Development of a Flexible Fueled Snowmobile Operating on Ethanol Blended Gasoline for the 2011 SAE Clean Snowmobile Challenge

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ABSTRACT

Clean snowmobile technology has been developed and applied to an existing commercially available snowmobile. The goals of this effort included reducing exhaust emissions to levels which are below the U.S Environmental Protection Agency (EPA) 2012 standard. Additionally, noise levels were to be reduced to below the noise mandates of 78 dB(A). Further, this snowmobile can operate using any blend of gasoline and ethanol from E20 to E30. All of these goals were achieved while keeping the cost affordable. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective to produce.

The details of this design effort including performance data are discussed in this paper. Specifically, the effort to modify a commercially available snowmobile using a three cylinder, four-stroke engine is described. This snowmobile was modified to run on a range of ethanol blended fuels using a closed-loop engine control system. Additionally, a new exhaust system which features customized catalytic converter and mufflers to minimize engine noise and exhaust emissions has been developed.

INTRODUCTION

Snowmobiles were first introduced into the commercial market for emergency and utility usage. The first snowmobile, developed in 1935, was capable of carrying 12 people. The introduction of the snowmobile meant that emergency medical personnel could get to those in need of immediate care even during heavy snowfall. Other early uses included farming and ranching. It was not until the late-1950s that snowmobiles started being used for recreation. However, once recreational snowmobiling began, it grew rapidly. For example, within a decade, dozens of manufacturers were producing snowmobiles. Today, there are only four primary manufacturers remaining, with global industry sales of approximately 164,000 snowmobiles annually [1].

Due to the rising environmental concern pertaining to the noise and exhaust emissions of recreational snowmobiling, they have come under increased scrutiny by the federal government. As snowmobiles are used in the winter season, the environmental impacts are greater due to the cold dense air. The cold, dense ambient air will not disperse the exhaust emissions as rapidly, which tends to trap the concentrated exhaust; thus leading to locally higher concentrations of pollutants. These hazards are especially of concern to ecologically sensitive areas such as Yellowstone National Park as well as other national parks where recreational snowmobiling is popular.

Snowmobiling is important to the local and national economy. According to the International Snowmobile Manufacturers Association (ISMA), snowmobiling generates over 29 billion US dollars (USD) of economic activity annually in the world economy. New snowmobile sales directly account for about 1.2 billion USD, while the remainder is accounted for by apparel and accessories, registrations, permits, tourism and spare parts. The snowmobiling industry accounts for over 90,000 fulltime jobs and nearly 2,200 dealerships.

Considering the economic impact of this market, a blanket ban on snowmobiling is not a feasible option. Currently, U. S. national parks are operating under a temporary winter use plan which restricts the number of snowmobiles entering the parks per day. All snowmobiles are required to be Best Available Technology (BAT), which are the cleanest and quietest commercially available snowmobiles. Further, the EPA has issued a three phase reduction on snowmobile emissions. The regulations include a 30% reduction in overall emissions by 2006, a 50% reduction overall by 2010, and a 70% reduction overall by 2012. The specific limits are shown in Table 1.

Table 1 Exhaust Emission Standards for Snowmobiles [2]

	Phase In	Emissions (g/kW-hr)		
Model Year	(% of sales)	HC	HC+NOx	CO
2006	50	100	-	275
2007-2009	100	100	-	275
2010-2011	100	75	-	275
2012 & later	100	75	90	275

This legislation has forced a rapid change upon manufacturers; and they have responded by further developing two-stroke technology as well as shifting to four-stroke engines in place of the typical two-stroke engines. While the two-stroke engine offers the advantage in terms of weight and power output compared to a four-stroke engine, the disadvantage is that it emits much higher levels of exhaust pollutants. The four-stroke engine is also quieter, and more fuel efficient when compared with an equivalent two-stroke engine. Nonetheless, the four-stroke engine weight and volume disadvantage is a substantial challenge to overcome in a lightweight vehicle like a snowmobile.

The Clean Snowmobile Challenge (CSC), which is part of the collegiate design series created by the Society of Automotive Engineers (SAE), was created to challenge students to reduce the environmental impact of snowmobiles, while retaining the essential performance and cost limitations required to ensure a successful recreational market.

