Research Studies Related to Snowmobiling Impacts

AIR QUALITY / EMISSIONS

1. **Yellowstone Over-snow Vehicle Emission Tests – 2012: Preliminary Report.** Ray, J.D., Bishop, G., Schuchmann, B., Frey, C., Sandu, G., & Graver, B. (2012) National Park Service Air Resources Division, University of Denver – Chemistry Department and North Carolina State University – Department of Civil Engineering. http://www.nps.gov/yell/parkmgmt/upload/pem_of_snowcoaches-snowmobiles_3-2012.pdf

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.

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.

2. **Winter air quality in Yellowstone National Park: 2009–2011.** Ray, J. D. (2011) Natural Resource Technical Report NPS/NRSS/ARD/NRTR—2012/551. National Park Service, Denver, CO. http://www.nps.gov/yell/parkmgmt/upload/2009-2011_yell_winteraq.pdf

Executive Summary: The air quality in Yellowstone National Park was monitored at two locations within the park and at a location near the center of West Yellowstone city as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less (PM2.5). New measurements of nitrogen oxides (NOx) have been added at the West Entrance station.

The monitoring data from West Entrance near the town of West Yellowstone, MT, is used to characterize for overall air quality and its relationship to traffic, because of its longer record and detailed traffic counts. Old Faithful is a destination for most of the winter use vehicles and another congestion point; CO and PM2.5 concentrations are lower at Old Faithful than at the West Entrance. CO and PM2.5 are also monitored outside the park in the city of West Yellowstone, MT in cooperation with the Montana Department of Environmental Quality (MT DEQ); summary data from the urbanized area are reported here for comparison.
This report updates prior air quality and emission reports. Prior reports (http://www.nature.nps.gov/air/studies/yell/yellAQwinter.cfm) provide monitoring and instrument details and background information.

The notable findings for this two year period are:

- Hourly and 8-hour concentrations of CO are at low at the West Entrance and have repeated in the same range for the last 3-7 years; at Old Faithful, concentrations are slightly lower than at the West Entrance.
- Air quality at Yellowstone meets the national standards set by the Environmental Protection Agency (EPA) for CO and PM2.5 to protect human health. The CO, however, is present above regional background concentrations (between 0.1 and 0.2 ppm) in areas near vehicle routes, especially during the winter.
- Daily average concentrations of PM2.5 continue to decrease in the park while measurements of PM2.5 within the city of West Yellowstone are the same or higher than previous winters. PM2.5 concentrations in the City of West Yellowstone do not violate the national standard.
- At current vehicle emission levels from over-snow vehicle (OSV) traffic, the majority of PM2.5 concentrations appear to be coming from non-park traffic sources at the West Entrance and at Old Faithful.
- Nitrogen dioxide (NO2) concentrations road-side at the West Entrance are a larger percentage of the new 1-hour health standard for NO2 than CO or PM2.5 are for their standards. Although the NO2 concentrations are of concern, the NO2 is below the standard.

3. **Winter air quality in Yellowstone National Park: 2007—2008.** Ray, J. D. (2008) Natural Resource Technical Report NPS/NRPC/ARD/NRTR—2008/139. National Park Service, Fort Collins, CO. http://www.nps.gov/yell/parkmgmt/upload/aq70-08__final.pdf

Executive Summary: The air quality in Yellowstone National Park was monitored at two locations as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less (PM2.5).

The West Entrance near the town of West Yellowstone, MT, is the primary indicator for overall air quality and the relationship to traffic, because detailed entry counts could be obtained at that site. Old Faithful is a destination for most of the winter use vehicles; CO and PM2.5 concentrations are lower at Old Faithful than at the West Entrance.

This report is an update to prior air quality and emission studies. The notable findings this year are:

- Maximum hourly concentrations of CO and PM2.5 are up slightly at the West Entrance, but are nearly the same as last year at Old Faithful.
- Air quality at Yellowstone meets the national standards set by the Environmental Protection Agency (EPA) for CO and PM2.5 to protect human health. The CO air pollutant, however, is present above natural regional background concentrations (between 0.1 and 0.2 ppm) in areas near vehicle routes, especially during the winter.
- There is a high degree of uncertainty in changes associated with winter traffic at the West Entrance or Old Faithful to any differences in measured air quality during the winter 2007-2008 season. Weather and traffic density are important factors to explain the daily and hourly variations in ambient air pollutant concentrations.

