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Yellowstone Over-snow Vehicle Emission Tests – 2012

Summary Vehicle Data and Fleet Estimates for Modeling

Natural Resource Technical Report NPS/NRSS/ARD/NRTR—2013/661

ON THE COVER
A guided group of snowmobiles passing bison along Firehole River.
Photograph by: Jim Peaco, Yellowstone National Park; January 2011

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John D. Ray[1], Gary Bishop[2], Brent G. Schuchmann[2] Chris Frey[3], Gurdas Sandhu[3], Brandon Graver[3]

[1]National Park Service
Air Resources Division
P.O. Box 25287
Denver, CO 80225

[2]Chemistry Department
University of Denver
Denver, CO

[3]Department of Civil Engineering
North Carolina State University
Raleigh, NC 27695

January 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Denver, Colorado

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Please cite this publication as:

Ray, J. D., G. Bishop, B. G. Schuchmann, C. Frey, G. Sandhu, and B. Graver. 2013. Yellowstone over-snow vehicle emission tests – 2012: Summary vehicle data and fleet estimates for modeling. Natural Resource Technical Report NPS/NRSS/ARD/NRTR—2013/661. National Park Service, Denver, Colorado.

NPS 101/119449, January 2013

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Abstract/Executive Summary

This report provides summary tables of on-road emissions and fleet averages of over-snow vehicle emissions for EIS scenario modeling. Emission data from newer model snowcoaches and snowmobiles were obtained by direct tailpipe measurements and are now available for modeling. A comparison is made with prior data. Summary values for different categories are provided that can be used in the modeling. Fleet averages are calculated based on snowcoach categories and the estimated number of vehicles in each category. The fleet average emissions are provided so that each of the alternatives in the SEIS can be modeled.

Disclaimer

Ideally, multiple snowmobiles of the same type would be measured for emissions; however, time and available funding did not allow repeated measurements on the same model type of snowmobile. Likewise, multiple test runs of the OSVs would have helped determine and quantitate environmental effects and variability of an individual vehicle. Time to complete this study was strictly limited. These results are the best available for the NEPA process at this time.

Acknowledgments

Many people helped on this project: John Klaptosky, Yellowstone NP, assisted the project team with the physical details of instrumenting the OSV. Wade Vagias picked the vehicles to test, made arrangements with the businesses to rent their vehicles, and provide many useful comments. David Jacob and Lori Fox provided direction and arranged for the necessary contracts. The following businesses and contacts were critical; we are grateful for their patience, use of their vehicles and facilities, and their advice: Scott Carsley, Alpen Guides; Randy Roberson, Buffalo Bus; Todd Scott and Rob Love, Xanterra. Charlie Fleming, Julie Hannaford, and Roy Renkin (Yellowstone NP) were instrumental in obtaining work space, snowmobiles, and needed materials.

1. Introduction

The use of snowmobiles and snowcoaches (collectively referred to as “over-snow vehicles”, OSV) in Yellowstone National Park during the winter has been an issue from an air quality standpoint. The park tracks air quality and has made several measurements of OSV emissions (Ray, 2012a, b; Bishop, 2001; Bishop, 2006a, b; Bishop, 2007; Bishop,2009). Several policy changes have been made by the park that limit the number of OSV and for snowmobiles put a limit on emissions (NPS, 2011a). Vehicle emission values are used in modeling exercises to estimate the impact of different policy scenarios. The emissions from OSV in the configurations actually used and under winter conditions have to be measured to provide inputs to the models. Prior measurements have used remote sensing (Bishop, 2001) and direct, in-use measurement methods, otherwise known as portable emission measurements (aka PEM) (Bishop, 2007; Bishop, 2006a,b). The last emission measurements were done in winter of 2006, so data for newer vehicles was needed.

As before, the preferred method is to measure vehicle emissions with an on-board PEM analyzer during actual vehicle operation under normal operating conditions. This was judged to be more representative of actual OSV use than the dynamometer tests which are typically just engine tests and are more representative of on-road driving sequences and loads. The rolling resistance of the various track and ski combinations are not accounted for in the dynamometer test. The load conditions to the OSV from the snow conditions, road slope, speed, and acceleration are better represented in the on-road tests.

The objective of the current report is to provide enough information for the scenario modeling to proceed for the Supplemental Environmental Impact Statement (SEIS) (NPS, 2012).

2. Methods

A repeat of the methods used in 2006 to measure emissions from vehicles in-use (Bishop 2007) was used in this March 2012 study. In-use measurements via PEM device are more desirable than laboratory test data as laboratory test data may not reflect actual operating conditions in Yellowstone, as high altitude and low winter temperatures in the parks are likely to decrease overall snowmobile and snowcoach engine performance and increase relative emission levels. Therefore, whenever possible, PEM data are used in lieu of laboratory data.

Vehicles equipped with a PEM device traveled a standard route from the west entrance to a turn-around about 1 mile past the Madison Junction rest stop (Figure 1). The distance is approximately 30 miles. Vehicles were driven in a similar manner as normal tours and with weights to simulate 8 passengers in the snowcoaches. For the snowmobiles, only the driver and the measurement equipment were used for the rider/passenger loading. The PEM device was made by Clean Air Inc. and was used for all the tests (Frey, 2003; Zhang, 2008). The PEM was carried in or on the vehicle and recorded emission data continuously during the trip plus obtained GPS data to calculate position, distance, and speed. The amount of fuel used was estimated by the analyzer and checked by recording the amount required to refill the tank to a known level. Insulated lines and heated instrument boxes were used to keep the lines from freezing or filling with condensate from the vehicle exhaust. Engine data was obtained from the OBD II connector (snowcoaches) or from engine probes (snowmobiles) and assembled in a separate database referenced by time during the tests.

The 1-sec data from the PEM was filtered for different speeds and assembled into averages. Conversions were made into units suitable for the modeling (mainly, g/mile). The results are presented in Tables 1 - 4 as summaries by vehicle tested. More detail on engine performance and behavior are included in the subcontractor report (Frey, 2012) to Louis Berger Group. Five snowcoaches and 3 snowmobiles were tested. Two snowcoaches had diesel engines (compression ignition) and all others were gasoline engines (spark ignition).

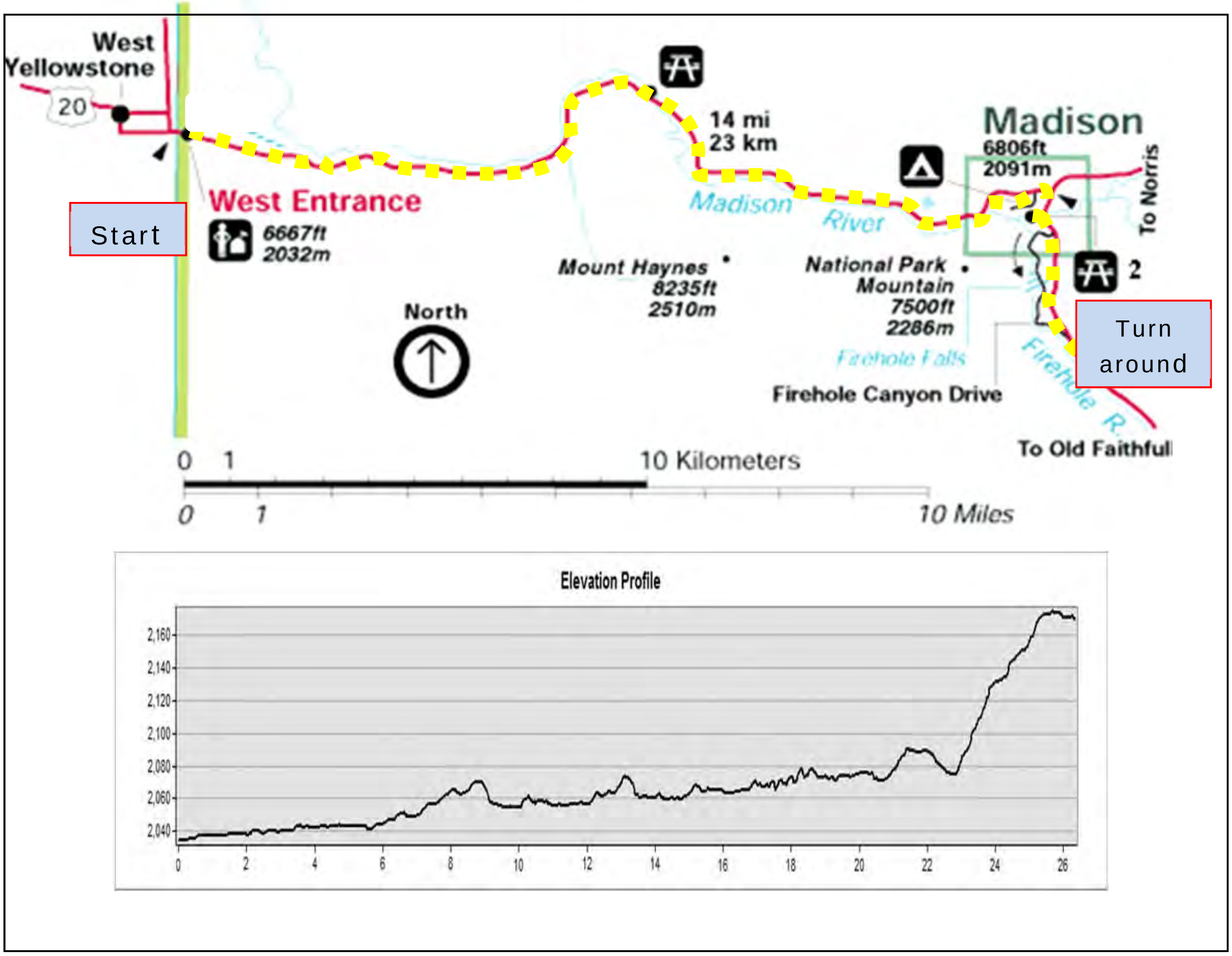

Figure 1. Map of emission testing route in Yellowstone National Park and elevation map for roadway along the route. Distance in miles, elevation in meters above sea level.

3. PEM Test Results

Emission measurements from five snowcoaches and three snowmobiles were made from March 5-11, 2012 from an operations base at West Yellowstone, MT. The data was processed by North Carolina State University (NCSU) (Chris Frey, Brandon Graver, and Gurdas Sandhu) to provide emission averages for idle, low speed, and cruise (Frey, 2012). The emission data determined are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx), and particulate matter, for diesel engines, at 10 micrometer size or less (PM or PM10). The calculations and assumptions used are given in the Bishop et al., 2007 report. Table 1 gives the results for individual snowcoaches and Table 2 gives a breakdown of the times and miles traveled at the different speeds for the five different snowcoaches. Tables 5 and 6 break out the results by engine type for gasoline and diesel engines. Details on the models, engines, and track types of vehicles tested along with pictures are in Appendix A of this report.

3.1 Snowcoach emissions

The data from the snowcoaches traversing the test-cycle route was processed to apply calibration and instrument parameters, merged with location information provided by the GPS , and sorted by vehicle speed. Additional details are provided in the contractor report (Frey, 2012). Results are presented in Table 1 for the snowcoaches tested in 2012. The emissions are expressed in several ways to be consistent with previous studies. The pollutant emissions in g/hr for idle and g/mile during travel are needed for the SEIS scenario modeling. Those units will be used in further discussions in this report.

Table 1. Emission results from the 2012 study for snowcoaches[t].

