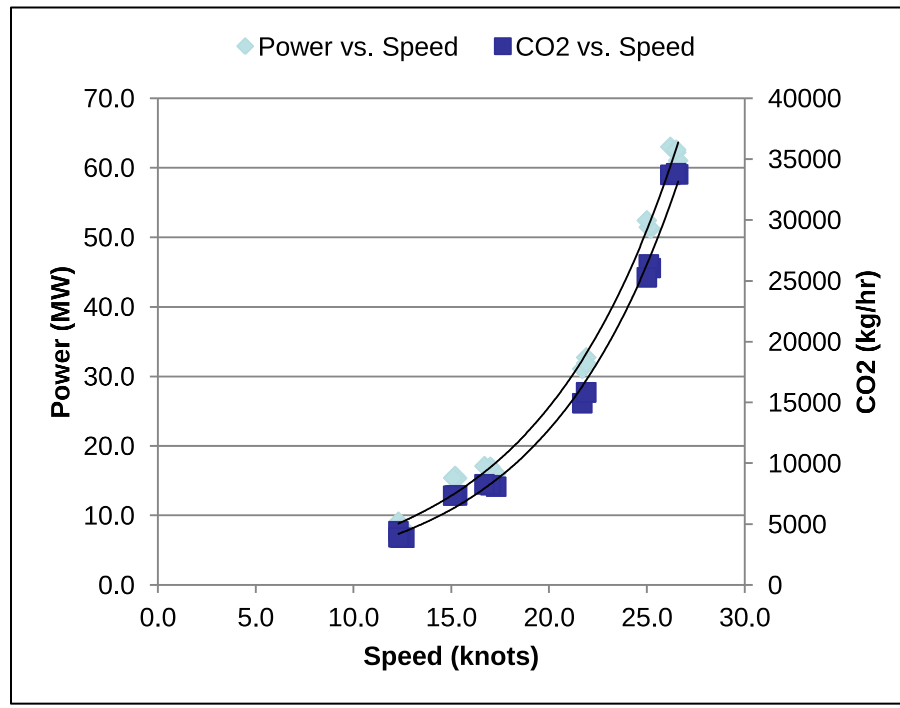
- Two container ships; typical in CA water
  - Panamax: 1997; 36.7MW; 4,062 TEUs
  - Post Panamax: 2010; 68.5kW; 8,501 TEUs
- Two fuels: HFO & MGO
- Emissions measured at certification test loads using ISO & US EPA methods.
- Analysis explored scenarios to reduce criteria pollution & green house gases

Test Plan

Vessel	Engine	VSR measurements	Fuel	Engine Load (%)	Vessel Speed	Gaseous/PM/EC-OC Measurements
1	Sulzer 9RTA84C	Out of Long Beach Port	MGO	11	11	Yes/Yes/Yes
			MGO	21	15	Yes/Yes/Yes
		Into Oakland Port	HFO	10	12	Yes/Yes/Yes
1	Sulzer 9RTA84C	Out of Long Beach Port	MGO	9	13	Yes/No/No
			MGO	18	14	Yes/Yes/No
		Into Oakland Port	MGO	17	14	Yes/No/No
2	Hyundai B&W 11K 98ME7	Out of Long Beach Port	MGO	9	12	Yes/No/No
		Into Oakland Port	MGO	12	12	Yes/Yes/Yes
			MGO	23	15	Yes/Yes/Yes