4. **Air quality at a snowmobile staging area and snow chemistry on and off trail in a Rocky Mountain subalpine forest, Snowy Range, Wyoming.** Musselman, R.C. & Korfmacher, J.L. (2007). USDA Forest Service Region 2 Rocky Mountain Research Station, Fort Collins, CO. http://www.fs.fed.us/rm/boise/AWAE/scientists/profiles/Musselman/Musselman%20Korfmacher%20Snowmobile%20EM&A2007.pdf

Abstract and Conclusions: A study was begun in the winter of 2000–2001 and continued through the winter of 2001–2002 to examine air quality at the Green Rock snowmobile staging area at 2,985 m elevation in the Snowy Range of Wyoming. The study was designed to evaluate the effects of winter recreation snowmobile activity on air quality at this high elevation site by measuring levels of nitrogen oxides (NOx, NO), carbon monoxide (CO), ozone (O3) and particulate matter (PM10 mass). Snowmobile numbers were higher weekends than weekdays, but numbers were difficult to quantify with an infrared sensor. Nitrogen oxides and carbon monoxide were significantly higher weekends than weekdays. Ozone and particulate matter were not significantly different during the weekend compared to weekdays. Air quality data during the summer was also compared to the winter data. Carbon monoxide levels at the site were significantly higher during the winter than during the summer. Nitrogen oxides and particulates were significantly higher during the summer compared to winter. Nevertheless, air pollutants were well dispersed and diluted by strong winds common at the site, and it appears that snowmobile emissions did not have a significant impact on air quality at this high elevation ecosystem. Pollutant concentrations were generally low both winter and summer. In a separate study, water chemistry and snow density were measured from snow samples collected on and adjacent to a snowmobile trail. Snow on the trail was significantly denser and significantly more acidic with significantly higher concentrations of sodium, ammonium, calcium, magnesium, fluoride, and sulfate than in snow off the trail. Snowmobile activity had no effect on nitrate levels in snow.

Specific conclusions of this study include: 1) It was evident that more snowmobiles were present at the site weekends than weekdays, but the infrared counter proved inadequate for providing accurate snowmobiles counts. (2) There were significant differences in air quality between weekends and weekdays. Data show significantly higher concentrations on weekends in winter when more snowmobiles were present for CO, NO2, NO, and NOx, but not for O3. Concentrations of CO and NO were also higher weekends than weekdays during summer. Mean daily maxima of NO, NO2, and NOx occurred weekends during the winter. The data suggest that although NOx concentrations were generally low, increased weekend concentrations resulted from snowmobile activity. (3) Seasonal differences were evident in air chemistry, specifically for CO, NO2, and NOx, but not for NO or O3. NO2 and NOx were higher in summer than winter, while CO concentrations were higher in winter than summer. Nevertheless, air pollutant concentrations were generally low both winter and summer, and were considerably lower than exceedence levels of NAAQS. (4) PM10 was lower in winter than summer, and there were no significant weekend/weekday differences. (5) CO and O3 concentrations were higher, and NOx and NO2 were lower, when the wind was from the south. The monitoring was conducted just north of the roadway. O3 was lower and NO2 and NOx were higher when wind velocities were lower. The data suggest that under prevailing wind conditions air pollutant concentrations on the roadway were likely higher than those detected by our monitoring sensors. Nevertheless, an air pollution signal was detected that could be related to snowmobile activity; but the pollutant concentrations were low and not likely to cause significant air quality impacts even at this high snowmobile activity site. (6) Wind speed and physical site characteristics are probably the most important determinants of pollutant concentrations at the level of use described in most existing studies of snowmobile pollutants. There was greater dispersion of pollutants with high winds The open, high elevation Snowy Range site with high winds may be much less likely to experience pollutant levels at or near exceedence criteria than a (relatively) low-altitude site with somewhat restricted terrain and low wind speeds, (e.g., West Yellowstone). (7) Snow chemistry was significantly different between on and off trail for some analytes when sampling was designed to collect from areas with or without snowmobile activity. Na+, Ca2+, Mg2+, NHþ4, F− and SO2_ 4 appeared to be higher on the trail than off, especially early in the season. The trail followed a roadway, which may have affected on-trail snow chemistry concentrations. There were no differences in NO_3 on or off the trail. Snow density was higher on the trail than off.

