E85 Conversion Kit

A SENIOR REPORT

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Abstract

This goal of this project is to come up with a process to convert a gasoline engine to work with E85. E85 is a fuel that is made of 85% ethanol and 15% gasoline. Ethanol has a lower heating value but has a higher octane value which makes it a good replacement for gasoline. To make sure that the fuel burns completely, the group will focus on ignition timing and fuel injection control. Proper combustion chamber temperatures must be reached to assure full burn of the fuel for maximum power and minimum emissions. Blending of E85 and gasoline also must be considered due to the fact that in the United States E85 does not always represent a perfect mixture of 85% ethanol to 15% gasoline. For example, winter blends of E85 are often, in reality, 70% ethanol and 30% gasoline. All aspects of the engine must be considered to optimize the system for peak performance, optimal fuel economy, and the lowest emissions possible.
Table of Content

PROJECT BACKGROUND ............................................................................................................. 5

PROJECT OBJECTIVES ............................................................................................................. 6

PROJECT STATUS .......................................................................................................................... 6

PHASE I ......................................................................................................................................... 6

PHASE II ....................................................................................................................................... 7

PHASE III ..................................................................................................................................... 8

TECHNICAL ANALYSIS .................................................................................................................. 8

FLAMMABILITY AND EXPLOSION LIMITS .................................................................................... 8

CHEMICAL REACTION ................................................................................................................. 9

ANALYTICAL MODEL IN EXCEL .................................................................................................. 11

TORQUE AND POWER .................................................................................................................. 14

EMISSIONS .................................................................................................................................... 14

FINAL DESIGN ............................................................................................................................. 15

COMPONENTS OF DESIGN ........................................................................................................... 17

APPENDIX .................................................................................................................................... 19

APPENDIX A .................................................................................................................................. 19

APPENDIX B .................................................................................................................................. 20

APPENDIX C .................................................................................................................................. 288

APPENDIX D .................................................................................................................................. 355

APPENDIX E .................................................................................................................................. 357

APPENDIX F .................................................................................................................................. 358
Important Figures and Tables

Figure 1 Burn Fraction .................................................................................................................. 13
Figure 2 Pressure when mfb50 at 8 CA ...................................................................................... 19
Figure 3 Pressure, Work and Temperature when Theta SOC is -5 CA ........................................ 21
Figure 4 Pressure, Work and Temperature when Theta SOC is -2.5 CA .................................... 22
Figure 5 Pressure, Work and Temperature when Theta SOC is 0 CA ......................................... 24
Figure 6 Pressure, Work and Temperature when Theta SOC is +2.5 CA .................................... 25
Figure 7 Pressure, Work and Temperature when Theta SOC is +5 CA ........................................ 27
Figure 8 CEA-Otto first and second iteration ............................................................................. 34

Table 1 Ratios for chemical balance ............................................................................................ 9
Table 2 Chemical reaction equation ........................................................................................... 10
Table 3 US EPA chart on Laminar Flame Speed ......................................................................... 12
Table 4 List of Components needed .......................................................................................... 17
PROJECT BACKGROUND

E85 is a mixture that consists of 85% ethanol and 15% gasoline. Through research, it was determined that using E85 instead of gasoline in automobiles has many benefits. These benefits are environmental, economical, and also political. However, there are also some disadvantages upon the completion of an alternative fuel conversion. Therefore, it is necessary to determine the appropriate trade-offs where needed in order to complete a successful design. The following discussion outlines the way in which the use of E85 in automobiles will be beneficial for this generation as well as for generations to come.

There are many reasons that an E85 conversion would be advantageous. Today, the United States imports more than 50% of the oil, the United States is dependent on foreign oil as a nation, which is detrimental to the economy in many ways. Conversions to E85 would exponentially decrease the dependence of imported oil. Ethanol is a domestic product; it can be made, packaged, and sold right in the United States. The environmental benefits would impact the entire world, not just the population of this country. The E85 mixture burns a lot cleaner than gasoline does. Based on this fact alone, it can be stated that the use of E85 is an environmentally friendly alternative to gasoline. The amount of pollution emitted by automobiles would be reduced, thus reducing greenhouse gases that can cause global warming. The political implications of E85 conversions are quite obvious to some. The nation’s economy would improve from the creation of a huge market for a domestic product and the nation’s dependence on foreign oil would decrease significantly. The environment is also a very important aspect of politics in this age. There are many environmental movements occurring in the world, such as Green Peace and Live Earth, that are a committed to reducing the carbon footprint left on this planet. Widespread E85 conversions would allow automobile operators the opportunities to do their part in helping the economy and environment.

