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Fuel Economy and Power Generation of 30% Ethanol (E30) Splash Blended Fuel in Fuel injected Non-FFV Gasoline Engines

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Introduction

This study focused on two areas of research. The first being dynamometer testing to demonstrate that modern vehicles currently on the road today can adapt and take advantage of higher octane fuels. The second phase was the collection of actual, real world, on-road data showing how vehicles can adapt up to blends of E30 (20 percent more ethanol added to E10) and still operate within the vehicle's computer calibration range set by the manufacturer's engineers.

Watertown, SD for years has had multiple blender pumps at retail locations. This has allowed thousands of consumers the option to buy higher octane fuel at a lower cost per gallon simply by adding an additional 10 to 20 percent ethanol. Both Flex Fueled Vehicles (FFVs) and non-FFVs for years have benefited from this option. Follow up with local dealerships and independent auto repair shops have shown no reported issues associated with higher blends in non-FFVs.

The use of higher ethanol blends such as E15 and E20 in current non-FFVs has been the focus of many prior vehicle testing projects. The challenge with many of these prior studies is that varying results occurred, primarily due to how the test fuels were blended. In the testing presented in this paper, only splash blending of ethanol was allowed, meaning no changes to the consumer E10 fuel occurred and 20% additional ethanol was added to the original test fuel.

Results of this study indicate that non-FFVs can adapt to higher ethanol content fuels which also provide higher octane and thus offset much of the energy differences between E10 up to E30 blends while also providing better vehicle performance, drivability and increased power.

This study was conducted as a result of an increased awareness and ongoing discussions by the auto industry to research the use of mid-level ethanol blends as an option to provide a high octane source of fuel while reducing toxic emissions. The goals established for this research were two fold.

1. Show that all fuel injected vehicles can adapt to higher octane to improve performance and increase available power.

2. Show that all fuel injected vehicles can adapt to higher ethanol blends up to E30 and stay with-in the calibration range set by OEM's.

Future Automotive Industry Demand

The auto manufacturing industry is currently limited by additional technological demands with broadly available fuel octane ratings of 87 AKI. Octane is best described as a resistance to premature combustion under high temperature and pressure in the engine combustion chamber. Neat ethanol has been found to have an octane blending value rating of 109 Research Octane Number (RON). Yet due to the cooling combustion effect of ethanol the blending value could easily be 125 RON. Further fuel economy gains will require higher octane in the fuel supply. E30 is 94 octane and will enable further advancement such as twin turbo and EcoBoost technology to increase fuel efficiency. As an additional benefit to the industry and consumers alike, when denatured ethanol is splash blended with commercially available E0 or E10, it is found to burn cleaner, reducing toxic tailpipe emissions.

Blender pumps allow two certified fuels to be blended together and are calibrated to achieve specific fuel blends. This allows for a greater consumer experience, trial and acceptance of mid-level blends. E30 is increasing in popularity and availability in small towns and community fueling stations across eastern SD and MN. Current infrastructure of blender pumps continues to grow spurred by the $100 million Blender Incentive Program (BIP) created by the USDA in 2015. This is a cost sharing program to defray expenses to retailers leading to growth of equipment infrastructure and mid-level ethanol blend availability. Many state agencies have partnered with the USDA by coupling federal funds with existing state cost sharing programs. Blender pumps cost about $12,000 more than a standard fuel dispenser while often there is additional expense of another underground tank needed for the base ethanol fuel, usually E85. Most funds have now been allocated and blender pumps are being installed across the country.

The State of SD and the South Dakota Farmers Union have been primary forces in leading the way to improve availability while assisting in installation of the first blender pumps over a decade ago. Acceptance of E30 has been growing in eastern SD and is now reported to be a major item of sale at many local fuel coops and C-stores. E30 availability is also growing in MN and can be found again at many locations including local fuel coops that are vertically integrating their investments to create additional demand for recent record corn production.

Engine and Model Testing Selection

Three random vehicles were initially tested on a dynamometer in a controlled setting as results of horsepower and torque were recorded over the entire drive cycle. The vehicles observed are listed below.

2011 Ford F150 3.5 L Eco boost – 110,000 mi

2015 Dodge Ram 1500 2.7L Hemi - 2,500 mi

2012 Chevrolet Malibu 2.4L - 80,000 mi

Sufficient volume of trials to confirm reliability and repeatability was required. Glacial Lakes Energy partnered with ICM Inc, Lake Area Technical College and DynoTune Speed and Performance to develop the "E30 Challenge". Based on the advice of Urban Air Initiative (UAI), all candidates selected were non-shareholders of GLE to ensure impartiality and all vehicles were non-FFVs. The study covered 80,000 miles of driving with 40 various makes and models covering a wide range of weather and road conditions. Vehicles included pickup trucks, SUVs, crossovers, passenger cars, transit vans and mini vans.