5. **Winter Air Quality in Yellowstone National Park: 2006 – 2007.** Ray, J. D. (2007) Natural Resource Technical Report NPS/NRPC/ARD/NRTR--2007/065. National Park Service, Fort Collins, CO. http://www.nps.gov/yell/parkmgmt/upload/winteraq06-07_final.pdf

Abstract: Air quality monitoring for carbon monoxide (CO), particulate matter (PM2.5), and meteorological parameters was conducted during the winter of 2006-2007 in Yellowstone National Park at two busy traffic locations. Data from a West Yellowstone monitor and from other seasons at the two in-park monitors were also compared. The CO and PM2.5 concentrations are nearly the same as the previous two winter seasons and considerably lower than before the implementation of winter vehicle restrictions. Winter CO concentrations remain higher than the summer CO concentrations when there is much more traffic. PM2.5 concentrations are now higher during the summer because of the reduced snowmobile particulate emissions in winter and the frequent incidence of smoke during the summer that is unrelated to vehicle traffic. The restrictions on winter vehicle traffic imposed by the Temporary Winter Use Plan have been effective in bring down air pollution concentrations from values approaching the National Standards to values now less than 25% of the standards.

However, winter concentrations are still above the normal background concentrations expected for an isolated continental location where natural conditions should prevail.

Executive Summary: The air quality in Yellowstone National Park was monitored at two locations as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less (PM2.5).

The West Entrance near the town of West Yellowstone, MT is the primary indicator for overall air quality and the relationship to traffic, because detailed entry counts could be obtained at that site. A new monitoring station within the town of West Yellowstone shows higher CO and PM2.5 concentrations than observed at the park entrance. Old Faithful is a destination for most of the winter use vehicles; CO and PM2.5 concentrations are lower at Old Faithful than at the West Entrance.

This report is an update to prior air quality and emission studies. The notable findings this year are:

- Air quality at both the West Entrance and Old Faithful is well below the national ambient air quality standards for human health and considered by EPA to be acceptable. The EPA standard may be too high to be a target concentration for a remote natural area park such as Yellowstone.
- The CO concentrations were about the same as previous years despite an increase in the total number of winter vehicle entries at the west entrance.
- Summer concentrations of CO at the West Entrance and Old Faithful are lower for both the average and peak values than the winter concentrations despite the larger number of vehicles in the summer.
- PM2.5 concentrations no longer appear to be correlated to winter traffic at the current traffic volumes. The much lower particulate emissions from snowmobiles with 4-stroke engines have reduced PM2.5 concentrations so that other area sources begin to dominate the observed concentrations.

6. **Portable Emission Measurements of Snowcoaches and Snowmobiles in Yellowstone National Park.** Bishop, G. A., Stadtmuller, R., Stedman, D.H. & Ray, J.D. (2007) University of Denver – Department of Chemistry and Biochemistry and National Park Service Air Resources Division. http://www.nps.gov/yell/parkmgmt/upload/YNP_2006_snowcoach_snowmobile_study.pdf

Executive Summary: The University of Denver carried out a ten day, winter emissions collection program in Yellowstone National Park that concentrated on measuring the in-use emissions from commercial snowcoaches and snowmobiles operating out of the town of West Yellowstone, MT. Between January 25 and February 3, 2006 we instrumented ten snowcoaches and two snowmobiles with a portable emissions analyzer and collected approximately 22 hours of emissions and vehicle activity data. This report and all of the data sets collected are available for download at www.feat.biochem.du.edu.

- Snowcoach carbon monoxide (CO), hydrocarbon (HC) and nitrogen dioxide (NO2) emissions from the ten coaches tested this year were 60%, 83% and 54% less than the nine coaches measured in 2005. The average age of this year's fleet was nearly 5 years newer, 9 out of 10 snowcoaches in 2006 were port fuel injected (only 4 out 9 were in 2005) and the route driven less demanding.
- When combined with the previous year's data, emission trends generally decrease with decreasing age. Carbureted engines produce more excess emissions than throttle body injected engines which produce more emissions than port fuel injected engines. Emissions continue to decrease with age among the port fuel injected engines as the newest models continue to improve on capping the extent of excess emissions during power enrichment excursions.
- As observed during last year's testing the carbureted vintage Bombardier had the highest overall emissions and a Bombardier that had been upgraded to a modern port fuel injected engine had the lowest overall emissions. However, this year's carbureted Bombardier did not exhibit the huge HC emissions that were observed previously.
- Despite driving all of the snowcoaches over the same route and with the same passenger loading large variations in CO and HC emissions were still observed. For one set of five nearly identical snowcoaches (same make, engine and track system) CO emissions varied from 310 grams/mile to 12 grams/mile and HC

emissions varied from 2.4 grams/mile to 0.3 grams/mile. We believe that the large variation in readings is most likely a result of load differences produced by changes in the snow conditions.

