Paper Number

The New Silverado: An Ethanol (E85) Conversion by the University of Nebraska-Lincoln

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ABSTRACT

A 1999 Chevrolet Silverado was converted to dedicated use of E85 (85% ethanol, 15% gasoline) by a team of students from the University of Nebraska-Lincoln. The goal was to develop an all-around vehicle capable of performing beyond the expectations of a stock vehicle in performance, emissions, cold start, driveability and fuel economy categories.

A major emphasis was placed on regaining lost power due to fuel energy, while maintaining California's Low Emissions Vehicle (LEV) standards and low fuel requirements. An aggressive design was created implementing the power derived from LS-1 technology combined with flow characteristics and torque production of the LM-7 engine.

INTRODUCTION

In 1981, alcohol fuel expert Michael H. Brown was quoted as saying, "Even after all the top brains have figured out everything on paper and failed to make it work, they still have access to tons of diagnostic equipment and large chunks of money to find out "why not?" Normally, Detroit doesn't put things on the market unless most of the bugs have been ironed out. This ironing out process has so far taken over 80 years for the gasoline engine."[1] This statement reflects the fact that even after 80 years (100 years at the present time), gasoline engine technology was/is still evolving. Even though the first internal combustion engine produced in the U.S. in 1798, was an ethanol fuel engine and attempts to use ethanol as a main fuel have been made at various times in U.S. history, research on ethanol-fueled internal combustion engines is still in its infancy as compared to gasoline engines. Work on ethanol engines, however, is evolving rapidly, and will continue to do so as new technologies become available which improve the efficiency of these engines.

Increasingly stringent emissions laws are advancing the production of alternative fueled vehicles (AFV). In the United States and other nations, technology has allowed for the production of many types of AFV's. A main focus of AFV technology in this country, is the use of fuels that reduce imported oil consumption and produce fewer emissions. Alternatives such as natural gas and propane fulfill these requirements but, like imported oil, their supply is limited. A solution to this problem is to use fuels that are reproducible and yet exhibit properties similar to gasoline. Alcohols such as methanol and ethanol have similar properties to gasoline and have been combined with gasoline to make blends that reduce emissions while increasing octane number.

While methanol produces results similar to those of ethanol, it is not as favorable of a petroleum substitute because of its toxicity and corrosiveness as compared to ethanol. Ethanol is also produced exclusively from renewable resources widely available in the U.S.

Environmentally as well as financially, ethanol is an excellent choice as an alternative fuel. Not only does it reduce emissions but it adds $51 billion in revenues to the United States economy while at the same time producing up to 55,000 jobs both on and off the farm[2].

Currently 1.5 billion gallons of ethanol are produced and consumed every year in the United States in a fuel called gasohol, a mixture of 90% unleaded gasoline and 10% ethanol. The use of ethanol in the U.S. has reduced carbon monoxide emissions 35 - 46% according to the U.S. Department of Energy. As current emission laws necessitate the production of lower emission vehicles, there is a push to produce vehicles that use completely alternative fuels. Unfortunately, most research performed to date has been on low ethanol and methanol blends with gasoline such as E10.

The University of Nebraska-Lincoln efforts are part of the Ethanol Vehicle Challenge, an educational program which is designed to use and apply state-of-the-art technology to improve and optimize the use of ethanol as a motor fuel. The competition is centered around the overall conversion of a 1999 Chevrolet Silverado with a 5.3L, Generation III Vortec V8 engine to dedicated use of E85. Figure 1 is a side view of UNL's 1999 Ethanol Vehicle Challenge vehicle.

Figure 1 Quarter mile testing of University of Nebraska-Lincoln Ethanol Challenge Vehicle.

VEHICLE CONVERSION

MECHANICAL

The resultant engine configuration is essentially a cast iron reproduction of an LS-1 engine with slight modifications. The near stock LS-1 configuration of the engine could offer distinct possibilities for future E85 fueled vehicles. Changes made to the engine configuration were designed to increase power output without sacrificing economy or engine-out emissions. Cost of prototype production was a major factor in the choice of engine modifications.

Compression Ratio

An increase in compression ratio generally increases the thermal efficiency of the engine. This relationship is shown in Figure 2 along with ranges of compression ratios for engines which utilize E10 and E85 fuels. This increase in thermal efficiency provides benefits to both fuel economy and engine emissions as well as power output. The stock compression ratio of the Silverado engine was increased from 9.5:1 to 11:1. This was achieved by using OEM LS-1 pistons in combination with a 0.030 inch face milling of the cylinder heads.

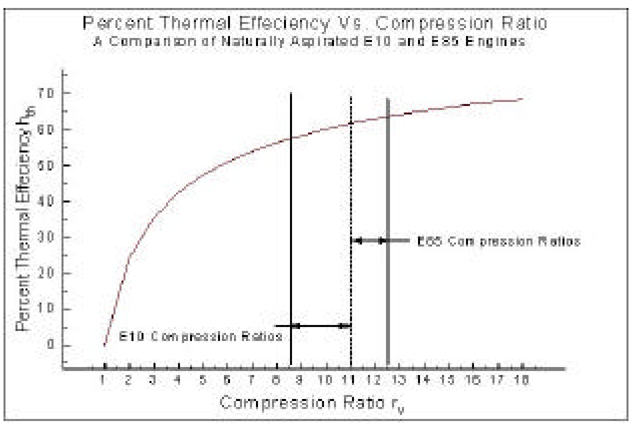


Figure 2 - Percent thermal efficiency vs. compression ratio for E10 and E85 engines.[3]

Pistons

The stock Silverado LM-7 pistons were replaced with General Motors OEM LS-1 pistons. To accommodate the larger diameter of the LS-1 pistons, the cylinder bore was increased 2.99mm to a new bore diameter of 99mm. The LS-1 pistons have a flat top crown design as opposed to a dished crown like those of the LM-7. Use of the flat top crown design over the dished crown piston design provided some of the contribution to the increased compression ratio.

Platinum Coating of LS-1 Piston Crowns

In an effort to enhance both combustion efficiency and provide a reduction in emissions, a submicron layer of platinum was applied via sputtering technology to the crowns of each LS-1 flat top piston. The catalytic effects of platinum have long been employed in the automotive industry, mainly in its use in catalytic converters for the reduction of harmful pollutants. By utilizing the catalytic effects of platinum in the combustion chamber, increases in both power and fuel economy can be achieved by more effective burning of the fuel. Catalytic combustion also allows for a reduction of harmful NO_x emission by lowering the complete combustion temperature. The non-reactive nature of platinum also provides a piston crown that resists oxidization resulting in reductions of abrasive carbon build-up that could shorten engine life.

Platinum deposition was performed utilizing the process of magnetron sputtering with ion assist. Magnetron sputtering is a physical vapor deposition process which allows for greater yields from the coating material by making use of magnetic fields. Ion assist is a process by which a bias voltage is applied to the part to be coated and allows for greater adhesion and uniformity of the coating. To prevent contamination from impurities during sputtering, the process is performed at sub-atmospheric pressures. A schematic for the sputtering process setup is shown in Figure 3.