To verify results, data loggers identical to those used by the EPA were purchased and installed into the vehicle's on board diagnostic (OBD) port during the testing to collect fuel trim, knock retard, calculated load data as well as other variables from the power control module (PCM) to determine the influence E30 has on a vehicle's PCM adaptability. Volunteers were required to record actual miles driven on three consecutive tanks of E10 vs three consecutive tanks of E30. During each drive cycle a file was created and stored in the data logger. VINs were recorded along with engine performance metrics taken every second or half second depending upon make or model. Data was summarized on 40 vehicles to validate the dynamometer findings when comparing real world driving with commercially available E10 and E30. There was no significant difference in average fuel economy, and many of the owners reported a feeling of more power especially upon acceleration or under load such as towing a trailer or a boat.

Test Fuels and Methodology

In a controlled setting, on a dynamometer, a direct comparison was made between E10 and E30 charting the results of each fuel to determine changes in horsepower and torque. A complete drive cycle was conducted on each of these vehicles from idle to wide open throttle (WOT) to determine engine performance on each fuel. Commercially purchased E10 was used first as this was the existing fuel already in the vehicle and the computer adaptive strategy was already established to be used in this vehicle per OEM owner's manual. Subsequent to conducting the dyno testing on E10 the keep alive memory was cleared, the base E10 fuel was drained completely, 20% ethanol was added to the original E10 to create E30 and refueled into the vehicle. The computer was reset to factory settings and an adaptive cycle of 20+ miles was driven to cause the vehicle's computer to sense and accurately adjust functionality to E30. Each vehicle was then dyno tested again with a graph of the performance on E30 overlaid on the graph of E10.

Test Results

All three vehicles experienced more horse power and more torque. The dynamometer showed an ignition timing increase relative to E10 of 8-10% on E30. Knock retard was also visually detected on the dynamometer graph of E10 on two of the vehicles. Histogram graphing of long term engine fuel trims demonstrated a range of no more than 11% from factory set point.

Direct Inject (DI) vehicles built since the mid 1990's have had knock retard sensors added to effectively detect and prevent engine knock which can be severely damaging to engines. The PCM is designed to retard spark ignition timing to most effectively utilize the fuel quality to prevent preignition. Fueling with lower quality (octane) fuels results in greater knock retard application which leads to reduced power generation and incomplete fuel burn. Without this feature there would be significant engine damage. As octane decreases, knock retard increases. In this study, knock retard was reduced by an average of 60% using 94 AKI Premium E30 and offset the reduced energy value in ethanol resulting in no loss in average fuel economy.

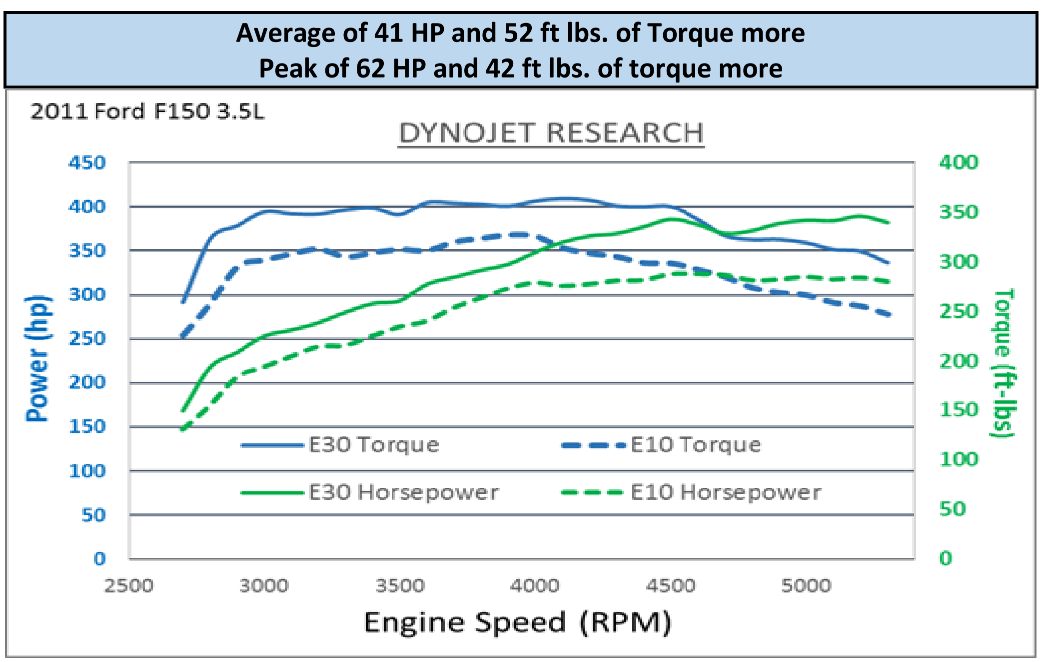
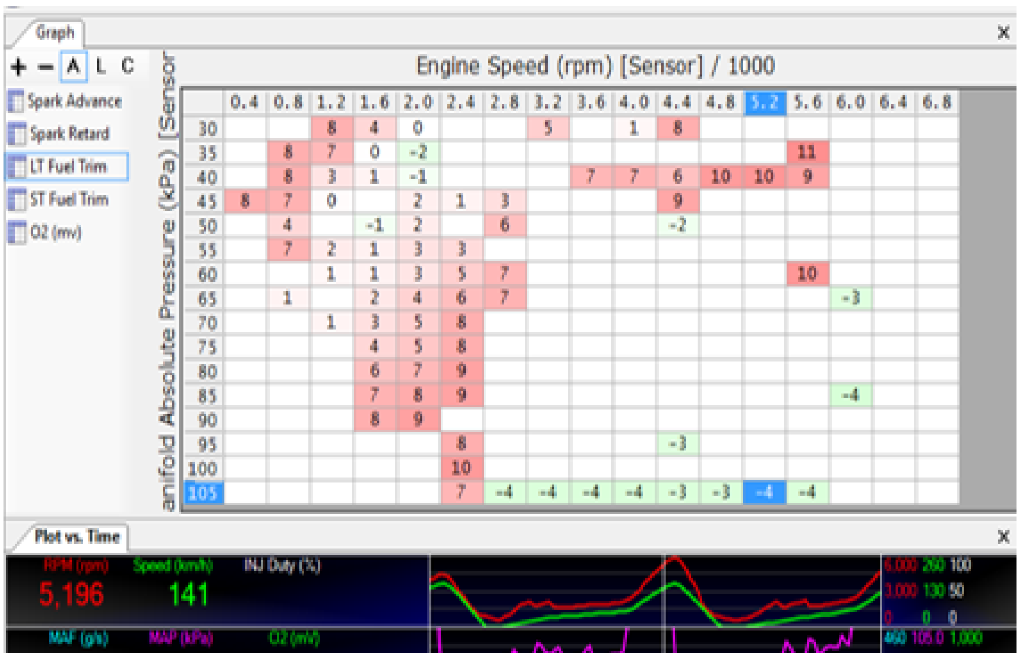