- Passenger loading appears to be only a minor influence on the overall CO and HC emissions of a snowcoach. More important factors are snow conditions, fuel injection technology, power to weight ratio of the vehicle and the overall surface area of the track and ski system.
- We successfully instrumented two snowmobiles a 2006 Arctic Cat T660 and a 2004 Ski Doo Legend GT and drove them over the same road course as the snowcoaches. Observed emissions validated emission trends observed with the remote sensing and PEMS measurements collected in 2005. The smaller, higher revving Arctic Cat engine had lower CO emissions but higher HC and NOx emissions than the larger, lower revving Ski Doo engine. Measured fuel economies from these two snowmobiles were 25.1 and 28.3mpg, much higher than either the previous measurement or estimates used previously.
- The transient emissions behavior of these two snowmobiles is quite different with the Ski Doo snowmobile's higher CO emissions being a result of power enrichment excursions during accelerations. These higher transient emissions are probably not observed during BAT certification testing since it is a steady state test.
- Through two seasons of testing we have found that emissions variability is much greater among the snowcoach fleet where even modern coaches with advanced emissions control equipment have days with very large excess emissions. The 4-stroke snowmobiles have very high power to weight ratios and do not appear to experience these emission extremes. When comparing this years snowmobile and snowcoach PEMS measurements the 4-stroke snowmobiles had on average lower gram/mile emissions for all species and lower gram/mile/person emissions for CO and HC than the average snowcoach.

7. **Winter Air Quality in Yellowstone National Park 2005-2006.** Ray, J.D. (2007) National Park Service Air Resources Division. http://www.nps.gov/yell/parkmgmt/upload/final_05-06_air_quality_report.pdf

Executive Summary: The air quality in Yellowstone National Park was monitored at two locations as part of the adaptive management program on the use of over-snow winter motor vehicles. The leading indicators used were ambient concentrations of carbon monoxide (CO) and particulate matter of 2.5 micrometers or less (PM2.5). Emission measurements in the last two years have indicated that snowmobiles and snowcoaches may have approximately equal contributions to the concentrations of CO. Detailed entry counts of each type of vehicle at the west entrance were used in the analysis. The West Entrance near the town of West Yellowstone, MT is the primary indicator for overall air quality and the relationship to traffic, because detailed entry counts could be obtained at that site. Old Faithful is a destination for most of the winter use vehicles; they are present mid-day and that area represents the highest density of winter vehicles.

This report is an update to prior air quality and emission studies. The notable findings this year are:

- Air quality at both locations is good during the winter and is now well below the national ambient air quality standards.
- The CO concentrations were about the same as last year despite an increase in the total number of winter vehicle entries (over last year's shorter season) at the west entrance.
- Even though summer traffic volumes are nearly 60 times higher than winter traffic volumes, the highest hourly CO concentrations at both locations occur during the winter. However, the mean CO concentrations in winter have decreased over the last several years to be less than a factor of 2 higher than the summer concentrations.
- PM concentrations now correlate only weakly to traffic counts at the West Entrance and not at all at Old Faithful. This reflects lower emissions by winter vehicle although other local sources remain.
- The combination of reduced winter vehicle entries to the park and reduced emissions by the snowmobiles, using Best Available Technology (BAT), has greatly reduced the CO concentrations. Air quality has been stable or improving over the last three winters when the BAT requirement has been in effect.

