University of Wisconsin
SAE Snowmobile Team

University of Wisconsin Madison

2011 SAE Clean Snowmobile Challenge

Design Presentation

Presented by:

Shawn Spannbauer

Kim Ruiz

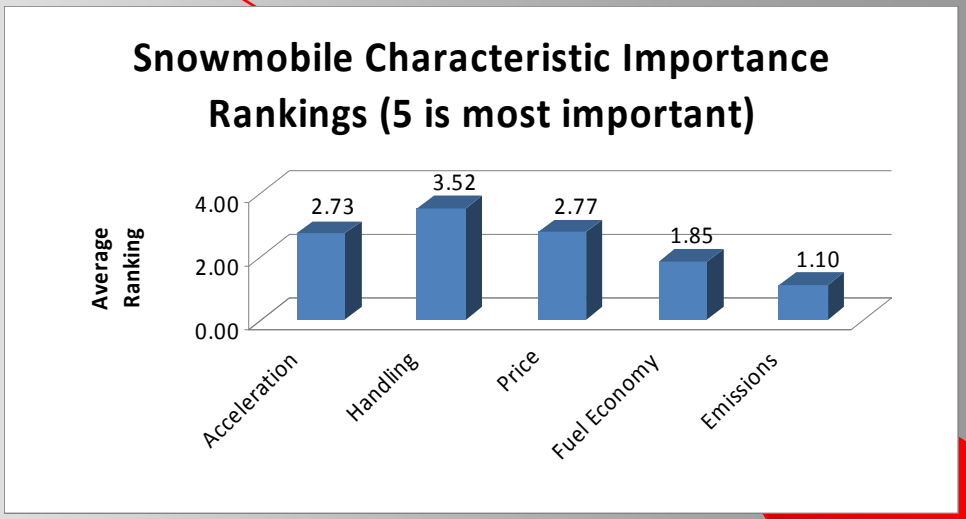
University of Wisconsin
SAE Snowmobile Team

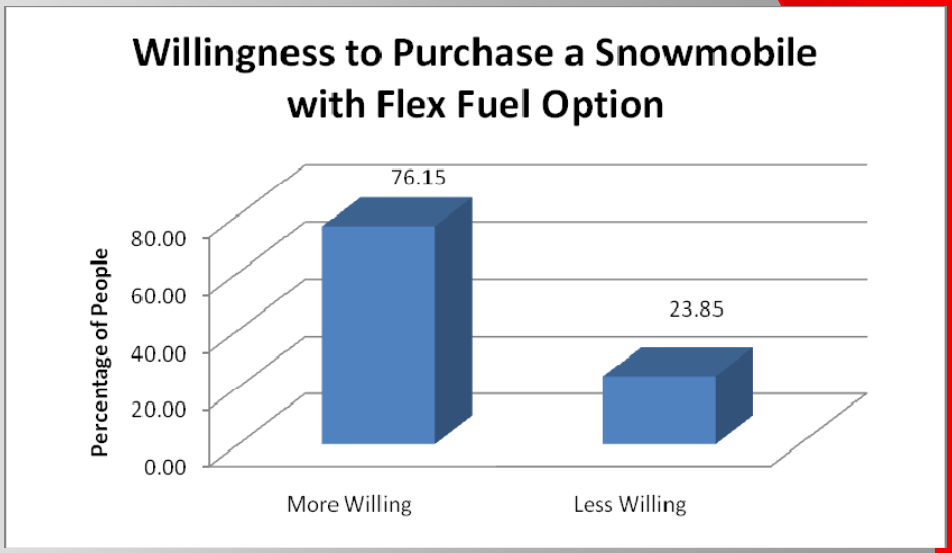
Clean
Quiet
FAST

Design Considerations:

Market Survey

- Survey at Hay Days Grass Drag show
  - Approximately 115 surveys
- Customers Want:
  - Trail Handling
  - Acceleration
- Historical Best Sellers
  - Ski-Doo Rev XP 600 SDI
  - Polaris IQ 600





University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Bucky 750 CFS

How it Appeals to Snowmobilers

H1

Ultra Quiet

Increased Fuel Economy

20+ mpgge

Flex Fuel

Improved Acceleration

Cruise Control Capable

Electric Start

BAT+ Compliant

2007 FST LX Chassis

105 peak hp operating on E85

Slide 3

H1 New Picture

Halfpixie, 3/7/2011

University of Wisconsin
SAE Snowmobile Team

Dealer & Outfitter Perspective

- Sales
  - Cleaner/Quieter Performance Model
  - Better Fuel Economy, BAT Compliant
- Maintenance
  - Integrated Catalyst/Muffler – Bolt-in Replacement
  - Plug and Play Flex-Fuel Intake/Fuel System
    - ETC, Flex Fuel Sensor
- Rider Comfort
  - OEM Seat, Handlebars, Suspension, Reduced Noise
- Novice Snowmobiler Operation
  - OEM Controls

University of Wisconsin
SAE Snowmobile Team

Engine Selection

- Engine emissions from current snowmobile engines
- Ski-doo SDI system reduces two stroke emissions by 50%
- Stock Polaris FS engine meets 2012 Emissions Certification

