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Natural Resource Stewardship and Science

Yellowstone Over-snow Vehicle Emission Tests – 2012: Preliminary Report

John D. Ray
National Park Service
Air Resources Division
P.O. Box 25287
Denver, CO 80225

Gary Bishop, Brent Schuchmann
Chemistry Department
University of Denver
Denver, CO

Chris Frey, Gurdas Sandu, Brandon Graver
Department of Civil Engineering
North Carolina State University
Raleigh, NC 27695

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Abstract/Executive Summary

This is a preliminary report to provide summary tables for the 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 and 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 full report will include more detail on vehicles tested, experimental methods, detailed results, and perspective on the findings.

Acknowledgments

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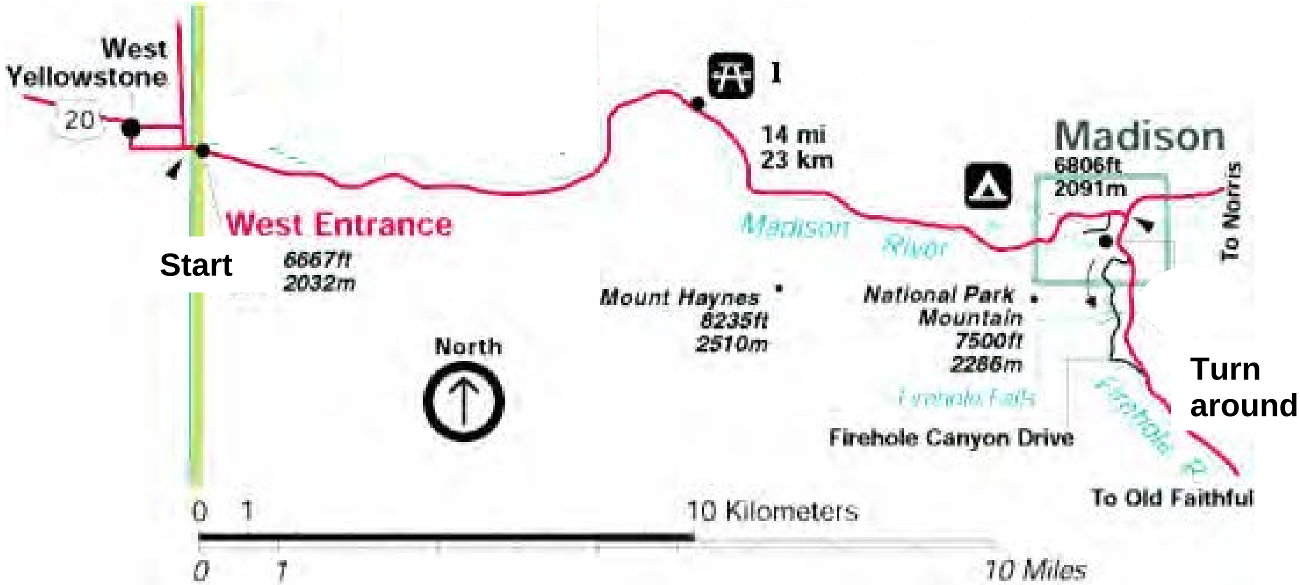
1. Introduction

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, 2012; Bishop, 2001; Bishop, 2007). Several policy changes have been made by the park that limit the number of OSV and for snowmobiles put a limit on emissions (NPS, 2011). 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 (Bishop, 2007; Bishop, 2006). 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 analyzer during actual operation under normal winter conditions.

2. Method

A repeat of the methods used in 2006 to measure emissions from vehicles in-use (Bishop 2007) was used in this March 2012 study. Instrumented vehicles 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. A portable emission monitor (PEM) made by Clean Air Inc. 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 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, gm/mile). The results are presented in Tables 1 - 6 as summaries by vehicle tested. More detail on engine performance and behavior will be included in the final report. Five snowcoaches and 3 snowmobiles were tested. Two snowcoaches had diesel engines and all others were gasoline engines.



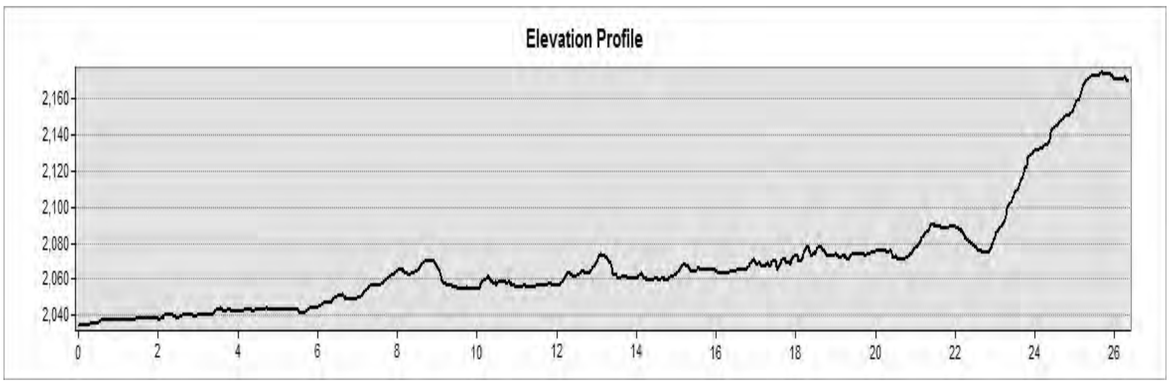


Figure 1. Map of emission testing route in Yellowstone National Park and elevation map for roadway along the route. Distance in miles, elevation in feet above sea level.

3. Results of Emissions Tests

Emission measurements were made from March 5-11, 2012 at West Yellowstone. The data was processed by North Carolina State University (Chris Frey, Brian Graver, and Gurdas Sandu) to provide emission averages for idle, low speed, and cruise. The calculations and assumptions used are given in the Bishop, 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. Five snowcoaches were tested in 2012. Tables 3 and 4 break out the results by engine type for gasoline and diesel engines. Complete details on the models, engines, and track types will be given in the final report. The objective of the current report is to provide enough information for the scenario modeling to proceed for the EIS.

Snowcoaches

Table 1. Emission results from the 2012 study for snowcoaches.