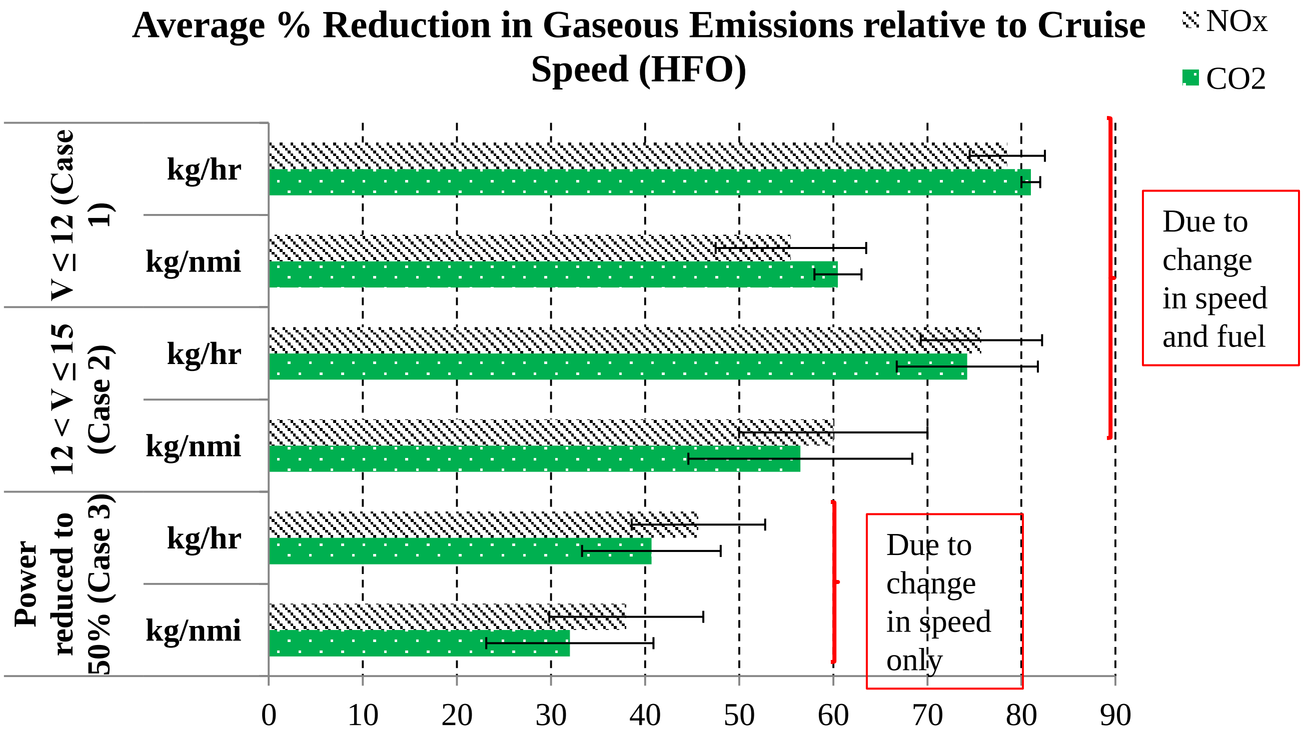
Theory vs. Data





(Ref: : Appendix E from MANN B&W Technical Report, *Basic Principles of Ship Propulsion*