Eventually, the oil supply is going dry up because it is not renewable. Therefore there needs to be a form of renewable energy available to fuel automobiles. E85 can be the answer. Ethanol is totally renewable, since a new crop is grown every year and will be always be available. However, there are many other factors that contribute not only to the feasibility of a conversion but also the practicability of completing a conversion. The chemical composition of ethanol contains a significantly less amount of stored energy than regular gasoline does. One gallon of E85 has about 73% the energy of one gallon of gasoline. Therefore more E85 has to be burned to create the same amount of power. This can be over come with larger fuel injectors and gas tanks. Some testing shows that vehicles burning E85 instead of gasoline can experience a fuel economy drop of 10%-20%. On the other hand, E85 is currently a little more than a dollar cheaper per gallon than gasoline and provides the benefits to the environment and the economy.

Opponents of using E85, and of the conversion kits, say that the fuel itself is inefficient. Producing a gallon of E85 requires an investment of about half as much energy as it produces. They believe that electric and hydrogen-fueled cars are the future of the automobile industry and that the investment in E85 technology, research, and development is waste of time and money. Ford and General Motors are under scrutiny from critics about spending their resources on
ethanol. Right now, there is no way to know what impact E85 conversion kits will have on vehicles and on the oil industry. As a quick answer to America's dependence on foreign oil, they appeal to many people. There isn't enough information available to know if they will be a long-term solution. Through the testing of E85 performance and the lifting of the EPA's ban, that prohibits conversion because of emission concerns, researchers and vehicle owners can explore those questions.

PROJECT OBJECTIVES

The objective of this senior design project is to design a conversion kit that is capable of converting a gasoline engine to fully operate using E85 as the fuel source. To do this, the group will fabricate a control system unit to manage the engine’s operation. The project goal include but are not limited to developing an E85 Flex Fuel conversion kit meeting EPA certified emissions testing while maximizing the fuel efficiency, increasing performance, and reducing emissions. The conversion kit should provide the public with a simple alternative fuel option on their existing automobiles without major modifications to the engine. The group is interested in the endless benefits that an E85 option offers the public. The group has researched the benefits of alternative fuels and the behavior of the engine using ethanol-gasoline blends.

PROJECT STATUS

The senior design project is entering PHASE IV. Through the first three Phases the group has learned a great deal about the topic. The first three Phases included conceptual design, technical analysis and engineering design. Each Phase had a specific purpose and was an essential part of the entire process. At this point the group is prepared to order the needed materials. The group is to build and test the system in the coming months. The group has also learned to manage their time and to plan according with the use of a Gantt chart. The Gantt chart is attached with the most current information available.

PHASE I

During Phase I, the group was presented with the project at hand and initiated the preliminary stages of the design process. The first thing completed was to define the project objectives. This took a significant amount of time to complete because of all of the different design approaches that the group could have pursued. This was a very critical decision, as it would affect the direction and scope of the project. The options available to the group were as follows: a proof of concept which would have included in depth analysis of the engine’s performance and operation, modify a carbureted engine by altering its parameters to operate on E85 while testing emissions and performance, convert the SAE competition car to run on E85, or use a small motorcycle engine with a conversion control system that allowed full control of the engine parameters to optimize the performance. This was a difficult part of the process because of the uncertainty that surrounded the resources available, the testing procedures available, and the general scope and direction of the project. From that point research was performed, to learn about the current uses and about any research that has been done on E85. The groups discovered
what others have done and are doing with the alternative fuel. The group determined the demands and significance of our project in relation to everyday life. This was completed by researching existing devices, searching related commercial information, and finding patents that have been rewarded relating to the use of E85 in automobiles. At this point a comparison matrix was constructed to highlight and compare the design options at hand. The group choose the control system design option because, of the flexibility it allows with the engine management. The proof of concept was eliminated because several research papers were found of the essential data. At the end of PHASE I it was determined that the group would develop a piggyback system for the engine’s computer that would essentially be a closed loop feedback control system consisting of three sensors: a flex fuel sensor, an emission gas temperature sensor, and an O2 sensor. The control system would use the feedback from the three sensors strategically located in the automobile to make adjustments to the engine’s performance on the fly. The control system would alter parameters such as ignition timing and fuel control.