In order to meet this challenge, Kettering University has chosen to use four-stroke engine technology, reasoning that this technology offers the best long-term potential to meet increasingly stringent exhaust and noise emissions levels.

DESIGN OBJECTIVES

The design objectives included reducing exhaust emissions to levels which are below the 2012 standard. Additionally, noise levels were to be reduced to below the noise mandates of 78 dB(A). Minimizing the cost and performance compromises were also major considerations. Snowmobiling is, after all, a recreational sport; thus the snowmobile must remain fun to drive and cost effective.

Competition requirements outlined that the snowmobile must be able to run on a range of ethanol blended fuels in a flex fuel mode. Fortunately, the use of ethanol also provided a benefit of improved emissions, reducing the formation of both carbon monoxide and unburned hydrocarbons.

Kettering University first demonstrated snowmobile operation using E85 during testing at Southwest Research Institute in 2002. Results of this and subsequent work are summarized in Figure 1. This work has demonstrated that a switch to E85 or other ethanol blended fuels can yield substantial reductions in exhaust emissions.

For the competition, this engine will only operate on blends of ethanol up about 30%; however, the engine is designed to operate on fuel blends up to 85%. The benefits shown below for E85 will be reduced somewhat with lower blends, but the trend in improvement should still be seen.

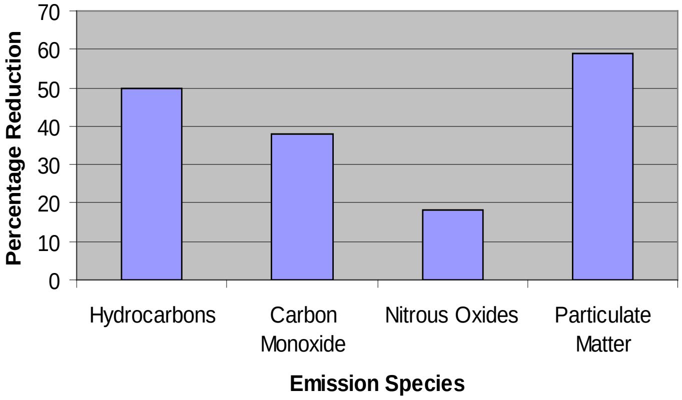


Figure 1 Reduction in Snowmobile Engine Emissions Using E85 as Compared with Gasoline [3]

In order to meet these objectives, a commercially available 2010 Yamaha FX Nytro was modified for the 2011 Clean Snowmobile Competition.

The base snowmobile was chosen because it was equipped with a four-stroke engine, under-seat exhaust system, and it was lightweight. The team focused on reducing emissions and noise, while maintaining the performance, comfort, safety and durability of the sled. The under-seat exhaust system provided more room to install catalytic convertors and mufflers necessary to reduce the emissions and noise.

ENGINE SELECTION

The Yamaha FX Nytro comes factory-equipped with a 1049cm^3 four-stroke, 130 horsepower (hp), naturally aspirated three-cylinder engine. Due to a power limit of 130 hp for the 2011 Clean Snowmobile Competition, the team decided to swap the standard 130 hp Nytro engine for the 120 hp engine from a Yamaha Vector snowmobile. The only major difference between these two engines is the camshaft. The camshaft in the Vector engine has a different lobe pattern which reduces power, but also results in improved fuel economy. The engine was then modified for use with ethanol blended fuels to improve emissions.

In original form the Yamaha Genesis 120 engine was rated to produce 120 bhp (90 kW) while operating on gasoline. Aaen Performance performed dynamometer testing on the Genesis 120 engine for Snow Tech Magazine. This testing confirmed that the Genesis 120 engine produced a power output of 122.6 bhp (91 kW) and 82.9ft-lbs (112.5Nm) [8]. The specifications for this base engine are presented below.