Recommendations:

- Monitoring could be reduced. The particulate monitoring measures more PM2.5 from summer wildfires than from motor vehicles. The PM2.5 and meteorological measurements at Old Faithful could be reduced to just winter-time CO without compromising the adaptive management metrics.
- The question of how much CO concentrations will increase if snowmobile traffic is allowed to increase up to the winter use plan limit is unresolved. It is recommended that the monitoring at the West Entrance continue and better vehicle counting and identification methods be used.
- Efforts should continue to keep the amount of vehicle queuing at the West Entrance to a minimum and to spread out the entry of vehicles. The direct emissions testing indicates that older snowcoaches are now more polluting than BAT snowmobiles. Some effort should be made to equalize the snowcoach emissions (such as a snowcoach BAT) and to take advantage of the lower emissions that are possible as observed with newer snowcoaches or those retrofitted with new engines.

8. **In-Use Emission Measurements of Snowmobiles and Snowcoaches in Yellowstone National Park.** Bishop, G. A., Burgard, D.A., Dalton, T.T., & Stedman, D.H. (2006) University of Denver – Department of Chemistry and Biochemistry and the National Park Service. http://www.nps.gov/yell/parkmgmt/upload/bishopreport11_05.pdf

Executive Summary: The University of Denver conducted a twelve day, winter, emissions measurement program in Yellowstone National Park that involved the collection of emissions data from in-use snowcoaches and snowmobiles between February 7 and February 18, 2005. In all more than 34 hours and 500 miles of mass emissions data were collected from nine snowcoaches and more than 960 snowmobile measurements were made. This report and all of the data sets collected are available for download from www.feat.biochem.du.edu.

- Both snowcoaches and 4-stroke snowmobiles have lower emissions per person than the 2-stroke snowmobiles. 4-stroke snowmobile emissions reductions averaged 61% for CO and greater than 96% for hydrocarbons compared to 2-strokes.
- 4-stroke snowmobiles have lower emissions per person than the measured mix of snowcoaches for CO. However, newer coaches with modern pollution controls have lower per person emissions than the current 4-stroke snowmobiles.
- The reduction in 4-stroke snowmobile hydrocarbons was significant (< 96%) and readily observed. Visible exhaust plumes and odor were greatly reduced. The greater engine efficiency is reflected in an improved gas mileage by the 4-stroke snowmobiles.
- Among 4-stroke snowmobiles, the average CO emissions varied by a factor of 3 between manufacturers. The ration of CO/NO emissions varied greatly based on the engine tuning by the manufacturer.
- The Arctic Cat and Polaris 4-stroke snowmobiles emitted roughly half as much CO and HC as the Ski Doo snowmobiles. No statistically significant difference in emissions was observed by model year.
- Higher CO and HC emissions were observed from the guide snowmobiles that had been turned off and restarted at the entrance gate.
- Snowmobile emissions were NOT observed to increase with speed on a gm/mile basis. Emissions are greatest during initial startup and idling, especially when the engine is cold.
- The mean snowmobile emissions measured in the gate area appear to provide a representative average emissions value for overall park snowmobile emissions.
- The conversion vans operate often in off-cycle engine mode when much greater pollutants are emitted. The time weighted off-cycle operations for all the coaches averaged 20% of the time for the inbound trips and 29% for outbound. This is primarily caused by the high load on the engine and underpowered coaches that causes the transmission to shift up and down. Newer vans with larger engines were found to have lower emissions.
- The Bombardier snowcoach with an uncontrolled carbureted engine had the highest CO and HC emissions and operated in this high region 98% of the time. Extremely high CO emissions were also observed at the west entrance from several additional vintage Bombardiers. Vans and coaches with efficient fuel-injected engines and catalytic converters can be nearly as clean as modern wheeled passenger vehicles.

9. **Results from Yellowstone National Park Winter Air Quality Study 2004-2005.** Ray, J.D. (2005) National Park Service, U.S. Department of Interior Air Resources Division. http://www.nps.gov/yell/parkmgmt/upload/winteraqstudy04-05.pdf

Summary of Results: Ambient monitoring during the winter activity season was conducted at Old Faithful and at the West Entrance for the air pollutants, carbon monoxide (CO) and fine particulate matter (PM2.5). Summertime measurements at the West Entrance and vehicle entrance counts were used to compare to the winter season. Results from the ambient monitoring and a closely related emissions study are presented:

- CO was lower during the winter 2004-2005 season than in previous years at both monitoring stations and well below the level of the national standard.
- PM2.5 was also lower this season than in previous years at the West Entrance. Both locations are below the level of the standard.
- The historical decreasing trend in the number of snowmobiles is mimicked by decreasing CO concentrations and is the primary reason for the lower ambient CO concentrations.
- Sources of PM2.5 other than snowmobiles are contributing to the observed PM at Old Faithful. The greatest amount of PM2.5 at Old Faithful is now from Snow Lodge and from the uncontrolled wood stoves in the warming huts.
- Summer traffic with wheeled-vehicles contributes a much smaller amount of CO and PM than winter activity with snowmobiles and snowcoaches, despite much greater numbers of vehicles in summer.