PHASE II

The main objective of PHASE II was technical analysis. Since the project scope and objectives have been clearly defined, the next step was to determine the best configuration and operation of the control system. Through research it was found that the most important aspect to focus on was the ignition timing. This would affect all of the other outputs that the group was concerned about such as performance, horsepower, and emissions. The timing would be the basis of the technical analysis. However since there were four main areas of technical analysis required, the group also looked into the explosion limits of E85, the emissions of the engine, and the power and torque produced by the E85. Since the group wanted the engine to have the ability to run on all blends of ethanol and gasoline (since in reality availability is an issue), the technical analysis was performed for many different mixtures. Depending on geographical location in the United States, E85 can be as close as around the block or as far as 150 miles away. From Hoboken, NJ, the closest public gas station that sells E85 is in Philadelphia, PA. However, as the use of E85 spreads, the availability will increase. Today there are just over 1200 E85 stations in the country with another 300 to be opening in 2008, 17 of which are in New Jersey. It was necessary to analyze different blends because ethanol is often sold in different mixtures. For example during the cold winter months, E70 is sold instead of E85 to reduce cold start problems. The technical analysis was used to determine certain design specifications so that the engine will be able to run on any mixture of ethanol and gasoline, from 100 % gasoline up to E85. The group wanted the conversion kit to be different and unique. Some kits available today require the use of a switch to allow an engine to run on E85. The switch method is also not the most practical in situations were one may need to fill up with a tank of regular gasoline because E85 is not available. The tank mixture may end up in between the two operating mixtures causing unpredictable results. The conversion designed by the group will require no interaction and will be able to make all the adjustments using the closed loop feedback system. At this point some results obtained were as follows: variation of ignition timing will affect temperature, pressure, and work; the system will have universal compatibility and will be fully tunable; and a 5% increase in power is expected while running on E85.
PHASE III

PHASE III focused on engineering design, wrapping up all the work of the entire first semester. The information gathered from research and the technical analysis was used to finalize the design of the control system. The group used information gathered to make educated decisions about the features included in the final design. The group has a strong understanding of the technical capabilities of the control system. The control feedback loop will consist of an oxygen sensor for air/fuel ratio control, flex fuel sensor determined fuel composition which will essentially decipher the blend of ethanol and gasoline being used in the engine, and the exhaust gas temperature sensor monitors the temperature of the exhaust gases and essentially the emissions. During this Phase, the design and layout were finalized and testing procedures were discussed. The proper testing procedures are expensive and difficult to perform, however the group feels confident that the testing can be performed using alternative method and directly comparing the performance of the same engine running on gasoline versus E85. At this point in the project, the group has developed a table of the needed materials that have to be purchased and a detailed summary of the budget required with this particular project. The parts needed to construct the conversion kit will be ordered soon, so that the group can get an early start on PHASE IV and begin the building Phase of the project.

TECHNICAL ANALYSIS

The team’s technical analysis focused on four major areas: flammability limits, Timing, power/torque and emissions. Spark ignition timing is an important parameter in engine designs because pressures and temperatures inside the cylinder chamber have a strong dependence on this parameter. It also affects the efficiency of the engine to the point where the power output might be optimal or not efficient. The same dependence occurs with emissions where the product from the chemical reaction inside the cylinder chamber might emit more pollutants if the pressures are too high. Therefore, a tradeoff between emissions and power will be necessary and will affect the pressure.