Table 2 Yamaha Genesis 120 Specifications

Displacement:	1049 cm^3
Configuration:	Inline Triple Cylinder
Block Material:	Aluminum
Valve Actuation:	DOHC
Ignition:	Coil on plug
Valves per cylinder:	Three
Compression ratio:	11.3:1
Bore:	82 mm (3.23 in)
Stroke in/mm:	66.2 mm (2.61 in)
Aspiration:	Normal
Engine Control System:	BigStuff3
Snowmobile Weight:	237 kg (522 lb)
Front Suspension Travel	216 mm (8.5 in)
Rear Suspension Travel	368 mm (14.5 in)
Track Length	3073 mm (121 in)

MODIFICATIONS TO IMPROVE EMISSIONS AND FUEL ECONOMY

Starting with the four-stroke baseline engine the team worked on the following emissions reductions and fuel economy improvement strategies:

1. Fuel Selection – Ethanol blended fuel was chosen as the fuel to reduce emissions. The exact blends could range from 20 to 30% ethanol during the competition. However, the team chose to design to accommodate blends up to 85% for enhanced flexibility and increased emissions benefits.

2. Tighter Fuel Control – An aftermarket closed-loop control system was chosen to provide tighter control over the fuel-air mixture. This system also allowed measurement of the ethanol concentration in the fuel.

3. Exhaust After-treatment – A three-way catalytic converter was used to reduce emissions formed in the engine.

4. Minimize Weight– In order to improve fuel economy and reduce emissions, the team chose a relatively lightweight snowmobile and made every effort to reduce weight gains with added systems.

5. Track and Suspension Modifications – The original track was replaced with a thinner and lighter system. Additional idler wheels were also employed to reduce friction losses.

Each of these strategies is discussed below.

MODIFICATIONS TO ACCOMMODATE THE ETHANOL FUEL BLEND

Ethanol blended fuels have several advantages over gasoline in terms of power output and emissions production. Also, in comparison to gasoline, E85 is safer to transport since alcohol is water soluble and biodegradable. Further, ethanol is made from renewable resources such as corn or sugarcane. However, the use of ethanol blends does present some trade-offs. The major challenges posed by the use of ethanol blended fuels include material compatibility, increased flow requirements, and lower fuel economy on a volumetric basis.

Before ethanol blended fuels could be used in the snowmobile several of the standard fuel system components had to be upgraded due to the corrosive nature of ethanol. These components included the fuel pump, and filter. Also, an ethanol compatible, adjustable fuel pressure regulator was added to the system.

In the past the Kettering CSC team has sampled fuel system components and performed immersion testing in E85 in order to ensure that they were compatible with the high-blend ethanol fuel. The team recorded the initial condition of these component samples, and then placed them in a solution of E85 and sealed the containers. The samples were examined after a two week soaking period with no visual effects of deterioration observed. They were then returned to the container for a year with still no visible deterioration. Based on this past experience, the team believes that the original fuel system parts that are retained will remain durable when in contact with ethanol blended fuels.

In order to understand the magnitude of some of the fuel flow challenges, it is educational to study the effects of operation using E85 for which there is a larger collection of data. A comparison of gasoline, ethanol, and nominal E85 fuels is presented in Table 3.

Looking at the lower heating values of the fuels, the energy density of E85 is about 70% that of gasoline; therefore, in order to deliver the same power (assuming all other factors are roughly equal), an engine will consume about 1.4 times more E85 on a volumetric basis. This would lead to a reduction in fuel economy, on a miles-per-gallon basis, of about 29%. However, in practice, automobiles have shown only about a 25% reduction [4].

Operating an engine at stoichiometric air-fuel mixtures will produce an increase in power because E85 has a stoichiometric air to fuel ratio of about 10 to 1, whereas that of gasoline is 14.7 to 1. Therefore, by running E85 and assuming similar volumetric efficiencies, more fuel can be utilized by the engine. For the same amount of air as the equivalent gasoline fuelled engine, an engine operating on E85 can use approximately 1.48 times more fuel, while only 1.4 times as much fuel is required to release the same amount of energy. This potentially increases the power and torque output of the engine by about 6%. Of course, in practice, many other operating variables can influence the performance. For example, sizing of the fuel injectors can limit upper end performance due to time and fuel flow limitations.

In order to accommodate the higher flow requirements of the ethanol blends, the in-tank fuel pump was replaced with an ethanol compatible, inline, external Walbro fuel pump. The original paper fuel filter was also replaced with a sintered metal filter to accommodate the required increase in fuel flow.