10. **Laboratory Testing of Snowmobile Emissions.** Lela, C.C. & White, J.J. (2002) Southwest Research Institute (SwRI 08.05486) for the National Park Service and Montana Department of Environmental Quality.

Executive Summary: Snowmobile engine emissions are of concern in environmentally-sensitive areas, such as Yellowstone National Park. A program was undertaken to measure emissions from commercially-available four-stroke snowmobiles, as well as student-designed snowmobiles, and to compare their emissions to two-stroke sleds. Test vehicles included a 2002 Arctic Cat 4-Stroke Touring snowmobile, a 2002 Polaris Frontier 4-stroke engine, and two 4-stroke snowmobiles that competed in the 2002 SAE Clean Snowmobile Challenge (CSC). Fuels used were a reference gasoline and E10/gasohol (10 percent ethanol). For comparison, one of the student-designed snowmobiles was also tested on E85 (85 percent ethanol) to examine potential emission benefits with this fuel.

Emission were measured using three different test protocols including the five-mode ISMA/SwRI snowmobile engine dynamometer test cycle, a four-mode chassis dynamometer cycle, and at snowmobile speeds of 15, 25, 35, and 45 mph, as well as top speed on the chassis dynamometer. Emissions measured included hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), carbon dioxide (CO_2), and particulate matter (PM). Selected Arctic Cat engine tests also determined individual hydrocarbon species (C_1-C_{12}), including ketones, aldehydes, and alcohols. The following observations were made:

- Commercially-available 4-stroke snowmobiles are significantly cleaner than 2-stroke sleds. Compared to previously tested 2-strokes, these 4-stroke sleds emit 98 – 95 percent less HC, 85 percent less CO, and 90 – 96 percent less PM. Four-stroke snowmobile NO_x, however, is considerably higher than from a 2-stroke, being increased by a factor of seven to twelve.
- The commercially-available 4-stroke snowmobiles emit roughly 90 percent less toxic hydrocarbons, such as 1,3-butadiene, benzene, formaldehyde, and acetaldehyde, than 2-strokes.
- Four-stroke snowmobiles achieve approximately 40 percent better fuel economy than 2-stroke sleds.
- Use of a catalyst can further reduce snowmobile emissions. The University of Idaho CSC 2002 sled, that incorporates a 4-stroke, closed-loop controlled engine with catalyst, generated the lowest emissions of all sleds tested. Compared to the 4-stroke Arctic Cat sled, the Idaho sled emitted 64 percent less HC, 29 percent less CO, 99 percent less NO_x, and 36 percent less PM.
- Operation on E10 generally produced lower HC and CO emissions, but higher NO_x emissions, compared to reference gasoline.

11. **Review of Research Related to the Environmental Impact Statement for the Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway.** (2000) University of Wyoming, Institute of Environment and Natural Resources; p 19-45.
http://wyotrails.state.wy.us/pdf/review.pdf

Executive Summary: Air Quality Issues Pertaining to Yellowstone National Park Studies – the studies by Carroll and White (1999), White and Carroll (1998) and Morris et al (1999) together give good information on snowmobile engine emissions. It is clear that snowmobiles that use 2-srtoke engines emit substantially higher hydrocarbon (HC) (approximately factor of 50) and particulate matter (PM) concentrations (approximately a factor of 100) than similar size 4-stroke engines. Emissions of carbon monoxide (CO) and oxides of nitrogen (NOx) are broadly similar. Off-road vehicle emissions are at present unregulated, and as such, manufacturers of snowmobiles have no incentive to attempt to reduce emissions from snowmobile engines. (*NOTE: this has since changed*) Substantial pollution emission reductions would be achieved by adopting direct injection 2-srtoke engines. Levels would be further reduced if 4-stroke engines were used. The adoption of catalytic converters would reduce pollutant emissions further still. However, at this time, emission standards are still in the development stage.