Figure 1

Figure 1 above is a graph on the dynamometer of the 2011 F150. The evolution of EcoBoost technology allows the vehicle to increase fuel efficiency on 94 octane E30. The keep alive memory was cleared when switching fuels and multiple drive cycles over the road were completed to ensure an accurate recording of fuel trims in all three test vehicles.

Figure 2 is a histogram of the fuel trims recorded using a data logger for the Ford F150 throughout the drive cycle over the road. Each cell represents thousands of readings with the darker shade representing a greater intensity of recordings at that level.



	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0	6.4	6.8
30			8	4	0			5		1	8						
35		8	7	0	-2									11			
40		8	3	1	-1				7	7	6	10	10	9			
45	8	7	0		2	1	3				9						
50		4		-1	2		6				-2						
55		7	2	1	3	3											
60			1	1	3	5	7							10			
65		1		2	4	6	7								-3		
70			1	3	5	8											
75				4	5	8											
80				6	7	9											
85				7	8	9									-4		
90				8	9												
95						8					-3						
100						10											
105						7	-4	-4	-4	-4	-3	-3	-4	-4			

Figure 2

For each 10% increase of ethanol there is a loss of 3.2% of BTUs in the finished fuel while the vehicle's PCM actually offsets with a greater fuel to air ratio of 4%. The chart in figure 2 demonstrates the greatest percent of long term fuel trim increase is 11% while generally averaging 8% increase and is consistent with the additional 20% ethanol content. The fuel trim adjustments were over 50% below the upper 25% level limitation to trigger a check engine light (CEL) event.

The results of the Chevy Malibu on the dynamometer are in Figure 3. Vehicle capability increased by 2.5% or 4 HP more and 1.6% or 2 foot lbs. more torque as evidenced by the red lines representing E30 vs versus the blue E10 lines.

Also significant and identifiable on this chart is the noticeable drop in power as knock retard is magnified while using E10 which is seen at 4300 rpm and again at 4900 rpm. While using E30 this effect is largely eliminated.