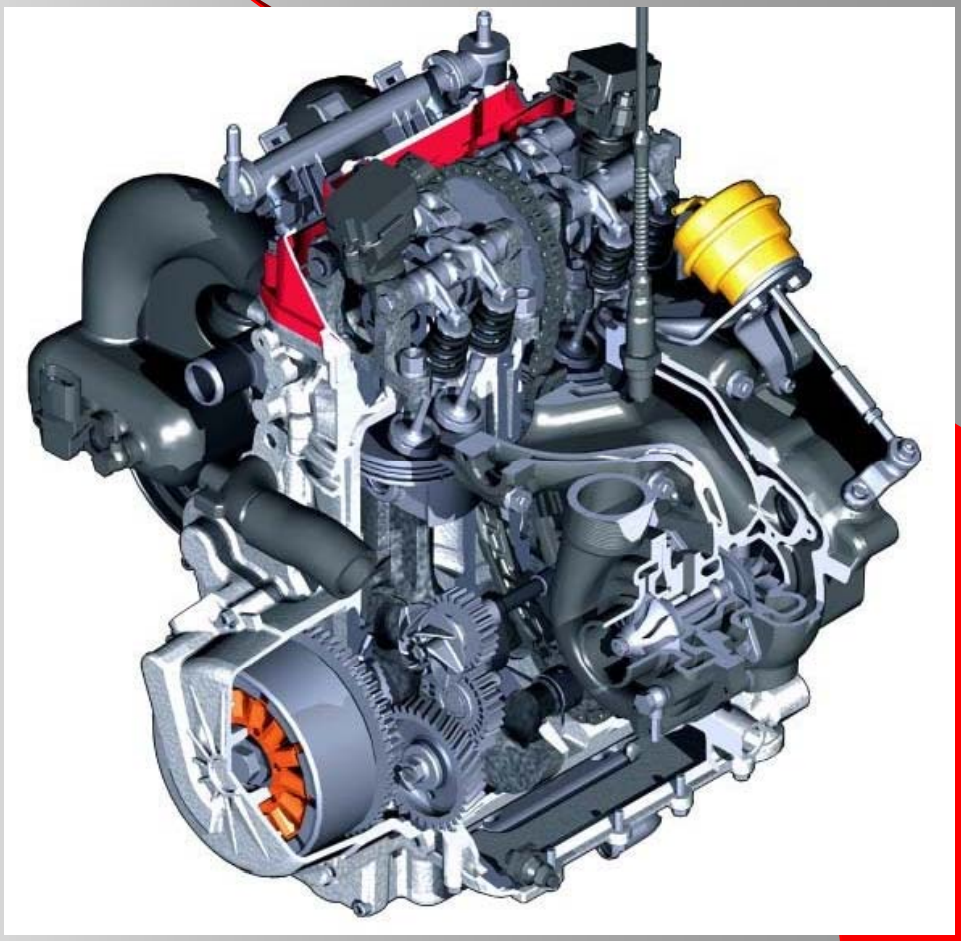
Snowmobile Engine Emissions Testing

	HC g/kW-hr	CO g/kW-hr	NO_x g/kW-hr
2010 2-stroke (comp. avg)	189	517	0.72
Arctic Cat 660 (4-stroke)	6.2	79.9	10.6
Polaris FS (4-stroke)	9.3	38.6	1.5

Sources: SWRI, CSC

University of Wisconsin
SAE Snowmobile Team

Turbo Charged Weber MPE 750 with Automotive Camshaft



Engine Type	Four Stroke
Cooling	Liquid
Cylinders	2
Displacement	750 cc
Bore x Stroke (mm)	85 x 66
Ignition	Bosch
Exhaust	Single
Fueling	EFI
Compression Ratio	9:1

University of Wisconsin
SAE Snowmobile Team

Engine Control and Emissions Reduction

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Engine Management

Woodward/Mototron PCM555

Ratings:

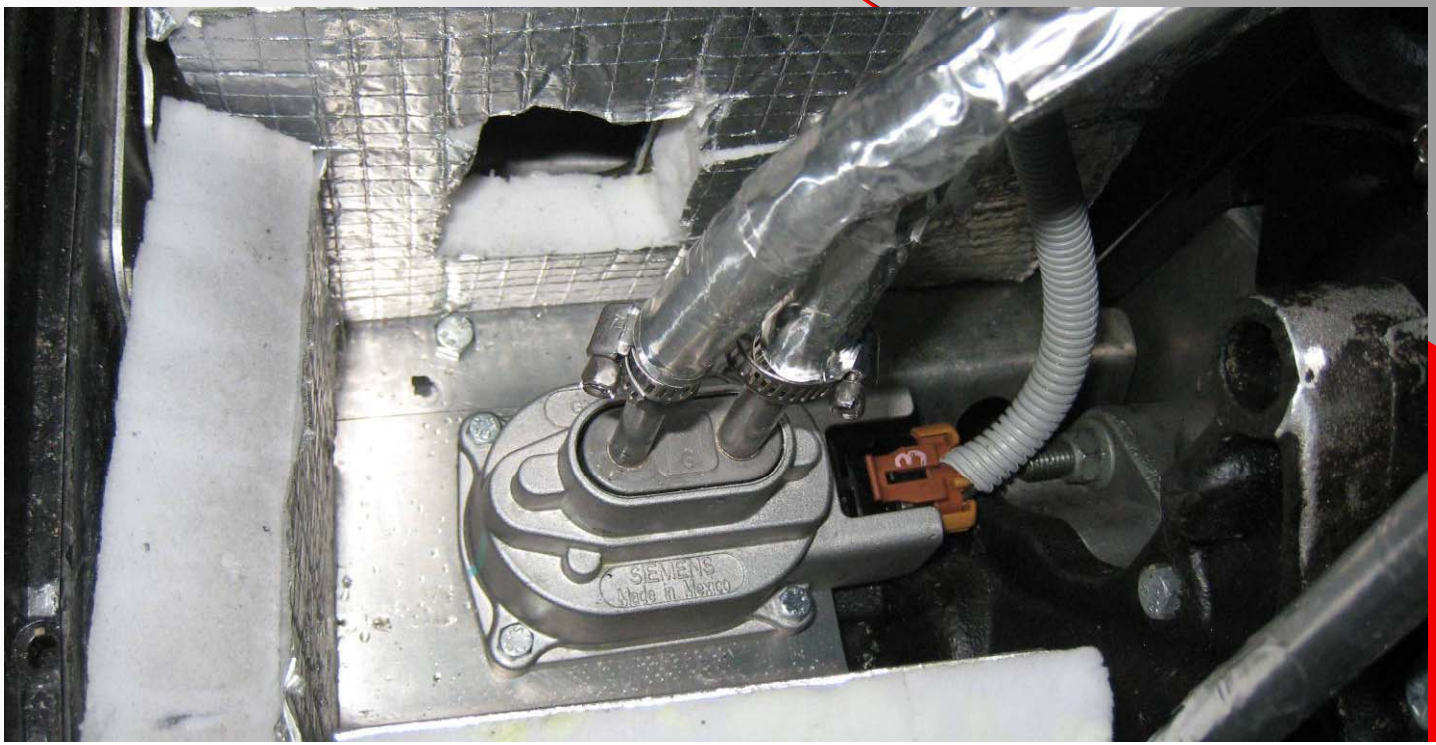
- Automotive/Marine Environments
- -40° – 130 °C
- 18 g Shock Load
- Up to 3 Meters Underwater