The studies by Morris et al. (1999) and Kado et al. (1999) provide some degree of assessment of the impact of snowmobile use on the air quality of YNP. While both studies suffer from methodological issues some broad conclusions can be drawn. Various measurements at the West Entrance site reveal that concentrations approaching National Ambient Air Quality Standards (NAAQS) and Occupational Health and Safety Administration Standards (OSHA) are being measured. While the studies do not directly assess these standards, other work by the Montana Department of Environmental Quality (MDEQ) that does claim to meet EPA protocols, has reported concentrations almost equal to the NAAQS. Therefore, it is clear that there is a genuine air quality problem. It is interesting to note that atmospheric deposition data by U.S. Geological Service (1999) indicates that water quality is probably not threatened at present.

The National Park Service (2000) report is an excellent summary paper of the YNP air quality issue with respect to snowmobile usage. It is evident that the problem can be seen as an ambient air quality issue with respect to NAAQS, a workplace exposure issue with respect to OSHA standards and a Clean Air Act issue with respect to the Class I status of Yellowstone National Park.

For the first two issues it is also clear that the entry point of West Entrance is the primary cause for concern. Pollution levels may be reduced by redesigning the entrance area at West Yellowstone. The kiosks could be separated in a manner to enhance dispersion.

Alternatively, pollution from snowmobiles entering the park should be reduced. This can either be achieved by reducing emissions from snowmobiles or reducing the number of snowmobiles. In the short term, the latter is the only viable solution. Emission control legislation, even if passed tomorrow, will take time to affect the overall fleet emission profile. Thus, in terms of the NAAQS and OSHA limitation of snowmobile use would be a viable solution if the relevant standards were exceeded.

The situation is less clear for meeting the requirements of the Clean Air Act. The Class I status of YNP means that the highest level of protection is required. If, for example, scenic vistas are being affected by snowmobile emissions then this would be a violation of the stated Clean Air Act goal of “the prevention of any future, and remedying of any existing, impairment in mandatory Class I Federal area which impairment results from manmade air pollution.”

The National Park Service (2000) states that management Policies are clear that in cases of doubt as to the impacts of existing or potential air pollution on park resources, the Park Service will err on the side of protecting air quality and related values for future generations.

In order to meet the requirements of Class I status it would again appear that one of two options could be justified, namely emission reduction or emission elimination. The latter option would be a ban on snowmobiles. This approach would be harder to justify given that automobiles and snow coaches would presumably still be allowed within National Parks. If emission level is the issue, maybe the use of 4-stroke snowmobiles needs to be considered. If a ban is put in place based purely on air pollutant emissions, then the question remains as to whether these types of snowmobiles would be allowed entry to YNP.

It is clear from the reports evaluated that more monitoring and modeling is required. This work should focus on whether ambient or workplace air quality standards are being exceeded and whether the Clean Air Act with respect to the Class I status of YNP is being violated.

An assessment of the validity of any decision is not possible since a final decision with respect to snowmobile use has not yet been made. Furthermore, it is inappropriate for a "second guess" since we do not at present have access to all the information used to make this decision.

12. **Real-time Remote Sensing of Snowmobiles Emissions at Yellowstone National Park: An Oxygenated Fuel Study.** Morris, J.A., Bishop, G.A. and Stedman, D.H. (1999) University of Denver, Department of Chemistry and Biochemistry

Executive Summary: In the winter of 1999, the University of Denver conducted a remote sensing study at Yellowstone National Park. The objective of the study was to identify the effect of oxygenated fuels on the exhaust emissions from snowmobiles. Ratios of CO, HC and toluene to CO2 were measured and used to calculate %CO, %HC and parts per million of toluene. From the measured ratios we also calculated the grams per gallon of fuel, grams per mile and grams per kilogram of fuel for CO and HC. The ambient air temperature was collected and correlated to the remote sensing measurement to account for temperature effects.