Table 3 Fuel Properties [4]

Physical Fuel Properties			
	Gasoline - Regular Unleaded	**Ethanol**	**E-85**
Formulation	C_4 TO C_{12} H/C-chains	C_2H_5OH	85% ethanol (by volume) 15% gasoline (by volume)
Average Analysis (%mass)	C: 85-88 H: 12-15	C: 52 H: 13 O: 35	C: 57 H: 13 O: 30
Octane – (R+M)/2	87	98-100	96
Lower Heating Value kJ/kg (Btu/lb$_m$)	43,000 (18,500)	26,750 (11,500)	29,080 (12,500)
Lower Heating Value - kJ/liter (Btu/gal)	32,250 (115,700)	21,240 (76,200)	22,830 (81,900)
Heat of Vaporization - kJ/Kg (Btu/ lb$_m$)	330-400 (140-170)	842-930 (362-400)	812 (349)
Stoichiometric A/F (mass)	14.7	9	10
Conductivity – mhos/cm	$1x10^{-14}$	$1.35x10^{-9}$	$1.4x10^{-9}$

Due to an unusual injector physical configuration, the team was unable to find compatible higher flow injectors; thus the original injectors were retained, but to meet the increased flow demands when using ethanol blended fuels, the fuel system pressure was increased. The team increased the fuel system pressure by installing the Walbro GSL393 inline fuel pump and an adjustable fuel pressure regulator. This also required changing fuel line to ensure that it withstood the increased pressure. The downside to this approach is that the fuel spray pattern can sometimes change causing wall wetting leading to transient operation problems. Fortunately, this did not occur.

FUEL/ENGINE CONTROL UNIT SELECTION

The snowmobile was factory equipped by Yamaha with a Mitsubishi engine control unit (ECU); however there was no way for the team to access and reprogram it. Further, the original system did not provide closed-loop fuel control. Therefore, a new ECU was needed.

In previous years, the team had chosen the BigStuff 3 ECU, and decided to use it again for the 2011 CSC competition. This aftermarket ECU provides closed-loop, wide-band oxygen sensor feedback and flex fuel adjustment capabilities. This allows the ECU to monitor the oxygen content of the exhaust gases and adjust the air/fuel mixture accordingly. The flex fuel adjustment allows the ECU to read a GM-type flex fuel sensor and then to adjust the engine mapping to best fit the gasoline/ethanol ratio that is present in the engine. Engine fuel maps are developed for E85 and E10; the ECU then interpolates values in-between the two maps for other blends. The oxygen sensors are used to fine-tune the resulting air-fuel mixtures, providing both long and short-term corrections.

Unfortunately, the aftermarket ECU was not designed for engines with less than 6 cylinders. This meant that the team had to “fool” the ECU into thinking that it was operating a six-cylinder engine. A typical six cylinder engine has even firing intervals of 120 crankshaft degrees; however, the three cylinder engine has firing intervals of 240 crankshaft degrees, as shown in figure 2. Although the crank spacing is 120 degrees, the actual firing is staggered at 240 degrees. This meant that the team had to connect every other cylinder of the “six cylinder” engine to get a 240 degree interval. For example, suppose the “six-cylinder” engine had a firing order of 1-6-5-4-3-2-1, the real three cylinder engine has a firing order of 1-3-2-1. In order to function properly, the ECU would have to be fooled using the following cylinder mapping: cylinder one would map to cylinder one of the real engine, cylinder 5 would map to cylinder 3 of the real engine, and cylinder 3 would map to cylinder 2 of the real engine. Cylinder 6, 4, and 2 of the “six-cylinder” engine would not be used.

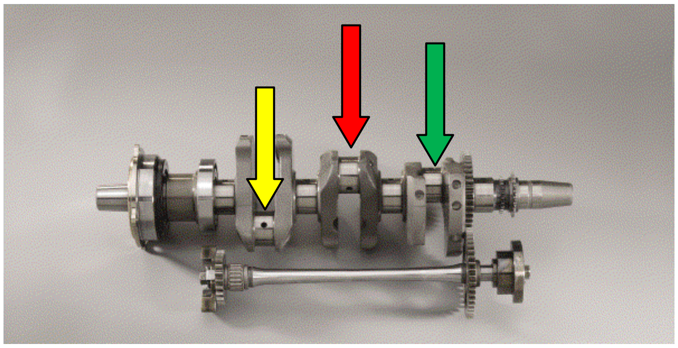


Figure 2 Yamaha 1049cm^3 120 degree Crank Spacing

Through the use of the ECU calibration software, the engine map was adjusted to avoid undesirable, excessively rich mixtures which increase HC and CO emissions. Maintaining fuel economy based on speed and load conditions with the switch to ethanol blended fuels was also a goal of the new engine calibration. The new ECU allowed for tuning of the fuel delivery for individual cylinders, which gave the team even greater capabilities in adjusting for improved emissions.