MATLAB/Simulink Engine Modeling

MotoHawk Automatic Code Generation

University of Wisconsin
SAE Snowmobile Team

Flex Fuel Sensor



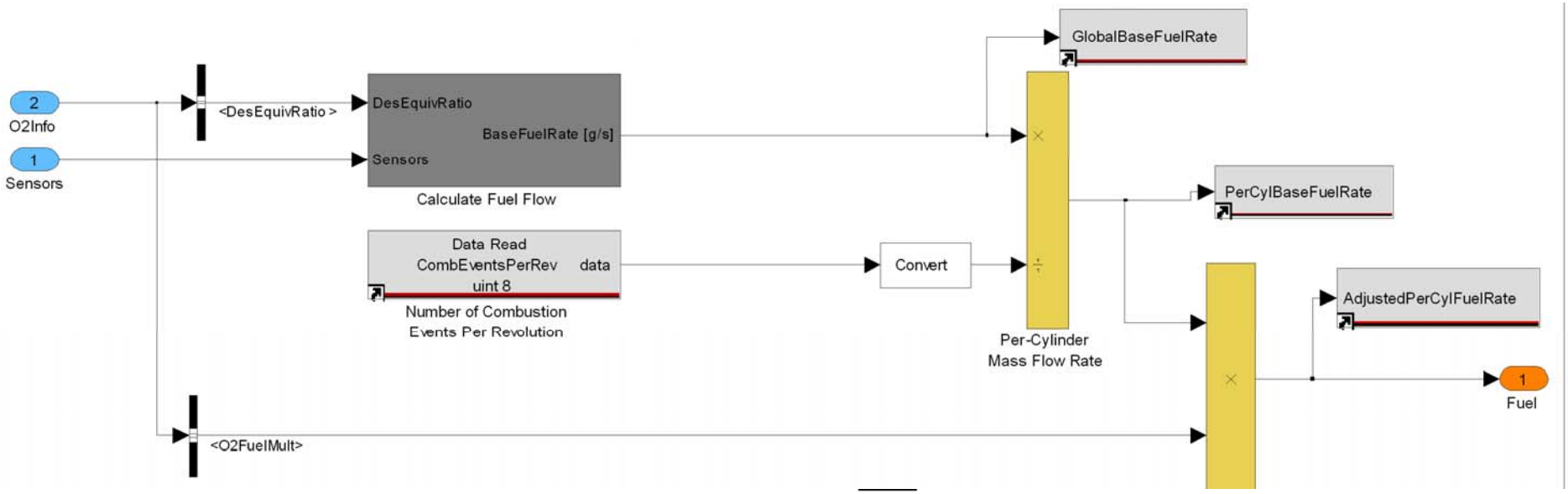
Continental Flex Fuel Sensor

- Reports ETOH Content & Fuel Temperature

University of Wisconsin
SAE Snowmobile Team

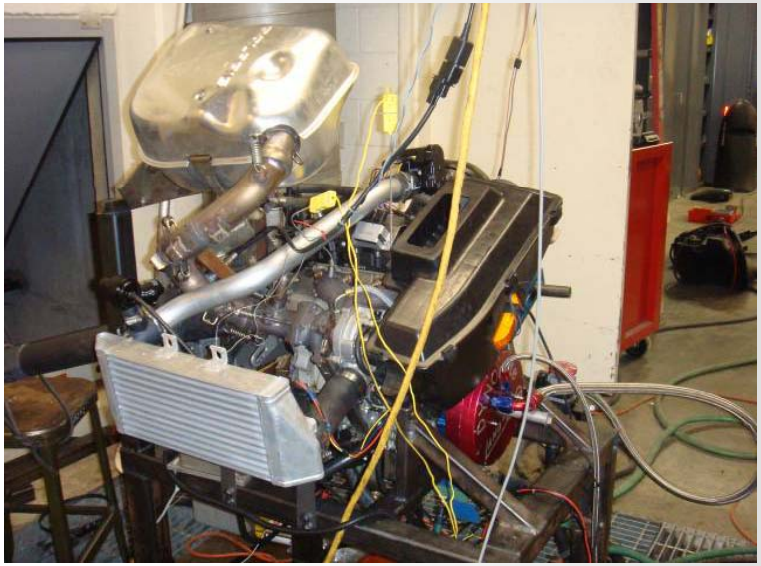
Clean
Quiet
FAST

Flex Fuel Control Algorithm



University of Wisconsin
SAE Snowmobile Team

Engine Calibration



- DYNOmite Water-Brake Dyno
- Horiba CO & CO_2 NDIR Analyzer
- Heated wide-band O_2 sensor
- Chemiluminescent NOx Analyzer
- Exhaust Thermocouples

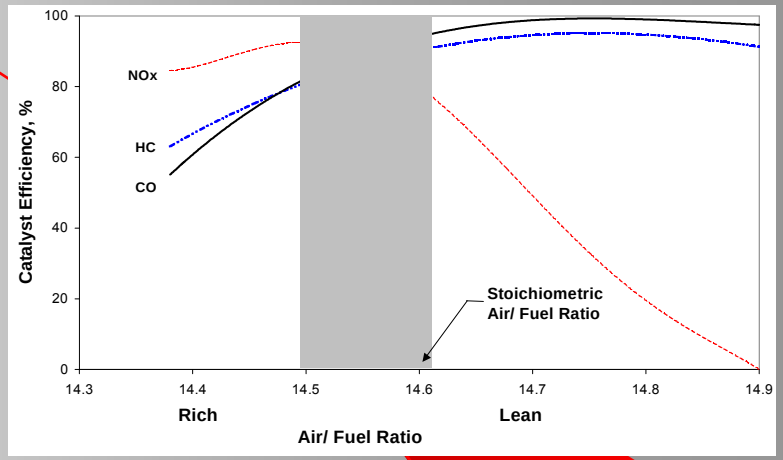
- Calibrated Spark Advancement
- Calibrated Volumetric Efficiency within 1% of Stoichometric
  - 160 cal points
  - Increments: 500 rpm, 0.1 PR
  - Each within ±0.01λ (open-loop)
- Feedback from O_2 Sensor
  - Lean/rich target switching

University of Wisconsin
SAE Snowmobile Team

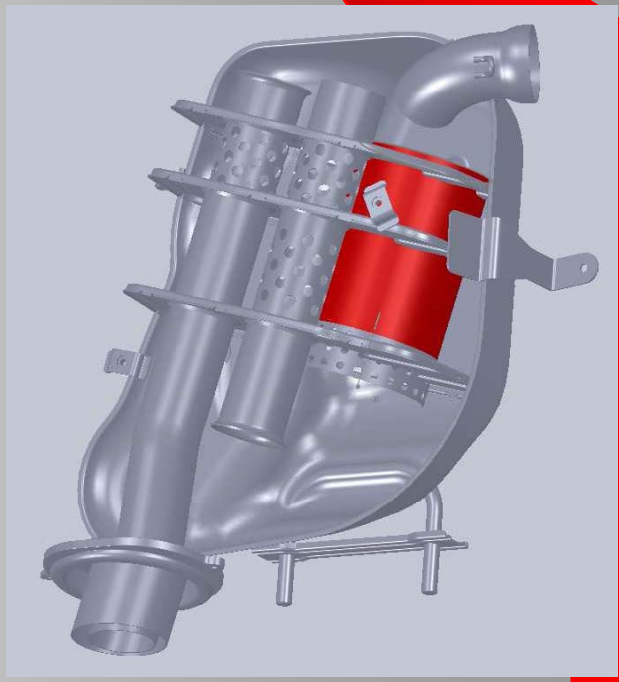
Catalytic Emissions Reduction

Improvements for 2011

- Lean/Rich Switching maximizes three-way catalytic efficiency
- Exhaust system re-designed to minimize weight, engine back-pressure and risk of pre-catalyst leaks