Measurements of CO and HC were made at the West Entrance, South Entrance and west exit of Yellowstone where there were 974, 376 and 163 valid readings respectively. The mean CO exhaust emissions in percent were 6.0, 6.4 and 7.1 respectively and the medians were 6.1, 6.5 and 7.4. For CO emissions of snowmobiles the observed distribution looks normal compared to the observations from automobiles where their distribution is very skewed with most measurements low and very few high emitters. At the West Entrance where an ethanol blend was used in the snowmobiles there was a 7 ± 4% decrease, corrected for temperature, in CO emission compared to the South Entrance where nonoxygenated fuels were used. The mean HC emissions measurements in percent were 2.5 for the West Entrance, 2.2 for the South Entrance, and 2.0 at the West Exit and the medians were 2.5, 2.1 and 1.9 respectively. Since HC emissions from snowmobiles are variable with many different parameters that could not be controlled, an ethanol effect could not be c1early identified and an ethanol penalty cannot be discounted.

The first ever measurement of aromatics from mobile sources in realistic operation was made at the West Entrance of Yellowstone. There were 470 valid measurements made for toluene. The mean was 1976ppm and the median was 1734ppm. The data show, on average, a correlation between higher HC emissions and higher reported toluene measurements with r2 = 0.93 with an equation ppm toluene = 0.105 * ppm HC - 619.

13. **Emissions from Snowmobile Engines Using Bio-Based Fuels and Lubricants.** White, J.J. and Carroll, J.N. (1998) Southwest Research Institute for the State of Montana Department of Environmental Quality

Executive Summary: Snowmobile engine emissions are of concern in environmentally sensitive areas, such as Yellowstone National Park (YNP). A program was undertaken to determine potential emission benefits of use of bio-based fuels and lubricants in snowmobile engines. Candidate fuels and lubricants were evaluated using a fan-cooled 488-cc Polaris engine, and a liquid-cooled 440cc Arctic Cat engine. Fuels tested include a reference gasoline, gasohol (10% ethanol), and an aliphatic gasoline. Carburetor jets were not changed between fuels. Lubricants evaluated include a bio-based lubricant, a fully synthetic lubricant, a high polyisobutylene (PIS) lubricant, as well as a conventional, mineral-based lubricant. Emissions and fuel consumption were measured using a five-mode test cycle that was developed from analysis of snowmobile field operating data. Emissions measured include total hydrocarbons (THC), carbon monoxide (CO), nitrogen oxides (NOx)' carbon dioxide (C02), particulate matter (PM), polycyclic aromatic hydrocarbons (PAH, both particulate bound and vapor-phase), individual hydrocarbon species (C1-C12 and C13 - C22), ammonia, and sulfur dioxide.

The following observations were made:

- Gasohol produced 16 percent less HC, 9 percent less CO, and 24 percent less PM emissions compared to gasoline with the fan-cooled engine. NOx emissions were slightly increased, and engine power was about the same.
- The liquid-cooled engine was less sensitive to fuel differences than the fan-cooled engine. With gasohol, CO and PM were reduced 6 percent and 3 percent, respectively, compared to gasoline. Oxides of nitrogen emissions increased 6 percent, and HC emissions increased 5 percent. PM emissions were more than double those of the fan-cooled engine.
- Proper engine setup for temperature and elevation is important. HC, CO, and PM emissions were all significantly increased by richer operation resulting from incorrect setup.
- Lubricant formulation affects PM emission rates. The high PIB TORCO Smoke-less lubricant created significantly less PM than the three other lubricants tested.
- Particulate emission levels are influenced by lubrication rate, and may also be influenced by engine cooling system design. The fan-cooled engine had significantly higher spark plug seat temperatures (and, by inference, cylinder temperatures), and substantially lower PM emissions, than the liquid-cooled engine.
- The aliphatic fuel, while increasing total hydrocarbon emissions, yielded the lowest ozone formation potential of the three fuels tested. It also yielded the lowest benzene emissions.
- Toxic hydrocarbon species are present in snowmobile exhaust in proportions similar to those observed from other sources such as passenger cars fueled with gasoline.

Results show that moderate reductions in emissions can be achieved in the near term through the use of gasohol and low PM lubricants. Subsequent to this project, gasohol was used extensively in snowmobiles in the YNP area during the winter of 1997/8. Both National Park Service and rental sleds operated out of West Yellowstone, Montana were fueled with gasohol. The visible haze associated with snowmobile operation in congested areas was reportedly reduced compared to the previous winter. Operators reported excellent service with gasohol noting equivalent performance, and reduced engine maintenance. No fuel freeze ups were reported. Further studies of snowmobile particulate matter emissions and infield emissions are planned for late 1998.