Vehicle	Species	Idle			Low Speed				Cruise			
		mg/s	g/gal	g/kg	mg/s	g/mi	g/gal	g/kg	mg/s	g/mi	g/gal	g/kg
120305_1956-Bombardier-Kitty (2002, gasoline, 5.3L)	CO	3.6	29.6	10.6	23.4	9.6	45.7	16.4	49.9	7.1	35.5	12.7
	HC	0.1	0.8	0.3	0.4	0.2	0.8	0.3	0.7	0.1	0.5	0.2
	NO_x	0.2	1.6	0.6	7.6	3.1	14.8	5.3	34.4	4.9	24.5	8.8
	MFF (g/s)	0.34			1.43				3.92			
120307_2011-Ford-F450-Glaval (2011, diesel, 6.7L)	CO	0.001	0.004	0.001	1.6	0.7	1.4	0.4	9.4	1.4	2.8	0.9
	HC	0.2	1.5	0.5	0.7	0.3	0.6	0.2	0.4	0.1	0.1	0.0
	NOx	5.6	40.7	12.7	50.6	23.7	43.5	13.6	87.8	13.2	26.0	8.1
	PM	0.01	0.04	0.01	0.04	0.02	0.03	0.01	0.08	0.01	0.02	0.01
	MFF (g/s)	0.44			3.72				10.8			
120308_2011-Ford-F550-SY8 (2011, diesel, 6.7L)	CO	3.7	45.5	14.2	2.1	1.3	2.8	0.9	0.03	0.01	0.01	0.00
	HC	0.1	1.2	0.4	0.2	0.1	0.3	0.1	0.9	0.1	0.3	0.1
	NOx	1.8	22.2	6.9	9.3	5.7	12.4	3.9	42.1	6.9	16.3	5.1
	PM	0.01	0.08	0.02	0.03	0.02	0.04	0.01	0.09	0.01	0.03	0.01
	MFF (g/s)	0.26			2.4				8.29			
120307_2008-Chevy-Express (Gasoline)	CO	6.4	45.7	16.3	101.1	42.0	93.9	33.5	2518	396	1003	358
	HC	0.04	0.3	0.1	0.5	0.2	0.5	0.2	3.0	0.5	1.2	0.4
	NOx	0.04	0.3	0.1	2.6	1.1	2.4	0.9	26.3	4.1	10.5	3.7
	MFF (g/s)	0.39			3.02				7.03			

MFF = mass fuel flow (g/s)

Vehicle	Species	Idle			Low Speed				Cruise			
		mg/s	g/gal	g/kg	mg/s	g/mi	g/gal	g/kg	mg/s	g/mi	g/gal	g/kg
120308_2011-Ford-E350-SY3 (Gasoline)	CO	0.6	3.6	1.3	13.2	12.5	16.0	5.7	84.3	16.1	39.9	14.3
	HC	0.1	0.6	0.2	0.4	0.3	0.4	0.2	1.0	0.2	0.5	0.2
	NOx	0.01	0.1	0.02	0.2	0.2	0.2	0.1	1.6	0.3	0.8	0.3
	MFF (g/s)	0.47			2.3				5.91			
Time-Weighted Means	CO	3	25	9	20	10	29	10	552	86	225	75
Time-Weighted Means	HC	0.1	1	0.3	0.4	0.2	0.5	0.2	1.2	0.2	0.5	0.2
Time-Weighted Means	NO_x	1.6	13.9	4.7	10.5	4.8	15.1	5.1	39.3	6.1	16	5.3
Time-Weighted Means	PM	0.01	0.07	0.02	0.03	0.02	0.04	0.01	0.08	0.01	0.03	0.01

Table 2. Snowcoach emission tests supporting data on distance and time.

Vehicle	Hours Sampled			Miles Traveled			Mean Low Speed 0 < GPS Speed ≤ 15 mph	Mean Cruise Speed GPS Speed > 15 mph
	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise		
120305_1956-Bombardier-Kitty	0.49	0.75	1.08	0.0	6.6	27.2	8.8	25.2
120307_2011-Ford-F450-Glaval	0.31	0.13	1.45	0.0	1.0	34.6	7.8	23.8
120308_2011-Ford-F550-SY8	0.86	0.36	1.36	0.0	2.1	29.8	5.8	21.9
120307_2008-Chevy-Express	0.17	0.10	1.38	0.0	0.8	31.6	8.7	22.9
120308_2011-Ford-E350-SY3	0.29	0.17	1.35	0.0	1.4	31.1	8.4	23.1
Totals and Weighted Means	0.42	0.30	1.32	0.0	11.9	154.3	7.9	23.3

Table 3. Summary results by pollutant of emission from gasoline engine driven snowcoaches.

2012 tests	Gasoline engines	Idle	Low Speed	Cruise Speed
Pollutant		(g/hr)	(g/mile)	
CO	average	59.1	21.3	139.7
HC	average	1.3	0.2	0.3
NOx	average	1.37	1.45	3.12

Table 4. Summary data for emissions from diesel engine driven snowcoaches.

2012 tests		Idle	Low Speed	Cruise Speed
Pollutant		(g/hr)	(g/mile)	
CO	average	30.8	1.0	0.7
HC	average	2.5	0.2	0.1
NOx	average	61.7	14.7	10.1
PM	average	0.10	0.02	0.01

Snowmobiles

Snowmobiles are a bit harder to instrument and do measurements on. The emission analyzer has to be carried on the snowmobile which requires a heated shelter 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). Two snowmobiles, an Arctic Cat TZ1 and a Ski Doo Bombardier, were tested over the full course. A third Arctic Cat, a 2008 model T660, was tested on about a third of the course before testing was stopped because of excess water in the sample lines. The 2011 Arctic Cat TZ1 has higher emissions at all speeds that the model T660 previously tested in 2006. The Ski Doo emissions in 2012 are close to those in a different model Ski Doo measured in 2006 – this provides us some confidence that the PEM instrument provided comparable emission data. Snowmobile emission results are given in Table 5 along with the supporting speed and distance metrics.

Table 5. Summary information of emissions by pollutant and supporting speed and distance data.

Vehicle	Sampled		Mean Speed	Fuel Use	Gram/Mile Emissions		
	Hours	Miles[a]	(mph)	(mpg)	CO	HC	NO_x
Arctic Cat	1.7	33.1	19.8	14.4	102	4.1	9.0
Ski Doo	1.3	29.2	22.0	15.8	4.9	0.2	11
Totals and Time-Weighted Means	1.5	31.2	20.8	15.0	60	2.4	9.9

[a] Mileage calculated using the GPS data.