Manufacturer	W.C Heraeus GmbH
Diameter	105mm
Length	140mm
Substrate	SuperFoil® Metal Honeycomb
Density	600 cpsi (cells per square inch)
Loading	Platinum 11.1 g/ft^3 Palladium 55.6 g/ft^3 Rhodium 8.3 g/ft^3



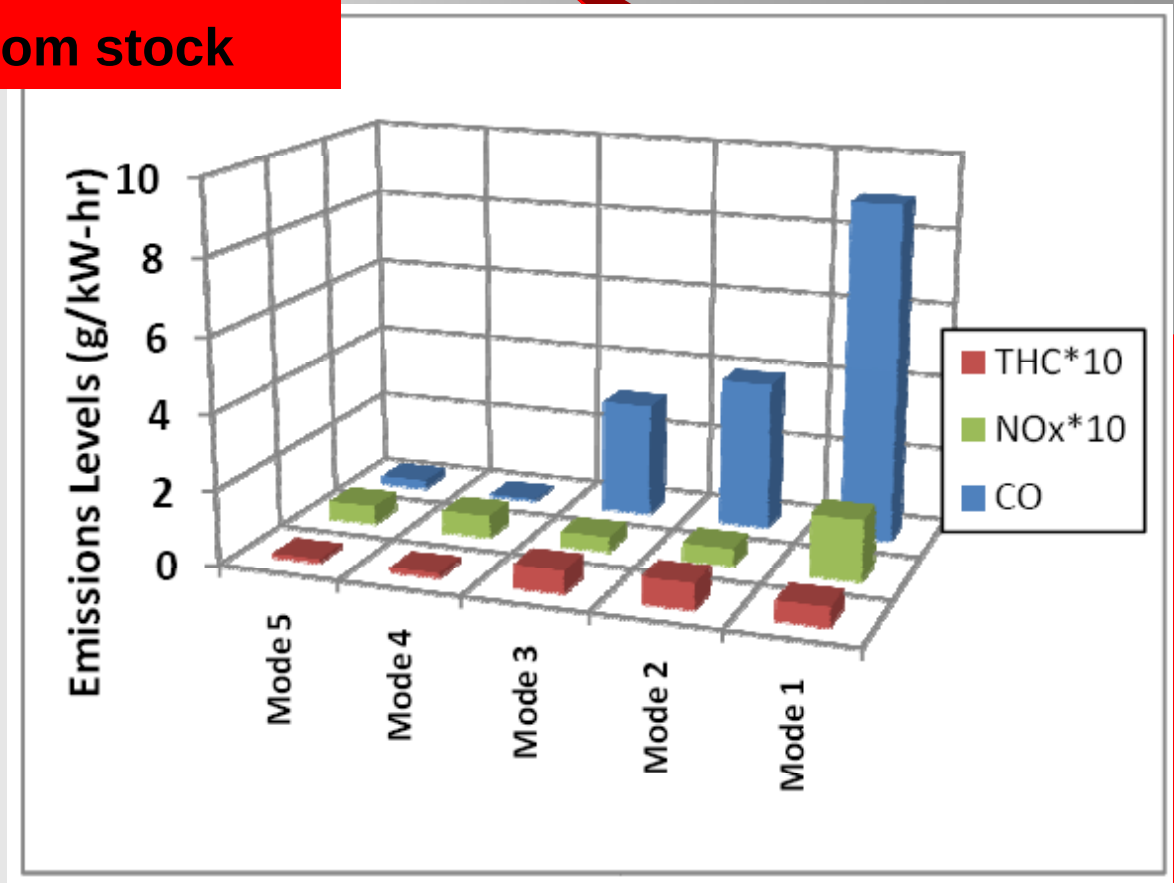
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Emissions Results

2011 Emissions Testing Results

Up to 98% reduction from stock



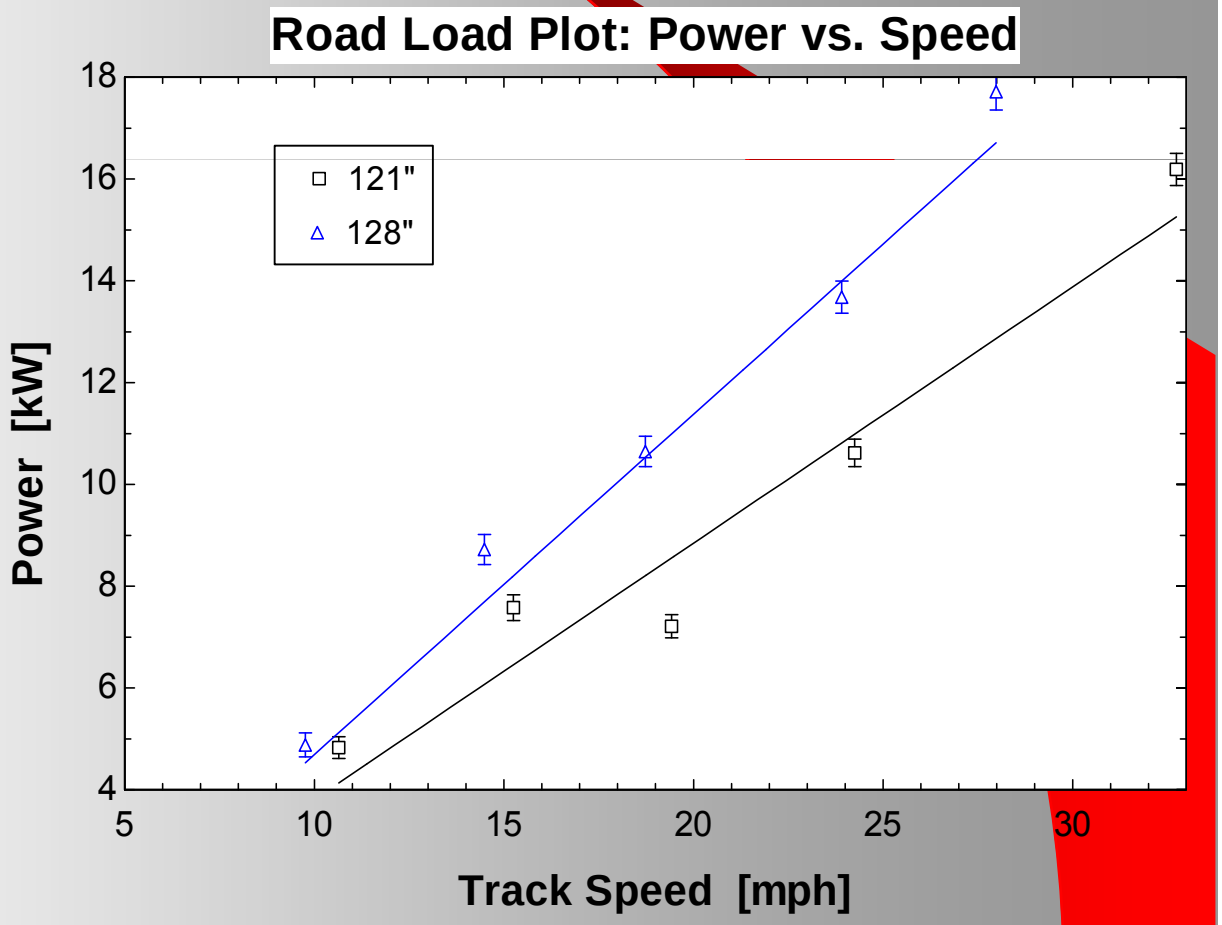
University of Wisconsin
SAE Snowmobile Team

