Development of a Flexible Fueled Snowmobile for the 2012 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 E10 to E39. 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 two 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 featuring custom catalytic converters to reduce pollutant emissions and a muffler to minimize noise emissions and noise has been developed.

INTRODUCTION

Snowmobiles were first introduced into the commercial market 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 care even during heavy snowfall. Other early uses included farming and ranching. It was not until the late-1950s that snowmobiles began being used for recreation. However, once recreational snowmobiling began, it grew rapidly. For example, within a decade, dozens of manufacturers were producing snowmobiles. Today, only four primary manufacturers remain 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 rapidly; this tends to trap the concentrated exhaust leading to locally high 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]

Model Year	Phase In (% of sales)	Emissions (g/kW-hr) 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 and 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.

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 to 39%; 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.

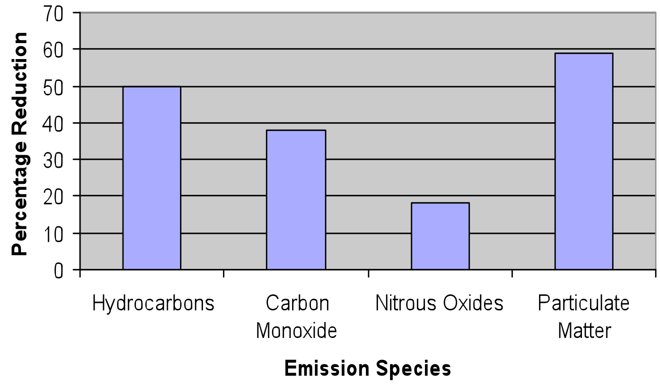

Figure 1 Reduction in Snowmobile Engine Emissions Using E85 Compared to Gasoline [3]

In order to meet these objectives, a commercially available 2011 Ski-Doo Renegade XP 600 ACE was modified for the 2011 CSC competition.

The base snowmobile was chosen because it is equipped with a four-stroke engine, meets 2012 EPA BAT requirements, and is lightweight through the use of the lithe Rev-XP chassis and the Camoplast Cobra track. The team focused on reducing emissions while maintaining the performance, efficiency, noise output, comfort, safety and durability of the sled.

The 137 in. long (medium-length) track of the Renegade crossover model makes it best suited for meeting the needs of a wide cross-section of snowmobilers with its ability to go off-trail and handle deep snow. The Renegade 600 ACE is thus the Kettering choice for a low-emissions, high-efficiency, general-purpose sled.

ENGINE SELECTION

The Ski-Doo Renegade XP comes factory-equipped with a Rotax 600 ACE (Advanced Combustion Efficiency) 600cm^3 four-stroke, 56 horsepower (hp), naturally-aspirated two-cylinder engine. The specifications for this base engine are presented below.

Table 3 Rotax 600 ACE Specifications

Displacement:	600 cm^3
Configuration:	Inline 180 Deg. Two Cylinder
Block Material:	Aluminum
Valve Actuation:	DOHC
Ignition:	Coil on Plug
Valves per cylinder:	Four
Compression ratio:	12:1
Bore:	74 mm (2.91 in)
Stroke:	69.7 mm (2.74 in)
Aspiration:	Normal
Engine Control System:	Bosch ME17.8.5
Snowmobile Weight:	213 kg (470 lb)
Front Suspension Travel	229 mm (9 in)
Rear Suspension Travel	340 mm (13.4 in)
Track Length	3487 mm (137 in)

The SAE paper published by Rotax for the development of the 600 ACE engine details several notable characteristics of the powerplant. Of great significance to the Kettering CSC team is the fact that the engine has been designed to run lambda 1.1 and leaner at part load for increased fuel economy. [4] Rotax credits the combustion stability made possible by a hemispherical combustion chamber for the engine's ability to run lean during much of its operation. Dynamometer testing was performed at Kettering with the unmodified snowmobile to characterize its calibration. The results of the calibration characterization can be seen in Figure 2. With knowledge of the speeds and loads at which the factory sled runs lean and rich of stoichiometric, calibration of the flex-fuel capable engine control unit can be completed more quickly and safely.