AFTER TREATMENT SYSTEM

In addition to the conversion to ethanol blended fuels and altering the engine management accordingly in an effort to curb emissions, the team employed the use of a 3-way catalytic converter designed to handle carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NOx) emissions. The catalyst brick is a custom unit from Heraeus. It features a metallic substrate with cell density of 600 cells per square inch measuring 105 mm (4.1 in.) inside diameter and 74.5 mm (2.9 in.) long. This catalyst is mounted just before the stock muffler.

WEIGHT MINIMIZATION

Chassis modifications were kept to a minimum since the base FX Nytro was already a relatively light sled with a dry weight of only 237 kg (522 lb). Some sound deadening material was added to the body panels to reduce engine and clutch noise as discussed later.

The 2010 Yamaha FX Nytro came with a 307 cm (121 inch) track. To reduce some of the weight of the sled, the standard Camoplast Ripsaw Dual Ply track was removed and replaced with a Camoplast Single Ply Ripsaw Track. The tread pattern and depth did not change, just the overall thickness of the track, which helped to reduce weight and rotational mass. This change removed approximately 4 pounds from the total sled weight.

In the 2008 competition, the forward set of idler wheels in the suspension of the snowmobile had been removed in an attempt to reduce noise. However, it was found that this had only a minimal effect on noise levels and no one was sure if the elimination of the wheels significantly increased drag on the track. To test this, the 2009 snowmobile was dragged behind a vehicle while attached to a load cell at speeds of 16 kph (10 mph) and 24 kph (15 mph). Multiple runs were made and averaged both without and with the forward idler wheels. As is shown in Table 4, when the forward idler wheels were put into the suspension, drag was reduced by 20.6% and 29.2% at 16 kph (10 mph) and 24 kph (15 mph) respectively. Although speeds were not increased beyond these levels because of safety concerns, it seems logical that these drag reductions would increase, or at least remain constant, at higher speeds. Another logical conclusion that can be drawn from the drag testing results is that additional idler wheels would make further reductions in drag.

Accordingly, the idler wheels will remain in place for this snowmobile. An additional set was also added to further reduce drag.

Table 4 Drag Test Results

	Drag (N/lb$_f$)			
	16 kph (10 mph)		**24 kph (15 mph)**	
	With Wheels	Without Wheels	With Wheels	Without Wheels
Trial 1	338 (76)	423 (95)	360 (81)	494 (111)
Trial 2	347 (78)	440 (99)	347 (78)	507 (114)
Average	343 (77)	432 (97)	354 (80)	501 (113)
Delta		89 (20)		147 (33)
Reduction %		20.6%		29.2%

COLD START MODIFICATIONS

One of the trade-offs of using higher blend ethanol fuels is poorer cold start-ability. Of course, this is of paramount importance for a snowmobile; therefore modifications must be made to allow for cold starting ability. The reason for poorer cold start-ability is shown in Table 3. The heat required for vaporization of ethanol blended fuels is much higher than that of gasoline. In cold weather starting conditions this presents a problem as ethanol will not vaporize at temperatures below 11°C [4].

In order to compensate for this, the team programmed the ECU to adapt for the cold at startup using fuel enrichment. This is done by injecting a greater volume of fuel into the cylinder during a cold start in order to allow enough gasoline into the cylinder to vaporize and initiate combustion. The cold start enrichment levels were determined through testing.

The final change that was made to the snowmobile to improve its cold starting was a switch to “hotter” spark plugs. By operating at higher temperatures, the plugs were more able to avoid fouling and ignite the cold air/fuel mixture, leading to reliable engine starting. As with the enrichment levels, proper plug characteristics were determined through testing.