FLAMMABILITY AND EXPLOSION LIMITS

Before work could be started on the project it had to be shown that the idea was feasible. Although there has been work done in the past using E85, it was decided to re-evaluate the project to obtain the learning experience. Flammability and explosions limits of gasoline and ethanol were determined to figure out if combustion was likely. The range for flammability limits fell inside those explosion limits so it was decided to only evaluate the flammability limit to be sure that there would be no problems with combustion. The equation used for combining the flammability limits is:

\[
\text{LEL} = \left( \frac{P_1 + P_2 + ... P_n}{P_1/\text{lel}_1 + P_2/\text{lel}_2 + ... P_n/\text{lel}_n}\right)
\]

LEL is the lower explosion limit for the combined fuel, P is the volume fraction of the component and lel is the lower explosion limit of the component. Using this information and
engineering charts the upper and lower limits were found for each mixture. By replacing the lower explosion limit with upper explosion limit we can also obtain the results for the maximum fuel to air concentration for proper combustion.

The lower explosion and upper explosion limits for gasoline were found to be 1.4% and 7.6% respectively. This can be related to lambda and thus air fuel ratio. The stoichiometric value for gasoline is a 6.3% ratio or 14.7 parts of air to 1 part of fuel. Using these values the air to fuel ratio can be found for the upper and lower explosion limits. The lean limit for gasoline is found to be 70.4:1 air to fuel ratio. The rich limit is found to be 12.15:1 air to fuel ratio. Although these values may seem slightly impractical it must be realized that these are the values at standard temperature and pressure. Once you increase the temperature and pressure as in the internal combustion engine the air to fuel ratio range widens. The standard range for gasoline is 11:1 to 19:1 so the calculated values are more than feasible given the increase in pressure and temperature.

The same process is now repeated for E85. For E85 the calculated upper and lower explosion limits are calculated to be 2.8% and 13% respectively. The stoichiometric percentage for E85 is 9.3%. The stoichiometric air to fuel ratio for E85 is 9.733:1. Thus the corresponding air to fuel ratios given the explosion limits would range from 6.69:1 to 34.7:1 air fuel ratio. Again, these values are typical in an internal combustion engine. The chart in the appendix A.4 shows the maximum power for a given air to fuel ratio for the different fuels.

### CHEMICAL REACTION

E85 is 85% of ethanol and 15% gasoline by volume. Knowing the density of both ethanol and gasoline, we can calculate to what ratio that the two fuels should be mixed to have E85. The ratio in the table below was calculated by using the following equation and assumption.

\[
\text{Ratio} = \frac{\%\text{Fuel} \times \rho}{m_{\text{fuel}}}
\]

**Table 1 Ratios for chemical balance**

<table>
<thead>
<tr>
<th></th>
<th>% by volume (m³)</th>
<th>Density (Kg/m³)</th>
<th>Mass (Kg)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel 1</td>
<td>85</td>
<td>780</td>
<td>46</td>
<td>14.41304</td>
</tr>
<tr>
<td>Fuel 2</td>
<td>15</td>
<td>750</td>
<td>114</td>
<td>0.986842</td>
</tr>
</tbody>
</table>

For example, assuming in 1m³, you have 0.85m³ of ethanol, you can find the mass of ethanol in 1m³ by multiplying this volume by the density. Then by dividing the mass of ethanol in 1 m³ by the mass of ethanol for 1 mole, you would get the right mole ratio to plug in the chemical balance equation. The same method can be applied to find the mole ratio for gasoline.
Table 2 Chemical reaction equation

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Coefficient</th>
<th>Component</th>
<th>Subscript</th>
<th>Product</th>
<th>Coefficient</th>
<th>Component</th>
<th>Subscript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel 1</td>
<td>14.4130434</td>
<td>C</td>
<td>2</td>
<td>36.720823</td>
<td>8</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>14.4130434</td>
<td>H</td>
<td>6</td>
<td>36.720823</td>
<td>8</td>
<td>O</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>14.4130434</td>
<td>O</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel 2</td>
<td>0.98684210</td>
<td>C</td>
<td>8</td>
<td>52.120709</td>
<td>4</td>
<td>H</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.98684210</td>
<td>H</td>
<td>18</td>
<td>52.120709</td>
<td>4</td>
<td>O</td>
<td>1</td>
</tr>
<tr>
<td>Air</td>
<td>55.5746567</td>
<td>O</td>
<td>2</td>
<td>208.96070</td>
<td>9</td>
<td>N</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>208.96070</td>
<td>N</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To verify that the chemical reaction was correct, the air-fuel ratio was calculated and turns out to be $9.83 \approx 10$ for E85.