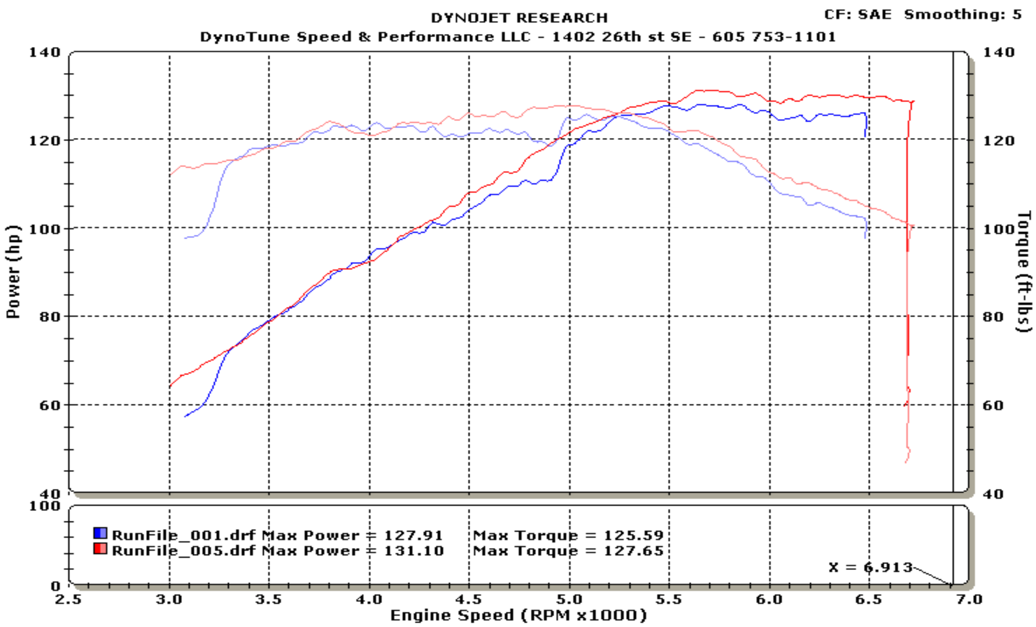


Figure 3

A 2015 Dodge Ram was the third vehicle that was tested on the dynamometer. The results were similar to the other two vehicles. More HP and torque as seen in Figure 4.

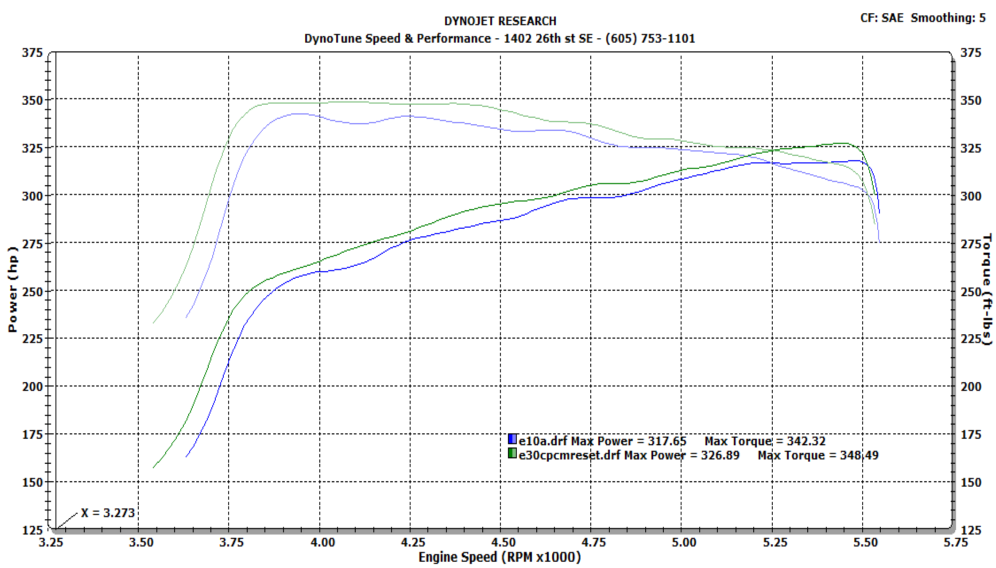
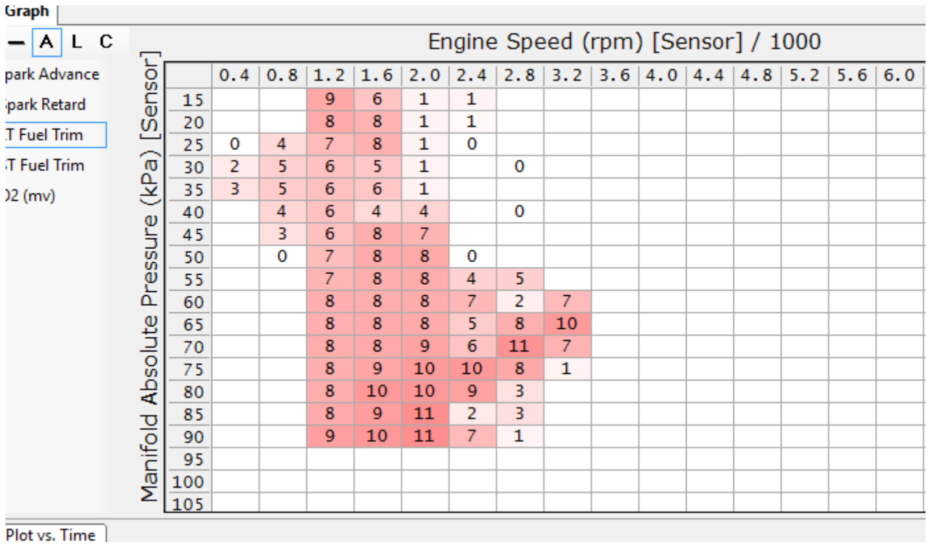


Figure 4

At Peak HP, the gains were 9 HP and 6 ft lbs. of torque. The average increases across the entire test were 7 HP and 9 ft lbs. of torque. After clearing keep alive settings allowing the computer to revert to OEM factory settings, multiple drive cycles were conducted to adjust long term fuel trims on E30.

In Figure 5, this histogram shows the results yielded a maximum of 11% increase in long term fuel trim at peak with an average closer to 8% variance.