Vehicle Measured	Species	Idle				Low Speed			Cruise		
		mg/s	g/hr	g/gal	g/kg	g/mi	g/gal	g/kg	g/mi	g/gal	g/kg
1956 Bombardier Kitty	CO	3.64	12.96	29.9	10.7	9.5	45.9	16.4	7.1	35.5	12.7
	HC	0.10	0.36	0.8	0.3	0.1	0.7	0.2	0.1	0.5	0.2
	NO_x	0.24	0.72	1.9	0.7	3.1	14.9	5.3	4.9	24.5	8.8
2008 Chevy Express	CO	6.40	23.1	45.9	16.4	38.7	94.5	33.8	454	1010	362
	HC	0.04	0.13	0.3	0.1	0.2	0.5	0.2	0.5	1.2	0.4
	NO_x	0.04	0.14	0.3	0.1	1.0	2.5	0.9	4.7	10.5	3.8
2011 Ford E350 SY3	CO	0.62	2.20	3.6	1.3	5.4	16.1	5.8	13.4	39.8	14.3
	HC	0.10	0.37	0.6	0.2	0.1	0.4	0.2	0.2	0.5	0.2
	NO_x	0.01	0.03	0.1	0.0	0.1	0.2	0.1	0.3	0.8	0.3
2011 Ford F450 Glaval	CO	0.001	0.002	0.004	0.001	0.7	1.4	0.4	1.4	2.8	0.9
	HC	0.16	0.72	1.2	0.4	0.3	0.6	0.2	0.1	0.1	0.04
	NO_x	5.60	20.16	41.1	12.9	23.3	43.6	13.6	13.3	26.0	8.1
	PM	0.01	0.02	0.04	0.01	0.02	0.03	0.01	0.01	0.02	0.01
2011 Ford F550 SY8	CO	3.71	13.32	45.3	14.2	1.3	2.7	0.9	0.01	0.01	0.004
	HC	0.07	0.36	0.9	0.3	0.1	0.3	0.1	0.1	0.3	0.1
	NO_x	1.76	6.48	21.4	6.7	5.8	12.4	3.9	6.9	16.3	5.1
	PM	0.01	0.02	0.08	0.02	0.02	0.04	0.01	0.01	0.03	0.01

Note: g/mi, g/gal and g/kg results are calculated from the reported miles traveled, g/sec emissions, and g/sec fuel consumption. The density of gasoline is assumed to be 2,791 g/gallon and for diesel 3,200 g/gal[t] Note: A June 2012 draft of this report used preliminary values that were revised by the NCSU researchers after additional data processing. The latest values from Frey et al, 2012 are presented here.

Supporting information on the snowcoach emissions tests are provide in Table 2. Fuel usage was recorded electronically and checked by refueling the vehicles after the test cycle and using the gas pump readouts.

Table 2. Supporting data on distance and time for snowcoaches in the 2012 emission tests.

	Hours Sampled			(Miles Traveled)			Mean Low Speed	Mean Cruise Speed
Vehicle Measured	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**0 < GPS Speed < 15 mph**	**GPS Speed > 15 mph**
1956 Bombardier Kitty	0.49	0.75	1.08	0	6.6	27.2	8.8	25.2
2008 Chevy Express	0.17	0.1	1.38	0	0.8	31.6	8.7	22.9
2011 Ford E350 SY3	0.29	0.17	1.35	0	1.4	31.1	8.4	23.1
2011 Ford F450 Glaval	0.31	0.13	1.45	0	1	34.6	7.8	23.8
2011 Ford F550 SY8	0.86	0.36	1.36	0	2.1	29.8	5.8	21.9

Fuel Use Comparison

Vehicle Measured	**$Fuel_{pump}$ (gal)**	**$Fuel_{OBD}$[a] (gal)**	**Diff.[b] (%)**	**Distance[c] (miles)**	**MPG_{pump}[d]**	**MPG_{OBD}[e]**
1956 Bombardier Kitty[f]	6.1	7.4	21.7	35.5	5.8	4.8
2008 Chevy Express	16.2	15.0	-7.0	34.4	2.1	2.3
2011 Ford E350 SY3[g]	16.2	14.7	-9.2	43.7	2.7	3.0
2011 Ford F450 Glaval	21.1	21.7	2.7	38.9	1.8	1.8
2011 Ford F550 SY8	17.6	16.8	-4.7	34.9	2.0	2.1

a Fuel use estimated from On Board Diagnostic (OBD) second-by-second gal/hour data
b Difference = $(Fuel_{OBD} – Fuel_{pump}) / Fuel_{pump}$
c Distance estimated from Garmin GPS second-by-second data. Distance includes driving from pre-test installation point up to post-test fuel top off at gas pump. Distance does not include the driving from pre-test fuel top off at gas pump to the pre-test installation point, which is typically less than 2 mile.
d MPG_{pump} = Distance/$Fuel_{pump}$
e MPG_{OBD} = Distance/$Fuel_{OBD}$
f Fuel top off before and after the test was not to the same level
g This vehicle was used for sound level measurements and did multiple passes for a section of the route; hence the larger distance in miles

3.2 Snowmobile emissions

Snowmobiles are a bit harder to instrument and do measurements on primarily because of the lower carrying capacity, lack of an OBD II plug of engine parameters, limited power availability, and the awkward configuration of the engine exhaust. The PEM analyzer has to be carried on the snowmobile which requires a heated, insulated box and enough power to run the analyzer. A custom insulation-foam container was constructed and a small gasoline powered electrical generator was used. These were mounted on the rear carrier (see picture in appendix C). Emissions measured by the PEM came from a sampling probe inserted directly in the exhaust pipe. The electric auxiliary generator exhaust was on the snowmobile back carrier and directed away from the PEM so that no portable-generator emissions were being measured by the PEM. Two snowmobiles, an Arctic Cat TZ1 and a Ski Doo Expedition, were tested over the full course. A third snowmobile, a 2008 Arctic Cat model T660, was tested on about a third of the course before testing was stopped because of excess water in the instrument sample lines. Snowmobile emission results are given in Tables 3 and 4 along with the supporting speed and distance metrics.

Table 3. Emissions estimates for individual snowmobiles tested in 2012 by direct exhaust sampling and analysis [t].

Vehicle Measured	Species	Idle				Low Speed			Cruise		
		mg/s	g/hr	g/gal	g/kg	g/mi	g/gal	g/kg	g/mi	g/gal	g/kg
2008 Arctic Cat T660	CO	111	399.6	1869	584	34	392	123	17	336	105
	HC	4	14.4	67	21	4.3	50	15	2.1	42	13
	NO_x	0.35	1.26	5.9	1.8	15	169	53	18	359	112
2011 Arctic Cat TZ1	CO	145	522	2017	630	240	2202	688	27	493	154
	HC	4.8	17.28	67	21	9.6	88	28	1.6	28	8.8
	NO_x	0.52	1.872	7.2	2.3	1.4	13	3.9	8.8	160	50
2011 Ski Doo Expedition ACE 600	CO	60	216	698	250	25	233	83	4	68	24
	HC	3.7	13.32	43	15	1.3	12	4.4	0.1	2.3	0.8
	NO_x	0.17	0.612	2	0.7	5.2	49	18	11	191	69

g/gal and g/kg results are calculated from the reported g/sec emissions and fuel consumption and the density of gasoline is assumed to be 2,791 g/gal

[t] Note: A June 2012 draft of this report used preliminary values that were revised by the NCSU researchers after additional data processing. The latest values from Frey et al, 2012 are presented here.

Table 4. Summary information of emissions by pollutant and supporting speed and distance data.

Vehicle	Sampled		Mean Speed (mph)	Fuel Use (mpg)	Gram/Mile Emissions		
	Hours	Miles[a]			CO	HC	NO_x
2008 Arctic Cat T660	1.0	19.9	24.2	15.1	18	2.2	18
2011 Arctic Cat TZ1	1.7	33.0	19.8	14.4	39	2.0	8.4
2011 Ski Doo ACE 600	1.3	29.2	22.0	15.8	4.4	0.1	11

Vehicle	Hours Sampled (Miles Traveled)			Mean Low Speed 0 < GPS Speed < 15 mph	Mean Cruise Speed GPS Speed > 15 mph
	Idle	Low Speed	Cruise		
2008 Arctic Cat T660	0.16 (0)	0.13 (0.9)	0.69 (19.0)	7.2	27.4
2011 Arctic Cat TZ1	0.32 (0)	0.24 (1.8)	1.11 (31.2)	7.4	28.0
2011 Ski Doo Ace 600	0.31 (0)	0.10 (0.6)	0.91 (28.6)	5.8	31.3

[a] Mileage calculated using the GPS data.

4.0 Discussion of PEM Test Results

Data from the 2012 PEM tests are summarized and compared to prior PEM studies in this section. Additionally, this section explores the representativeness of PEM findings and fuel efficiency of various OSVs tested. Section Five of this report categorizes vehicles, weights them according to the relative number in each modeling scenario, and provides emission factors for each modeling scenario to be estimated.

4.1 Comparison of 2012 emission data to prior work

Snowcoaches For both the gasoline (table 5) and diesel engine snowcoaches (table 6) the newer engines and coach configurations have lower emission averages than the older vehicles measured in 2005 and 2006. One exception was the Chevy Express snowcoach that had higher emissions than expected. This is the snowcoach that we observed operated only in 1st and 2nd gears during the testing. The Ford SY3 had a much lower gear ratio in the differential than the Chevy Express and prototype tracks to give it more surface area. The Chevy Express had a V8 with 6.0 L of displacement (305 HP), the Ford SY3 was a V10 with 6.8L displacement (300 HP). Both of these vehicles fit the Tier 2 definition as described in the Yellowstone Winter Use Plan / Supplemental Environmental Impact Statement (NPS, 2012; EPA, 2000).

Review of the raw emissions data and QA records on the analyzer do not reveal a reason to discredit or discard this data (Frey, 2012). The researchers had this to say about the Chevy Express van:

> "The gasoline-fueled Chevrolet Express had HC and NOx emission rates that were typically lower than or comparable to those of the Bombardier. However, the CO emission rates were higher, ranging from 46 g/gallon at idle to over 1,000 g/gallon during cruise. The very high rate during cruise was double checked, and found to be a valid result based on the measured data. The Chevrolet appeared to be underpowered for this type of service, and the engine was often operated at or close to full throttle. Under conditions of high power demand, gasoline engines can be periodically commanded by the ECU to operate in a fuel rich mode, which can lead to high emissions of CO. Another possibility is that the engine combustion was itself inefficient, which would also account for the relatively low NOx emissions. NOx emissions tend to be higher during complete combustion that leads to higher flame temperature." (Frey, 2012)

Although the results from the Chevy Express van are probably not the emissions desired from a BAT snowcoach, they may reflect what happens when a road vehicle is simply modified for over-snow use by the substitution of Mat-traks for wheels. In the bottom portion of Table 5, the three newer gasoline-engine snowcoaches tested in 2012 that would meet the proposed BAT standard are averaged. The gasoline engine emissions can be compared to the diesel engine emissions for the 2012 tests in Table 6.

Table 5. Summary results by pollutant of emissions from port-fuel injected gasoline engine powered snowcoaches.

2006 tests	Gasoline engines, port fuel injection	Idle	Low Speed	Cruise Speed
Pollutant		(g/hr)	(g/mi)	(g/mi)
CO	Average, N=8	42.4	27.2	107.4
HC	average	11.2	1.3	1.4
NOx	average	2.1	3.8	5.8
2012 tests	Newer coaches (PFI, Tier 2)			
CO	Average, N=3	12.8	17.9	158.2
HC	average	0.3	0.1	0.3
NOx	average	13.3	14.6	10.1

Table 6. Summary data for emissions from diesel engine powered snowcoaches.

2006 tests		Idle	Low Speed	Cruise Speed
Pollutant	NPS yellow bus and van	(g/hr)	(g/mi)	(g/mi)
CO	Average, N=2	19.3	16.5	6.0
HC	average	NA	NA	NA
NOx	average	50.4	46.3	38.5
PM	average	0.2	0.3	0.2
2012 tests	Newer coaches, meet proposed BAT			
CO	Average, N=2	6.7	1.0	0.7
HC	average	0.4	0.2	0.1
NOx	average	13.3	14.6	10.1
PM	average	0.04	0.02	0.01

NA - The 2006 PEM could measure HC or PM but not both during the same test.