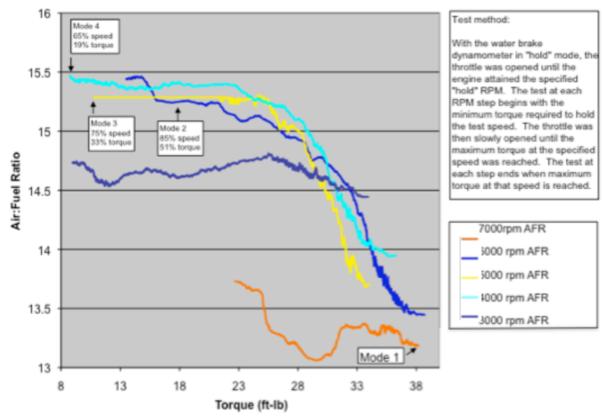

Figure 2 Rotax 600 ACE Factory Lean-Burn Calibration of the 2011 Skidoo Renegade 600 ACE

In addition to designing an efficient combustion chamber, Rotax utilized an advanced diamond-like carbon (DLC) coating on the valve tappets to reduce frictional losses in the engine. Other design criteria which decreased the 600 ACE FMEP include minimizing the amount of oil in the cylinder head and reducing pumping losses in the crankcase through the use of a dry sump.

MODIFICATIONS TO IMPROVE EMISSIONS AND FUEL ECONOMY

Starting with the base four-stroke 600 ACE 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 10% to 39% ethanol during the competition. However, the team has designed to accommodate blends up to 85% for enhanced flexibility and increased emissions benefits.

2. Exhaust After-treatment – Close-coupled three-way catalysts (TWC) and a hydrocarbon lean NOx catalyst with E85 reductant have been implemented.

3. Lean Calibration – To maintain the original fuel efficiency of the sled, calibrating the aftermarket engine control unit lean for much of the engine's operation was necessary.

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.

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. Compared to gasoline, E85 is safer to transport because alcohol is water soluble and biodegradable. Furthermore, 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.

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 [5].

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 combusted 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.

Table 4 Fuel Properties [5]

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	$1x10^{-14}$	$1.35x10^{-9}$	$1.4x10^{-9}$

ENGINE CONTROL UNIT SELECTION

The snowmobile was factory equipped by Ski-Doo with a Bosch ME17.8.5 engine control unit (ECU); however there was no way for the team to access and reprogram it. Furthermore, the original system did not provide closed loop fuel control. A new ECU was required.

In previous years, the team had used the BigStuff 3 engine control unit. However, for the 2012 CSC competition, a MotoTron ECU provided by New Eagle will be used. The 128-pin ECU houses a 32-bit 56 MHz Freescale MPC 565 processor and has the ability to operate in temperatures between -40°C and 105°C. Sealed connectors allow the ECU to remain operable when submerged in up to 10 ft. of water, among other various tough environmental conditions.

Professional EFI Systems (ProEFI) software has been flashed to the New Eagle MotoTron controller. ProEFI software was chosen for its ability to integrate the MotoTron hardware control of a Siemens flex-fuel sensor and Bosch LSU 4.2 wideband oxygen sensors (Bosch CJ125 chip) into its closed- and adaptive-open-loop operation. The ProEFI calibration software is an end-user GUI developed in MotoHawk for the racing industry and spares Kettering the expense and time of developing MotoTron control algorithms from scratch. This allows the team to focus on engine calibration instead of software development.