CEA-Otto and a program in excel was used to simulate the cycle of a Suzuki GSX-R. Having the chemical composition of the fuel, it was put into CEA-Otto. This analytical model is used to calculate the pressures in the spark ignition engine and will be used as a starting point in the experimental setup of the engine. This model follows closely the work done by Lars Erikson “An Analytical Model for Cylinder Pressure in a Four Stroke SI Engine.” The emissions were not modeled as they are very complicated to describe in an analytical model but will be discussed. The effects of ignition timing will also be explained.
ANALYTICAL MODEL IN EXCEL

Assumptions

- $\theta_{ivc}$ is 150°
- $p_{ivc}$ is approximately 1.01325 bar
- $k_c$ and $k_e$ are selected to be 1.25 and 1.3 respectively
- The equivalence ratio is 1

Pressure and Temperature modeling

The model for the pressure plot consists of three parts: the two polytropic processes for the compression and the expansion stroke and the combustion process which is an interpolation between the two processes. To proceed with the pressure plot, we must first find the pressure when the intake valve is closed ($p_{ivc}$).

Initial pressure

The pressure when the intake valve is closed depends on the intake manifold pressure $p_{im}$.

\[ p_{ivc} = p_{im}(\theta_{ivc}) + c_1 + c_2N \]

Where $c_1$ and $c_2$ are parameters that have to be determined and take into account when the throttle is closed or wide open. From the equation, the speed of the engine factors in the initial pressure. However, for simplicity, we will use the following relation:

\[ p_{ivc} = p_{im}(\theta_{ivc}) \]

Initial Temperature

This model depends on the CEA-Otto simulation that takes into account residual mass and heat transfer.

Compression process

The compression process can be modeled with accuracy by a polytropic process. The following equations for the compression process are described by the exponent $k_c$ and the conditions at the intake valve closing.

\[ p_r(\theta) = p_{ivc} \left( \frac{V_{ivc}}{V(\theta)} \right)^{k_c} \]

\[ T_r(\theta) = T_{ivc} \left( \frac{V_{ivc}}{V(\theta)} \right)^{k_c-1} \]

This part of the cylinder pressure is accurate until the start of ignition.

Expansion process
The expansion process is modeled in the same manner that the compression process was described. However, the polytropic exponent \( k \) is different and \( V_3, T_3, \) and \( p_3 \), must be determined. Those values are taken from CEA-Otto since it takes into account the properties of the fuel and gas in the combustion chamber.

Combustion process – interpolation

Combustion phasing

The pressure in the combustion process is strongly affected by the ignition timing and combustion phasing. To have the combustion at top dead center (TDC), the position of the crank angle is \( 0^\circ \) and is given by the following equation

\[
\theta_c = mfb_{50} - MFB_{50, opt}
\]

Where \( mfb_{50} \) is the angle for 50\% of the mass fraction burned gas and \( MFB_{50} \) is the optimal angle for 50\% of the mass fraction burned gas. The optimal angle for 50\% mass fraction of burned gas is usually between 0 and \( 10^\circ \) and in this case it is chosen to be \( 8^\circ \). The actual mass fraction burned is given by

\[
\Delta \theta = \frac{\theta_d}{2} + \theta_b
\]

Since we do not know the flame development angle \( \theta_d \) and the fast burn angle \( \theta_b \) of our engine, the burn duration of our model was estimated in a different way. Since we could easily find the laminar flame speed of both gasoline and ethanol and the combustion duration of typical gasoline engines, the following equation was used

\[
\frac{\Delta \theta_{Gasoline}}{\Delta \theta_{Ethanol}} \approx \frac{\text{Turbulent flame speed of Gasoline}}{\text{Turbulent flame speed of Ethanol}} = \frac{LFS_{Gasoline} \times C}{LFS_{Ethanol} \times C}
\]