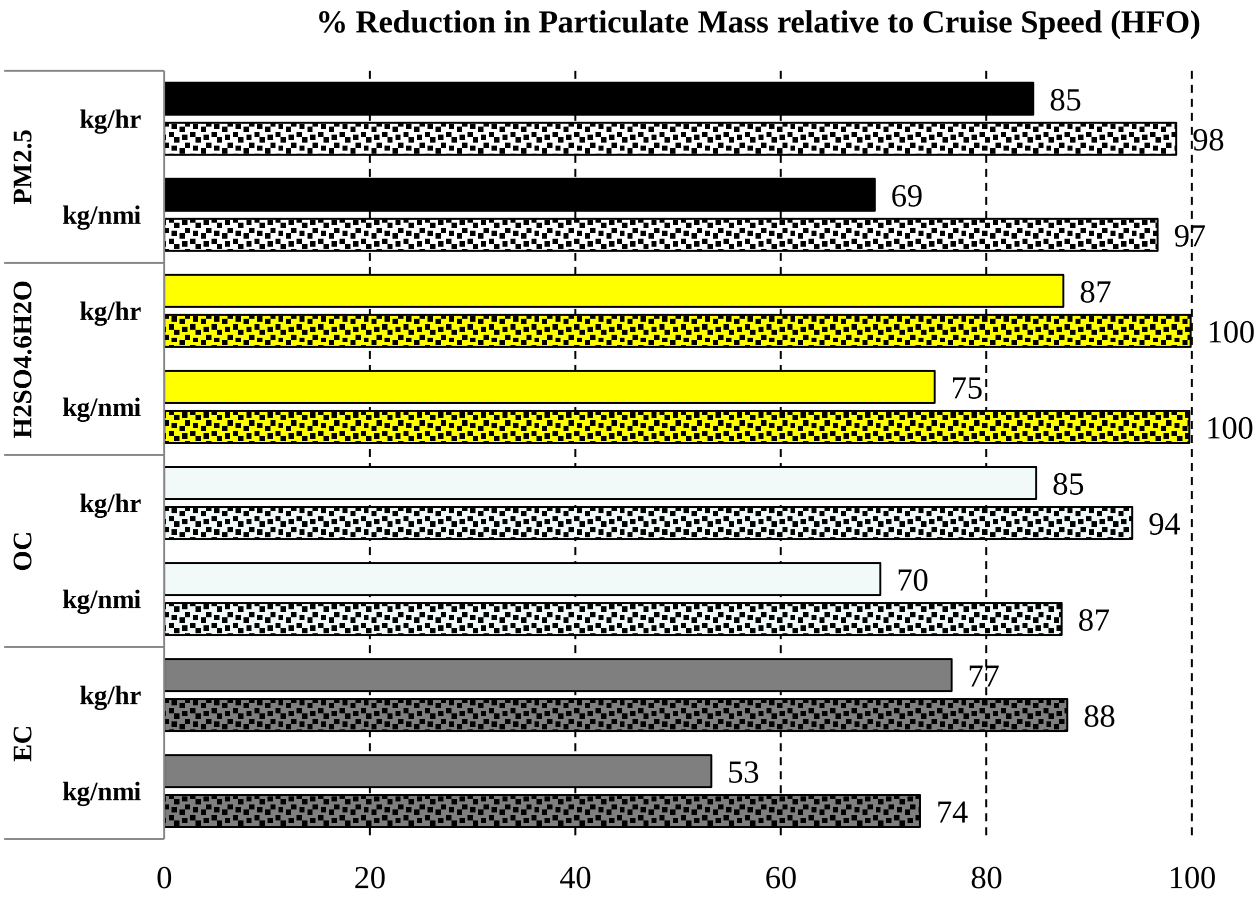
Results: NOx & CO_2 Emission Benefits



On a REGIONAL scale: VSR to 12 knots yielded approx. 61% and 56% reduction in CO_2 & NOx

On a GLOBAL scale: On average, CO_2 & NOx reduced to 32% and 38%, respectively by merely reducing speed of the vessel by 3-6 knots

Results: $PM_{2.5}$ Emissions Benefits

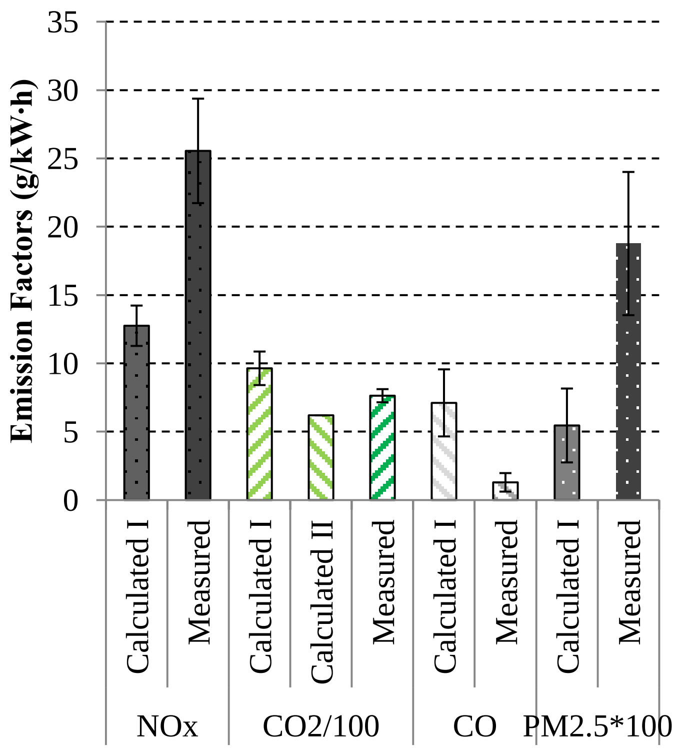


- Up to 70% $PM_{2.5}$ reduction; reduction improved to 97% when fuel was switched from HFO to MGO
- Significant reduction in EC, OC and hydrated sulfate was also found