Vehicle	Hours Sampled (Miles Traveled)			Mean Low Speed 0 < GPS Speed < 15 mph	Mean Cruise Speed GPS Speed > 15 mph
	Idle	Low Speed	Cruise		
Arctic Cat	0.03 (0)	0.53 (1.9)	1.11 (31.2)	3.6	28.0
Ski Doo	0.31 (0)	0.10 (0.6)	0.91 (28.6)	5.8	31.3
Totals and Weighted Means	0.17 (0)	0.32 (1.3)	1.01 (29.9)	3.9	29.5

Vehicle Measured	Species	Idle			Low Speed			Cruise		
		mg/s	g/gal	g/kg	g/mi	g/gal	g/kg	g/mi	g/gal	g/kg
Arctic Cat	CO	143	1,700	611	953	2,010	722	49	656	235
	HC	4.9	60	21	42	87	31	1.8	25	9.1
	NO_x	0.47	5.6	2.0	3.5	7.9	2.8	9.0	137	49
Ski Doo	CO	60	706	253	44	257	92	4.1	69	25
	HC	3.7	44	16	1.9	12	4.4	0.2	2.6	0.9
	NO_x	0.17	2.0	0.7	5.1	45	16	11	191	68
Time-Weighted Means	CO	67	794	285	809	1,740	622	29	392	140
	HC	3.8	45	16	36	75	27	1.1	15	5.4
	NO_x	0.20	2.3	0.8	3.8	14	4.9	9.9	161	58

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/gallon.

Table 6. Summary emission data for snowmobiles.

2012 Emission testing - Snowmobiles				
		Idle	**Low Speed**	**Cruise Speed**
Pollutant	**Test period**	**(g/hr)**	**(g/mile)**	
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	1691.7	503.5	26.6
HC	2012	71.7	22.0	1.0
NOx	2012	5.3	4.3	10.0

Comparison data for emissions are summarized in Table 6 for snowmobiles measured in 2006 and 2012. Emissions at cruise speed are much lower than at idle for all the vehicles. The fact that 2012 cruise emissions are within a factor of about 2X with the 2006 values is encouraging. The higher emissions of CO from the Arctic Cat TZ1 at idle are unusual. This may indicate this particular snowmobile had some tuning problems or that the manufacturer paid less attention to idle mode (See Appendix A). 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. Ideally multiple snowmobiles of the same type would be measured for emissions, however, time did not allow repeated measurements on the same model type of snowmobile.

Fleet Emissions for Use in Modeling

For purposes of scenario modeling it was necessary to use an average emission rate. 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 use. After examining all the test data, it was observed that vehicles with port fuel injected engines had less emissions that carbureted engines and that more recent pollution-controlled vehicles had lower emissions. The cut off point for these components was about year 2000. Very recent snowcoaches (since 2010) have tended to have larger engines and better pollution controls. All the snowcoaches were categorized into 3 classes with 2 subclasses. There were representative test vehicles in each class. Fleet averages were calculated by calculating 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. Although the tool could take into account the percentage of time that that category of vehicles was used, the needed data on percentage of daily trips that individual snowcoaches make was not available. 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 dependant 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 (detail in Appendix A):

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

The following numbers of snowcoaches were used by category in the fleet calculations:

Current Number	BAT 1 BAT (after 2012)ŷ Number	BAT 2 BAT w/ replacementsŧ Number	Category	Fuel Type
15	0	0	I	Gasoline
6	8	8	I	Gasoline
47	40	40	II	Gasoline
0	0	10	IIB	Gasoline
17	17	17	III	Diesel
0	0	4	IIIB	Diesel
85	65	79	TOTAL in fleet	

ŷ Assumes carbureted Bombardiers and older snowcoaches phased out, no replacements

ŧ Assumes 10 replacement gasoline and 4 clean diesel replacement snowcoaches. Replacements are generally larger with more passenger capacity.

The following averages (Table 7) from the emission test results were used for the categories. The fleet averages that were used in the EIS scenario modeling are Tables 8, 9, and 10. A listing of all the vehicles used to define a category and calculate the category average emissions is given in the Appendix.

Table 7. Current fleet of snowcoaches used in the fleet calculation of emissions.

Current fleet = Uses all of snowcoaches in table above.					**CO**			**HC**			**NOx**			**PM**		
Name	**Categories**	**Description**	**Current # in use**		**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g./hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**
Historic	Class I	modernized Bombardiers	6	Avg	11.9	9.4	6.5	2.1	0.7	0.4	0.3	2.0	3.1		NO DATA	
				std dev	2.2	3.1	2.7	2.4	0.6	0.4	0.3	1.0	1.8			
	Class I	older engines, Bombardiers	15	Avg	1188	410.0	445.0	46.8	10.6	27.2	0.7	22.2	21.5		NO DATA	
				std dev	356.4	240.4	190.9	0.0	6.3	33.7	0.5	18.1	20.5			
Gas BAT	Class II	light and medium duty	47	Avg	13.2	14.7	121.0	2.8	0.9	0.8	0.4	4.6	6.3		NO DATA	
				std dev	17.2	15.3	153.3	4.7	1.0	0.5	0.5	7.4	9.9			
Diesel BAT	Class III	diesel w/ controls	17	Avg	12.5	3.6	2.5	0.33	0.10	2.85	28.1	23.8	22.4	0.11	0.05	0.04
				std dev	12.1	4.6	3.2	0.04	0.00	3.89	26.5	18.2	21.6	0.12	0.04	0.05
		Total	85													

BAT 1 fleet = Assumes all old engine Bombardiers go away, older snowcoaches phased out, conversion of 2 (by Alpine Guides)

					CO			**HC**			**NOx**			**PM**		
Name	**Categories**	**Description**	**Expected # in use**		**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g./hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**
Historic	Class I	modernized Bombardiers	8	Avg	11.9	9.4	6.5	2.1	0.7	0.4	0.3	2.0	3.1	--	--	--
	Class I	older engines, Bombardiers	0	Avg	1188.0	410.0	445.0	46.8	10.6	27.2	0.7	22.2	21.5	--	--	--
Gas BAT	Class II	light and medium duty	40	Avg	13.2	14.7	121.0	2.81	0.86	0.75	0.41	4.61	6.34	--	--	--
	Class IIB	replacements	0	Avg	12.72	21.35	139.72	0.18	0.23	0.27	0.30	1.47	3.10	--	--	--
Diesel BAT	Class III	diesel w/ controls	17	Avg	12.48	3.63	2.54	0.33	0.10	2.85	28.08	23.80	22.37	0.11	0.05	0.04
		Total	65													

BAT 2 fleet = Assumes all old engine Bombardiers go away, conversion of two Bombardiers and addition of 10 snowcoaches with 2012, 4 diesels study emission rates																
					CO			HC			NOx			PM		
			Expected		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	modernized Bombardiers	8	Avg	11.9	9.4	6.5	2.1	0.7	0.4	0.3	2.0	3.1			
	Class I	older engines, Bombardiers	0	Avg	1188.0	410.0	445.0	46.8	10.6	27.2	0.7	22.2	21.5			
Gas BAT	Class II	light and medium duty	40	Avg	13.2	14.7	121.0	2.81	0.86	0.75	0.41	4.61	6.34			
	Class IIB	replacements	10	Avg	12.72	21.35	139.72	0.18	0.23	0.27	0.30	1.47	3.10			
Diesel BAT	Class III	diesel w/ controls	21	Avg	12.48	3.63	2.54	0.33	0.10	2.85	28.08	23.80	22.37	0.11	0.05	0.04
		Total =	79													

A snowcoach best available technology (BAT)

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:

- newer than 2000 (engine)
- have modern pollution and engine controls
- use computerized controls for port fuel injection.
- may be either gasoline or diesel engines

Snowmobile Fleet Averages

Two model brands were tested in 2012 and used for the averages as representative of the currently used snowmobiles in the fleet.