The MotoTron ECU replaces the original Bosch ECU rather than simply running in parallel with it. The stock wiring harness is connected to diagnostic plugs which connect to the original Bosch ECU harness connectors. Wires are soldered to the diagnostic plugs and then routed to the ECU. This allows the original wiring harness to remain intact. The ECU has a multitude of inputs and outputs which enable improved engine performance through the ability to control both the fuel injection and ignition timing. It also has inputs for dual oxygen sensors as well as VR/Hall crank and cam position sensors that allow for greater engine feedback and control. This allows the ECU to monitor the oxygen content of the exhaust gases, reference the reading against a table of desired equivalency ratios, and adjust the air/fuel mixture accordingly. The flex fuel adjustment algorithm uses the Siemens GM OE flex-fuel sensor input frequency and adjusts fuel injector pulsewidths according to the automatically calculated stoichiometric value of the fuel mix. The flex fuel sensor input is also used to interpolate between low- and high-octane ignition timing maps to provide the best-timed spark for the fuel entering the engine.

AFTERTREATMENT SYSTEM

In addition to the conversion to ethanol blended fuels and altering the engine management accordingly in an effort to decrease emissions, Kettering CSC has implemented two (one per cylinder) close-coupled three-way catalytic converters (TWC) to catalyze carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) emissions. The catalysts are used in a motorcycle application with similar exhaust mass flow and are thus sized for proper catalyst space velocity on the 600 ACE engine. The metallic substrates feature a cell density of 400 cells per square inch, measure 54 mm (2.125 in.) inside diameter, and are 101.6 mm (4 in.) long. Each features a BASF washcoat features a platinum/rhodium (1/0/1) loading of 40 g.

The greatest potential for emissions reduction over the stock 600 ACE engine involves NOx abatement. Three systems were investigated: a lean NOx trap (LNT), a urea-SCR, and a hydrocarbon-lean NOx catalyst. The LNT is attractive due to the only hardware required being an extra catalyst with the proper washcoat for converting NOx into N2 and O2. The alternating lean/rich calibration required, however, is difficult to implement with the ECU software available to Kettering CSC.

Urea-SCR, while the status quo in modern diesel aftertreatment for NOx abatement, presents severe challenges for operation in cold climates. The urea reductant gels at -11 degrees Celsius and it is common for diesel vehicles to contain heating elements in their diesel exhaust fluid (DEF) storage tanks, heated reductant lines, and heated reductant injectors. The requisite heating elements for urea use on a snowmobile make this option too complicated for Kettering CSC.

The hydrocarbon-lean NOx catalyst (HC-LNC) system developed by GE, Tenneco, and Umicore employs a process similar to selective catalytic reduction, but instead uses a silver-based washcoat loading and features diesel or high-blend ethanol as its reductant. Because the sled is intended to be operated on E85 fuel, Kettering has chosen the HC-LNC system and E85 as the reductant used. When E85 is used as the snowmobile's fuel, tank fuel can be supplied to the HC-LNC system supply pump.

Due to the uncertainty surrounding the ethanol blend at the CSC 2012 competition, a small tank has been implemented to carry 500 mL of E85 reductant for the week-long competition. A student-built Arduino-based controller has been created and programmed with a reductant injection calibration based upon an engine speed input. The controller with a high-current transistor drives a Thomas Magnete piston pump which supplies one 65 cubic millimeter metering of reductant per 25 ms pulsewidth. The reductant is supplied to the inlet diffusion cone of the catalyst through a small nozzle. The HC-

LNC ceramic substrate is 143 mm in diameter, 160 mm in length, and is designed for diesel applications 100 hp and less. The large catalyst was the smallest prototype available at the time, but packages without problem in the large underhood space of the Rev-XP chassis.

WEIGHT MINIMIZATION

Chassis modifications were kept to a minimum because the base Renegade model utilizes the REV-XP chassis which incorporates an aluminum frame. This makes it a relatively light crossover snowmobile with a dry weight of only 213 kg (470 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 that was previously used had a dry weight of 237 kg (522 lb). When compared to the 2011 Renegade that was used, the total weight reduction equates to 24 kg (52 lb).