Snowmobiles Comparison data for emissions are summarized in Table 7 for snowmobiles measured in 2006 and 2012. Emissions for CO and HC at cruise speed are generally lower than at low speed for all the vehicles. The 2012 cruise emissions are within a factor of about 2X from the 2006 values when using a similar test procedure and a PEM analyzer . The higher emissions of CO from the Arctic Cat TZ1 at idle and low speed are somewhat higher than expected. . The fuel-rich operation of the TZ1 may be its normal emissions or it may indicate a malfunction in the fuel-to-air control system of the vehicle. (See Appendix B for discussion on gas mileage). The high values are not due to engine warm-up – warm-up data were removed and idle periods occurred at several points along the measurement course. There were no anomalies in the PEM data that would indicate a problem with the analyzer (Frey, 2012).

The 2011 Arctic Cat TZ1 has higher emissions at all speeds than the model T660 previously tested in 2006, however, the TZ1 has nearly twice the engine displacement of the older T660 model. The Ski Doo Expedition emissions in 2012 are close to those in a different model Ski Doo measured in 2006. The displacement on the Ski Doo models was decreased from 2006 to 2012.

Table 7. Summary emission data as averages of all snowmobiles tested in 2012 and 2006.

		Idle	**Low Speed**	**Cruise Speed**
Pollutant	**Test period**	**(g/hr)**	**(g/mi)**	**(g/mi)**
CO	2006	201.6	37.0	14.0
HC	2006	7.7	1.7	1.0
NOx	2006	1.2	4.0	4.5
CO	2012	379.2	99.7	16.0
HC	2012	15.0	5.1	1.3
NOx	2012	1.2	7.2	12.6

Average emissions using equal weighting for each tested vehicle, N=3 for 2012 and N=2 for 2006.

4.2 Representativeness of Snowcoach PEM Test Results

After the previous emission study a chart was prepared that compared model year and fuel type for the snowcoaches by model year (Bishop, 2006a; 2006b). The results from 2012 emissions measurements have been added to the chart for comparison (Figure 2). Only port fuel injection equipped snowcoaches and diesel snowcoaches are shown on an expanded scale in Figure 3. The 2012 diesel emissions are lower than emissions from the two vehicles tested in 2005 & 2006. CO and HC emissions for the new diesels barely show on the scales used and NOx is lower than in prior measured coaches.

For the gasoline engine coaches, the Bombardier (Kitty) with a 2002 Chevy engine and the 2011 Ford SY3 had low emissions that were quite close for CO and HC, but notability lower in NOx for the SY3. The 2008 Chevy Express van had very high CO emissions by comparison (largest green bar on the right of Figure 2). This style of 12 passenger van is a common configuration and several older models were tested in 2005 and 2006. In Figure 3, similar vans to the Chevy Express are compared that show this van is not grossly out of line. Typically, these are vans used in summer operations on the road then are converted to Mat-traks or skis for winter use.

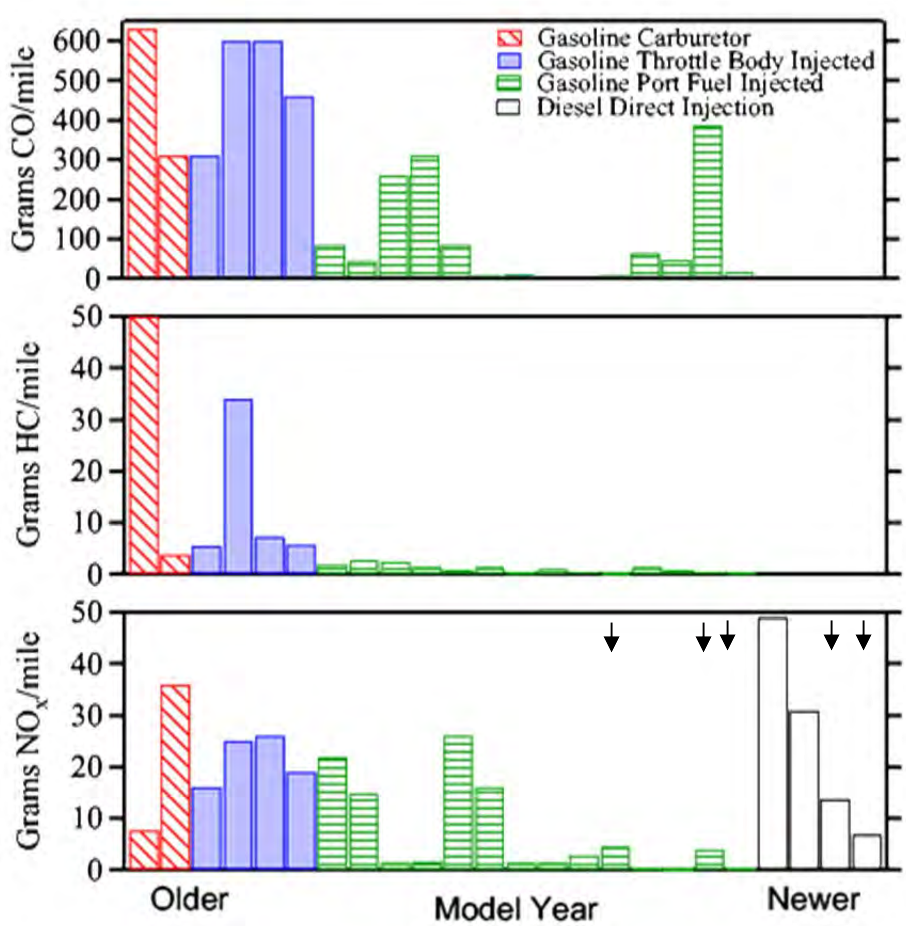

Figure 2. Summary chart comparing model year and engine type to the measured emissions from snowcoaches. The newer snowcoach emission results are on the right side (arrows). Several values on this scale are so low they barely are about the baseline except for NOx in the diesel coaches.

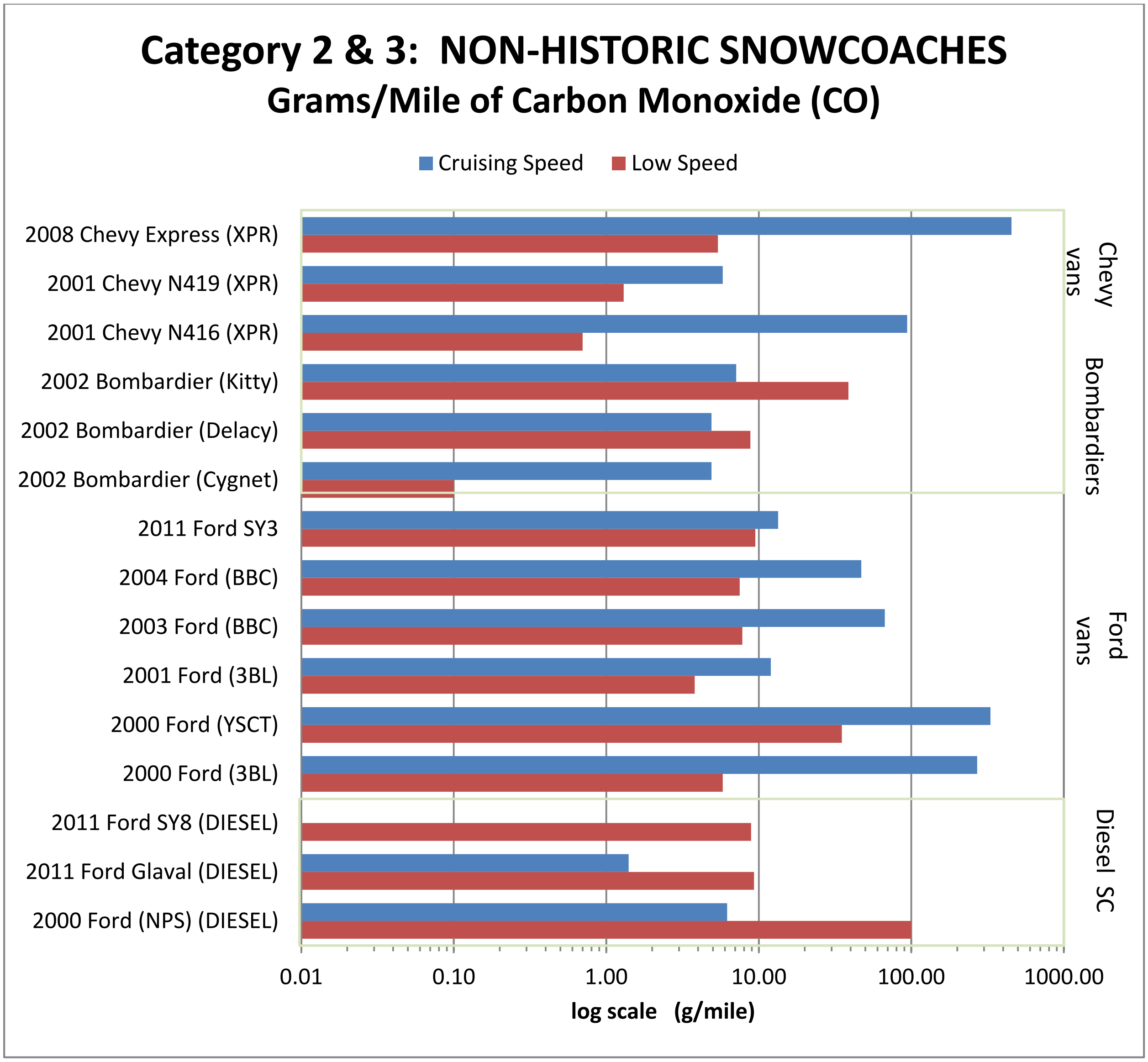

Figure 3. Comparison of emissions from port fuel injection (PFI) equipped snowcoaches and diesel engine snowcoaches. A log scale is used for the emissions so the full range can be seen.

In general, the port fuel injected gasoline engines and the diesel engine snowcoaches of newer model year were cleaner than the older and carbureted engines. However, the newer port fuel injected snowcoaches are not automatically cleaner than some slightly older port fuel injected models. We can infer from available data the following:

- Tier 2 designation is not comprehensive for a snowcoach BAT; on-road emissions may not translate to low emissions on vehicles converted to over-snow use.
- Replacing carbureted and throttle-bodied snowcoaches with port fuel injection (PFI) or diesel snowcoaches are steps towards lower emissions.
- Emissions are influenced by additional factors such as available power, gearing ratios in differential, and road (snow) environmental conditions.

Table 8. Comparison of 2012 emission data by engine type for gasoline and diesel.

2012 tests			
Gasoline SNOWCOACH - BAT			
Pollutant	**Idle (g/hr)**	**Low Speed (g/mi)**	**Cruise Speed (g/mi)**
CO	12.8	17.9	158.2
HC	0.29	0.13	0.27
NOx	0.3	1.4	3.3
PM-10*	NA	NA	NA
Diesel SNOWCOACH - BAT			
Pollutant	**Idle (g/hr)**	**Low Speed (g/mi)**	**Cruise Speed (g/mi)**
CO	6.7	1.0	0.7
HC	0.42	0.20	0.10
NOx	13.3	14.6	10.1
PM-10	0.04	0.02	0.01

NA - The 2006 PEM could measure HC or PM but not both during the same test.