Driveline Efficiency Testing

University of Wisconsin
SAE Snowmobile Team

Track Length Comparison

- 128” track length standard on 2007 Polaris FST LX
- Tested 121” vs. 128” using electric snowmobile
- Found a 22% reduction in power required to drive at 25 mph when using 121”
- Overall weight reduction of 28.6 lbs.

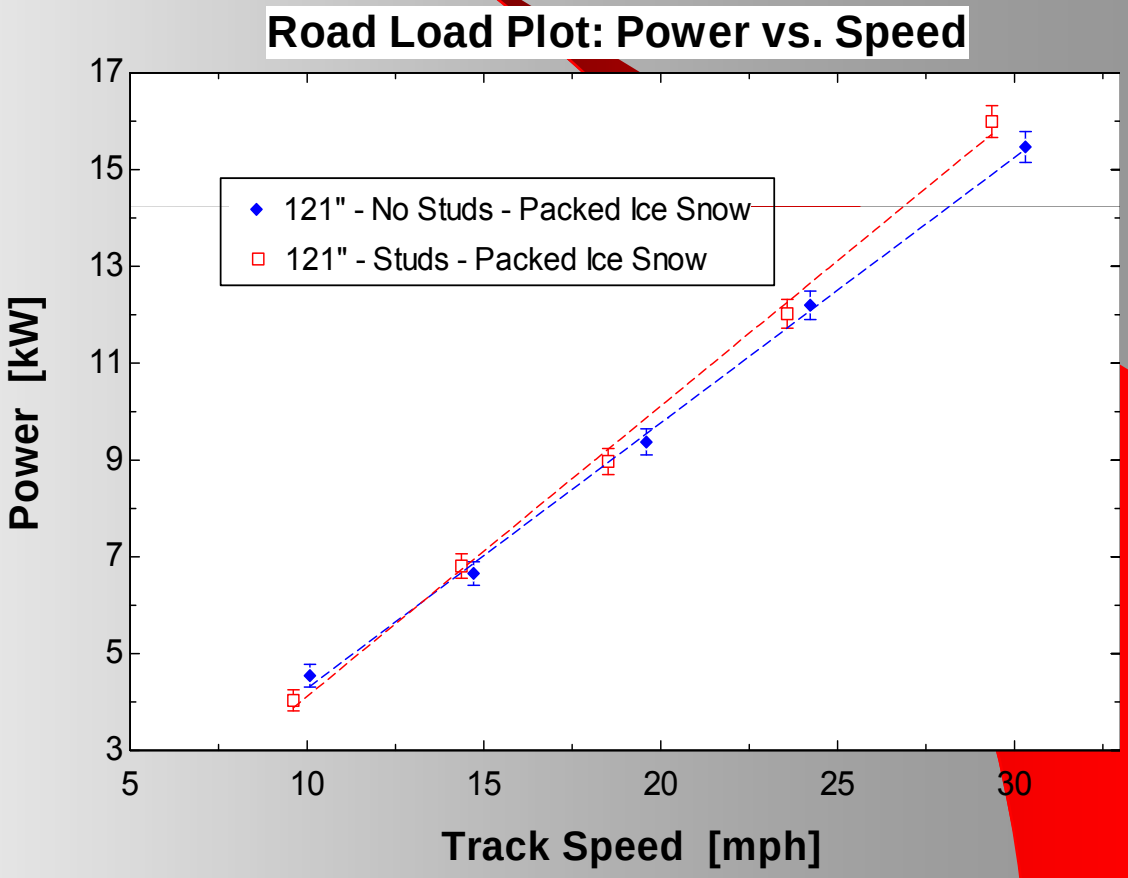


University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Effect of Studs

- Tested same track studded vs. non-studded
- Found a 4% difference in power required to drive at 25 mph
- This impact was weighed against the positive aspects of studs



University of Wisconsin
SAE Snowmobile Team

Sound Testing

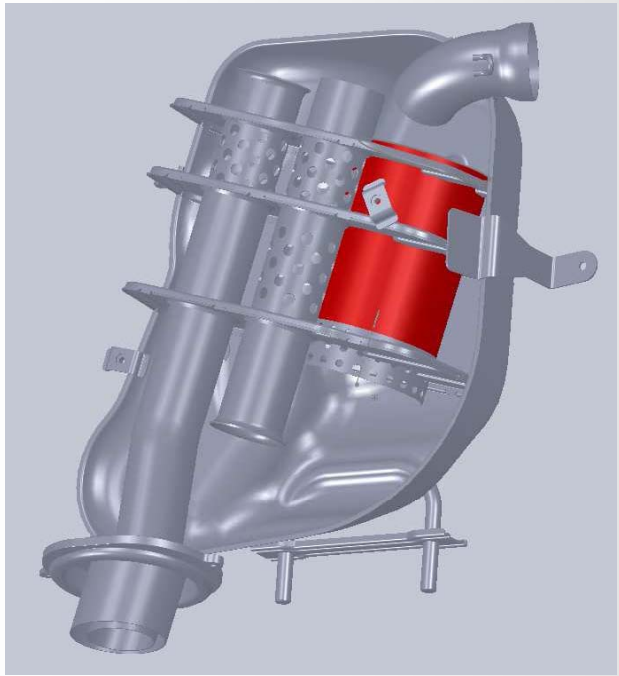
University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