	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6	6.0
15			9	6	1	1									
20			8	8	1	1									
25	0	4	7	8	1	0									
30	2	5	6	5	1		0								
35	3	5	6	6	1										
40		4	6	4	4		0								
45		3	6	8	7										
50		0	7	8	8	0									
55			7	8	8	4	5								
60			8	8	8	7	2	7							
65			8	8	8	5	8	10							
70			8	8	9	6	11	7							
75			8	9	10	10	8	1							
80			8	10	10	9	3								
85			8	9	11	2	3								
90			9	10	11	7	1								
95															
100															
105															

Figure 5

Validation – Road Testing

The slide in Figure 6 was an important educational piece explaining to interested parties what happens in an engine and how the computer system adapts to the 94 octane supplied by E30.

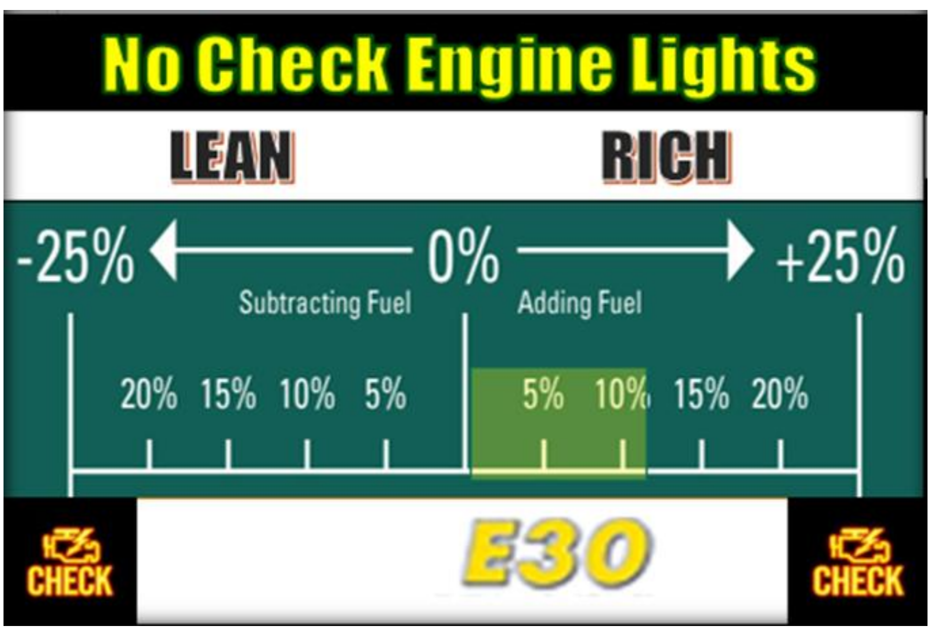


Figure 6

As people understood the value provided, that they received more power for less money and did not have to give up mpg, a number of local citizens volunteered to validate that E30 is compatible with all modern fuel injected vehicles today regardless of FFV designation or not.

To accomplish the objective of this study local auto technicians, dealers, retailers and consumers were provided with initial observations from DynoTune's Andy Wicks confirming that using E30 would not harm their vehicle. E30 availability was a key component of the study with six locations offering 28 blender pumps making E30 available in a town of 22,000. By the end of the study, two retailers added two locations with 12 more pumps.

Real world testing was conducted to validate our findings in the controlled environment. Knock retard readings were recorded in 40 road tested vehicles with data loggers over 80,000 miles. All vehicles in the study were non-FFVs on original factory settings. Study participants were questioned after completion of their trials. No CELs or other malfunctions were reported on any vehicle. An average reduction of 60% in knock retard was identified once data was collected and evaluated from the data loggers.

Consumer and Vehicle Response

Part of the data collection objective was to identify the possible events associated with a CEL illumination. There is a limited chance that some older vehicles with a narrow operational fuel trim adjustment may illuminate a check engine light with E30 in colder temperatures. Any issue related to a CEL should not be deemed as a failure and is better described as an event. Auto technicians should determine the root cause. In no case is it recommended to continue driving a vehicle with a CEL illuminated. E30 could be viewed more correctly as a diagnostic tool identifying a preexisting condition already latently present but as yet unidentified by the PCM.

Upon completion of the driving trial, many participants commented that they felt slightly more power especially from a standing stop or under acceleration, otherwise no significant difference in vehicle performance. This validated the dynamometer findings. When comparing actual miles driven versus fuel consumed there was a range of performance from 3.05 mpg gain to 3.21 mpg loss. Upon further investigation it could be determined by data collected from the data logger that there was as much as a 9 mph average speed differential between fuels with one vehicle leading to a wide variance in fuel economy. This magnifies the importance of a larger sample size to eliminate the skewing of results due to an inadequate number of participants.

Figure 7 validates the mpg response based on information collected from 40 vehicles. There was no difference in average fuel economy between E10 and E30. When we investigated further we found that 4 cylinder vehicles showed an improvement of .87 mpg.