As seen before, the diesel engine snowcoaches have lower CO and HC, but higher NOx and PM-10 emissions (Table 8) than the gasoline engine snowcoaches. The newer diesel snowcoaches, when compared to the two vehicles measured in 2005 & 2006, have lower NOx and PM10 (Table 6). Diesel engines are inherently low emitters for CO and HC, however, additional controls are used under Tier 2 regulations to lower NOx and PM10 emissions (EPA, 1999). Such devices as exhaust gas recirculation, turbochargers, lean NOx catalysts, selective catalytic reduction (SCR), or NOx absorbers are used. A urea SCR injects precise amounts of urea to control NOx emissions. Getting the urea injection rate correct can be difficult under varying load and road conditions. For PM control, oxidation catalysts and filter traps are used. The traps are regenerated by “burning off” the collected material.

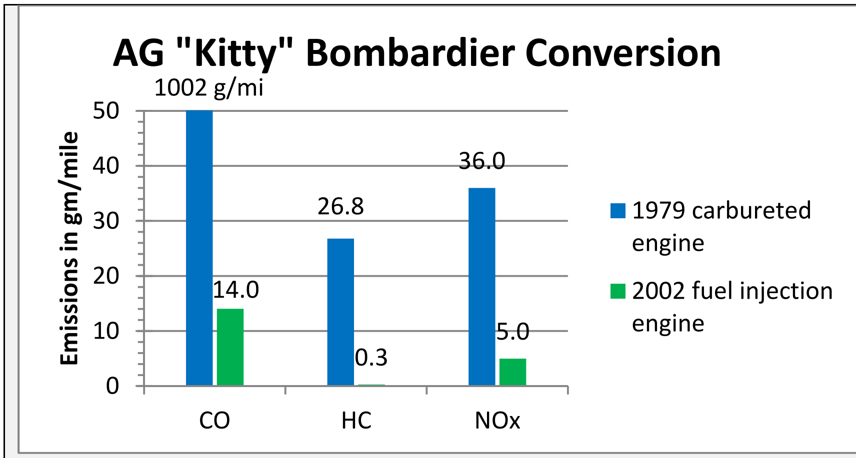

Figure 4. Conversion of the carbureted engine in the "Kitty" Bombardier to a 2002 Suburban engine with fuel injection, computer control, and emission control equipment resulted in much cleaner emissions vehicle.

One success story is illustrated by the conversion of an older Bombardier (the Alpen Guides "Kitty") from a carbureted engine without pollution control to a modern 2002 engine from a wrecked Suburban SUV. The classic Bombardier design has an excellent power to weight ratio which leads to good over snow operation and economy (~4-8 mpg compared to 1-2 mpg for Mat-trak snowcoaches). The converted Bombardiers with modern engines have proven to be some of the cleanest of snowcoaches (Figure 3 & Figure 4).

4.3 Representativeness of Snowmobile PEM Test Results

Although time and funds did not allow for repeated measurements of different snowmobiles of the same model, a repeated measurement was done on an Arctic Cat model T660 snowmobile (Table 9). In the published FEL emission tests for model 2006 years and 2008, the FEL is listed (Table 10) as the same for each model year (105 CO g /kW-hr). The model T660 snowmobiles are still being used for administrative travel; however, the rental shops have all replaced these snowmobiles with newer models.

The two tests of the Arctic Cat model T660 are compared more closely in Table 9. The snowmobiles were different model years and they were tested with a different PEM analyzer 6 years apart. Although the course was the same, the snow conditions and ambient temperature were different. When the average emission rate (in g/mile) is compared over the test course (Figure 1), the emission values at cruise speed are similar and within 3 g/mi for CO, 0.6 g/mi for HC and 10 g/mi for NOx. The biggest difference is that NOx increased with speed more in the 2012 test. These numbers help illustrate the repeatability of this type of in-use measurement under varying field conditions.

Table 9. Emission comparison for two measurements of the same model snowmobile.

		Idle	Low Speed	Cruise Speed
Pollutant	**Vehicle**	**(g/hr)**	**(g/mi)**	**(g/mi)**
CO	2006 Arctic Cat T660	238	21	13
CO	2008 Arctic Cat T660	400	34	17
	Difference	162.0	13.0	4.0
HC	2006 Arctic Cat T660	9.0	2.3	1.5
HC	2008 Arctic Cat T660	14.4	4.3	2.1
	Difference	5.4	2.0	0.6
NOx	2006 Arctic Cat T660	1.5	7.5	7.7
NO_x	2008 Arctic Cat T660	1.3	15	18
	Difference	-0.2	7.5	10.3

The most notable thing about the emissions from the snowmobiles tested in 2012 is the high CO emissions from the Arctic Cat (Table 3). Nothing was found in the data or instrument performance that indicates an error (Frey et al., 2012); the emissions data appear to be valid for this snowmobile. If the emissions values are high then it is because of design, tuning or other problems that the snowmobile had. It is hard tell from the g/mi units of measure if the TZ1 actually meets BAT requirements (NPS, 2009; NPS 2011b) since the FEL is based on dynamometer tests and reported in g/kW-hr. Both HC and NOx emissions are higher in the newer models. It was noted that the Arctic Cat TZ1 has a throttle limiting device on the handlebar. It is not known if this is to keep emissions down, to limit the possible speed of the snowmobile, or to keep sound emission levels below uppermost BAT limits. The TZ1 had plenty of power to travel at posted speeds on the Yellowstone roads.

Each vehicle in a fleet will normally have a slightly different emission rate that follows a distribution. In any fleet there are always some that are higher emitters than others. Each model of snowmobile has its own frequency distribution for emissions of a fleet. Data collected on snowmobiles in winter 2005 using remote sensing (Bishop, 2006a) provides the fleet distribution of emissions for 589 snowmobiles (Figure 5). Also in Figure 5 are the in-use direct measurements for the snowmobiles tested in 2012 (arrows) to compare and provide perspective. The units of gm CO emissions per kg fuel are used are used so that the direct measurements and the remote sensing data can be compared; g/kg emissions are reported in Table 3.

Here is what can be learned from Figure 5. Each make and model of snowmobile has a distribution of different emissions, not a single value. The shape and relative emission levels differ for each model fleet. The model T660 snowmobile data from 2006 and 2012 tests falls within the range of the most frequently observed emissions of the Arctic Cat fleet. The Arctic Cat TZ1 falls at the high end of the range for the model T660 snowmobiles but we don't know exactly what the TZ1 model distribution looks like. The engine size went from 660 cc (model T660) to 1100 cc for the model TZ1. The model TZ1, as delivered as a BAT snowmobile for use at Yellowstone, had a throttle limiter device installed on the handlebar.

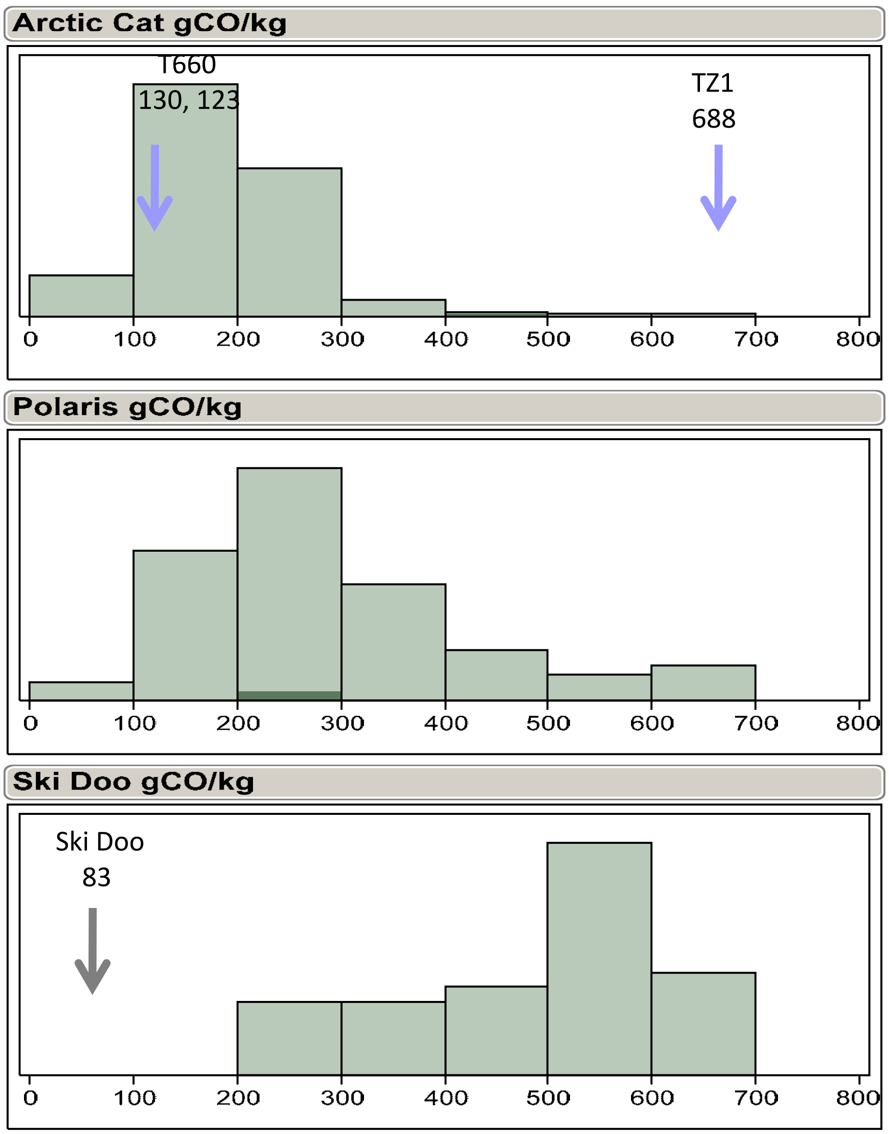

Figure 5. Comparison of 2012 CO emissions to fleet emissions frequency distributions determined on 589 snowmobiles by remote sensing (Bishop, 2006).

The Ski Doo ACE 600 Expedition Sport emissions falls below the distribution of the Ski Doo Legend (tested in 2006). The Ski Doo Expedition with an Ace 600 engine is rated at 60 hp versus 123 hp for the TZ1. In the Ski Doo literature, the manufacturer claims "very low emissions, surpassing the 2012 model year US EPA standards" (http://www.ski-doo.com/technologies/engine-technologies/4-strokes.aspx). Although the TZ1 is on the high end of emissions and the Ski Doo Expedition is on the low end, it does not tell us why. The emissions values are, however, plausible and cannot be dismissed as errors or outliers. The data from both snowmobiles are retained in the averages used for the current fleet.

4.4 Comparison of snowmobile emissions

Snowmobiles: The test snowmobiles were driven along the course so as to simulate a typical guided trip. There were stopping points for wildlife viewing, a rest stop at Madison Junction, and travel at varying speeds. Data was sorted into three modes (idle, low speed, and cruise) to provide inputs for the scenario modeling. In Figure 6 the data is presented by pollutant for each of the modes. CO and HC emissions generally decrease, when expressed as g/mile, as the travel speed increases. NOx increases with speed. The Arctic Cat TZ1 followed these trends but had higher emissions of CO and HC and lower emissions of NOx that the other snowmobiles.