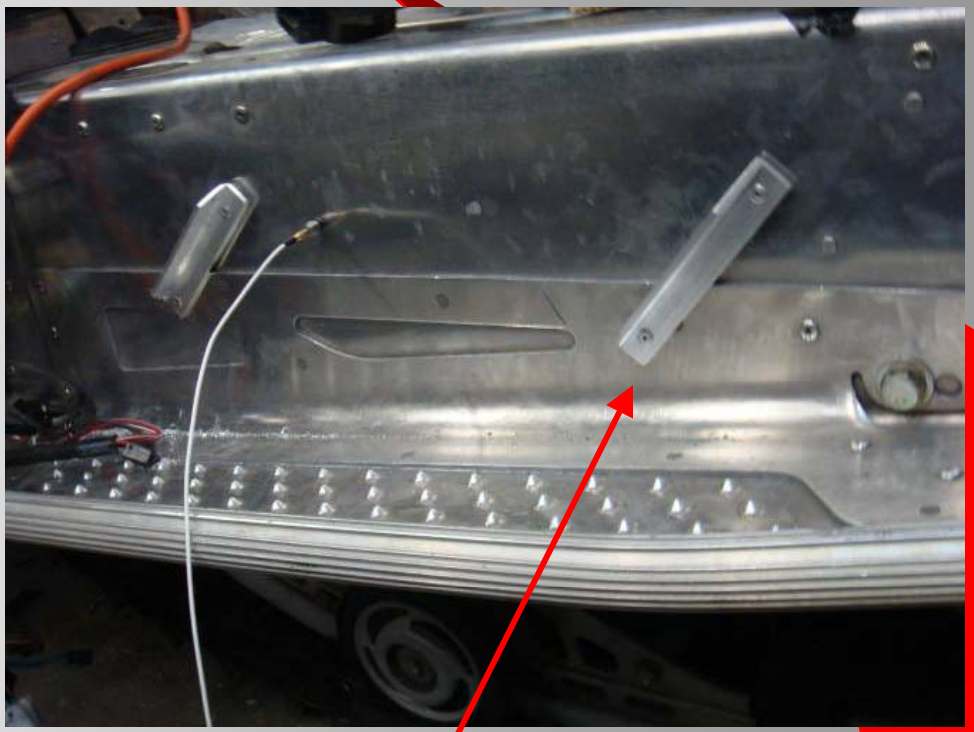
Sound Reduction

Engine

- Three Stage Exhaust System
  - Turbocharger turbine
  - Catalyst
  - Custom-Modified Muffler