\( C \) is a constant that relates the turbulent flame speed to the laminar flame speed. LFS is the laminar flame speed of the fuel. From the figure below, we can see that for an equivalence ratio of 1, the laminar flame speed of gasoline is 27 cm/s and 42 cm/s for ethanol. The typical combustion burn duration for a SI engine is about 40-50 crank angle degrees. Therefore, if we pick a combustion duration of 45\(^\circ\) CA, the typical combustion duration for E85 can be approximated. The burn combustion for E85 is estimated to be 30 crank angle degrees.

Table 3 US EPA chart on Laminar Flame Speed

![Graph showing Laminar Flame Speed](image-url)
Pressure interpolation

By using a pressure ratio that behaves like the mass fraction burned of the fuel, the combustion part of the process can be calculated from the Weibe function:

\[
P_{R}(\theta) = 1 - e^{-\left(I\theta - \theta_{SOC}\right)^{m}}
\]

Where \(a\) and \(m\) in the Weibe function fit experimental data for values of 5 and 2, \(\theta_{SOC}\) is the crank angle at start of combustion and \(\Delta\theta\) is the burn duration. The intermediate part of the pressure modeling from the start of combustion to the end was defined by:

\[
p(\theta) = (1 - P_{R}(\theta))p_{b} + P_{R}(\theta)p_{e}(\theta)
\]

Result and Discussion

Optimization

Given that the optimal mass fraction of burned fuel should be between 0 and 10\(^{0}\) CA (8 in this case,) the optimal spark timing can be estimated.

![Burn Fraction](image)

**Figure 1 Burn Fraction**

If that crank angle of 8 is chosen, it is not the best spark timing for this design and it can be shown in the pressure plot in Appendix. This can be explained by the faster combustion rate of E85. By varying the timing, the best timing will be determined by the best pressure plot.

Effect on Pressure

Pressure is strongly dependent on the start of combustion. By changing the start of combustion timing from -5 to 5\(^{0}\) CA, the pressure decrease from 95 bar to 75 bar. This decrease can be explained by the relief of the pressure when the piston starts moving down.
Effect on Work and Temperature

In the model, work was calculated by using the pressure and the volume differential

\[ dW = P \frac{dV}{d\theta} \]

Work is affected by timing because of the burn rate. The more you move away from the optimal burn fraction, the lesser the work. However, work does not vary significantly. The temperature was modeled using the following formula

\[ T = \frac{PV}{mR} \]

Where the mass was calculated using the initial values of the pressure and the volume. The temperature decreases as timing goes from -5 to 5°CA. The maximum temperature went from around 2800 to 2500 K.

TORQUE AND POWER

The power output from the engine depends on timing also. The equations for torque and power are given by Heywood [2.12-2.13]

\[ T = Fb \]

Where F is the force on the output shaft and b is the arm length.

\[ P = 2\pi NT \]

Where N is the engine speed and T the torque. The force on the output shaft can be determined from the pressure. The maximum brake torque can be obtained by varying the spark timing.

EMISSIONS

Emission can be affected by ignition timing. The trends and the behavior different blend of ethanol and gasoline will be discussed with the experimental data. Nevertheless, others have done experimental tests and have shown the trend of emissions with different blends of ethanol and gasoline. For example, Al-Hasan studied the effects of gasoline and ethanol blends on engine performance and found that the brake power, thermal efficiency and volumetric efficiency increased while CO and HC emissions were reduced significantly. However, 20% ethanol showed the best results. On the other hand, He et al while performing test for catalyst conversion found that unburned ethanol and acetaldehyde emissions were increased. Finally, Alasfour found that NOx emissions increased when timing was advanced.