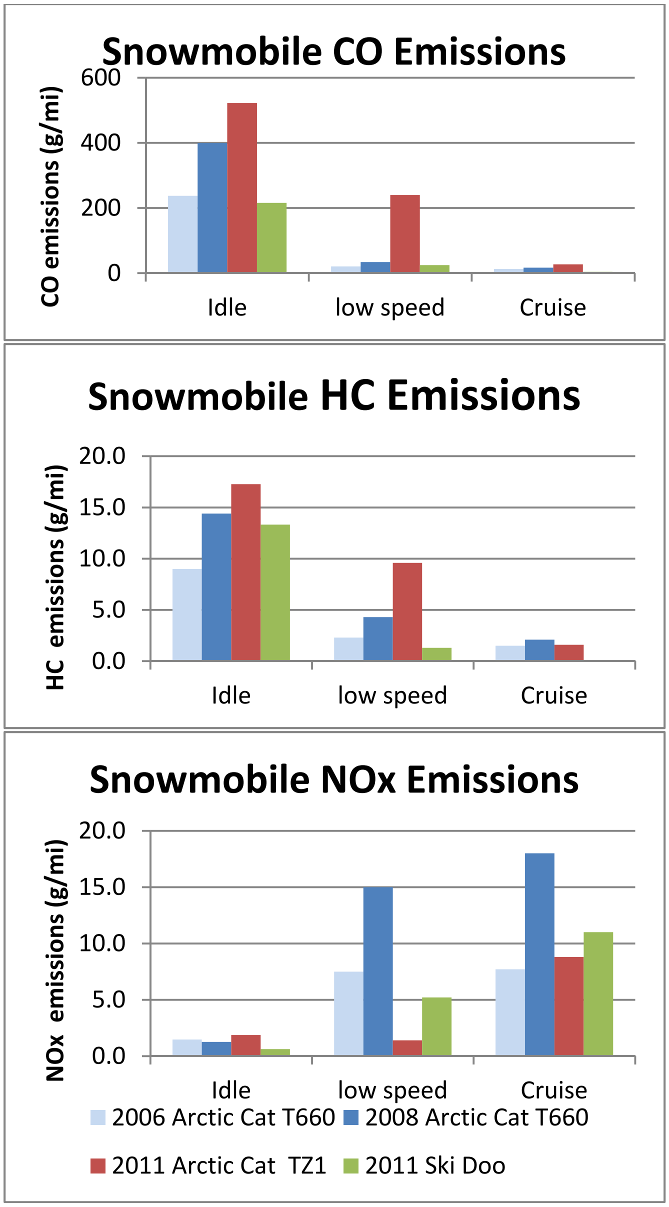

Figure 6. Comparison of measured snowmobile emissions by speed mode. Low speed is 0-15 mph; cruise is >15 mph. The 2006 Arctic Cat T660 was tested in winter 2006 (Bishop, 2006).

Figure 6 shows the change in emissions with model year of the BAT snowmobiles for Arctic Cat and Ski Doo. The Arctic Cat TZ1 had higher CO by a factor of 2 while HC and NOx stayed about the same. For Ski Doo, the CO dropped and NOx went up. The Arctic Cat engine size went up and the Ski Doo engine size down. The reported FEL BAT fleet emissions data provided by the manufacturer are shown in table 10 (NPS 2011).

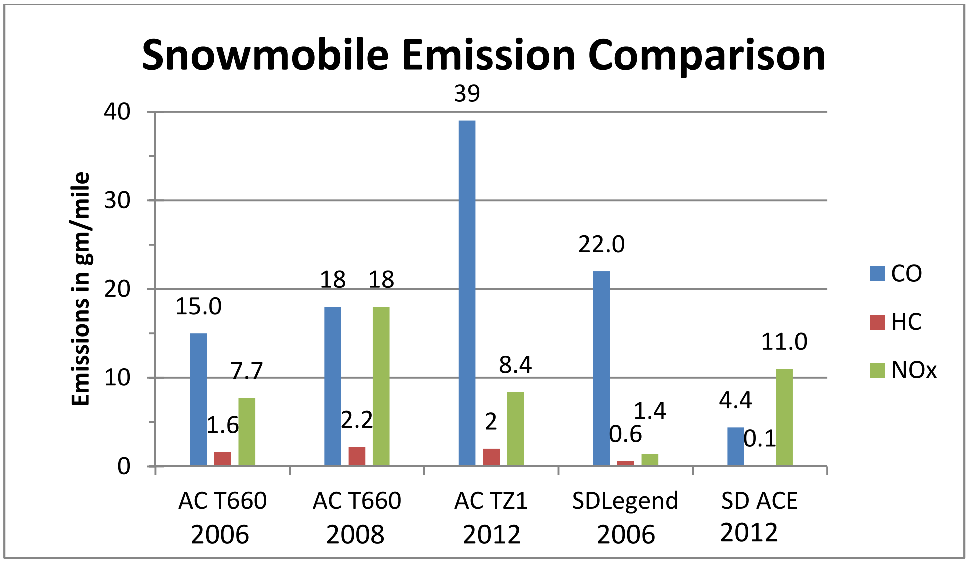

Figure 7. Comparison of BAT snowmobiles from 2006 to the 2012 models.

Table 10. Family Emission Limits (FEL) from the BAT snowmobiles list.

Model year	Model	CO emission g/kW-h FEL	HC emission g/kW-h FEL
2007	2007 Arctic Cat Bearcat 660 W/T, Panther 660 Touring, Panther 660 Trail, 660 Touring	105	8
2008	2008 Arctic Cat 660 Touring, Bearcat 660 W/T and Panther 660 Touring	105	8
2011	2011 Arctic Cat Z1 LXR and TZ1 / TZ1 LXR, throttle-limited snowmobiles	99	9
2012	2012 Arctic Cat TZ1 / TZ1 LXR, M 1100, and XF 1100 / F 1100, Bearcat Z1 XT throttle-limited snowmobiles	99	9
2008	2008 Bombardier Ski-Doo Legend Trail, Legend Touring,	120	8
2011	2011 Bombardier Expedition Sport 600 ACE	90	8

Source: http://www.nps.gov/yell/parkmgmt/current_batlist.htm

5. Fleet Emissions Estimates for Use in Modeling

5.1 Snowmobile Fleet Averages for Modeling

For the 2012 draft SEIS air quality modeling (Wu, 2012), the NPS utilized one set of emission factors for snowmobiles (Ray, 2012a). For the modeling, snowmobile tailpipe emissions for the Final SEIS, the NPS utilized three different sets of emission factors, depending on modeling scenario (alternative).

The 2012 fleet consists of the following percentages of the available snowmobiles . Measurements of the winter traffic through the west entrance were 80% rental snowmobiles, 14% snowcoaches, and 7% admin vehicles. The park estimates the admin traffic at less than 10%. The snowmobile traffic is about 50% Arctic Cat, 25% Ski Doo, and another 25% composed of Yamaha, unknown, and admin snowmobiles. Future BAT snowmobiles are expected to be Arctic Cat and Ski Doo unless another manufacturer decides to add a BAT snowmobiles to the models offered (presently only Arctic Cat and Ski Doo produce Yellowstone-compliant BAT snowmobiles). Only the Ski Doo meets the new BAT standard and it remains to be seen if other manufacturers will build a new BAT snowmobile.

Current Conditions Model Estimates: Two snowmobile model brands were tested in 2012 and used for the averages as representative of the currently used snowmobiles in the fleet. The emissions were weighted according to the current fleet census as 63.3% Arctic Cats and 36.7% Ski Doo. The administrative snowmobile fleet is assumed to have the same make-up as the commercial fleet. Search and rescue has eight 2-stroke snowmobiles that are used infrequently when needed for deep-snow off-road conditions. Therefore, for current conditions, new-BAT and E-BAT snowmobiles, the commercial, non-commercial, and administrative snowmobiles emissions are the same within a specific alternative (scenario) (see table 11).

Table 11. Average fleet# emissions from current and estimated future snowmobiles at Yellowstone*.

Current fleet -BAT, 4-stroke				
		Idle	Low Speed	Cruise Speed
Pollutant	Test period	(g/hr)	(g/mi)	(g/mi)
CO	2012	409.7	161.1	18.6
HC	2012	15.8	6.6	1.0
NOx	2012	1.4	2.8	9.6

Only the Arctic Cat TZ1(63.3%) and Ski Doo Expedition ACE 600 (36.7%) are included

new BAT	(Ski Doo Expedition)		
	Idle	Low Speed	Cruise Speed
Pollutant	(g/hr)	(g/mi)	(g/mi)
CO	216.0	25.0	4.0
HC	13.3	1.3	0.1
NOx	0.6	5.2	11.0

Enhanced-BAT (E-BAT)	(66.7% of N-BAT)		
	Idle	Low Speed	Cruise Speed
Pollutant	(g/hr)	(g/mi)	(g/mi)
CO	144.1	16.7	2.7
HC	8.9	0.9	0.1
NOx	0.4	3.5	7.3

New BAT Model Estimates: The 2011 Ski Doo Expedition Ace 600 measured in March 2012 meets the proposed New BAT standard for snowmobiles. PEM values obtained from this machine were used to as emission factors for all modeling scenarios calling for 'New BAT.'

Enhanced BAT (E-BAT): The E-BAT for purposes of the modeling exercise was taken as 66.7% of the New BAT snowmobile emissions.

5.2 Snowcoach Fleet Averages for Modeling

The fleet emission averages are estimated by putting different OSV into categories and using the emissions data from PEM tested vehicles in the category to determine averages. The types of snowcoaches and the numbers in each category are based on the census of vehicles assembled by the park from vendor input (Table 12) (Vagias, 2012). The number of snowcoaches by model year (Figure 8) shows a large portion are 2000 and newer. The largest group of pre-2000 snowcoaches are historic Bombardiers that are using older carbureted engines.

Table 12. Commercial Snowcoaches in Operation (for visitor use) Winter 2011-12.

	Fleet Summary		Class I: Purpose Built		Class II: Vans & SUVs		Class III: Coaches	
	N	% of Total	N	% of Total	N	% of Total	N	% of Total
Snowcoaches in Operation	78	100.0	21	26.9	37	47.4	20	25.6
Average Vehicle Year	1995	- -	1967	- -	2003	- -	2008	- -
Average Engine Year	2004	- -	2002	- -	2004	- -	2008	- -
Average Max Capacity	14	- -	12	- -	13	- -	19	- -
Gasoline Fuel Injected	48	61.5	9	11.5	35	44.9	4	5.1
Gasoline Carbureted	12	15.4	12	15.4	0	0.0	0	0.0
Diesel	18	23.1	0	0.0	2	2.6	16	20.5
Example Vehicles			Bombardier (B-12)		(SCM) Express, E-350		Vanterra, Krystal	

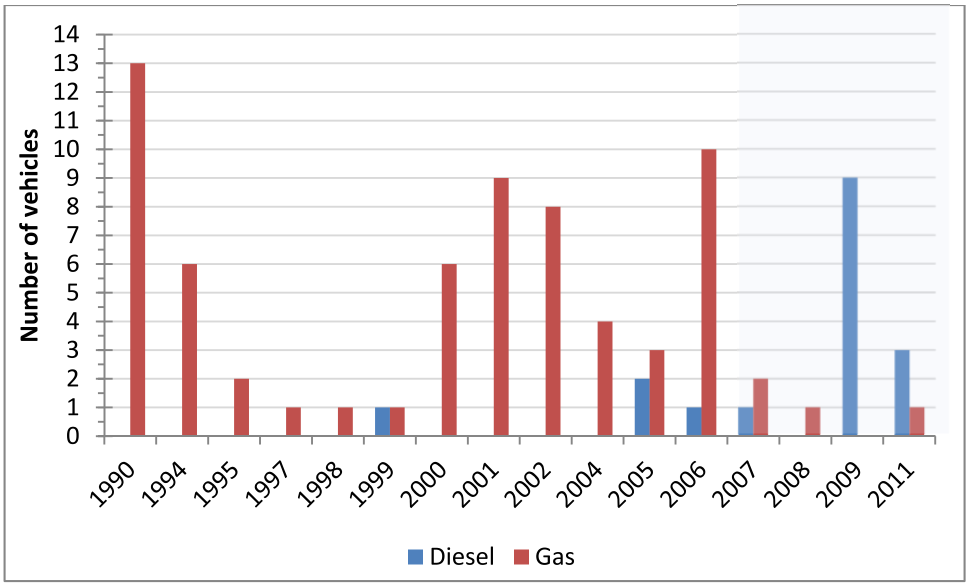

Figure 8. Number of gasoline and diesel snowcoaches by model year that are in current use at Yellowstone (Vagias, 2012).