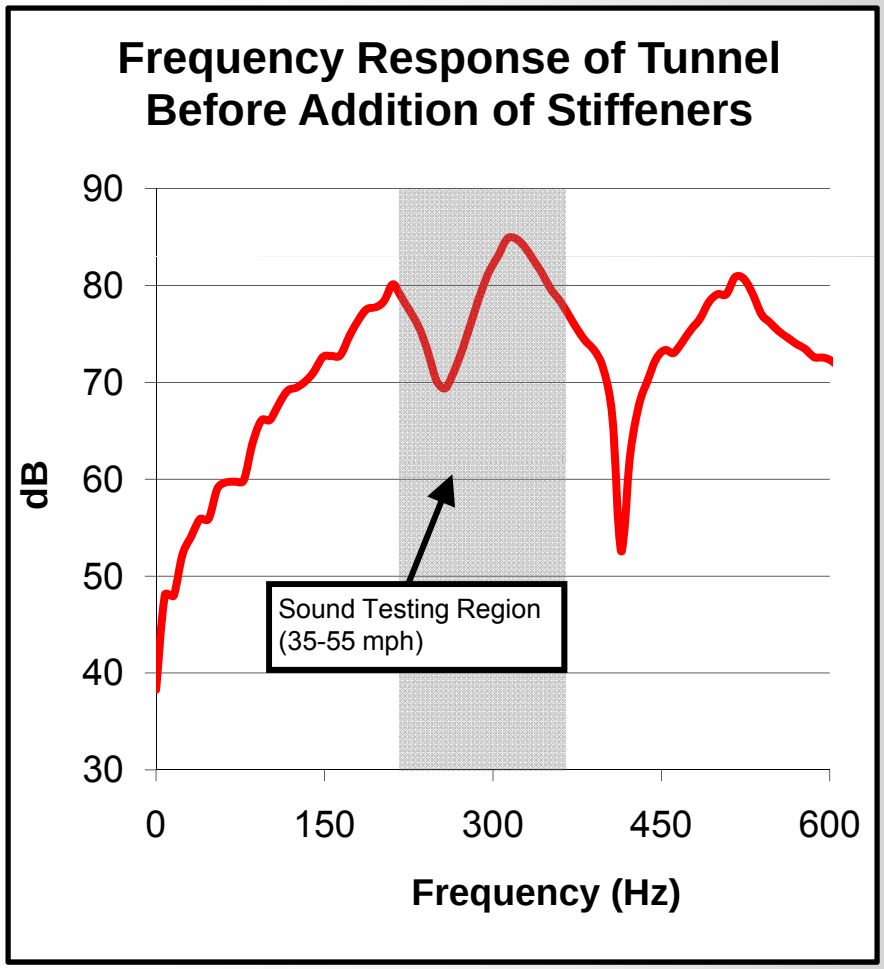
Chassis

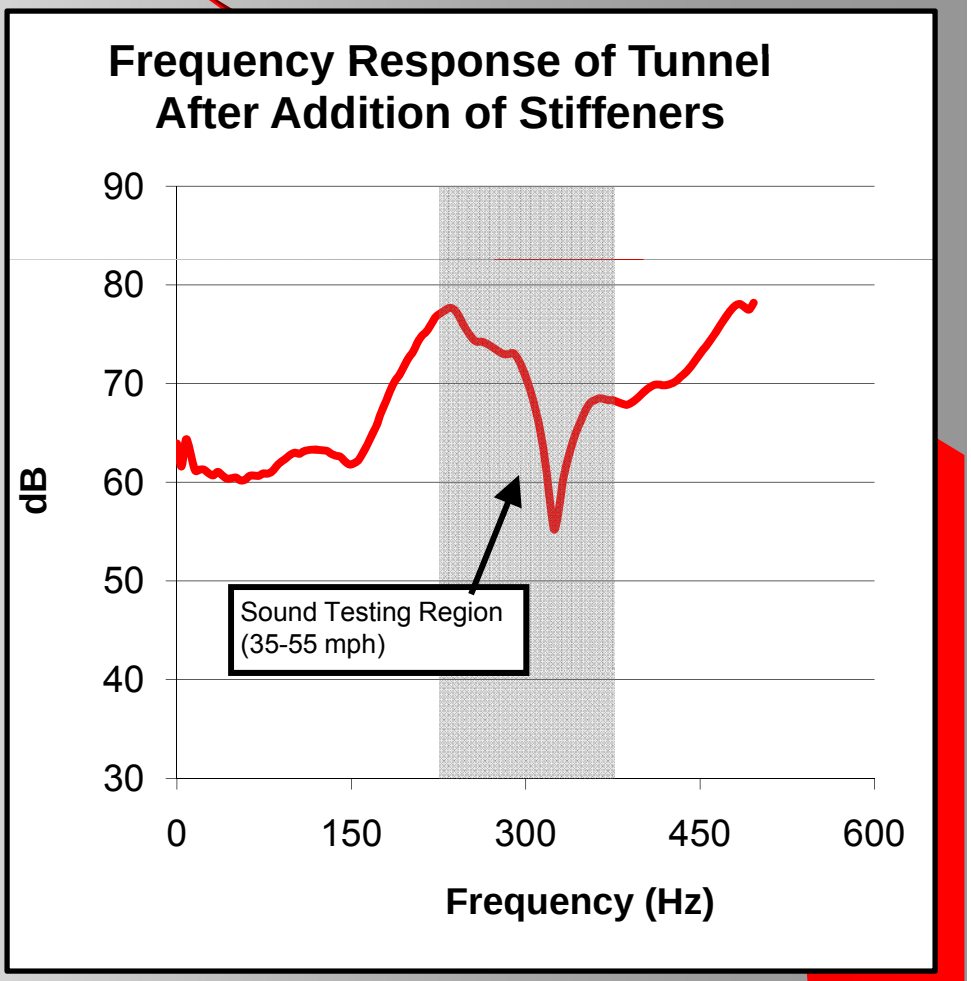


University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Resonance of Tunnel





University of Wisconsin
SAE Snowmobile Team

Total Sound Reduction

- Measured sound level of based on pass-by testing - SAE Standard J192

- J192 Limit – 78 dBA maximum
- Stock Muffler – 76 dBA
- Bucky CFS – 72 dBA

- 60% Noise Reduction

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Questions?

Modifications

- Custom exhaust
- Mototron control system
- Electric Throttle Control
- Ethanol compatible fuel system
- Fuel oxygenation sensor
- Studded track
- Shorter, lighter suspension
- Chassis noise reduction
- Lightweight Drive Shaft
- Improved Idle Cooling

University of Wisconsin
SAE Snowmobile Team

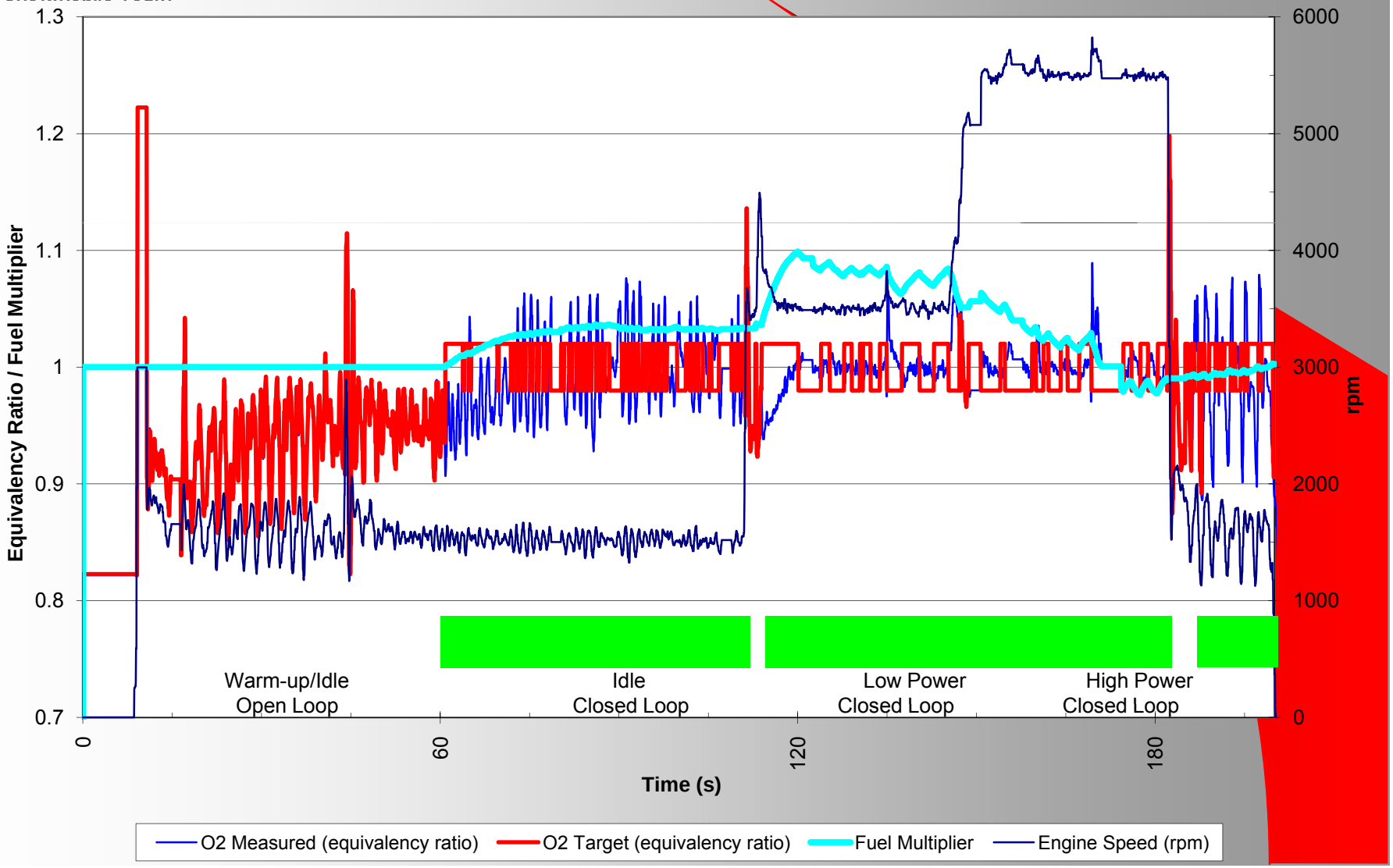
Emissions and Standards

Standards	HC	CO	E-number
EPA Phase 1 (‘06-’09)	<100	<275	75
EPA Phase 2 (‘10-’11)	<75	<275	91
EPA Phase 3 (‘12)	<75	<200	110
EPA BAT	<15	<120	170
SAE CSC 2011	<90	<275	100

Vehicle	HC	CO	E-number
UW CSC 2009	0	5	208
BRP 600ACE (4-stroke)	8	90	182
BRP 800 ETEC (DI 2-stroke)	?	?	?

University of Wisconsin
SAE Snowmobile Team

Closed-loop operation after cold start



University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Why Not DI2S?