Measured vs. EPA/CARB EFs at Loads ≤ 20%

- Regulatory Agencies relies upon a formula developed by EEIA to estimate EFs at low loads
- y (g/kW-hr) = a (*fractional load*)$^{-x}$ + b
- Where *fractional load* = (actual speed/max. speed)^3

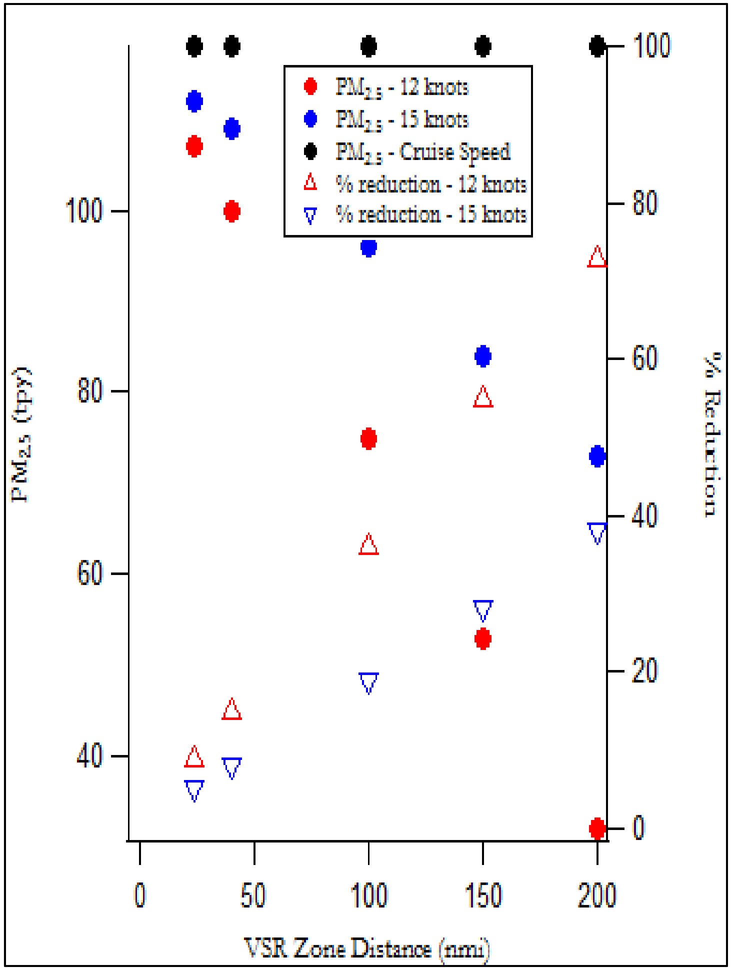
pollutant	exponent (x)	intercept (b)	coefficient (a)
NO_x	1.5	10.4496	0.1255
$PM_{2.5}$	1.5	0.2551	0.0059
CO_2	1	648.6	44.1
CO	1	0.1458	0.8378