For purposes of scenario modeling it was necessary to calculate an average emission rate for each modeling scenario. Using a straight average of the snowcoaches tested doesn't weight the average by the number of vehicles of that type or their percentage of usage for a given management scenario. After examining all the test data, it was observed that vehicles with port fuel injected engines had less emissions than carbureted engines and that more recent pollution-controlled vehicles had lower emissions (the 2008 Chevy Express van at cruise speed being an exception to the generalization). The cut off point for these components was about year 2000. A proposed snowcoach BAT would require new vehicles to be Tier 2 compliant (EPA, 1999; EPA, 2000) which means model year 2007 or newer for spark ignition engines (gasoline) and 2010 or newer for compression ignition engines (diesel).

All the snowcoaches were categorized into 3 classes with 2 subclasses (Vagias, 2012). There were representative test vehicles in each class. Fleet averages were calculated by taking the fraction of fleet vehicles in that class and weighting the total by the fraction contribution of each category. A fleet calculation tool was created in Excel to do this task. The fleet average, therefore, has an assumption that all snowcoaches are used approximately equally. Since every snowcoach is not used every day, the usage being dependent on the number of visitors that want tours each day, the fleet average is recognized as being only approximate.

Below are the categories used for snowcoaches in use at Yellowstone National Park (Vagias, 2012) based on a census of snowcoaches (detail in Appendix A):

Category	Coach type	How rated?	Example
I	Historic, carbureted, gas	Non-BAT	Bombardiers - non-BAT
I B	Historic - Port fuel injected, gas	BAT	converted Bombardiers
II	2000 or newer, PFI, pollutant controls, gas	mixed	conversion vans, airporters, new models
II B	2007 or newer (gas) - replacements	BAT	conversion vans, airporters, new models
II C	Older than 2007	Non-BAT	Conversion vans
III	diesel powered (2010 or newer)	BAT	land yachts, "airporter" style coaches
IIIB	cleaner diesel (BAT) w/ SCR	BAT	as tested snowcoaches (2012)

The following numbers of snowcoaches (Table 13) were used by category in the fleet calculations for current conditions assuming the total stayed the same while only BAT snowcoaches were used.

Table 13. Number of vehicles by category in the current snowcoach fleet.

Current gas	Current diesel	Current fleet Gas & diesel	Cleaner Fleet BAT w/ replacements		
Number	Number	Number	Number	Category	Fuel
12	0	15	0	I	Gas
9	0	9	21	I B	Gas
25	0	25	0	II	Gas
9	0	9	34	II B	Gas
5	0	5	0	II C	Gas
0	8	8	0	III	Diesel
0	10	10	23	III B	Diesel
60	18	78	78	← Totals	

The following averages (Table 14) from the emission test results were used to estimate emissions for each snowcoach category. The fleet averages for use in the EIS scenario modeling are Tables 15 and 17. A listing of all the vehicles used to define a category and calculate the category average emissions is given in Appendix A.

Table 14. Emissions by category of snowcoaches used in the fleet calculation of current and future fleets .

Current fleet = All of the snowcoaches in OSV census (Vagias, 2012).				**CO**			**HC**			**NOx**			**PM**		
			Current	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**
Name	**Categories**	**Description**	**# in use**	**g/hr**	**g/mi**	**g/mi**	**g./hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**
Historic	Class I	older engines, Bombardiers	6	1188	410	445	46.8	10.6	27.2	0.7	22.2	21.5	NO DATA		
	Class IB	modernized Bombardiers	15	11.9	8.3	5.6	2.2	0.7	0.4	0.4	2.0	3.1	NO DATA		
Gas BAT	Class II	2000 to 2006	47	14.1	23.3	118.0	3.4	1.2	1.1	0.47	5.3	6.8	NO DATA		
	IIB	2007 and newer		12.6	22.1	233.7	0.25	0.15	0.35	0.09	0.55	2.50	NO DATA		
	IIC	Older than 2000		149.4	44.0	64.0	40.9	3.1	2.1	7.7	11.3	19.5	NO DATA		
Diesel BAT	Class III	diesel	17	12.9	8.7	3.3	0.4	0.2	0.1	31.8	30.5	24.3	0.2	0.2	0.1
	IIIB	Diesels, 2010 & newer		6.68	1.00	0.71	0.42	0.20	0.10	13.25	14.75	10.10	0.20	0.11	0.01
		Total	85												

Snowcoach best available technology (BAT)
(as proposed in the SEIS, Appendix A)

Because of the wide range in body types, engine sizes, passenger capacity, track type, and fuels used, a functional definition is used for BAT. Specifically, BAT snowcoaches are Tier 2:

- newer than 2007 (Sl engine) or 2010 (Cl engine)
- have modern pollution and engine controls
- use computerized controls for port fuel injection.
- may be either gasoline or diesel engines

Data from both the 2006 emission tests and the 2012 tests are used as appropriate to calculate the current fleet averages. Each snowcoach was put into a vehicle category and the number of vehicles in the category was used to get a fleet average. Average emissions for each category are from the in-use emission vehicles tested. No attempt was made to weight the emissions for specific models of vehicles because almost all vehicles are unique combinations of engine, body and track style, model year, gear ratios, etc.

Table 15. Fleet average emissions for current snowcoaches at Yellowstone.

Current - Gasoline (N=60)			
Pollutant	**Idle (g/hr)**	**Low Speed (g/mi)**	**Cruise Speed (g/mi)**
CO	207.7	83.7	166.0
HC	12.1	2.8	5.3
NOx	1.99	5.72	6.62
PM10	No data		
Current – Diesel (N=18)			
CO	21.2	10.0	4.2
HC	0.9	0.5	0.2
NOx	48.39	48.94	36.93
PM10	0.464	0.318	0.118
Current Fleet (gas & diesel) N= 78			
CO	201.9	77.9	138.4
HC	11.3	2.3	4.8
NOx	6.53	10.42	9.93
PM10	0.048	0.033	0.012

Assumptions: the tested snowcoaches represent a reasonable cross-section of the fleet. The mix of vehicles tested approximates the in-use snowcoaches. Note that the 15 carbureted Bombardiers add significantly to the CO numbers for the fleet.

The SEIS has several policy alternatives (NPS, 2012) with different numbers of snowcoaches and allowed emissions. Tables 13 and 16 give the number of vehicles in each category, The emissions within a category for different speed ranges are given in Table 14.

The equation to calculate the weighted average emission for each pollutant and each speed range is given below. An Excel calculation tool was used to assemble and calculate the fleet averages based on inputs of the number of vehicles in each category.

$$\text{Weighted Average Emissions}_Z = \sum_{n=1}^{7} W_n * E_n$$

where n is the snowcoach category, W is the fleet percentage, and E_n is the emissions for that category (g/mi). Z is the speed range for emissions. E_n emissions are those given in Table 14.

Table 16. Future fleet combinations of BAT snowcoaches for different EIS alternatives. Number of vehicles in each category is listed along with the total at the bottom. The weighed percent are calculated for these values.

	Alternatives								
Category	**2B**	**3B,4C**	**4A**	**4B**	**4D**	**5A**	**5B**	**5C**	**5D**
I B	21	21	21	21	21	21	21	21	21
II B	34	63	21	53	127	17	46	55	113
IIIB	23	36	18	32	64	16	29	32	58
Total	78	120	60	106	212	54	96	108	192

The assembled fleet emission averages are provided in Table 17 for the base case (labeled “null”) and alternatives 2A through 5D. The green text indicates the per OSV emissions for current conditions. From table 17 one can see that emissions go down as BAT is used for snowcoaches and the snowmobile emissions are lessened with a new BAT and an enhanced BAT (E-BAT).

Table 17. Fleet emissions (g/mi for individual OSV) data used for each policy alternative for use in scenario modeling.

					SNOWCOACHES				SNOWMOBILES			
ALT	Alternative Description	Total N of Snowcoaches	Total N of Commercial Snowmobiles	Total N of Non-commercial Snowmobiles	Snowcoach Pollutant	Idle (g/hr)	Low Speed (g/mile)	Cruise Speed (g/mile)	Snowmobile Pollutant	Idle (g/hr)	Low Speed (g/mile)	Cruise Speed (g/mile)
Null	Current Conditions (for comparison purposes)	37	192	0	CO	201.9	77.9	138.4	CO	409.70	161.10	18.56
					HC	11.3	2.3	4.8	HC	15.83	6.55	1.05
					NOX	6.53	10.42	9.93	NOX	1.41	2.79	9.61
					PM10	0.048	0.033	0.012	PM10			
2A	Interim Regulation	78	318	0	CO	201.9	77.9	138.4	CO	409.70	161.10	18.56
					HC	11.3	2.3	4.8	HC	15.83	6.55	1.05
					NOX	6.53	10.42	9.93	NOX	1.41	2.79	9.61
					PM10	0.048	0.033	0.012	PM10			
2B	Interim Regulation but with BAT Snowcoaches & 'Current' BAT Snowmobiles	78	318	0	CO	10.7	12.1	103.6	CO	409.70	161.10	18.56
					HC	0.8	0.3	0.3	HC	15.83	6.55	1.05
					NOX	4.05	5.12	4.89	NOX	1.41	2.79	9.61
					PM10	0.058	0.032	0.003	PM10			
3A	Phase I of SM phase-out (identical to Alternative #2A)	78	318	0	CO	201.9	77.9	138.4	CO	409.70	161.10	18.56
					HC	11.3	2.3	4.8	HC	15.83	6.55	1.05
					NOX	6.53	10.42	9.93	NOX	1.41	2.79	9.61
					PM10	0.048	0.033	0.012	PM10			
3B	Phase II of SM phase-out (complete phase-out of SM)	120	0	0	CO	10.7	13.3	123.9	CO			
					HC	0.6	0.3	0.3	HC			
					NOX	4.09	5.06	4.88	NOX			
					PM10	0.059	0.033	0.003	PM10			
4A	BAT Snowcoaches & New BAT Snowmobiles	60	460	20	CO	10.6	10.9	84.0	CO	216.00	25.00	4.00
					HC	1.0	0.4	0.3	HC	13.32	1.30	0.10
					NOX	4.14	5.31	4.98	NOX	0.61	5.20	11.00
					PM10	0.059	0.033	0.003	PM10			
4B	BAT Snowcoaches, Zero Commercial Snowmobiles, and New BAT Non-commercial Snowmobiles	106	0	20	CO	10.7	13.0	118.2	CO	216.00	25.00	4.00
					HC	0.7	0.3	0.3	HC	13.32	1.30	0.10
					NOX	4.12	5.12	4.91	NOX	0.61	5.20	11.00
					PM10	0.060	0.033	0.003	PM10			
4C	BAT Snowcoaches, E-BAT Commercial Snowmobiles, and E-BAT Non-commercial Snowmobiles	120	460	20	CO	10.7	13.3	123.9	CO	144.00	16.67	2.67
					HC	0.6	0.3	0.3	HC	8.88	0.87	0.07
					NOX	4.09	5.06	4.88	NOX	0.41	3.47	7.33
					PM10	0.059	0.033	0.003	PM10			
4D	BAT Snowcoaches, Zero Commercial Snowmobiles, and New BAT Non-commercial Snowmobiles	212	0	20	CO	10.8	14.3	140.8	CO	216.00	25.00	4.00
					HC	0.5	0.2	0.3	HC	13.32	1.30	0.10
					NOX	4.09	4.98	4.85	NOX	0.61	5.20	11.00
					PM10	0.060	0.033	0.003	PM10			
5A	BAT Snowcoaches & New BAT Snowmobiles	54	420	20	CO	10.6	10.5	76.0	CO	216.00	25.00	4.00
					HC	1.0	0.4	0.3	HC	13.32	1.30	0.10
					NOX	4.10	5.31	4.97	NOX	0.61	5.20	11.00
					PM10	0.059	0.033	0.003	PM10			
5B	BAT Snowcoaches, Zero Commercial Snowmobiles, and New BAT Non-commercial Snowmobiles	96	0	20	CO	10.7	12.7	113.4	CO	216.00	25.00	4.00
					HC	0.7	0.3	0.3	HC	13.32	1.30	0.10
					NOX	4.13	5.15	4.92	NOX	0.61	5.20	11.00
					PM10	0.060	0.033	0.003	PM10			
5C	BAT Snowcoaches, E-BAT Commercial Snowmobiles, and E-BAT Non-commercial Snowmobiles	108	420	20	CO	10.7	13.1	120.3	CO	144.00	16.67	2.67
					HC	0.7	0.3	0.3	HC	8.88	0.87	0.07
					NOX	4.05	5.03	4.86	NOX	0.41	3.47	7.33
					PM10	0.059	0.033	0.003	PM10			
5D	BAT Snowcoaches, Zero Commercial Snowmobiles, and New BAT Non-commercial Snowmobiles	192	0	20	CO	10.8	14.2	138.4	CO	216.00	25.00	4.00
					HC	0.5	0.2	0.3	HC	13.32	1.30	0.10
					NOX	4.10	4.99	4.86	NOX	0.61	5.20	11.00
					PM10	0.060	0.033	0.003	PM10			