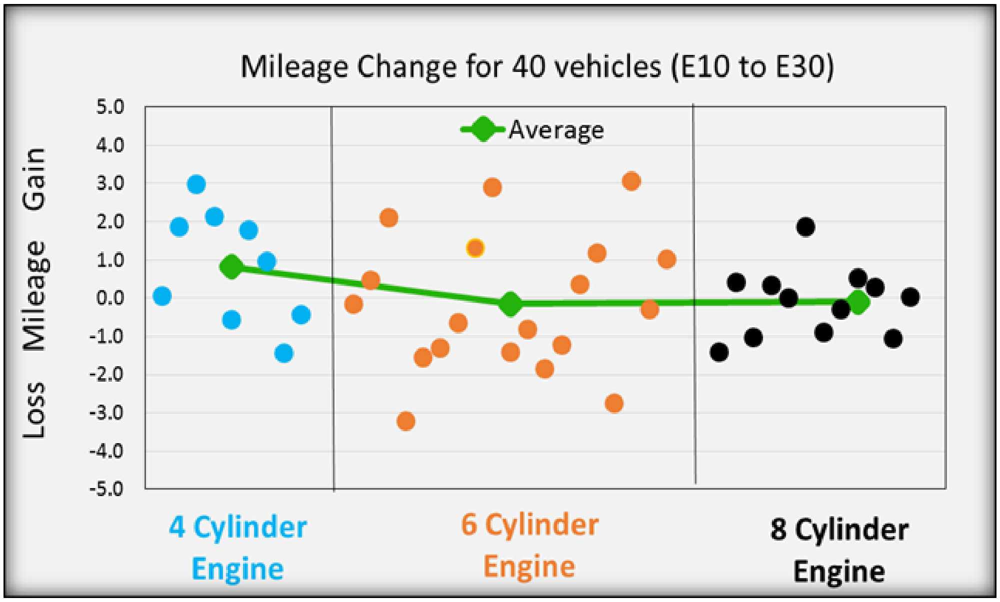


Figure 7

There is a close correlation to calculated load value and PCM application of knock retard. As smaller engines tend to be under greater load there was a greater reduction in average knock retard on E30 which resulted in better average mpg. The 94 octane (higher quality) Premium E30 allowed for more aggressive engine timing compared to E10 offsetting the difference in quantity of BTUs in E30. IE, “the quality offsets the quantity”.

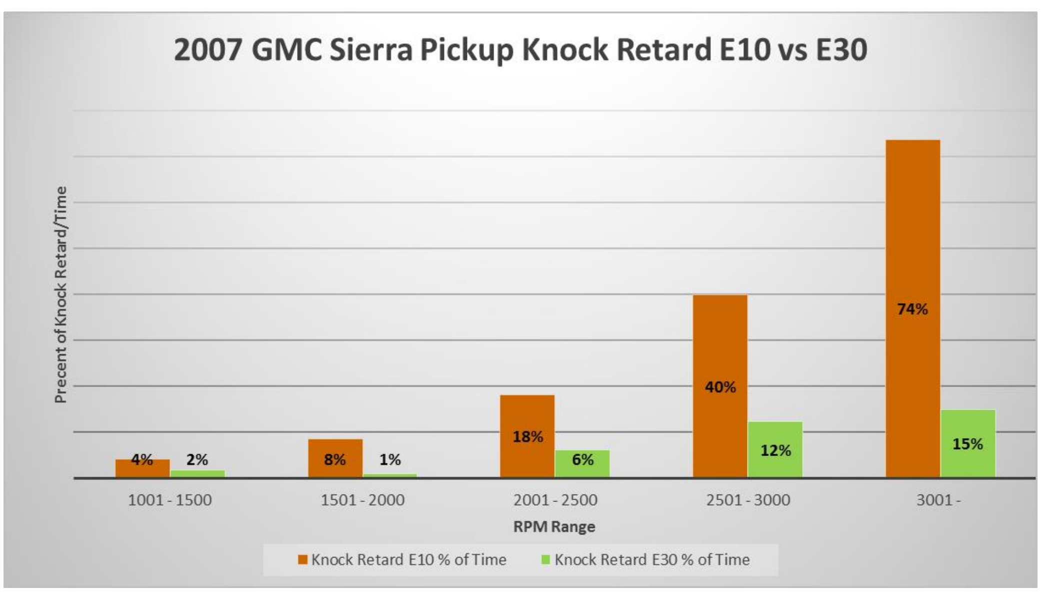


Figure 8

Figure 8 shows knock retard relative to engine RPM. There was an average of 60% reduction comparing E30 to commercially available E10 fuels on a 2007 GMC Pickup with 165,000 miles.