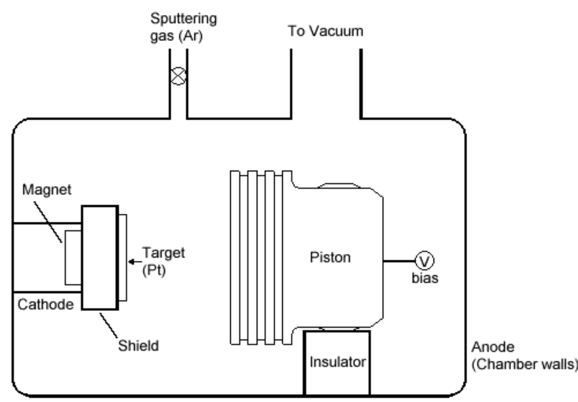


Figure 3 - Schematic of Platinum sputtering setup.

Heads

The stock aluminum 5.3L cylinder heads were replaced with production 5.7L LS-1 heads. The intake valve diameter was increased by 2.8mm to reduce pumping losses of the engine.

Exhaust

The Silverado's stock exhaust was modified to incorporate a true dual exhaust system with an equalization pipe. The stock muffler was replaced with dual Dynomax™ high flow, low restriction mufflers. 2.5" stainless steel pipe was used for the entire system to further reduce exhaust flow restriction. The pipe was flanged at the catalytic converters to aid in converter mounting and development.

Camshaft

The production LS-1 camshaft was used to help increase cylinder pressures and reduce pumping losses. The dimensions of the camshaft lobes provided an increase in lift of 0.40mm and 0.31mm for the intake and exhaust valves respectively. Also, increases in valve duration of 8° on the intake and 17° on the exhaust were achieved. The increase in lift and duration contribute to power gains in the engine by helping to create a more dense cylinder air charge.

Intake

An AirAid™ system (Figure 4) was incorporated to provide larger volumes of cool air for the air induction system. By supplying cooler air, more efficient air compression can be obtained with less heat created in the cylinder. Not only does this system create cooler cylinder temperatures, but it also allows for an increase in airflow through the filter. The increase in flow is needed to supply the 5.7L engine above 4500 RPM's with sufficient air to account for the increase in fuel as well as the increase in compression. The AirAid™ system replaces the original air box with a Cool Air Dam and a large low-restriction, cone-style filter.

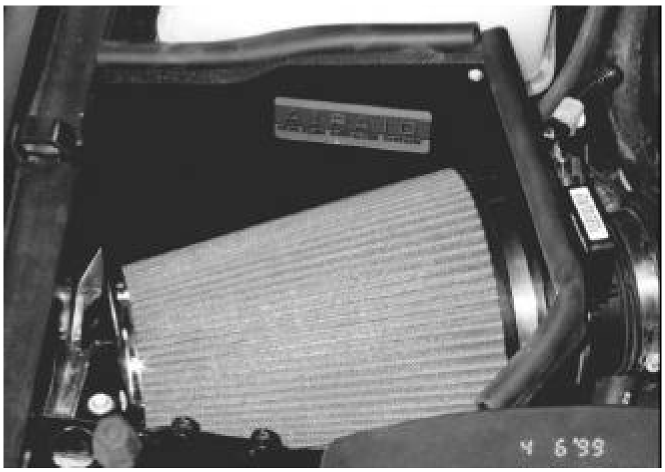
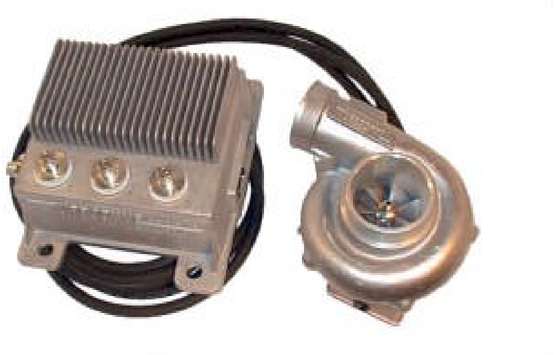


Figure 4 AirAid intake system and cool air dam.

Electrically Driven Supercharger

A Turbopac™ 2500 instant-on electric driven supercharger provided by Turbodyne Technologies, Inc. (Figure 5) was installed in the vehicle to further increase the power by providing boost pressures up to 3.5 psi.



The Turbopac™ produces low-end torque while eliminating constant parasitic draw of engine output as with conventional superchargers. Also, the near instant response time of the system eliminates any lag associated with conventional turbochargers. The system was installed prior to the mass airflow (MAF) sensor and the throttle body with a Y-shaped check valve located in-line with the induction system. This allowed the system to be added without changing the operation of the engine under normal conditions. The electric motor is controlled with a trigger relay, which turns the system on only under extreme throttle situations,(90% or greater throttle engagement), at which time the electric motor spins the supercharger, creating positive air pressure boost and increasing engine torque and power.

Batteries

The stock battery was replaced with dual Optima Deep Cycle batteries (Figure 6) running in parallel. This change was dictated by the demands of supplemental systems such as the air intake heater, air compressor, supercharger and a laptop computer. These additional current draws would cause the stock battery to deep cycle discharge up to 70% of it's total capacity, which dramatically shortens the life of batteries not designed for this use. A true deep cycle battery uses a stronger acid and a heavier paste material, to allow the batteries to cycle more often without damaging the batteries. These batteries also use SPIRACELL™ technology which improves vibration resistance by immobilizing the plates and provides increased power to size ratio. Each battery is rated at 750 cold cranking amps (CCA) individually and when run in parallel will produce a total of 1500 CCA, which will guarantee that there will be ample power at cold starts. Running the batteries in parallel also doubled the total capacity to 135Ah.

Figure 6 Optima deep cycle batteries

Spark Plugs

Normally, in a gasoline engine an increase in compression ratio from 9.5:1 to 11:1 would require the use of a slightly colder spark plug due to the increased cylinder pressures. However, with E85 as the fuel there was some uncertainty.

Several tests were run using a five-gas analyzer, which tests for the presence of CO, CO_2, O_2, NO_x, and HC. The tests were performed for different combinations of air/fuel mixtures ranging from 10.5:1 to 11:1. Also several plugs with different heat ranges were tested with both a 5° advanced and retarded ignition curve. Testing identified two sets of plugs that performed satisfactorily. They included the stock AC Delco plug, PN 41-952, and a Beru Ultra-X plug, PN UXF79. Both of these plugs are considered hot on the heat range scale and compared very closely on their individual tests.

One area of note was the satisfactory operation of the stock spark plugs under the increased cylinder temperatures. This is attributed to running a slightly rich air/fuel mixture for this testing, which required the plug to have a higher operating temperature to keep the electrode tip in the optimum temperature range so that complete combustion could be reached without the plug fouling.

Powertrain Control Module (PCM) Calibrations

Ethanol is an oxygenated fuel, which means that the air/fuel ratio must be adjusted if the engine is to run stoichiometric. For E85 combustion, the air/fuel ratio for stoichiometric operation will be lower than that for gasoline. Thus more ethanol fuel must be used as compared to gasoline. Part of the problem associated with burning more fuel can be offset by the increase in useable compression ratio, therefore taking advantage of the thermal efficiency allowed by the higher octane rating of ethanol.