Table 8. Average fleet emissions from current snowmobiles at Yellowstone.

Current -BAT, 4-stroke, gasoline				
		Idle	Low Speed	Cruise Speed
Pollutant	Test period	(g/hr)	(g/mile)	
CO	2012	416.2	653.0	34.2
HC	2012	16.2	28.8	1.3
NOx	2012	1.3	4.0	9.7

*Assumptions: the current rental fleet is most like the snowmobiles tested in 2012. No administrative snowmobiles are explicitly included in the averages. In general the models tested in 2006 had lower CO and HC emissions, but most of those snowmobiles have been phased out.

Snowcoach Fleet Averages⅄

Data from both the 2006 emission tests and the 2012 tests are used to calculate the fleet averages. Each snowcoach was put into a category and the number of vehicles in the category was used to get a fleet average.

Table 9 Fleet average emissions from snowcoaches at Yellowstone.

Current - Gasoline			
	(g/hr)	(g/mile)	g/mile
Pollutant	Idle	Low Speed	Cruise Speed
CO	289.7	110.5	184.6
HC	17.2	3.3	6.8
NOx	1.38	8.90	10.74
PM10	No data		
Current - Diesel			
CO	12.9	8.7	3.3
HC	0.3	0.1	2.9
NOx	31.86	30.48	24.28
PM10	0.108	0.140	0.105

⅄ 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.

Two snowcoach BAT fleets were calculated, BAT1 assumes non-BAT snowcoaches are retired without replacement. Since this seems unlikely, BAT2 assumes replacements with newer snowcoaches, both gasoline and diesel plus some more conversions of Bombardiers to newer engines.

Table 10. Expected average emissions from future snowcoach fleet.

BAT1# - Gasoline

	(g/hr)	(g/mile)	g/mile
Pollutant	**Idle**	**Low Speed**	**Cruise Speed**
CO	34.0	24.7	104.5
HC	8.4	1.2	1.0
NOx	1.49	4.94	7.42
PM10		No data	

BAT2Ŧ - Gasoline	(g/hr)	(g/mile)	g/mile
Pollutant	**Idle**	**Low Speed**	**Cruise Speed**
CO	30.5	24.6	110.2
HC	7.4	1.2	1.0
NOx	1.30	4.82	7.14
PM10	No data		

For snowcoaches 2000 or newer with port fuel injection. No replacements added to fleet.
Ŧ Assumptions: 10 new gasoline engine snowcoaches and 2 modernized Bombardiers

BAT - Diesel

	(g/hr)	(g/mile)	g/mile
Pollutant	**Idle**	**Low Speed**	**Cruise Speed**
CO	6.7	1.0	0.7
HC	0.54	0.20	0.10
NOx	13.32	14.70	10.05
PM10	0.04	0.02	0.01

4. Discussion

After the previous emission study a chart was prepared that compared model year and fuel use type for the snowcoaches (Figure 2). The results from 2012 emissions measurements have been added to the chart for comparison. 2012 diesel emissions are lower than emissions from the two vehicles tested in 2005 & 2006. HC and NOx are lower for the newer snowcoaches, however, the CO is slightly higher when compared to the 2006 emission vehicles that were chosen as being cleaner and suitable as BAT snowcoaches. 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 new snowcoaches are not automatically cleaner than some slightly older models.