6. Conclusion

New emission data are now available for newer models of snowmobiles and recent additions to the snowcoach fleet. This updates the data collected in 2005 and 2006. Emissions are generally lower for newer snowcoaches compared to mean values of the earlier fleet and especially compared to the older carbureted engine snowcoaches.

It is less clear that the model year 2011 snowmobiles are meeting desired emissions policy objectives that snowmobile emissions should decrease over the years as newer, better models are introduced. Emissions for, at least, one model are higher than from previous models.

Emissions data are now available for the modeling exercise (Tables 15 and 17). The different snowcoaches are put into categories according to their emissions, fuel type, and engine configuration. The overall “fleet” is a mixture of these different types. The current fleet is the snowcoaches that are most prevalent. The future fleet is the snowcoaches allowed under a new snowcoach BAT policy and whatever new vehicles are added as replacements.

Fleet emissions by OSV and by category are provided for modeling of the policy alternatives.

7. References

Bishop, G., J. Morris, et al. 2001. Snowmobile contributions to mobile source emissions in Yellowstone National Park. Environmental Science and Technology 35(14): 2874-2881.

Bishop, G. A., D.S. Burgard, T.R. Dalton,and D.H. Stedman, 2006a. In-use Emission Measurements of Snowmobiles and Snowcoaches in Yellowstone Nation Park, final report to National Park Service, Coop. agreement H2350042097, Chemistry Department, University of Denver, Denver, CO. Available from: http://www.feat.biochem.du.edu/reports.html

Bishop, G. A., D.S. Burgard, T.R. Dalton, D.H. Stedman, and J.D. Ray. 2006b. Winter Motor-Vehicle Emissions in Yellowstone National Park, Environmental Science & Technology, p. 2505. http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm

Bishop, G. A., R. Stadtmuller, and D. H. Stedman, 2007. Portable emission measurements of snowcoaches and snowmobiles in Yellowstone National Park, Final Report prepared for the National Park Service, Coop. agreement H235004097, Chemistry Department, University of Denver, Denver, CO. Available from: http://www.feat.biochem.du.edu/reports.html

Bishop, G. A., R. Stadtmuller, D. H. Stedman, and J. D. Ray. 2009. Portable emissionmeasurements of snowcoaches and snowmobiles in Yellowstone National Park. J. Air & Waste Manage. Assoc. 59, 936–942 (2009) , Chemistry Department, University of Denver, Denver, CO. Available from http://www.feat.biochem.du.edu

EPA, 1999. Regulatory Impact Analysis – Control of Pollution from New Motor Vehicles: Tier 2, Air and Radiation Division, EPA420-R-99-023, Dec. 1999. Available from http://www.epa.gov/tier2/documents/r99023.pdf

EPA, 2000. Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, Final Rule- 40 CFR Parts 80, 85, and 86 / Federal Register, Vol. 65, No. 28 /Thursday, February 10, 2000. Available from http://www.epa.gov/tier2/

Frey, H. C., A. Unal, N. M. Rouphall, and J. D. Colyar, 2003. On-road Measurement of Vehicle Tailpipe Emissions Using a Portable Instrument, *J. Air & Waste Manage. Assoc*. **53**, 992-1002.

Frey, H. Christopher, G. Sandhu, B. Graver, and H. Hu, 2012. Measurement of Fuel Use and Emissions of Over-Snow Vehicles at Yellowstone National Park, Report to Louis Berger Group, Department of Civil, Construction, and Environmental Engineering, North Carolina State University, NC 27695, August 30, 2012

National Park Service. 2009. BAT, Federal Register, Vol. 74, N0. 223, November 20, 2009, Pg 60159.

National Park Service. 2011a. A winter timeline: Winter Use Plan in Yellowstone http://www.nps.gov/yell/parkmgmt/timeline.htm

National Park Service. 2011b. Snowmobile Best Available Technology (BAT) List for Yellowstone and Grand Teton national Parks, http://www.nps.gov/yell/parkmgmt/current_batlist.htm

National Park Service, 2012. Supplemental Winter Use Plan/ Environmental Impact Statement (SEIS), http://www.nps.gov/yell/parkmgmt/currentmgmt.htm

Ray, J.D. 2012a, Yellowstone Over-snow Vehicle Emission Tests 2012: Preliminary Report, Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2012. National Park Service, Fort Collins, Colorado. Draft V4.1, posted June 7, 2012. Available at http://www.nps.gov/yell/parkmgmt/upload/pem_of_snowcoaches-snowmobiles_3-2012.pdf

Ray, J. D. 2012b. Winter Air Quality in Yellowstone National Park: 2009-2011, Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2012/551. National Park Service, Fort Collins, Colorado. Available from http://www.nps.gov/yell/parkmgmt/winter_monitoring.htm

Roberson, Randy, 2012, Private communication, rental snowmobile fuel consumption log sheets.

Vagias, Wade, 2012, Private communication, OSV Census Data for 2011-12 Season (Yellowstone).

Wu, James, 2012. Air Quality Modeling Report Snowmobile and Snowcoach Emissions (Draft): Winter Use Plan Supplemental Environmental Impact Statement. Contractor report prepared for Yellowstone National Park. Air Resource Specials, Inc., Fort Collins, CO. June 28, 2012. Available at http://www.nps.gov/yell/parkmgmt/upload/Draft_SEISAirQuality_ModelingReport-June-28-2012.pdf

Zhang, K. and C. Frey, 2008. Evaluation of Response Time of a Portable System for In-use Vehicle Tailpipe Emissions Measurement, *Environ. Sci. Technol*. **42**, 221-227.

Appendix A – Snowcoach Fleet Emissions by Category

The following tables have the emission-tested snowcoaches arranged by the three categories. Averages from the categories are used to calculate the fleet emissions. The snowcoaches excluded as being non-BAT are listed separately.

Table A-1. List of snowcoaches in the historic Bombardier category. Category I and IB

					CO			HC			NOx		
		Engine	Fuel	Date	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise
Business	Identifier	Year	Delivery	Tested	g/hr	g/mi	g/mi	g/hr	g/mi	g/mi	g/hr	g/mi	g/mi
	Category IB	**modernized**											
Alpen Guides	DeLacy	2002	PFI	2005	13.3	7.5	4.9	4.7	1.4	0.8	0.11	1.4	1.4
AG	AG Cygnet	2002	PFI	2006	9.4	7.8	4.9	9.4	0.6	0.4	0.18	1.4	2.9
AG	AG Kitty	2002	PFI	2012	13.1	7.1	9.6	0.36	0.1	0.86	0.86	3.1	4.9
				Average	11.9	8.3	5.6	2.2	0.7	0.4	0.4	2.0	3.1
	Category I	**older engines**											
AG	AG Kitty	1979	Carbureted	2006	1440.0	240.0	310.0	46.8	6.1	3.3	0.36	35.0	36.0
Xanterra	#709	2001	Carbureted	2005	936.0	580.0	580.0	46.8	15.0	51.0	1.1	9.4	7.0
				Average	1188	410	445	46.8	10.6	27.2	0.7	22.2	21.5

Table A-2. List of snowcoaches in the gasoline engine current fleet. Category II.

Business	Identifier	Engine Year	Model	Date Tested	CO Idle g/hr	CO Low Speed g/mi	CO Cruise g/mi	HC Idle g./hr	HC Low Speed g/mi	HC Cruise g/mi	NOx Idle g/hr	NOx Low Speed g/mi	NOx Cruise g/mi
BBC	BBC Van	2003	Ford E350	2006	0.10	0.1	67	1.08	0.7	1.4	0.36	0	0.3
3BL	3BL Van5	2001	Ford E350	2006	8.6	3.8	12	1.44	0.7	0.3	0.18	3.5	1.2
Xanterra	#416	2001	Van	2005	17.3	5.8	94.0	4.0	0.9	0.8	1.4	21.0	27.0
BBC	BBC Vanterra	2004	Ford E350	2006	0.1	8.8	47	1.08	0.5	0.9	0.72	0.1	0.1
YSCT	YSCT Van	2000	Ford E350	2006	3.6	9.3	330	0.36	0.3	1.5	0.18	1	1.7
Xanterra	#419	2001	Van	2005	50.4	35.0	5.8	14.0	3.3	0.4	0.2	10.0	16.0
3BL	3BL Van2	2000	Ford E350	2006	18.7	100	270	2.16	1.7	2.5	0.18	1.4	1.5
		Category II		average =	14.1	23.3	118.0	3.4	1.2	1.1	0.5	5.3	6.8

Table A-3. List of gasoline engine snowcoaches that would meet a proposed BAT. Category IIB

Business	Identifier	Engine year	Model	Date Sampled	CO Idle g/hr	CO Low Speed g/mi	CO Cruise g/mi	HC Idle g./hr	HC Low Speed g/mi	HC Cruise g/mi	NOx Idle g/hr	NOx Low Speed g/mi	NOx Cruise g/mi
BBS	SY3 gas	2011	Ford-E350	2012	2.2	5.4	13.4	0.36	0.10	0.20	0.04	0.1	0.3
Xanterra	Express	2008	Chevy	2012	23.0	38.7	454.0	0.14	0.20	0.50	0.14	1.0	4.7
	Category IIB			average	12.6	22.1	233.7	0.3	0.2	0.4	0.1	0.6	2.5

Table A-4. List of gasoline engine snowcoaches older than 2000, non-BAT. Category IIC

					CO			HC			NOx		
Business	**Identifier**	**Engine year**	**Model**	**Date Sampled**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**
					g/hr	**g/mi**	**g/mi**	**g./hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**
YEXP	YEXP R350	1994	Dodge 350	2005	140.4	41	44	72	4.3	2.3	1.08	8.6	16
YEXP	YEXP R250	1994	Dodge 250	2005	158.4	47	84	9.7	1.8	1.8	14.4	14	23
		Category IIC average			149.4	44.0	64.0	40.9	3.1	2.1	7.7	11.3	19.5

Table A-5. List of diesel engine snowcoaches as current fleet. Category III.