In order to assist in configuring the PCM for optimum performance with E85 fuel, a Lambda sensor was installed adjacent to the O_2 sensor. The Lambda sensor was used to indicate lean/rich conditions and assisted in tuning the system for stoichiometry.

The air/fuel ratio was first calculated then fine tuned to account for vehicle specific requirements. The calculated value for a stoichiometric air/fuel ratio was 9.7:1. After testing, it was determined that an air/fuel ratio of 10.7:1 provided optimum performance for the engine as configured. Correct air/fuel ratio was determined by checking the fuel trim that the computer was using to correct emissions based on the oxygen sensors. With the stock 14.7:1 ratio the trim on E-85 was approximately +25%, indicating extreme lean burn conditions. When the air/fuel ratio was changed to 9.7:1 the trim was approximately -15%, indicating a slightly rich calibration. Eventually the air/fuel ratio of 10.7:1 was found in which fuel trim was approximately zero, indicating that the air/fuel ratio was as close to stoichiometric as possible.

During the air/fuel ratio refinement process, it was noticed that the engine also had a large number of misfires occurring during acceleration and deceleration. It was determined that this was the result of the colder set of spark plugs that were left in after second phase testing. The problem was narrowed to poor fuel quality coupled with cold plugs and was resolved with fresh fuel and hotter plugs.

FUEL SYSTEM

Materials Compatibility

Two general problems are associated with using E85 as a replacement to standard gasohol (E10). First, materials that would not normally be affected by gasohol may degrade in the presence of alcohols. Second, alcohols are more conductive than gasohol, which promotes galvanic corrosion by acting as an electrolyte. Materials that degrade in the presence of ethanol blends with high alcohol concentrations include brass, zinc, lead, and aluminum. Corrosion products from material degradation can damage and plug fuel system components.

Plastics and rubber components degrade in the presence of ethanol as well. These parts need to be replaced with an alcohol-resistant elastomer. Viton® is a flurohydrocarbon elastomer with the highest continuous heat resistance and outstanding resistance to swelling. Viton® has high resistance to permeation when in contact with aggressive alcohol fuels, such as E85.

The corrosion behavior of various commonly used materials in the presence of pure ethanol is detailed in Table 1.

Table 1 -Corrosion of materials in the presence of 100% ethanol[4]

Material	Compatibility Issue (Penetration level of)
Aluminum	< 2 Mils/year up to 180°F
Brass	< 20 Mils/year up to 210°F
Bronze	< 20 Mils/year up to 400°F
Carbon Steel	< 20 Mils/year up to 230°F
Copper	< 20 Mils/year up to 110°F
Nickel	< 20 Mils/year up to 200°F
Type 304 S.S.	< 20 Mils/year up to 210°F
Type 316 S.S.	< 20 Mils/year up to 420°F
Titanium	< 2 Mils/year up to 200°F

However, the penetration of materials in contact with ethanol is only half of the problem. Ethanol is most corrosive acting as an electrolyte in a galvanic corrosion environment. A galvanic series table should be consulted in conjunction with Table 1. For example, aluminum exhibits low penetration levels up to 180°F. However, aluminum is anodic to most materials and will corrode in a galvanic corrosion environment when in contact with a second dissimilar metal.

Currently, there is no galvanic series table indicating the activity/passivity of materials in a pure ethanol or E85 environment. It is thus necessary to make an assumption about the anodic/cathodic nature of various materials in an ethanol environment based on a known galvanic series in an environment such as seawater.

Component Changes for Compatibility

In order to develop a fully compatible ethanol fuel system, each component was analyzed in terms of corrosion penetration and galvanic corrosion. All components were required to be constructed of stainless steel or anodized aluminum and all seals were flurohydrocarbon elastomers. In the entire system, not one component fully met the requirements as specified, and all components were therefore replaced or duplicated with a suitable material.

Fuel Pump

An ethanol compatible fuel pump and gasket was supplied by Delphi to replace the non compatible stock unit. The main areas of concern for the compatibility of the fuel pump was with the internal seals of the pump and the fact that the pump was not completely electrically shielded. Due to the high electrical conductivity of E85, there is a possibility that a non-shielded pump and fuel level sensor could ignite the fumes within the tank.

Flexible Fuel Lines and Hard Plastic Lines

The factory flexible fuel lines and the hard plastic lines connecting the pump to the steel hard lines were reported to be non-ethanol compliant by GM and were replaced with Teflon lined stainless steel braided lines. However, the factory push-lock connectors were retained in order to connect these lines to the fuel pump, since there were not any replacement connectors available. The o-rings in these connectors were replaced with Viton B o-rings to comply with specifications.

Steel Fuel lines

The carbon steel fuel lines were not considered E85 compatible, due mostly to the possibility of galvanic coupling of the steel line with more noble materials. Corrosion byproduct clogging the fuel injectors and leading to a lean burn condition and the eventual self destruction of the engine was a possibility. The carbon steel lines were thus duplicated with a set of Type 304 stainless steel lines which retained all of the original factory positions. Because of the higher volumetric fuel flow required for E85, the fuel lines were tested to assure flow capability to sustain 5.7L fuel requirements at pressure . The stock line diameters of 3/8" on the supply line and 5/16" on the return line were found to be satisfactory and were maintained.

Fuel Filter

The fuel filter was replaced with an ethanol compatible filter manufactured by Paxton Fuel Systems as shown in Figure 7. The outer casing was anodized aluminum with the inner element of stainless steel mesh screen. Due to its length, the use of the filter required slight modifications over the original configuration which was accounted for on the replacement stainless fuel lines.

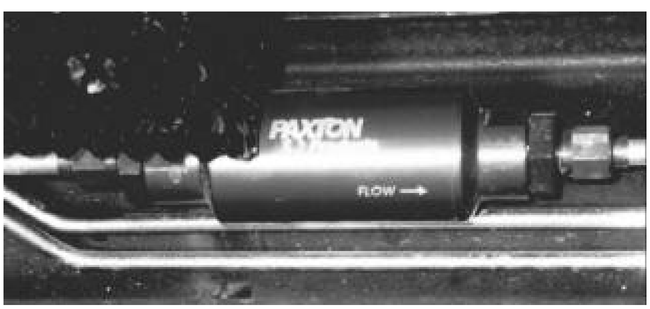


Figure 7 Paxton anodized aluminum fuel filter

Fuel Rails

The compatibility of the factory fuel rails was unknown and they were therefore replaced with anodized aluminum fuel rails designed to our specifications and manufactured by FORCE Corp., as shown in Figure 8. The original over-the-manifold H-style rail connection was replaced with a U-style connection fabricated with Teflon lined tubing. The U-style was chosen for manufacturing purposes and to allow the addition of a supplemental throttle body fuel rail.