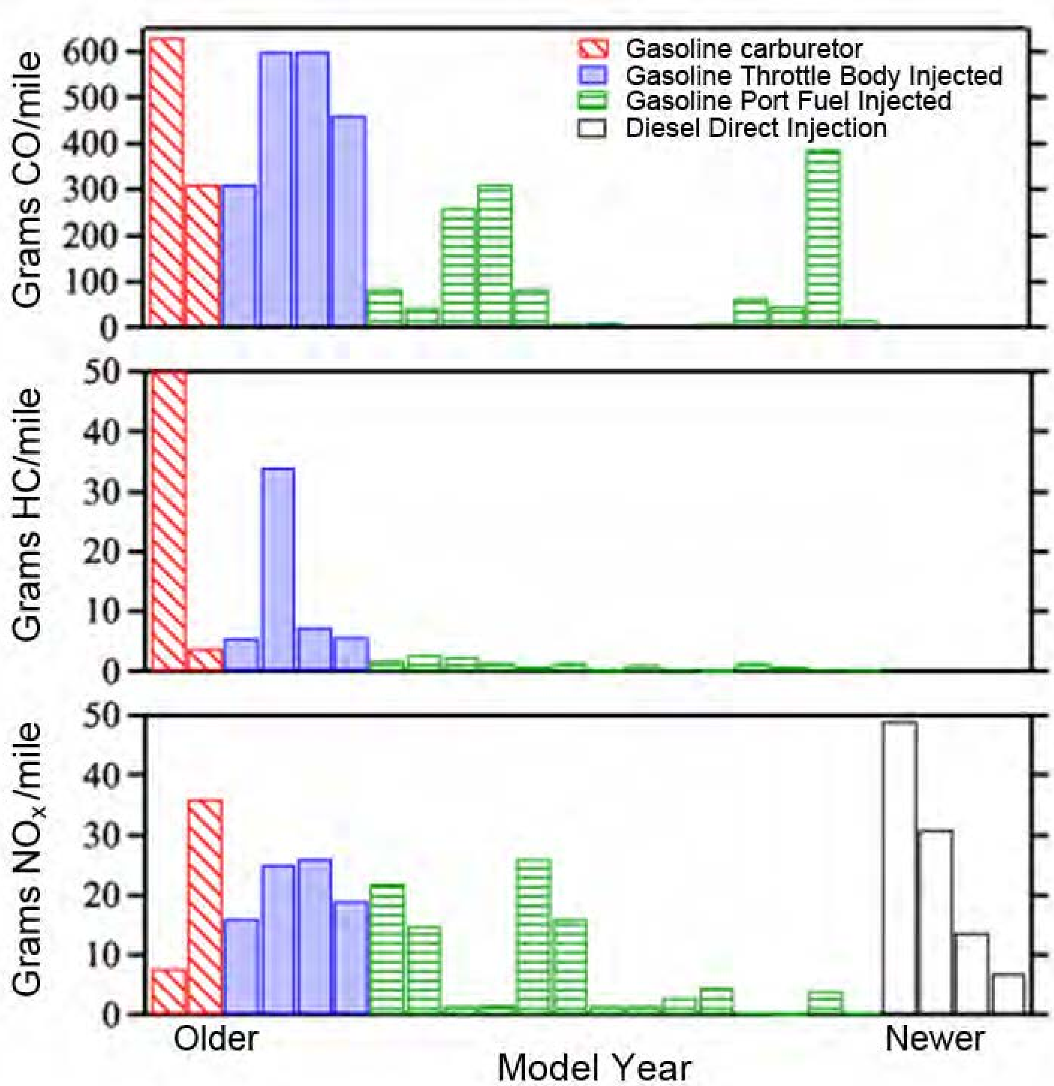


Figure 2 . Summary chart comparing model year and engine type to the measured emissions from snowcoaches. The newer snowcoach emission results are on the right side. Many values on this scale are so low they are barely above the baseline except for NOx in the diesel coaches.

Table 11. Comparison of 2012 emission data by engine type for gasoline and diesel.

2012 tests				
NON-DIESEL (Gasoline) SNOWCOACH - BAT				
Pollutant	**Idle**	**Low Speed**	**Cruise Speed**	**overall**
	(g/hr)	(g/mile)		avg
CO	12.7	21.3	139.7	98.0
HC	0.3	0.2	0.3	0.3
NOx	0.3	1.4	3.1	2.4
PM-10*	--	--	--	--

DIESEL SNOWCOACH - BAT				
Pollutant	**Idle**	**Low Speed**	**Cruise Speed**	**overall**
	(g/hr)	(g/mile)		avg
CO	6.7	1.0	0.7	2.0
HC	0.5	0.2	0.1	0.2
NOx	13.3	14.7	10.1	11.4
PM-10	0.02	0.02	0.01	0.02

As seen before, the diesel engine snowcoaches have lower CO and HC, but higher NOx and PM-10 emissions (Table 11) than the gasoline engine snowcoaches. The newer diesel snowcoaches, when compared to the two vehicles measured in 2005 & 2006, have lower NOx and PM10. Some significant differences were noted in the driving behavior of the two different diesel snowcoaches tested in 2012. A further evaluation will be presented in the final report by looking at the data plotted out for the whole trip.

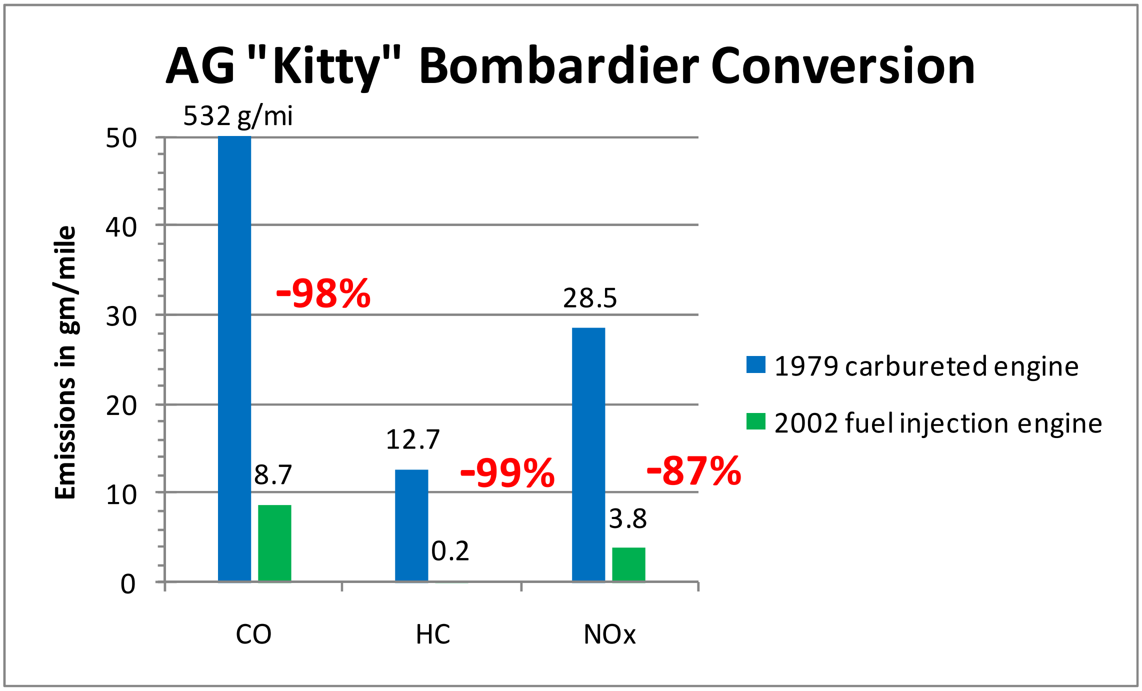


Figure 3. Conversion of the carbureted engine in the "Kitty" Bombardier to a 2002 Suburban engine with fuel injection, computer control, and emission control equipment resulted in much cleaner emissions vehicle.

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 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. The converted Bombardiers with modern engines have proven to be some of the cleanest of snowcoaches (Figure 3).

The most notable thing about the emissions from the snowmobiles tested in 2012 is the high CO emissions from the Arctic Cat (Table 5). It is hard tell from the current units of measure if the TZ1 actually meets BAT requirements (NPS, 2009; NPS 2011). That will be checked in the final report. Emissions significantly decrease as the average speed increases. 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 or just to limit the possible speed of the snowmobile. The TZ1 had plenty of power to travel at posted speeds on the Yellowstone roads.