Calculated I: EPA method; Calculated II: CARB method

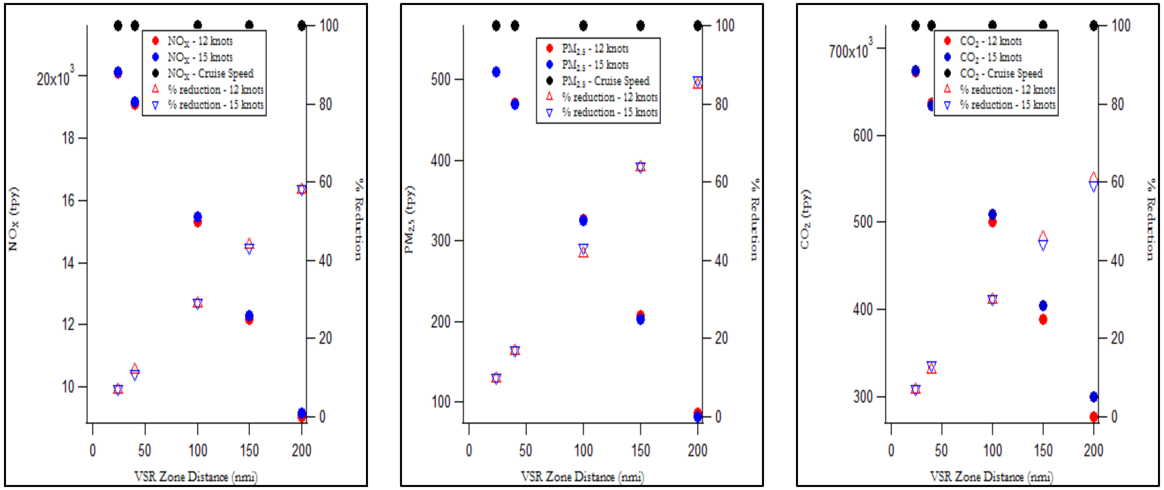
- On average, EPA and CARB **underestimates** $PM_{2.5}$ and NOx by 72% and 51%, respectively, and overestimates CO by 669%
- In case of CO_2, EPA **overestimates** by 20% and CARB **underestimates** by 20%

Effect of Controlling Regulated Boundary

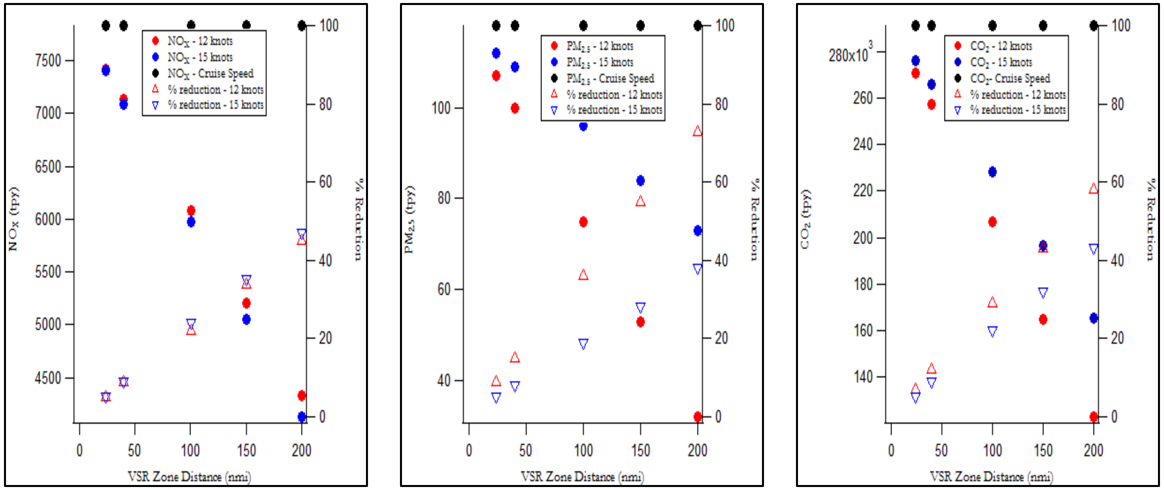


$TPE_{PM2.5}$ reduction almost doubled on reducing large vessel speed from 15 knots (5-38%) to 12 knots (9-73%)

Effect of Controlling Regulated Boundary (small and medium sized engines)



Effect of Controlling Regulated Boundary (large engines)



NOx **$PM_{2.5}$** **CO_2**

Summary

- Both criteria pollutants and greenhouse gases are reduced with VSR.
- Both global and regional emissions are important.
- References
  - CARB: robert.krieger@arb.ca.gov
  - UCR: wayne.miller@ucr.edu

Thank You & Questions

Photo: (John Calambokidis / Cascadia Research)