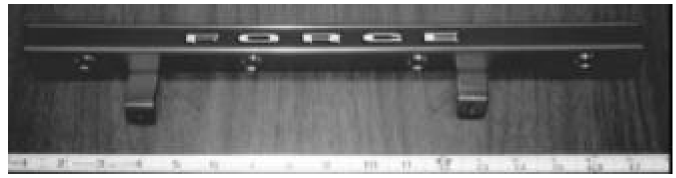


Figure 8 Custom Force fuel rail

Supplemental Fuel Rail and Injectors

A supplemental fuel rail (shown in Figure 9), which was designed to accept 3 additional injectors, was added for cold start purposes and fuel enrichment at high engine RPM (see Injector Control). The fuel rail and throttle body were constructed from anodized aluminum. The supplemental injectors were provided by Siemens, and were fully ethanol compatible with a flow rate of 4 g/s. Addition of the supplemental rail required the alternator to be pivoted out on its lower bracket, and a 2" longer accessory belt was installed to accommodate this change.

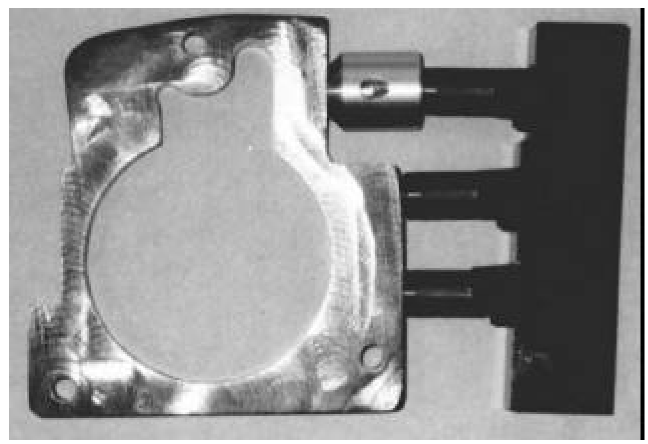


Figure 9 Supplemental throttle body and fuel rail injection system

Pressure Regulator

The U-style fuel rail made it possible to install an E85 compatible variable pressure fuel regulator to replace the stock pressure regulator. The regulator was fully adjustable from 40 psi to 150 psi, however the fuel pump was only capable of approximately 70 psi maximum. The regulator was installed between the fuel rail and return line to assure accurate fuel rail pressure.

Fuel Injectors

A dedicated ethanol engine requires 15-20% more fuel due to the lower energy content of ethanol. The OEM fuel injectors were replaced with ethanol compatible injectors supplied by Delphi. Because the OEM injectors flowed at approximately 65% duty cycle, it was only necessary to increase the flow rate 15% over the 5.3L gasoline injectors. The new injectors (shown in Figure 10) flowed 3.8 g/s and were acceptable for all engine speeds.

Flame Arrestor

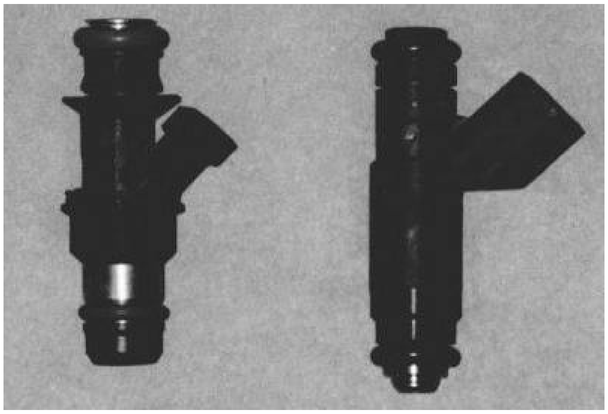


Figure 10 Ethanol compatible fuel injectors. Delphi 3.8 g/s main injector(left) and Siemens 4.0 g/s supplemental injector.

The flame arrestor was designed to meet competition requirements provided by GM and Argonne National Laboratory (ANL). The design consisted of a type 304 stainless steel housing containing two pipes, one with a 1.25” O.D. and one with 2.25” O.D. These dimensions allowed the OEM fuel fill and vent lines to be pulled over the stainless steel tubes and clamped with a hose clamp. A 12" section was removed from the original fuel fill and vent line to accommodate the flame arrester design.

Inside of the stainless steel tubes is a 40 mesh 304 stainless steel screen. The inside mesh is rolled in a 9“ long cone shape. The cone is intended to maximize the amount of fuel flow through the mesh as well as optimizing mesh surface area the fuel will be in contact with. The mesh will dissipate any heat entering the fuel fill hose from the outside and break up any propagating flame front. The outside mesh is connected at the top, forming a cone as well. The mesh is welded to the stainless steel tubing to insure long-term placement of the cones.

Supplemental Injector Control

The conversion of the stock 5.3-Liter LM7 engine to a 5.7-Liter LS1 increased fuel requirements above 4500 RPM as shown in Figure 11.[5] The LS1 engine requires roughly 2-3 grams/sec more than the stock LM7 configuration at this level. In order to utilize the cooling effects of the alcohol fuel which creates a more dense air fuel cylinder charge, a supplemental fuel injector system was created that would place two supplemental injectors between the existing throttle body and the intake manifold. These injectors are controlled by a Visual Basic computer program, run on a cab-located laptop computer that outputs the desired pulse waveform for injector control. The injectors are pulsed using a standard sink-to-ground design run by a digital output from the laptop. The Visual Basic program is based on analog throttle position sensor (TPS) voltage signal and analog CAM signal frequency. If the TPS reads a value greater than 95% and the CAM sensor indicates engine RPM above 2000 RPM, the supplemental program will enrich fuel flow. The PCM will manage anything below these two values since the fuel demands and maps are nearly identical to the LM7 configuration.

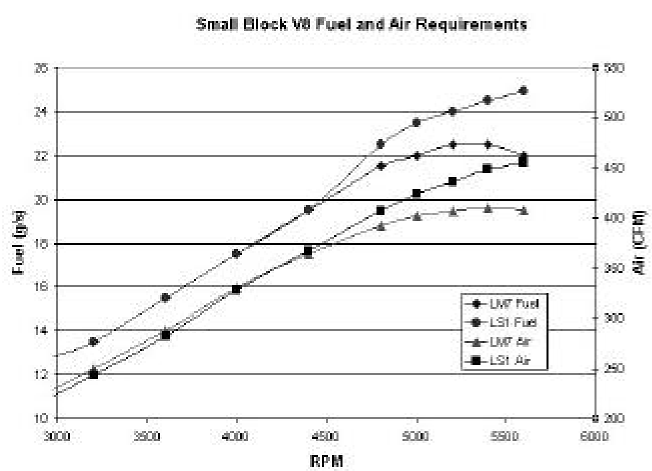


Figure 11 Small block V8 fuel and air requirements

EMISSIONS

Emissions are a major concern with any alternative fueled vehicle project. With concerns over the continual degradation of our environment growing daily, it is impossible for a alternative fuel to be considered as a viable replacement for performance proven gasoline without providing the possibility for reduced emissions.

Such is the case for ethanol. Although not a new fuel, ethanol has been historically avoided as a main automotive fuel except in times of long-lived oil shortages. Now with the development of low emissions vehicles powered by ethanol and ethanol blends, these fuels may be the most promising technology for low emissions.

Overview of Current Problem

Currently it is estimated that 60-80% of total vehicle emissions occur during the first few minutes of operation because the catalytic converters have not reached the required operating temperature. This is of considerable concern since a modern three-way converter is more than 90% efficient once it has reached its light-off temperature.