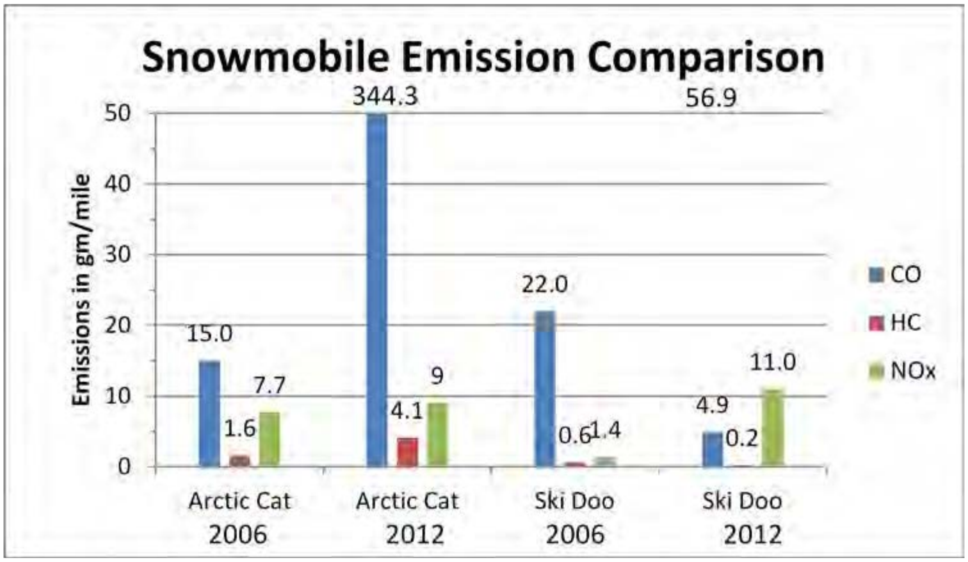


Figure 4. Comparison of BAT snowmobiles from 2006 to the 2011 models. Emissions are up slightly in the newer snowmobiles.

Figure 4 and Table 12 show the change in emissions with model year of the BAT snowmobiles for Arctic Cat and Ski Doo. The newer BAT snowmobiles in general have higher emissions than the older generation of 4-stroke snowmobiles. The model change in snowmobiles has not been a positive influence on air quality based on the emission data. The reported BAT fleet emissions data provided by the manufacturer also shows the emissions increasing for model years 2010 and 2011 compared to 2005 and 2006 (NPS 2011).

Table 11. Comparison of early model BAT snowmobiles to current BAT snowmobiles.

Test period	Pollutant	Vehicle Brand	Model	Idle (mg/s)	Idle (g/hr)	Low Speed (g/mile)	Cruise Speed (g/mile)	weighted average
2006	**CO**	Arctic Cat	T660	66.0	237.6	21.0	13.0	15.0
2006		Ski Doo	Legend GT	46.0	165.6	53.0	15.0	22.0
2012		Arctic Cat	TZ1	143	514.8	953	49	344.3
2012		Ski Doo	600ACE	60	216.0	44	4.1	56.9
Change in emissions:								
		Arctic Cat			**-116.7**	**-4438.1**	**-276.9**	**-2195.1**
		Ski Doo			**-30.4**	**17.0**	**72.7**	**-158.6**
Test period	**Pollutant**	**Vehicle Brand**	**Model**	**Idle (mg/s)**	**Idle (g/hr)**	**Low Speed (g/mile)**	**Cruise Speed (g/mile)**	**weighted average**
2006	**HC**	Arctic Cat	T660	2.5	9.0	2.3	1.5	1.6
2006		Ski Doo	Legend GT	1.8	6.5	1.10	0.44	0.6
2012		Arctic Cat	TZ1	4.9	17.6	42	1.8	14.8
2012		Ski Doo	600ACE	3.7	13.3	1.9	0.2	3.4
Change in emissions:								
		Arctic Cat			**-96.0**	**-1726.1**	**-20.0**	**-827.7**
		Ski Doo			**-105.6**	**-72.7**	**54.5**	**-468.3**
Test period	**Pollutant**	**Vehicle Brand**	**Model**	**Idle (mg/s)**	**Idle (g/hr)**	**Low Speed (g/mile)**	**Cruise Speed (g/mile)**	**weighted average**
2006	**NOx**	Arctic Cat	T660	0.41	1.5	7.5	7.7	7.7
2006		Ski Doo	Legend GT	0.23	0.8	0.5	1.3	1.4
2012		Arctic Cat	TZ1	0.47	1.7	3.5	9	7.1
2012		Ski Doo	600ACE	0.17	0.6	5.1	11	8.1
Change in emissions:								
		Arctic Cat			**-14.6**	**53.3**	**-16.9**	**7.5**
		Ski Doo			**26.1**	**-920.0**	**-746.2**	**-439.5**

Red values are negative, meaning the emissions have increased by that percentage from the 2006 test results.

5. Conclusion

New emission data are now available for newer models of snowmobiles and recent additions to the snowcoach fleet. 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 objectives. Emissions are higher than from previous models. Because our sample size is very small, it would be best to have some additional measurements. The manufacturers' fleet data supports the increase in emissions.

Emissions data are now available for the modeling exercise. Table 9 and 10 put the different snowcoaches 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 the rental shops use most. That actual mix may not be known, but is estimated from an inventory of all snowcoaches in use. The future fleet is the snowcoaches allowed under a new snowcoach BAT policy and whatever new vehicles are added as replacements.

Emissions by OSV and category were provided to the modelers.

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Appendix A

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-12. List of snowcoaches in the historic Bombardier category.

Category I - Historic Bombardiers

					CO			HC			NOx		
Business	**Identifier**	**Engine Year**	**Fuel Delivery**	**Date Tested**	**Idle** g/hr	**Low Speed** g/mi	**Cruise** g/mi	**Idle**	**Low Speed** g/mi	**Cruise** g/mi	**Idle**	**Low Speed** g/mi	**Cruise** g/mi
		modernized											
Alpine Guides	DeLacy	2002	PFI	2005	13.3	7.5	4.9		1.4	0.8		1.4	1.4
AG	AG Cygnet	2002	PFI	2006	9.4	7.8	4.9		0.6	0.4	4.7	1.4	2.9
AG	AG Kitty	2002	PFI	2012	13.0	12.96	9.6		0.20	0.10	1.44	3.1	4.9
											0.04		
				Average	11.9	9.4	6.5		0.7	0.4		2.0	3.1
		older engines											
AG	AG Kitty	1979	Carbureted	2006	1440.0	240.0	310.0		6.1	3.3		35.0	36.0
Xanterra	709	2001	Carbureted	2005	936.0	580.0	580.0		15.0	51.0	46.8	9.4	7.0
											46.8		
				Average	1188.0	410.0	445.0		10.6	27.2		22.2	21.5

Category II - Current fleet of gasoline engine snowcoaches representative of a BAT

Table A-13. List of snowcoaches in the gasoline engine current fleet category.