University of Wisconsin
SAE Snowmobile Team

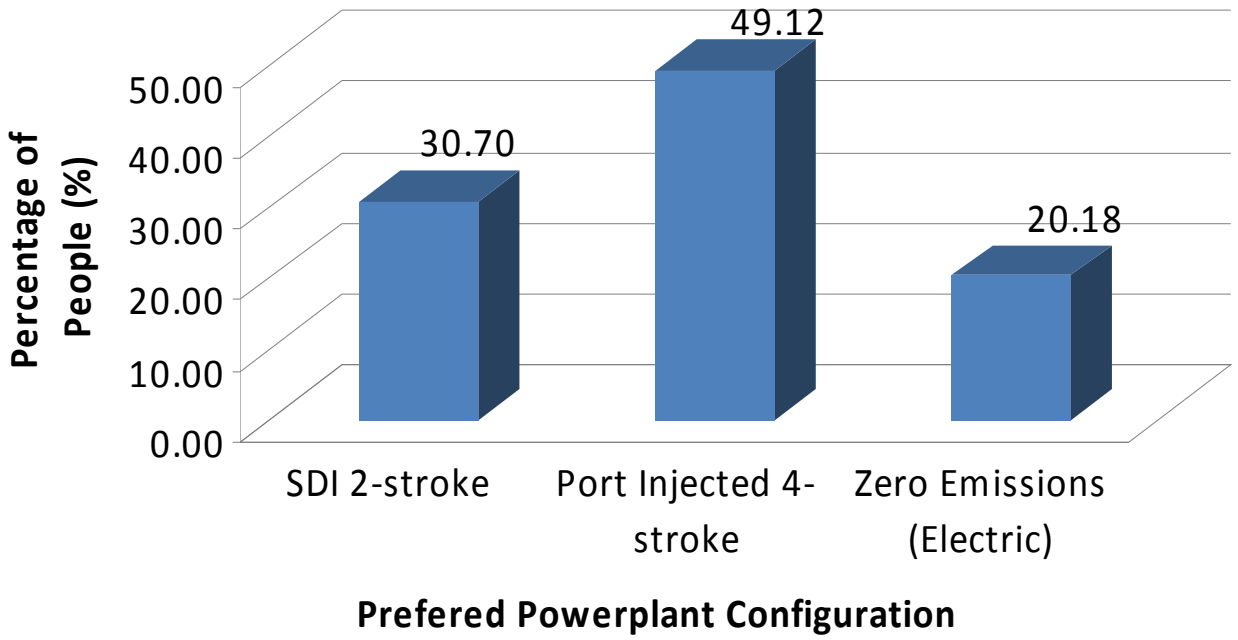
Emissions Testing Modes

	Engine Speed (rpm)	Torque (N-m)	Power (kW)
Mode 1 (WOT)	5500	105.9	61.0
Mode 2 (85%)	4675	54.0	26.4
Mode 3 (75%)	4125	34.9	15.1
Mode 4 (65%)	3575	20.1	7.5
Mode 5 (idle)	1500	0.0	0.0

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Customer Survey



University of Wisconsin
SAE Snowmobile Team

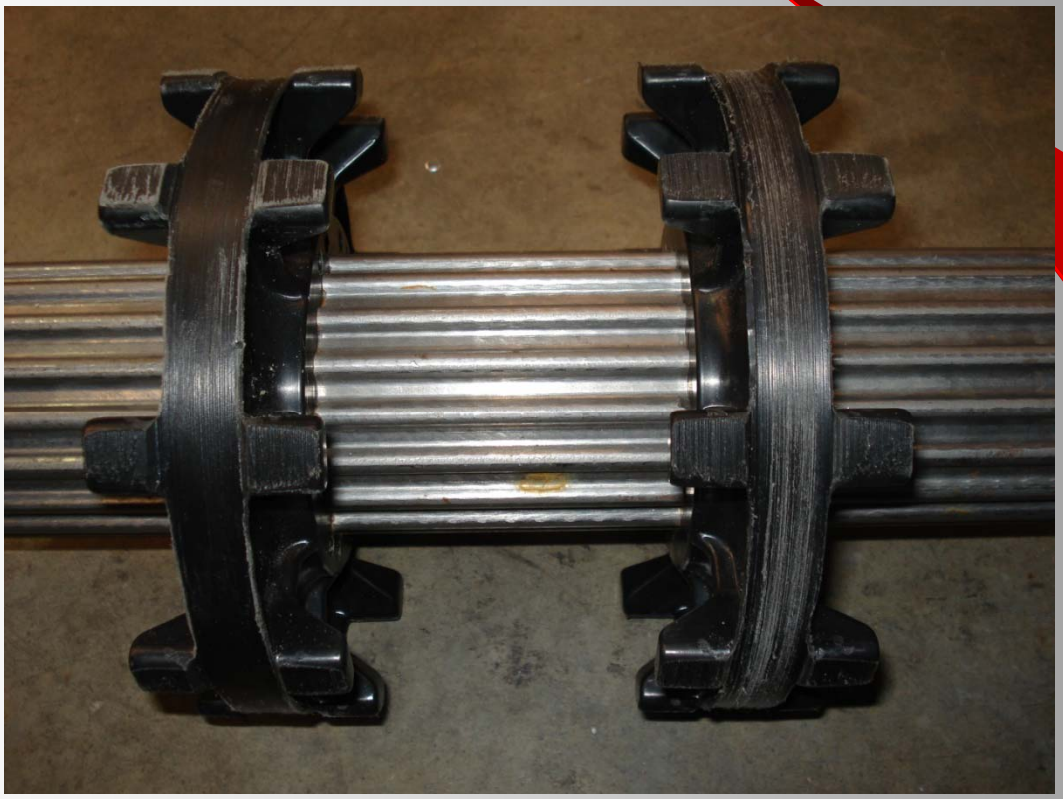
Catalyst Specs

Manufacturer	W.C Heraeus GmbH
Diameter	105mm
Length	140mm
Substrate	SuperFoil® Metal Honeycomb
Density	600 cpsi (cells per square inch)
Loading	Platinum 11.1 g/ft^3 Palladium 55.6 g/ft^3 Rhodium 8.3 g/ft^3

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Drive Shaft



University of Wisconsin
SAE Snowmobile Team

Tuning and Performance

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Clutch Tuning

- Goals:
  - Maximize fuel economy
  - Achieve desirable riding characteristics
  - Engine operation within a target rpm range
- Systematic Clutch Adjustments
- Calibration of rev and boost limits

Target
6000 rpm max engine speed
55 mph @ 5000 rpm

Run	Engagement RPM	Max RPM	Max Speed (mph)	Spring Color	Cam Arm Mass (g)
1	4000	6600	15	Black/White	50
2	3900	6600	15	Black/White	52.5
3	3600	6500	35	Orange	60.7
4	3500	6500	50	Orange	72.5
5	3200	6500	55	Orange	76
6	3000	6500	55	Pink	76
7	2200	7000	70	Pink	84
8	2000	6000	90	Pink	90
9	3000	6000	94	Orange	90

University of Wisconsin
SAE Snowmobile Team

Clean
Quiet
FAST

Performance

- Acceleration
  - 150 ft 50 mph
  - 300 ft 60 mph
  - 500 ft 69 mph
- Top Speed
  - 91 mph
- Fuel Economy
  - 20+ mpg gasoline equivalent