The use of E-85 in and of itself produces unique challenges for emissions reduction. Ethanol as a fuel tends to burn more rapidly and with a lower flame temperature than gasoline. The lower flame temperature of ethanol fuel means that less heat energy is released into the exhaust system from the engine, increasing the time to converter light-off.

Baseline Testing

Before any modifications were made to the existing emissions control system, baseline testing was performed on the stock configuration at Environmental Testing Corporation in Aurora, Colorado. Several FTP-75 cycles were run to establish baseline results.

Tests were run with both high-altitude certification fuel and E-85. As expected, lean-burn trouble codes were set during the baseline tests on E-85. As can be seen in Table 2, both HC and NO_x levels increased with the change to E-85. The rise on NO_x emissions was expected, and the increase in HC was determined to be the result of combustion near the lean flamability limit of the fuel, which caused misfire.

Table 2- Baseline Emissions Results

Fuel	HC	CO	NO_x
Shed 7.8	0.118	1.213	0.148
E-85	0.129	0.626	0.407

Tailpipe modal tests were also run in order to determine under what conditions the stock computer settings were allowing higher emissions. The testing results were compared to the ULEV standard since this was the ultimate goal.

On gasoline, the truck showed high levels for all three constituents during the first 2.1 minutes of the FTP test. After this time the converters reached the light off temperature and the O_2 sensors on the truck began cycling enough to aid the computer in closed loop fuel curve adjustments, as was indicated by a rapid fall off of all three pollutants. Once closed loop was reached, both CO and NO_x were at ULEV levels, while HC remained above ULEV throughout FTP testing.

The stock configuration running on E85 resulted in both HC and NOx emissions above ULEV for the entire test cycle. CO levels remained well below ULEV due to the lean operating conditions. The initial testing showed that the stock control strategy would need to be refined in order to meet ULEV standards with the 5.3L LM7. As can be seen in Figure 12, in the stock configuration hydrocarbon emissions is the only constituent that kept the

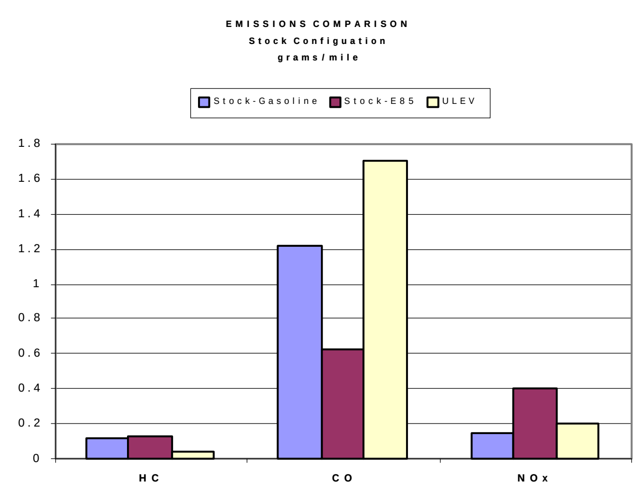


Figure 12 Comparison of emissions on stock engine configuration for E10 and E85

Silverado from achieving ULEV standards.

Cold Start Emissions Control Strategy

Prototype catalytic converters were manufactured by Delphi Automotive Systems with AESC coated catalysts as shown in Figure 13. These units were further modified by the UNL team in order to improve light off time and reduce overall emissions.

Basic changes included the addition of a phase change material (P-C-M) around the catalytic chamber and vacuum insulation of the entire unit. The P-C-M absorbs heat during operation of the system and eventually melts, absorbing large amounts of heat due the heat of fusion requirement. During non operation, the molten P-C-M slowly solidifies and releases this heat of fusion stored in

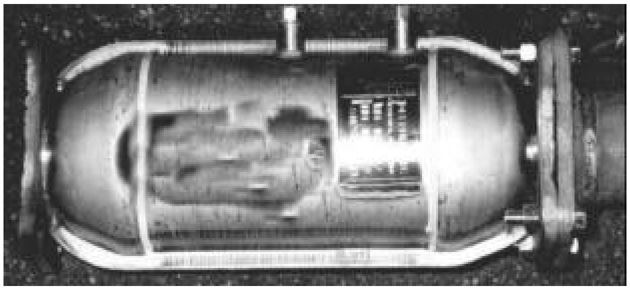


Figure 13 Delphi catalytic converter with AESC coated catalysts.

the material. This reversible heat storage strategy was used to keep the converters near operating temperatures at all times. The P-C-M layer was insulated with a vacuum wall which contained titanium hydride. When the outside wall containing the P-C-M reaches approximately 450°C, the hydride will begin to release hydrogen to the vacuum space, decreasing the vacuum to approximately 10^{-2} torr at 600°C This loss of vacuum increases heat loss of the system and prevents the converter from overheating. When the system cools below 450°C, the hydrogen is re-absorbed by the titanium hydride and the vacuum is re-established.

P-C-M shell construction consisted of encasing the catalytic converter in a shell with approximately ½" clearance. To do this a 12" length of #5 schedule 5 stainless steel pipe was welded to end caps so that the P-C-M would surround the monoliths of the converter. A hole was drilled to allow the P-C-M to be poured molten into the converter.

After construction of the shell the P-C-M was melted and poured into the converter. To accomplish this, the converter was heated to a temperature near the melting point of the P-C-M so that liquid P-C-M could be poured in without solidifying instantly upon contact with the shell. After the P-C-M was poured, the access hole was welded shut with a plate to seal the shell. The P-C-M in this application was an zinc alloy with a melting point of approximately 380°C.

At this point, the end caps for the vacuum shell were welded to the converter flanges, and the vacuum shell was sealed by welding a length of #6 schedule 5 stainless steel pipe to the end caps. After installing a small quantity of the metal hydride TiH_2 into the shell, a hole was drilled to allow the vacuum shell to be pumped down to a vacuum of 10-4 torr. After the shell was evacuated, it was sealed.

EGR Cooling and Control Strategies

Exhaust gas recirculation (EGR) has many effects on the emission characteristics of a vehicle. By increasing EGR it is possible to displace some air/fuel mixture, reducing fuel consumption and HC formation as well as decreasing the flame temperature to help lower NO_x levels. Again, a Visual Basic program and the laptop computer were used to control the EGR solenoid. This setup allowed rapid testing of several EGR strategies. The program used a data acquisition board to read engine RPM and MAP, then compared a table of EGR values before extrapolating the necessary output voltage for solenoid operation. The intention was to add extra EGR when cruising at constant speeds under low loads. When power was desired, the EGR was drastically reduced to allow the cylinder complete volumetric access for air/fuel mixture.

An EGR cooler was also added to the system. The cooler is essentially a tube-in-shell heat exchanger added to lower the EGR gas temperatures. It use engine coolant returning from the heater core to cool the exhaust gases. This increases the ability to lower flame temperatures so that higher reductions in NO_x can be achieved at constant engine speeds and low power demands.