						CO			HC			NOx		
Business	Identifier	Engine Year	Model	Track type Configuration	Date Tested	Idle g/hr	Low Speed g/mi	Cruise g/mi	Idle g./hr	Low Speed g/mi	Cruise g/mi	Idle g/hr	Low Speed g/mi	Cruise g/mi
BBC	BBC Van	2003	Ford E350	Mattracks	2006	0.10	0.1	67	1.08	0.7	1.4	0.36	0	0.3
3BL	3BL Van5	2001	Ford E350	Mattracks	2006	8.6	3.8	12	1.44	0.7	0.3	0.18	3.5	1.2
Xanterra	416	2001	Van	Mat-trax	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	Mattracks	2006	0.1	8.8	47	1.08	0.5	0.9	0.72	0.1	0.1
YSCT	YSCT Van	2000	Ford E350	Mattracks	2006	3.6	9.3	330	0.36	0.3	1.5	0.18	1	1.7
BBS	SY3 gas	2011	Ford-E350	Mat-traxs	2012	2.2	12.5	16.1	0.36	0.30	0.20	0.04	0.2	0.3
YEXP	YEXP R350	1994	Dodge 350	Snowbuster	2006	140.4	41	44	72	4.3	2.3	1.08	8.6	16
YEXP	YEXP R250	1994	Dodge 250	Snowbuster	2006	158.4	47	84	9.72	1.8	1.8	14.4	14	23
Xanterra	419	2001	Van	Mat-trax	2005	50.4	35.0	5.8	14.0	3.3	0.4	0.2	10.0	16.0
Xanterra	Express	2008	Chevy	Mat-trax	2012	23.0	42.0	396.0	0.14	0.20	0.50	0.14	1.1	4.1
3BL	3BL Van2	2000	Ford E350	Mattrax w/ Skis	2006	18.7	100	270	2.16	1.7	2.5	0.18	1.4	1.5
current ===>		Gas, light duty, BAT		**Category II average**		**38.4**	**27.8**	**124.2**	**9.7**	**1.3**	**1.1**	**1.7**	**5.5**	**8.3**
NOT INCLUDED														
non-BAT - high emissions - phased out														
Xanterra	164	1992	Van	Snowbuster	2005	104.4	64.0	490.0	23.8	5.9	4.9	3.2	27.0	17.0
Xanterra	165	1991	Van	Snowbuster	2005	540.0	65.0	330.0	50.4	6.3	4.8	2.9	21.0	15.0
Xanterra	163	1992	Van	Snowbuster	2005	61.2	88.0	660.0	32.8	7.0	6.4	9.4	38.0	24.0
Xanterra	166	1991	Van	Snowbuster	2005	468.0	360.0	510.0	54.0	22.0	30.0	1.1	28.0	22.0

Category IIB – meet a BAT for new gasoline engine snowcoaches (after 2012)

Table A-14. List of gasoline engine snowcoaches that would meet a proposed BAT.

						CO			HC			NOx		
Business	**Identifier**	**Engine Year**	**Model**	**Track type Configuration**	**Date Sampled**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**	**Idle** g./hr	**Low Speed g/mi**	**Cruise g/mi**	**Idle g/hr**	**Low Speed g/mi**	**Cruise g/mi**
BBC	BBC Van	2003	Ford E350	Mattracks	2006	0.10	0.1	67	1.08	0.7	1.4	0.36	0	0.3
BBC	BBC Vanterra	2004	Ford E350	Mattracks	2006	0.1	8.8	47	1.08	0.5	0.9	0.72	0.1	0.1
BBS	SY3 gas	2011	Ford-E350	Mat-traxs	2012	2.2	12.5	16.1	0.4	0.30	0.20	0.04	0.2	0.3
YSCT	YSCT Van	2000	Ford E350	Mattracks	2006	3.6	9.3	330	0.36	0.3	1.5	0.18	1	1.7
3BL	3BL Van5	2001	Ford E350	Mattracks	2006	8.6	3.8	12	1.44	0.7	0.3	0.18	3.5	1.2
Xanterra	416	2001	Van	Mat-trax	2005	17.3	5.8	94.0	4.0	0.9	0.8	1.4	21.0	27.0
3BL	3BL Van2	2000	Ford E350	Matttracks with Skis	2006	18.7	100	270	2.16	1.7	2.5	0.18	1.4	1.5
Xanterra	Express	2008	Chevy	Mat-trax	2012	23.0	42.0	396.0	0.14	0.20	0.50	0.14	1.1	4.1
Xanterra	419	2001	Van	Mat-trax	2005	50.4	35.0	5.8	14.0	3.3	0.4	0.2	10.0	16.0
		Gas, light duty, BAT		average		**13.8**	**24.1**	**137.5**	**2.7**	**1.0**	**0.9**	**0.4**	**4.3**	**5.8**

NOT INCLUDED **older than 2000**

	Engine			Track type	Date	CO			HC			NOx		
						Idle	Low Speed	Cruise	Idle	Low Speed	Cruise	Idle	Low Speed	Cruise
YEXP	YEXP R350	1994	Dodge 350	Snowbuster	2006	140.4	41	44	72	4.3	2.3	1.08	8.6	16
YEXP	YEXP R250	1994	Dodge 250	Snowbuster	2006	158.4	47	84	9.72	1.8	1.8	14.4	14	23
AG	AG Kitty	1979	Bombardier	Twin Tracks with Skis	2006	1440.0	240.0	310.0	46.8	6.1	3.3	0.4	35.0	36.0
Xanterra	709	2001	Bombardier	Bombardier	2005	936.0	580.0	580.0	46.8	15.0	51.0	1.1	9.4	7.0
Xanterra	163	1992	Van	Snowbuster	2005	61.2	88.0	660.0	32.8	7.0	6.4	9.4	38.0	24.0
Xanterra	164	1992	Van	Snowbuster	2005	104.4	64.0	490.0	23.8	5.9	4.9	3.2	27.0	17.0
Xanterra	165	1991	Van	Snowbuster	2005	540.0	65.0	330.0	50.4	6.3	4.8	2.9	21.0	15.0
Xanterra	166	1991	Van	Snowbuster	2005	468.0	360.0	510.0	54.0	22.0	30.0	1.1	28.0	22.0

[#] non-BAT - high emissions - phased out

Category III - Diesel engine snowcoaches (meeting an expected BAT)

Table A-15. List of diesel engine snowcoaches as current fleet and as a BAT fleet.