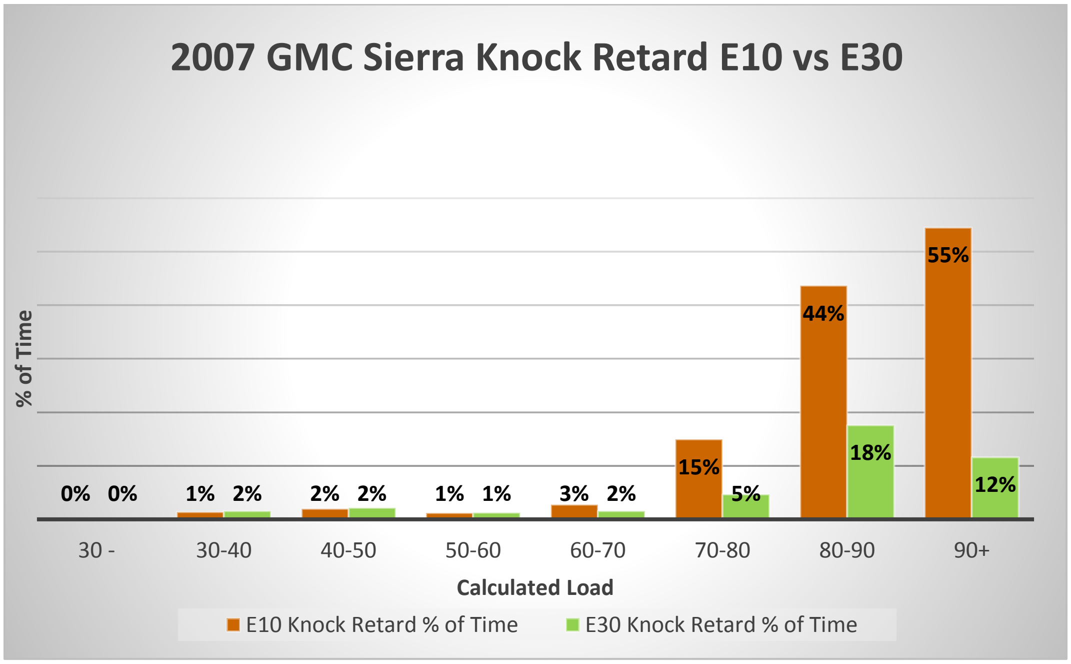


Figure 9

Figure 9 reveals a different summarization to reflect an alternative comparison of the two fuels vs calculated load rather than engine RPM. This data reflects a similar pattern of knock retard application. The greater the calculated load the greater amount of time the PCM applies knock retard to E10 vs E30.

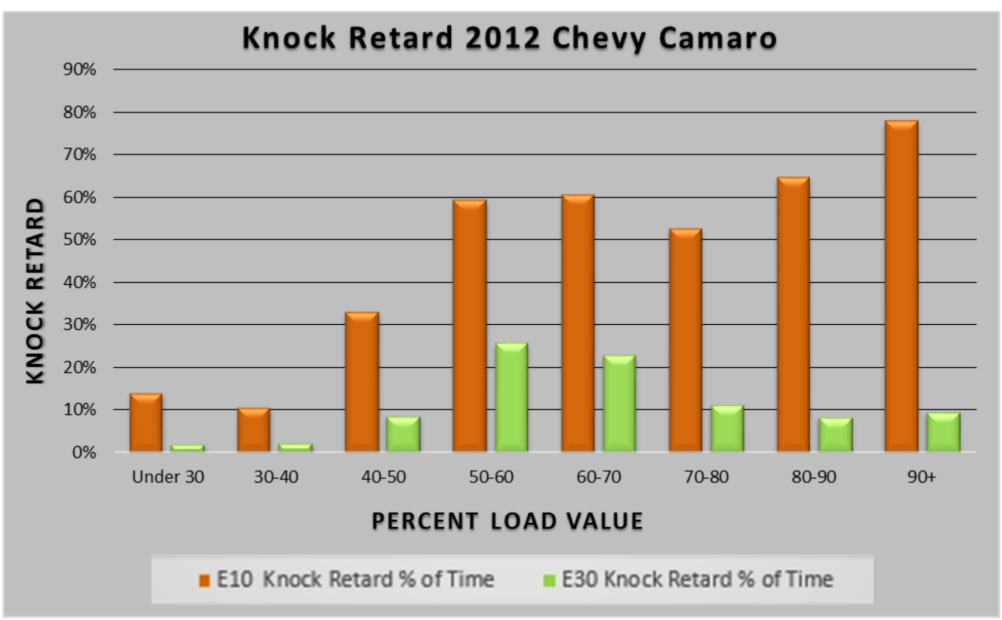


Figure 10

Figure 10 establishes a larger response variation to higher octane under various load conditions in a 2012 Chevy Camaro with 12,000 miles. All the data captured in the study showed a close correlation of greater fuel efficiency relative to calculated load or RPM. The higher the load, the greater the response to higher octane from E30.

Figure 11 summarizes the Watertown Area Transportation Company's actual driving statistics of five service vehicles from May 2015 through Sep 2015 on E10 comparing the same vehicles from May 2016 through Sep 2016 on Premium E30. Although there is an additional year of aging, records show an increase in mpg in all vehicles while the average increase was .4 mpg. Over 107,000 miles were driven on 14,000 gallons of fuel. Further research could be done in this area of service vehicle fleets as driving habits are different versus consumer light duty vehicles. More miles driven at slower speeds with more starts and stops and more intermittent idle cycles to pick up and drop off riders will result in different PCM strategies.