Phase Two Testing

Upon completion of the new engine configuration, the truck was once again taken to Environmental Testing Corporation for emissions testing. At this time the only changes made to the computer were a change in A/F ratio, and fuel injector slope. The A/F ratio was set to the calculated ratio for E-85 of 9.7:1. The injector slope rate was changed to compensate for the higher flow fuel injectors. The tests resulted in high levels of CO as shown in Table 3, which was most likely due to a extremely rich fuel table calibration.

Tests were also run with a set of colder spark plugs. These tests resulted in higher exhaust emissions of all three constituents.

Table 3-FTP results from phase two testing

	HC	CO	NO_x
E-85	0.266	13.688	0.432
ULEV	0.05	2.2	0.4

COLD START AND DRIVEABILITY

Cold starting and driveability are an important issue to address when using E85. It is very difficult to create vapor at low temperatures with E85 due to low vapor pressures and heat of vaporization. For the Ethanol Vehicle Challenge, the required cold starting temperature is 20°F. At this temperature, the Reid Vapor Pressure (RVP) is nearly zero for E85. E10 has a RVP of approximately 1.5 at this temperature, which allows for a much greater degree of vaporization. Thus, it was necessary to develop a way to vaporize fuel droplets and heat inlet air to effectively start at these temperatures and to rapidly heat the engine for improved driveability after startup. An inlet air heater and an air assisted fuel injector were used to counter the effects of low RVP.

Air Inlet Heater

An air inlet heater was constructed from a heating element and 4" aluminum pipe anodized black for heat rejection as shown in Figure 14. The element was insulated from the tube with ceramic washers and placed between the MAF and the hard polymer intake resonator. A controller was designed such that the heater turned on only if the engine coolant temperature was below 70°F. Also, to avoid melting of intake components, the intake air temperature was designed to not exceed 200°F.

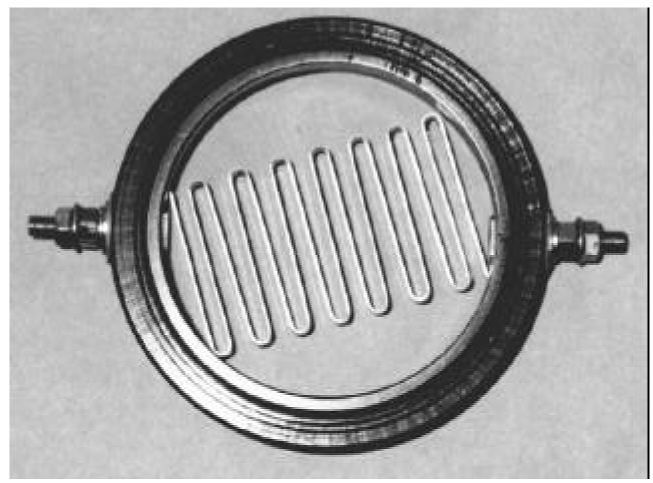


Figure 14 Inlet air heater

Two important components for heater control are the intake air temperature sensor and the coolant temperature sensor. The intake air temperature sensor is located between the intake air heater and the throttle body. The coolant temperature sensor is located in the intake manifold. A 5V signal is sent to the two temperature sensors as well as to two potentiometers. The sensors operate as thermistors, changing their resistance with temperature. Each temperature sensor is paired to a potentiometer. The circuit monitors the voltage output of the two temperature sensors separately and compares the voltage with the output voltage of their respective potentiometer. The output of the sensors and potentiometers goes into a dual op-amp which functions as two separate op-amps in the same chassis. The op-amp treats each one of the voltage inputs from the sensors independently and compares the voltage to a reference voltage for each of the sensors. If the sensor voltage output is lower than its respective reference voltage, the output of the op-amp switches from low to high voltage. Adjusting the respective potentiometer can change the reference voltage for each of the sensors which determines what temperatures the op-amps switch their output from low to high, thus dictating when the intake air heater is on or off. The two outputs from the dual op-amp then go into an and-gate. When both voltage inputs into the and-gate read high, voltage is allowed out of the and-gate to switch a transistor on. When on, the transistor allows current to pass into a 5V relay. The 5V relay then closes, energizing a 12V, 35A relay. The 12V, 35A relay then energizes a large starter-type relay which can carry the 90A of current necessary to power the intake air heater.

When the intake air temperature rises above 200°F, the circuit de-energizes the relays until the intake air temperature drops below 200°F, insuring that the intake heater will not overheat. The intake air heater only remains active until the coolant temperature rises above 70°F, at which point the heater shuts off. The circuit is designed such that the intake air heater will only operate when needed and not be detrimental to operation on warm days.

Air Assisted Injection

The secondary mechanism used for cold start was an air-assisted fuel injector, which consisted of a stainless steel cap that fits over the end of a standard ethanol injector. This acts as a supplement to the conventional port injectors and is located in the supplemental throttle body fuel rail.

The purpose of the air assist injector is to create a fine mist of fuel. As the air enters the cap, it comes in contact with the fuel and causes it to accelerate to a much higher velocity than under normal conditions. Since the fuel is traveling much faster than the manifold air, a collision takes place that applies shear forces on fuel droplets breaking them up into much smaller particles. The smaller particles have a much higher surface area to volume ratio, thus decreasing the energy required for ignition. It was determined that this was the most straightforward solution to overcome the problems of cold starting with ethanol. The basic stainless steel aircap is shown in Figure 15 and the vaporization action is shown in Figure 16 where it is demonstrated that a much finer mist is achieved with the air assist injector.

Figure 15 Stainless steel aircap

A low current 12V DC air compressor was selected to provide a sufficient reservoir of pressurized air in a tank that supplies air to the air- assisted fuel injector during cold start conditions. The air compressor would be used only to replenish the reservoir after the engine has started. A 12V DC normally closed solenoid valve controls the on/off flow of the air into a pressure regulator and

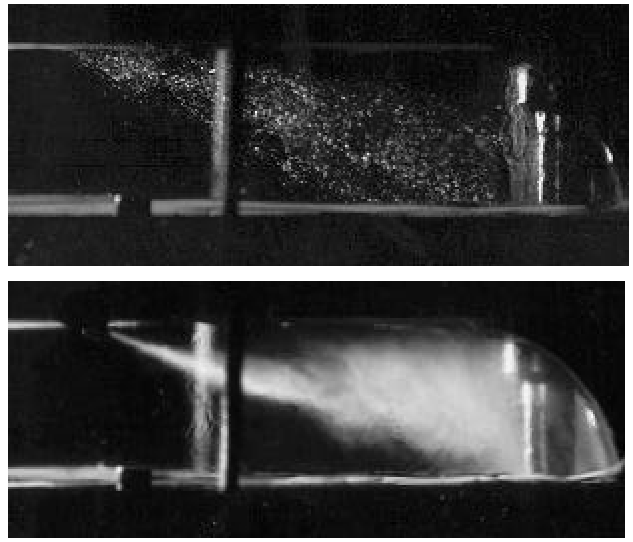


Figure 16 Injector fuel spray characteristics without (top) and with air assist. [8]

subsequently into the air injector cap. Precautions such as an inline pressure relief valve, pressure sensitive power switch, and a water and debris filter were added to insure safe operation of the compressed air delivery system. A schematic of the air injection system is shown in Figure 17.