Diesel engines				CO			HC			NOx			PM		
		Engine		**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**	**Idle**	**Low Speed**	**Cruise**
Business	**Identifier**	**Year**	**Model**	**g/hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**
Xanterra	Glaval - diesel	2011	Ford-F450	0.004	0.70	1.40	0.58	0.30	0.10	20.16	23.70	13.30	0.4	0.02	0.01
BBS	SY8 diesel	2011	Ford-F550	13.4	1.3	0.01	0.25	0.10	0.10	6.34	5.8	6.90	0.04	0.20	0.01
NPS	NPS Yel Bus	2006	International	14.0	24	5.7	NO DATA			43.2	50.5	30	0.11	0.40	0.30
NPS	E350 Van	2000	E350 Van	24.1	8.9	6.2	NO DATA			57.6	42.0	47.0	0.25	0.10	0.10
		Average =		12.9	8.7	3.3	0.42	0.20	0.10	31.8	30.5	24.3	0.22	0.18	0.11

Table A-6. List of diesel engine snowcoaches that meet BAT. Category IIIB

Diesel engines				CO			HC			NOx			PM		
		Engine		Idle	Low Speed	Cruise	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise
Business	**Identifier**	**Year**	**Model**	**g/hr**	**g/mi**	**g/mi**	**g./hr**	**g/mi**	**g/mi**	**g/hr**	**g/mi**	**g/mi**	**g/h**	**g/mi**	**g/mi**
Xanterra	Glaval - diesel	2011	Ford-F450	0.004	0.70	1.40	0.58	0.30	0.1	20.16	23.70	13.30	0.36	0.02	0.01
BBS	SY8 diesel	2011	Ford-F550	13.4	1.3	0.01	0.25	0.10	0.10	6.34	5.8	6.90	0.04	0.20	0.01
	n=2	Average =		6.68	1.00	0.71	0.42	0.20	0.10	13.25	14.75	10.10	0.20	0.11	0.01

[&] These vehicles were taken as examples of the expected newer diesel snowcoaches

Appendix B - Fuel usage of the Arctic Cat model TZ1

The idle emissions for CO on the model TZ1 were higher than expected. The question then is how representative is that snowmobile of the rental fleet ? One possibility we checked is if we had gotten the fuel usage wrong or if this was an unusual snowmobile in the rental fleet. The estimate fuel usage by the PEM and our recorded refueling record were in agreement. To assess representativeness, we used the snowmobile rental vendor fuel usage log (Roberson, 2012) for winter 2011-2012 for guided tours that went to Old Faithful and returned to West Yellowstone, a distance of 65 miles. The variability in mileage is due to snow conditions, how the sled is driven, if there is a passenger, and amount of idling time. The frequency distributions in Figure B-1 show the mean fuel usage (mpg) for each rental snowmobile (15 model 2011, 10 model 2012). The emission tested TZ1 is in the middle of the distributions. Based on the Arctic Cat tested in this study, using the distance and fuel usage, the calculated fuel usage is 4.4 gal. This is in the mid-range of the rental fleet and very close to the 2011 & 2012 median of 4.44 mpg which suggests that the test snowmobile is representative of the Arctic Cat model TZ1 from this vendor (Table B-1).

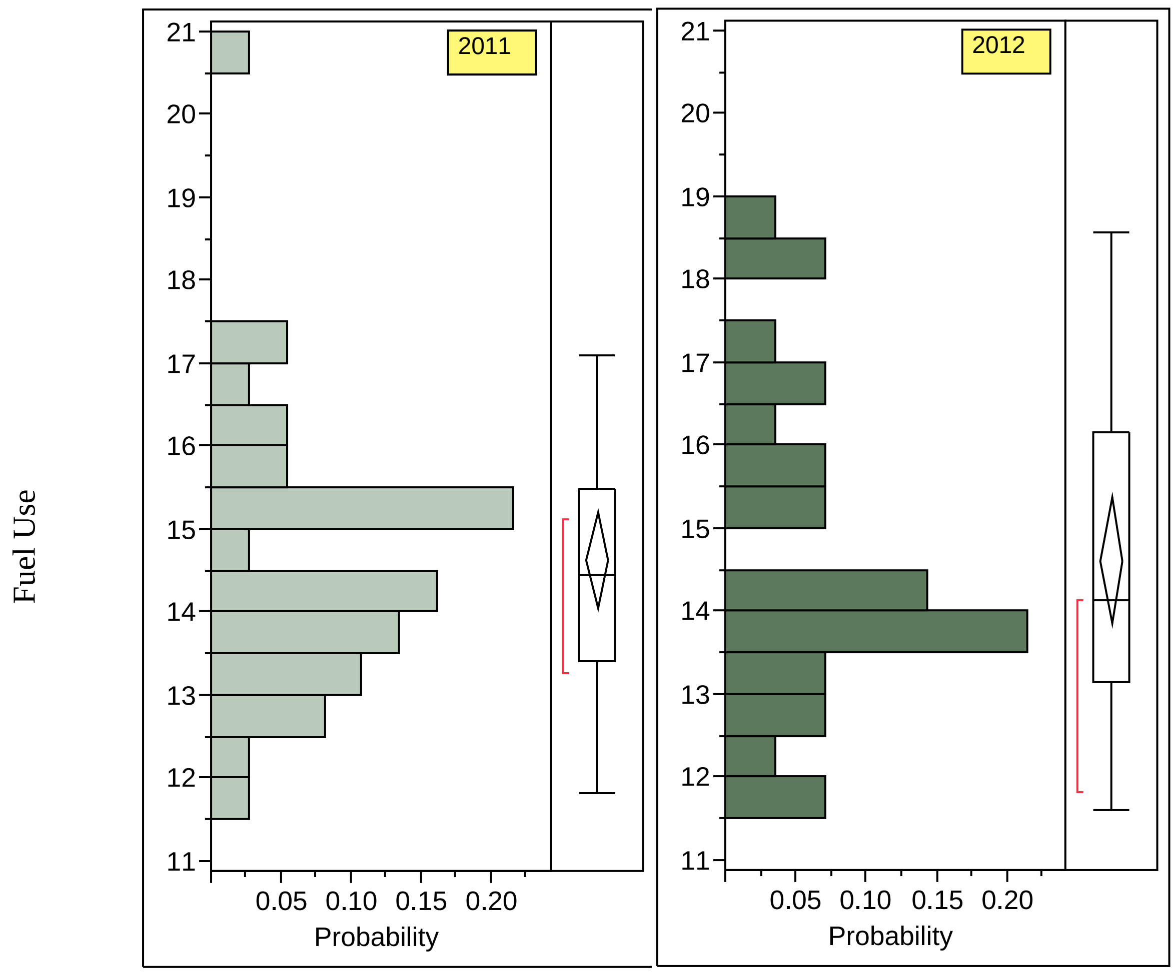

Figure B-1. Frequency distributions of fuel used (mpg) by model year of Arctic Cat TZ1 rental snowmobiles for round trip to Old Faithful from West Yellowstone.

Table B-1. Comparison of fuel usage by TZ1 model Arctic Cat Snowmobiles.

Model TZ1	Mean (gal)	Median (gal)	Fuel Usage (mpg)
2011 model year	4.49	4.5	13.8
2012 model year	4.52	4.6	13.7
Tested snowmobile	4.4	- -	14.4

Appendix C - Pictures of the Over-Snow Vehicles Tested in 2012

The following vehicles (Table C-1) were tested in the 2012 in-use emissions field program at Yellowstone National Park. Some basic information about the vehicles is provided.

Table C-1. Emission tested snowcoaches in 2012[a,b]. (Frey, 2012)

Business	Model Year	Vehicle Description	Engine size	Track type[C] /Drive Configuration	Fuel Type	Capacity (incl. driver)	Exhaust system components[d]	Approx. mpg
Xanterra	2011	Ford F-450 mini-bus	6.7 L V8	Mattracks 4x4	Diesel	~15	catalytic converter, urea	2
Xanterra	2008	Chevrolet Express Van	6.0 L V8	Mattracks 4x4	Gasoline	9	catalytic converter	1.8
Alpen Guides	2002	1956 Bombardier B-12 (aka: Kitty) - 2002 engine	5.3 L V8 fuel injection	Ski steer, Snowbusters drive	Gasoline ('02 PFI motor)	11	catalytic converter	7
Yellowstone Vacations	2011	Ford F-550 Bus (aka: Snow Yacht #8)	6.7 L 8 cyl	GripTracs 4x4	Diesel (w/ DPF & DEF)	33	DOC, urea filter	2
Yellowstone Vacations	2011	Ford E-350 Vanterra (aka: Snow Yacht #3)	6.7 L 10 cyl fuel injection	Mattracks 4x4	Gasoline	~15	catalytic converter	2

a All of the listed OSVs have 4-stroke engines

b Four snowcoaches (Chevy Express, Ford E350, Ford F450, and Ford F550) were modified from highway passenger vans to OSVs by replacing the wheels by tracks. The Bombardier was originally designed as snowcoach.

c Mattracks and GripTracks are commercial brands of snow treads that can be retrofitted to the axles of highway vehicles. For the retrofitted highway vehicles, there are four snow treads (one per wheel). Vehicles that are designed as OSVs, including the Bombardier and the snowmobiles, have two skies in the front used for steering, and one or two treads in the back used for propulsion.

d SCR = Selective Catalytic Reduction; DPF = Diesel particulate Filter

1979 Bombardier B-12 (aka: Kitty)

Business	Drive Configuration	Fuel Type	Capacity (incl. driver)
West Yellowstone	Ski steer Snowbusters drive 1956 Bombardier (aka: Kitty) w/ 2002 Chevy V8 engine, 5.3L	Gasoline (2002 motor)	11

2011 F-450 mini-bus (aka: Glavel)

Business,	Drive Configuration	Fuel Type	Capacity (incl. driver)
Xanterra, Mammoth	Mattracks x4 2011 ‘Glavel’ Ford F-450 Diesel	Diesel	~15

2008 Chevrolet Express Van (aka: Xanterra-430)

Business	Drive Configuration	Fuel Type	Capacity (incl. driver)
Xanterra, Mammoth	Mattracks x4 2008 Chevrolet Express Van	Gasoline	~11

2011 Ford E-350 Vanterra

Business	Drive Configuration	Fuel Type	Capacity (incl. driver)
Buffalo Bus, West Yellowstone	Mattracks x4 2011 Ford E-350 Vanterra	Gasoline	~15

2011 Ford F-550 Bus (aka: Krystal)

Business	Drive Configuration	Fuel Type	Capacity (incl. driver)
Buffalo Bus, West Yellowstone	GripTracs x4 2011 Ford F-550	Diesel	33

Table C-2. Emissions tested snowmobiles in 2012. All have 4-stroke engines.

Business	Model Year	Description	Engine displacement (cc)	Fuel	Riders
Yellowstone Vacations	2012	2012 Arctic Cat TZ1	1100	Gasoline	2
Yellowstone National Park	2008	2008 Arctic Cat T660	660	Gasoline	2
Yellowstone Adventures	2012	2012 Ski Doo Expedition Sport Snowmobile, 600 cc Ace 4-stroke engine	600	Gasoline	2

Arctic Cat snowmobiles

Arctic Cat TZ1 (left) and 2008 Arctic Cat T660 (last model year for T660) is on the right in the picture.

Business	Description	Fuel Type	Capacity (incl. driver)
Buffalo Bus, West Yellowstone	Snowmobile 2012 Arctic Cat TZ1	Gasoline	2
Yellowstone National Park	Snowmobile 2008 Arctic Cat T660	Gasoline	2

2012 Ski Doo (Bombardier) snowmobile

Business	Description	Fuel Type	Capacity (incl. driver)
Yellowstone Adventures	2011 Ski Doo Expedition Sport Snowmobile, 600 cc Ace 4-stroke engine	Gasoline	2

NPS 101/119449, January 2013

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