NOISE REDUCTION MODIFICATIONS

Noise from snowmobiles can be attributed to a variety of different sources, including the engine, intake, exhaust and track. The course layout for the SAE Recommended Practice J192 for snowmobile noise testing is shown Figure 3.

To perform the SAE J192 test, the snowmobile must approach the measurement areas at 24 kph (15 mph). At the entrance the rider must hold the throttle wide open and accelerate for 45.6 m (150 feet) while sound levels are recorded. This is performed for three passes in each direction. The results are averaged and both directions are reported in the form of dB(A).

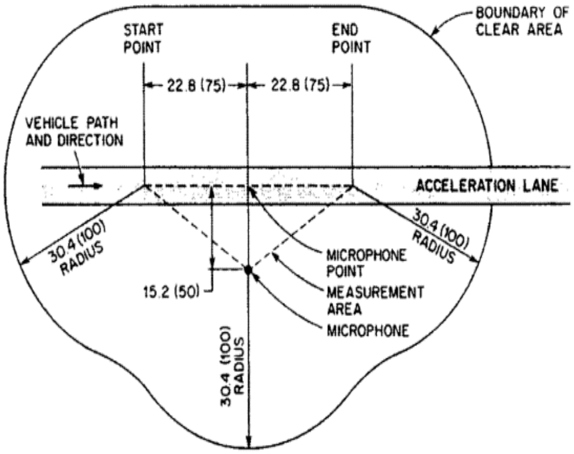


Figure 3 SAE J192 Microphone Locations (m/ft) [6]

In previous years, noise testing was performed before competition and it was found that with the rear facing exhaust, the noise levels were sufficiently quiet until the snowmobile got closer to the end of the course, when the microphone would then pick up more noise from the exhaust outlets at the rear of the sled. This caused the team to focus on exhaust routing to minimize noise.

EXHAUST ROUTING MODIFICATIONS

The original exhaust outlet exited directly from the back of the snowmobile, under the seat. This exhaust outlet was rerouted to exit into the tunnel housing the track. This allowed free expansion of exhaust gases (post-outlet) into a partially enclosed area preventing the direct emission of this sound power out of the snowmobile, without inducing further backpressure to the system.

On the unmodified Yamaha FX Nytro, the space provided by the stock exhaust routing was limited. The exhaust ports exit the back of the engine just in front of where the fuel tank is located. The exhaust then goes beneath the tunnel and is cooled by snow on the track. The muffler is mounted under the seat and the exhaust then exits behind the seat. Since there is only approximately 254mm (10 in) of exhaust tubing between where the 3 exhaust pipes collect into 1, packaging was a major concern. Further, the team needed to not only fit in mufflers, but also a catalytic convertor into the exhaust system.

The design for the 2011 competition is an exhaust system comprised of a catalyst and two mufflers in series. Muffler one is a glass-packed style, custom muffler unit. After the exhaust exits the first muffler, it makes approximately a 180° bend into muffler two which is placed within the confines of the custom heat shield, under the seat of the snowmobile. Muffler two is a motorcycle muffler that had been used on a Honda motorcycle. The end of the second muffler unit points into the tunnel, toward the snowmobile's track. The catalytic convertor is located just before muffler number 1. To make it possible to fit the extra exhaust components beneath the seat of the snowmobile, the stock header was shortened by approximately 4 inches overall.

Efforts were made to reduce the negative impact of higher exhaust backpressure due to the additional muffler, catalytic converter and bends in the exhaust by increasing the diameter of the exhaust.

MECHANICAL NOISE REDUCTIONS

To isolate the sources of mechanical noise, the snowmobile was placed on a stationary warm-up stand and run at different speeds. Sound readings were taken from different points around the snowmobile. The greatest noise levels contributed by mechanical systems were found to be coming from the engine compartment and the track tunnel.

In an effort to reduce mechanical noise, water and heat resistant foam insulation was installed under the hood deadening mat already used in the engine compartment.

The track noise is reduced through the use of a sound deadening coating on the inside of the track tunnel. The sound deadening coating applied to the inside of the tunnel also helped reduce the amount of vibration in the metal, which can help eliminate some of the resonance. These noise reducing techniques also contribute to the reduction of the exhaust noise since it is now routed into the tunnel. This will result in lower noise levels experienced by bystanders or in pass-by testing.