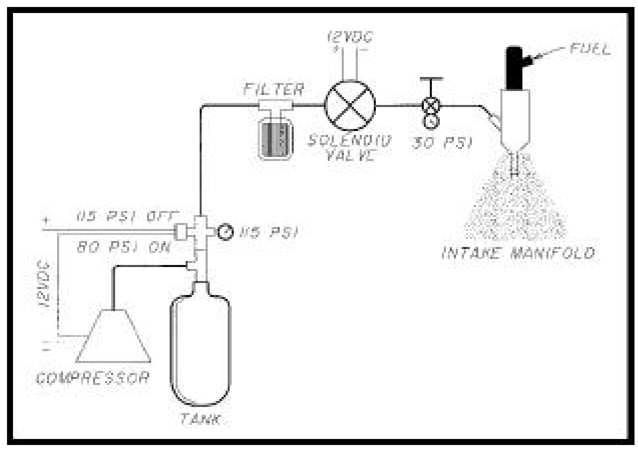


Figure 17 Cold start air injection schematic.

The air injection system was regulated by the Visual Basic program on the laptop using a PCMCIA card for input/output. The injector came on only when the coolant was below 50 °F and the starter was engaged. When the system was active, the air solenoid valve was opened, allowing 20 psi of air to be supplied to the assist cap via a ¼" line. The fuel injector was also cycled at this time.

BODY AND SUSPENSION

Paint and Appearance

The truck arrived with an onyx black exterior color from the factory. Upon arrival, the paint was sanded and scuffed in preparation for two solid Chromallusion stripes with Dupont Chromasystem base/clearcoats. The bed and cab were painted with True Blazberry, while the doors and hood were covered with True Fire Prizm. A solid gold Chevrolet bowtie was incorporated into the hood along with a large Husker 'N' on the roof. A top view of the truck is shown in Figure 18.

Chromed wheels were provided by Concept Neeper and B.F. Goodrich All-Terrain TA tires all were matched in size to original wheels and tires.

The factory grill was also replaced with a new billet aluminum grill.

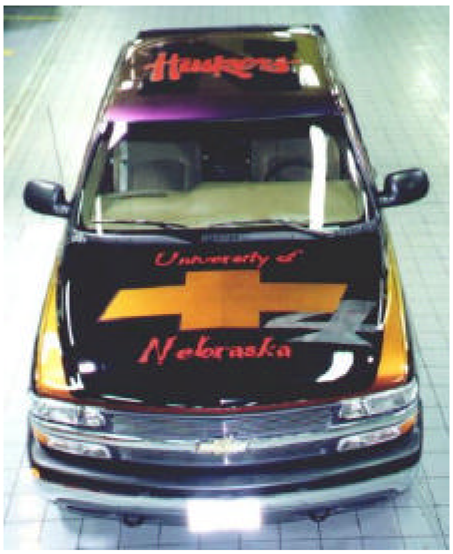


Figure 18 Top View of UNL EVC Truck.

Bed Locker

A flat, electrically-powered locking bed cover, manufactured by Bed Locker, was added to the bed for aerodynamic improvement and security for items stored in the bed.

Monroe Muscle LSE

The stock load support system was improved to allow the vehicle to handle larger loads. The Muscle LSE by Monroe was chosen to improve the stock system as shown in Figure 19. The Muscle LSE load supports consist of two hollow transfer-molded rubber springs that compress at a linear rate. These springs are larger and stiffer than the stock jounce bumper. This allowed for a more stable ride under loaded conditions than with the stock jounce bumpers without decreasing ride comfort under unloaded conditions. The system was designed to complement and reduce the stress placed on the original suspension. Consequently, Muscle LSE load support helps extend the life of the leaf springs and decreases the risk of costly repairs down the road.

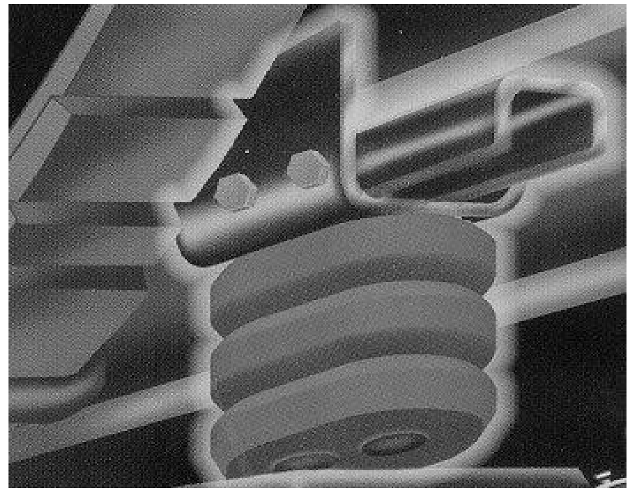


Figure 19 Muscle LSE load stabilizer.

Composite Driveshaft

A carbon composite driveshaft, provided by DANA (the manufacturer of the stock Silverado aluminum shaft) was installed. Because of its higher torsional stiffness, lighter weight and lower rotational inertia, the carbon composite driveshaft resulted in more effective transmission of power to the axle than the stock aluminum driveshaft.

Transmission

Modification to the OEM 4L60E was required to accommodate the increased horsepower/torque added to the truck. The stock transmission had a maximum torque rating of 350 ft-lbs. The estimated torque after engine modification was 400 ft-lbs of torque.

The overall objective for the transmission upgrade was to provide a stronger, firmer shift. This is a standard procedure when upgrading a transmission to handle a higher torque. This firmer shifting makes the overall ride more aggressive. The first modification was a master rebuild kit containing new gaskets, seals, sealing rings, friction plates, steel plates, front and rear bushings, lip seals and a filter. A set of first to second performance clutch plates and a high performance Kevlar band was then added to improve durability under high load shifting. Hardened pump rings were used to help stop ring breakage under severe use and to allow for a higher rpm. A large servo kit was installed to allow more hydraulic fluid to push against it creating more force, subsequently creating a firmer shift. Finally a Transgo™ shift kit, designed specifically for the 4L60E transmission, was added to provide a firmer shift, more control and to increase transmission durability.

The main concern was to replace items that encountered the most stress and that would provide a firmer shift. Slow gear engagement causes excessive wear on the clutches and surrounding parts. Overall, the transmission worked well with the upgrades and was built to handle the increased power of the engine.

TESTING AND RESULTS

Engine Dynamometer

The stock engine was used for the initial dynamometer testing and setup as shown in Figure 20. For baseline testing the engine was tested on a Superflow 7100 dynamometer in the as received configuration with both ethanol and gasoline. The stock flywheel was replaced with a manual flywheel from a 1998 5.3L engine. Then, 0.050" was turned off the face of the manual flywheel for clearance purposes (to engine bolts). The flywheel was fitted to accept an aluminum clutch plate and modified by removing all the fiber elements, retaining only the inner splined gear hub assembly and springs. The plate, hub and flywheel were all spin balanced as a unit. This unit acted as a torsional vibration damper as well as the engine-to-waterbrake link.