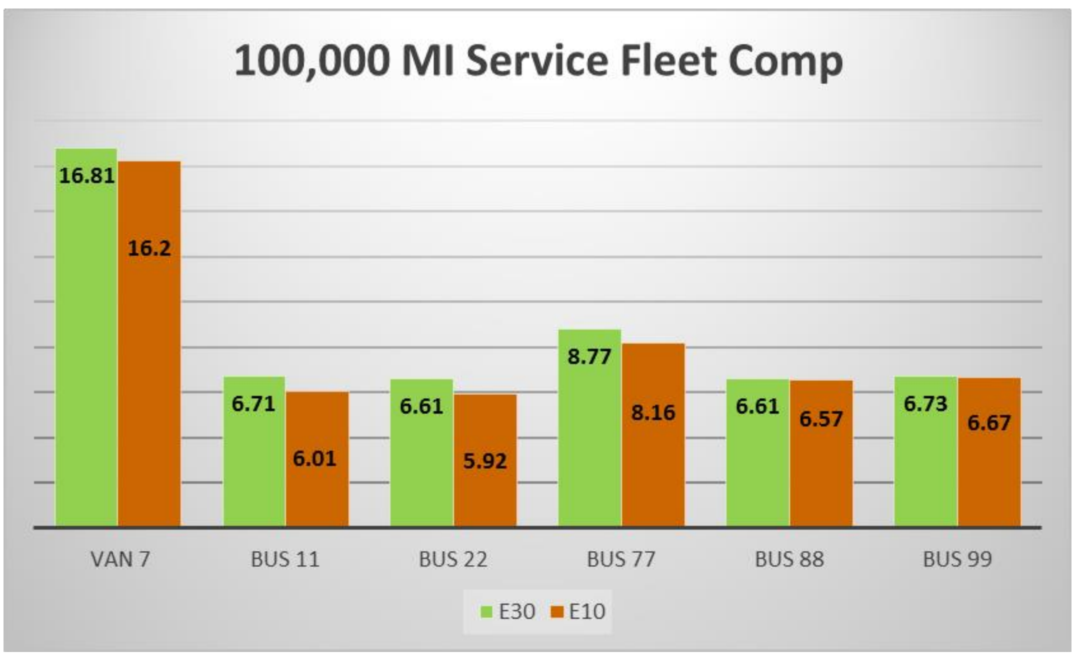


Figure 11

Economics

E30 has been selling for $.30/gal less than E10 in eastern SD. In the study, consumers' cost per mile driven on average was $.0137/mile less on E30. A consumer driving 20,000 miles annually could expect to save $274 each year. As field corn yields continue at record levels and global supplies are burdensome, this has led to low corn prices contributing to comparatively low feedstock costs for ethanol production from corn starch. Currently octane provided by ethanol is the lowest cost octane in the market. The USDA projects this to remain for several years.

Figure 12 exhibits a comparison of Watertown cumulative baseline E30 sales in 2015 vs 2016. Retailers could sell at a lower cost and maintain the same level of margin.

E30 Cumulative Gallons Sold Total			
Date	2015 Baseline	2016 Actual	% Change
MAY	24,098	87,628	264%
JUN	21,458	126,977	492%
JUL	22,146	111,515	404%
AUG	22,146	116,817	427%
SEP	21,458	118,615	453%
OCT	20,082	108,339	439%
NOV	19,529	101,883	422%
TOTAL	152,364	771,774	407%
E30 Additional Gallons Sold			619,410

Figure 12

Consumers recognized this value and retail sales of Premium E30 rose over 400%. Post promotional period, retailers have seen sales steadily increase and total net revenue improve. Although there was initial concern of cannibalization of existing fuel sales, that has not materialized. Instead, overall gross fuel sales for retailers offering E30 blends have improved by 10% since the beginning of the educational and promotional efforts.

Summary /Conclusions

- In all cases, non-FFVs tested on a dynamometer using splash blended E30 fuel provided greater horse power and torque based on data collected from idle to wide open throttle.

- Use of E30 in vehicles not labeled as FFVs reduced knock retard by 60% when compared directly to E10 in a six tank trial over 40 vehicles spanning in excess of 80,000 miles.

- Due to a reduction in knock retard, average mpg on the fleet of participants was not compromised. There was a gain in mpg on four cylinder vehicles using splash blended E30 vs E10. This is not consistent with responses previously reported in EPA certified lab testing using only certified fuels versus commercially available real world fuels.

- Service vehicles were found to gain .4 mpg or 5.5% increase in mpg over 107,000 miles traveled on over 14,000 gallons of fuel.

- Retailers demonstrated a gain in market share and improved net revenue through an educational process that was industry driven and community supported.

- Significant potential exists for new vehicles to be designed to more effectively use 94 octane E30 creating combustion efficiencies by increasing piston compression ratios from present levels of 9.5:1 to levels approaching 14:1. This increase can be leveraged to manufacture smaller, lighter, more efficient engines that are capable of delivering more power with less fuel.

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