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 5, 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.

In accordance with the testing performed, the idler wheels remain in place for this snowmobile so as to not decrease its fuel efficiency.

Table 5 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 startability. 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 startability 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 [6].

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.

To ignite rich charges while cranking and lean charges during snowmobile cruising, the original coil-on-plug ignition coils have been replaced with GM LS2 coil-near-plug units. These coils provide a powerful 120 mA of peak secondary current and have the proper logic-level trigger for the MotoTron ECU. The ignition coils are fired in wasted-spark, once per crank rotation, scheme for fast crank-to start times and decreased emissions.

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. 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 unmodified clutch was enclosed with the stock guard made of aluminum and plastic. A leak proof gel cell battery was placed in plastic enclosure 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. The stock DESS tether retains its functionality.

COST EFFECTIVENESS

The original Ski-Doo Renegade has a base Manufacturer's Suggested Retail Price (MSRP) of $8,499. However, added technology and performance enhancements drove this number up. After various fuel system improvements, a more advanced ECU, sound deadening treatment, and exhaust aftertreatment had been added to the snowmobile, the snowmobile cost increased to an estimated base MSRP of $11450.39. With the average base MSRP of a new snowmobile sold in North America in 2009 being $8800, this MSRP is somewhat high, but the 35% price increase over the original sled is to be expected for the added value and advanced technology. The cost of several components, the HC-LNC in particular, can be expected to decrease with proper sizing for snowmobiles and volume production.

PERFORMANCE RESULTS

In order to assess how the engineering changes to the snowmobile effected the emissions, a baseline test of the emissions was taken on the stock snowmobile.

The emissions were measured while operating the snowmobile on a water-brake emissions dynamometer and using a commercially available direct sampling emissions bench from Horiba. During testing, the snowmobile was operated using 87 octane unleaded gasoline. 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 6 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 stock 2011 Ski-Doo Renegade XP 600 ACE managed to achieve emissions number comparable to the 2012 Federal regulations.

Table 7 Comparison of stock 2011 Ski-Doo Renegade XP 600 ACE Operating on 87 octane gasoline to the 2012 Federal Emissions Standards

Snowmobile/Std	CO, g/kW-hr	HC+NOx, g/kW-hr
2012 Standard	275	90
2011 Ski-Doo 600 2011 600 ACE	256.5	123.2

Detailed emissions results are shown below, in table 7.

Table 8 Detailed Emissions Results for 2011 Ski-Doo Renegade XP 600 ACE Operating on 87 octane gasoline

CO, g/kW-hr	256.5
HC, g/kW-hr	13.4
NOx, g/kW-hr	109.8
HC+NOx, g/kW-hr	123.2

Engine and emissions system calibration is ongoing and Kettering CSC plans to decrease the baseline 600 ACE emissions of CO, HC, and NOx to levels which have not yet been achieved by a lean-burn gasoline four-stroke snowmobile engine.

CONCLUSIONS

The members of the 2012 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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REFERENCE

1 International Snowmobile Manufacturers Association (ISMA), www.snowmobile.org/pr_snowfacts.asp

2 Recreated from Code of Federal Regulations, 40CFR Part 1051.103

3 Davis, G. W., Pilger, C., "Effect of Biomass-based Fuels and Lubricants on Snowmobiles," American Institute of Aeronautics and Astronautics (AIAA), AIAA-2004-5681, 2004.

4 Gumpesberger, M. et al., "The New Rotax ACE 600 Engine for Ski-Doo", SAE Paper No. 2010-32-0001

5 Davis, G. W., “Using E85 in Vehicles,” Chapter 8, *Alcoholic Fuels*, CRC Press, Minteer, S. Editor, Final Submission, 2005.

6 U.S. Department of Energy, Handbook for Handling, Storing, and Dispensing E85, http://www.e85fuel.com/pdf/e85_technical_booklet.pdf