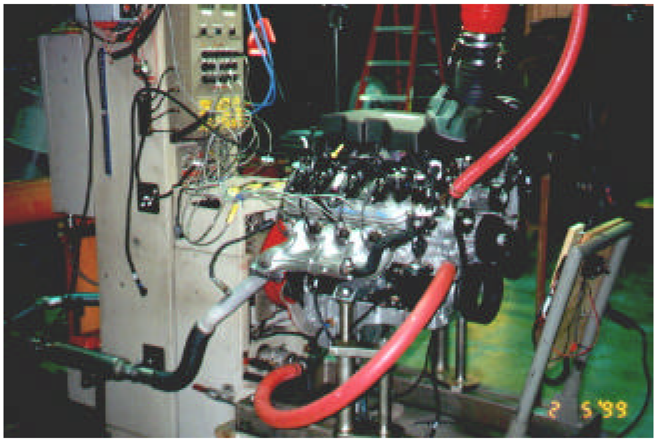


Figure 20 5.3L engine dynamometer setup.

The front of the engine was held using custom engine mounting brackets connected to the middle of the block in the stock mounting holes. Rubber bushings were used to absorb torsional vibration on the mounts. The brackets were then bolted to the dynamometer engine cart with two pedestal engine stands.The factory water pump was used along with all factory accessories. This allowed the use of the OEM belt to drive the pump. An oil filter cooling adapter was designed to allow extended periods of testing. The adapter cycled hot oil out through the filter, to the heat exchanger, and back through the engine.

Baseline Testing

An attempt was made to run the stock engine using the GM provided PCM with a dynamometer calibration. However, the injectors were not receiving a signal. The engine would crank, but no fuel was being delivered. According to Engine Data Bank 1 on the TEC II, the PCM had no fuel maps to read. The dynamometer calibrated PCM was taken to a local dealer to receive a truck calibration flash. Using the new truck PCM calibration, the engine started immediately and began to overrev. Tracing the wires revealed a factory reversed connection to the Idle Air Control, so the PCM thought it was correcting the overrev while inadvertently continuing to increase engine RPM.

Baseline power and torque as achieved on the stock configuration is given in Figure 21. The curves achieved for E85 were created after the PCM had undergone the learning process. The PCM has the ability to recognize and recover for lean/rich burn situations.

RESULTS

Emissions

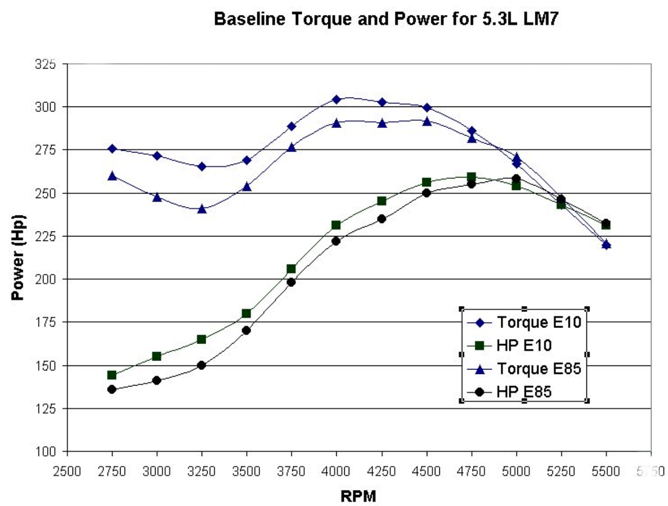


Figure 21 Baseline torque and power curves for the 5.3l LM7 on E10 and E85.

Once all modifications were complete, final testing was performed to obtain emissions and performance numbers. Emissions testing was done at both Delphi Automotive's Rochester, NY facility and at the General Motors Proving Ground in Milford, Michigan. Final emissions testing resulted with NO_x and CO well below the CARB ULEV standards and HC slightly better than Federal Tier 1 Emissions Standard. These results are shown in Table 4.

Table 4 - Final Emissions Results

	HC	CO	NO_x
E-85	0.207	1.431	0.315

Performance

Final engine torque and horsepower curves are shown in Figure 22, and were obtained through chassis dynamometer testing. Due to the use of a chassis dynamometer, the data displayed in Figure 22 was taken at the rear wheels.

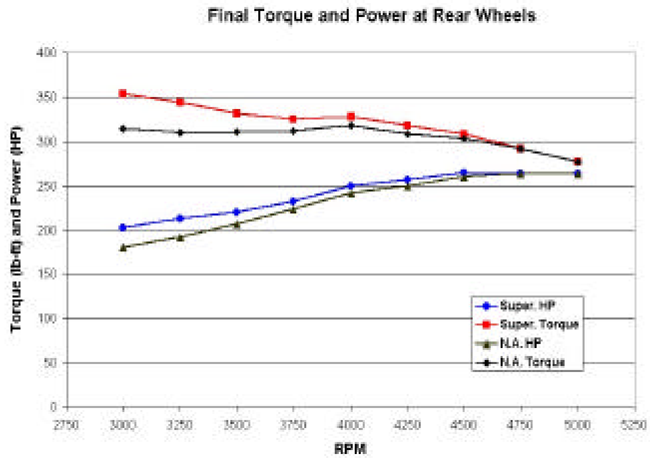


Figure 22 - Final torque and horsepower curves at the rear wheels

CONCLUSIONS

In summary, the following conversion features were implemented in the University of Nebraska-Lincoln EVC vehicle which resulted in better emissions, engine performance, and cold-startability:

- Cast Iron LS-1 Clone.
- Platinum Coated Flat Top LS-1 Pistons.
- LS-1 Aluminum Heads and Camshaft.
- 11:1 Compression Ratio
- 10.7:1 Air/Fuel Ratio
- Vacuum Insulated Catalytic Converters with Phase Change Material.
- Increased Induction System including Electric Supercharger.
- Supplemental Fuel Rail for High Engine RPM Fuel Enrichment and Cold Starting.
- Dual Exhaust with High Flow, Low Restriction Mufflers and Water Cooled EGR.
- Fully Ethanol Compatible Fuel System.
- Dual Deep Cycle Batteries.

Through the use of these existing and experimental technologies, the University of Nebraska-Lincoln was able to create a production feasible ethanol (E85) vehicle.

Existing LS-1 engine technology was used to increase compression ratio and overall torque and horsepower which led to better vehicle performance. Also, by fine tuning the vehicle's PCM through calibrations, the engine was allowed to operate in a range that benefitted emissions and fuel economy without sacrificing engine performance.

To aid in further vehicle emissions reduction, experimental vacuum-insulated, phase-change catalytic converters were fabricated. These catalytic converters used in conjunction with an EGR cooler reduced vehicle emissions below that of the stock gasoline vehicle.

Other experimental technologies, such as the air-assisted injection, combined with the air inlet heater, provided a solution to the problem of cold-starting the vehicle at temperatures close to 0°F.

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Siemens
Aamco Transmissons
TransGO
ArtCarr Performance
Valeo
ASEC
Bed Locker
Concept Neeper
Dana
T.O. Haas (B.F. Goodrich)
GoodYear Belts and Hose
Walker Mufflers
Monroe
AirAid - Evergreen Performance
Spanel Engines
Halvorsen Boys Toy Farm
TeleFlex
Dr. William Weins
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