Diesel snowcoaches

Diesel engines						CO			HC			NOx			PM		
Business	Identifier	Engine Year	Model	Track type Configuration	Date tested	Idle g/hr	Low Speed g/mi	Cruise g/mi	Idle g./hr	Low Speed g/mi	Cruise g/mi	Idle g/hr	Low Speed g/mi	Cruise g/mi	Idle g/hr	Low Speed g/mi	Cruise g/mi
Xanterra	Glaval - diesel	2011	Ford-F450	Mat-traxs	2012	0.004	0.70	1.40	0.30	0.10	5.6	20.16	23.70	13.20	0.04	0.02	0.01
BBS	SY8 diesel	2011	Ford-F550	GripTracs	2012	13.3	1.3	0.01	0.36	0.10	0.10	6.48	5.7	6.90	0.04	0.04	0.01
NPS	NPS Yel Bus	2006	International	Cleated Mattracks	2006	14.0	24	5.7		NO DATA		43.2	50.5	30	0.11	0.4	0.3
NPS	E350 Van	2000	E350 Van	Mat-trax	2005	24.1	8.9	6.2		NO DATA		57.6	42.0	47.0	0.25	0.10	0.10
				n = 3	average	**12.87**	**8.73**	**3.33**	**0.33**	**0.10**	**2.85**	**31.9**	**30.48**	**24.3**	**0.11**	**0.14**	**0.11**

Diesel BAT Snowcoaches (after 2012)[&]

Category IIIB

Diesel engines						CO			HC			NOx			PM		
Business	Identifier	Engine Year	Model	Track type Configuration	Date tested	Idle g/hr	Low Speed g/mi	Cruise g/mi	Idle g./hr	Low Speed g/mi	Cruise g/mi	Idle g/hr	Low Speed g/mi	Cruise g/mi	Idle g/hr	Low Speed g/mi	Cruise g/mi
Xanterra	Glaval - diesel	2011	Ford-F450	Mat-traxs	2012	0.004	0.70	1.40	0.30	0.10	5.6	20.16	23.70	13.20	0.04	0.02	0.01
BBS	SY8 diesel	2011	Ford-F550	GripTracs	2012	13.3	1.3	0.01	0.36	0.10	0.10	6.48	5.7	6.90	0.04	0.04	0.01
			n=2		average	**6.66**	**1.00**	**0.71**	**0.33**	**0.10**	**2.85**	**13.32**	**14.70**	**10.05**	**0.04**	**0.03**	**0.01**

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

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. The estimated fuel usage by the PEM and our recorded refueling record were in agreement. To assess representativeness, we used the snowmobile rental vendor fuel usage data for winter 2011-2012 for guided tours that went to Old Faithful and returned to West Yellowstone, a distance of 62 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 below show the mean fuel usage per trip for each rental snowmobile (15 model 2011, 10 model 2012). Based on the Arctic Cat tested, using the distance and fuel usage, the calculated equivalent for a full trip to Old Faith is estimated at 4.3 gal. This is in the mid range of the rental fleet which suggests that the test snowmobile is representative of the model TZ1 and not an outlier.

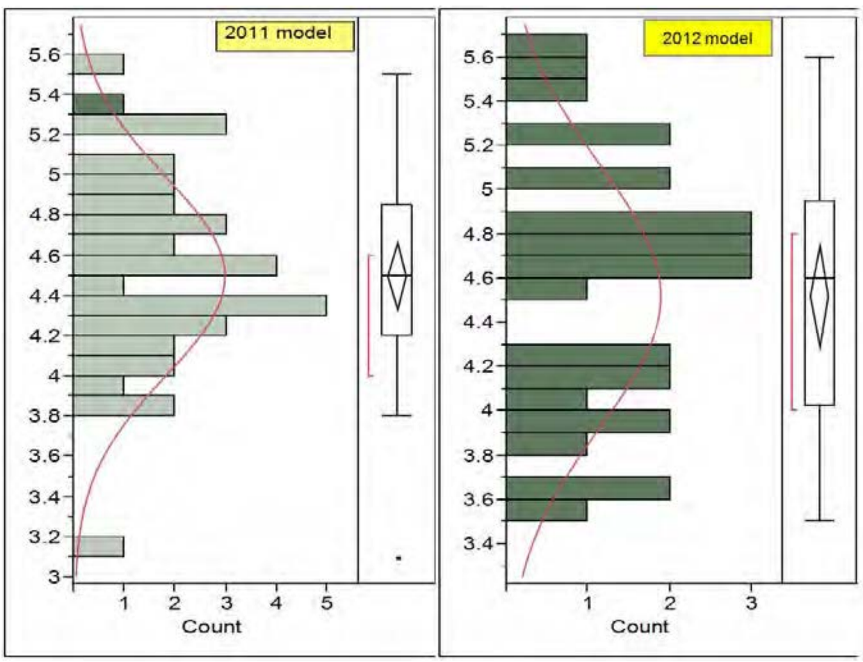

Figure A-1. Frequency distributions of fuel used (gal) by model year of Arctic Cat TZ1 rental snowmobiles for round trip to Old Faithful from West Yellowstone.

Model TZ1	Mean	Median	Units	MPG
2011 model year	4.49	4.5	gal	13.8
2012 model year	4.52	4.6	gal	13.7
Tested unit	4.3	- -	gal	14.4

Pictures of the Over-Snow Vehicles Tested in 2012

1979 Bombardier B-12 (aka: Kitty)

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Scott Carsley, West Yellowstone	Ski steer Snowbusters drive	Gasoline (2002 motor)	11	Yes	No (was before motor swap) We have data on a '02 PFI Bomb (aka: Cygnet)

2011 F-550 mini-bus (aka: Glavel)

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Xanterra, Mammoth	Mattracks x4	Gasoline	~15	No	No

200xx Chevrolet Express Van (aka: Xanterra-430)

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Xanterra, Mammoth	Mattracks x4	Gasoline	~11	Yes (Volpe 2009)	

2011 Ford E-350 Vanterra

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Coach	2011 Ford E-350 Vanterra	Randy Roberson, Buffalo Bus, West Yellowstone	Mattracks x4	Gasoline	~15

2011 Ford F-550 Bus (aka: Krystal)

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Randy Roberson, Buffalo Bus, West Yellowstone	GripTracs x4	Diesel (w/ DPF & DEF)	33	Yes (2009 model year vehicle), working on 2011	No

2012 Arctic Cat TZ1

Also pictured and tested: 2008 Arctic Cat T660 (last model year for T660) is on the right in the picture.

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Randy Roberson, Buffalo Bus, West Yellowstone 2012 TZ1	snowmobile	Gasoline	2	Yes (Volpe 2008, prototype machine)	No
Yellowstone National Park 2008 T660	snowmobile	Gasoline	2	Yes (Volpe 2008)	Yes, for T660 model in 2006

2012 Ski Doo (Bombardier)

Owner, Business, Location	Drive Configuration	Fuel Type	Capacity (incl. driver)	Acoustical Data	Emissions Data
Grand Teton (Shan Burson) West Yellowstone	snowmobile	Gasoline	2		No