RIDER SAFETY

As with any recreational vehicle there are safety hazards to consider. As per competition rules, the clutch was enclosed with a guard made of aluminum wrapped with Kevlar explosion containment belting. A leak proof gel cell battery was placed inside of a sealed aluminum box to prevent any potential hazards. In an effort to avoid arcing across the battery terminals, the interior of the box was lined with a rubberized, non-conductive material.

COST EFFECTIVENESS

The original Yamaha FX Nytro has a base Manufacturer's Suggested Retail Price (MSRP) of $10,669. However, added technology and performance enhancements drove this number up. By the time various fuel system improvements, a more advanced ECU, sound deadening treatment, and a catalyst had been added to the snowmobile, the additional component cost combined into an estimated base MSRP of $12,420. However, with the average base MSRP of a new snowmobile sold in North America in 2009 being $8800, this MSRP seems somewhat high. It appears more reasonable when the added technology is considered as well as the higher base price of the original machine [1]. Still more work is required to maintain snowmobile affordability in the recreational market.

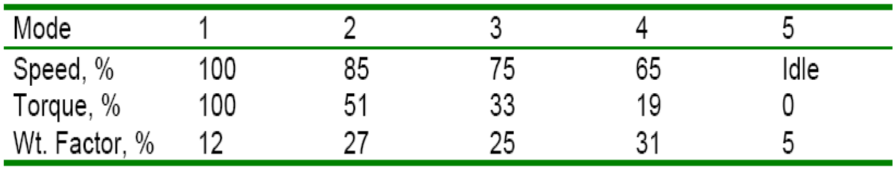
PERFORMANCE RESULTS

Time constraints limited the amount of data that has been gathered; however, the following data was measured: fuel economy, emissions, noise, and acceleration.

The fuel economy, as estimated from in-service emissions testing, was in excess of 20 mpg, which is a significant improvement over most commercially available snowmobiles.

The emissions were measured while operating the snowmobile on a water-brake emissions dynamometer and using a commercially available direct sampling emissions bench from AVL. During testing, the snowmobile was operated using E21 (21.2% ethanol by volume). The fuel analysis yielded: H/C-1.846, O/C-0.07. Testing was conducted using the 5-mode test cycle in accordance with EPA 40 CFR Part 1051 dated November 8, 2002. This cycle and weighting factors is presented below in table 5.

Table 5 Five Mode Emissions Test Protocol



Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

The emissions results are provided below in table 6, with 2012 standard levels for comparison. As is shown below, the clean snowmobile managed to achieve substantial emissions reductions as compared to the 2012 Federal regulations.

Table 6 Comparison of Clean Snowmobile Operating on E21 to the 2012 Federal Emissions Standards

Snowmobile/Std	CO, g/kW-hr	HC+NOx, g/kW-hr
2012 Standard	275	90
2010 KU CSC	59.1	9.5
% Reduction	79%	89%

Detailed emissions results are shown below, in table 7.

Table 7 Detailed Emissions Results for the Clean Snowmobile Operating on E21

CO, g/kW-hr	59.1
HC, g/kW-hr	1
NOx, g/kW-hr	8.5
HC+NOx, g/kW-hr	9.5
CH4, g/kW-hr	3.22
Soot, g/kW-hr	342.8

Noise testing was conducted in accordance with the SAE J192 recommended practice. Unfortunately, due to weather conditions, most of the snow was melted, leaving a hard-packed dirt surface for testing. This led to high noise results of 85 dBA noise level.

Our snowmobiles was tested from a standing start over a distance of 500 ft. The best time from two runs was used kept. We achieved a best time of 5.78 s.

CONCLUSIONS

The members of the 2011 Kettering University Clean Snowmobile Challenge team have produced a well-rounded snowmobile which is both clean and still fun to drive. The team has been able to deliver a quieter, cleaner, more efficient snowmobile without compromising the cost, durability, rider safety or performance. Through the use of ethanol blended fuels and add-on technology, the snowmobile has demonstrated much lower emissions than those required in the 2012 Federal regulations.

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- Robert Bosch Corporation
- Heraeus
- Walbro

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