Our experimental data will dictate the tradeoffs between emissions and power/torque to determine the best timing for different engine speed and loads.
The final design the team decided on was to incorporate the use of electronic controls over both fuel injection and ignition timing on a gasoline engine. This design will be utilized since more parameters can be adjusted on-the-fly electronically, allowing stable performance, fuel mileage, and emissions from an engine in various environments. A closed loop control system will be developed using various sensors for feedback and an ECM (Engine Control Module) for logic. This system will be sold as a “kit” with all the necessary equipment so it can be implemented on a gasoline-fueled vehicle. A base map for the ignition timing and fuel injection will be supplied in the ECM so the end-user will be able to start and operate the vehicle when installed. Installation and further tuning will be vital for proper operation; therefore a list of qualified companies will be included that can “fine tune” the system for their vehicle.

The design specifications include the following:

1) Megasquirt ECM
2) Flex Fuel Sensor (FFS)
3) Exhaust Gas Temperature Sensor (EGT)
4) Wideband Air/fuel (A/F) Sensor

The FFS will be installed in-line between the fuel pump and fuel rail which will determine the blend of ethanol and gasoline being injected into the engine. The signal will then be sent directly to the ECM so adjustments can be made accordingly. The system must be designed using a flex fuel sensor in order to compensate for different grades of E85, as well as summer and winter mixes. Although the system is designed for E85, any blend of the fuel should be able to produce comparable emissions.

The EGT sensor will help in further adjusting the ignition timing to achieve the desired combustion chamber temperatures. The temperatures of a combustion chamber can reach extremely high temperatures, which makes it very easy to melt engine internals, cause pre-detonation, or even fail to control emissions properly. As with every other device, a catalytic converter has an operating temperature that must be maintained for proper efficiency for removing harmful emissions. As well as helping with emissions, the EGT can be used to dynamically adjust ignition timing to achieve the highest power output possible.

A wideband oxygen sensor will be employed to determine the air-fuel ratio which will be located in the exhaust stream. All automobiles contain factory installed narrow-band sensors which will be removed and replaced with the wide-band sensor. The reasoning is the narrow-band sensor cannot determine readings accurately except within the close proximity of stoichiometric for the fuel. See appendix D.3 for details. The wide-band sensor allows accurate readings for very rich and lean mixtures giving the system higher capabilities when adjusting the fuel and ignition timing curves dynamically. The oxygen sensor is pre-calibrated to operate with ethanol and gasoline blends without affecting reliability or accuracy of the sensor. Based on the oxygen sensor readings in conjunction with the readings from the FFS, an optimum A/F ratio can be calculated. This A/F ratio can be used to adjust for fuel economy and power when demanded by the driver of the vehicle.

Based on the feedback from the FFS, the ECM can make the adjustments needed to the fuel injectors and ignition controller. The EGT feedback can be used to further optimize ignition
timing and change cylinder temperatures. The optimization of ignition timing involves setting the spark and RPM to ignite relative to the crank angle or position of the piston in the cylinder. As the piston approaches closer to the engine's top dead center position, maximum stroke, the cylinder pressures raise, thus raising exhaust temperatures. Cylinder temperature will directly affect different emissions components, for example, a higher EGT will result in higher NOx reading. With few sensors and the proper implementation of controls, a proper E85 conversion kit can be made. Installation time would still be under a few hours and could be done by the end user. Another thing to consider is that this would be the closest to a production vehicle out of all the kits on the market. If a manufacturer is adjusting the ignition timing and fuel for different blends of E85 there is definitely a reason behind it.

Currently, there are various companies producing E85 conversion kits available for gasoline fueled vehicles. Most of these kits are not EPA emissions approved making them illegal for use on public roadways. The kits that have passed EPA emissions are only available for newer vehicles which contain the necessary sensors from the factory (i.e. GM trucks). The kit our group designed will allow most automobiles built in 1990-present to be converted to operate on E85 while passing EPA emissions. The capability of the Megasquirt ECM used in our design is far superior to our competitors since many sensors can be implemented for feedback and every parameter can be adjusted until optimum results are achieved.

The hardware picked for our system was chosen for simplicity of installation, high adjustment of vehicle parameters, and universal capabilities. The test unit which will be designed will be a bit more complex than it could be. While this is looking into the future, the capabilities of our system are shown and what can be done to eliminate any issues the consumer may have upon assembly. The control loop was designed based upon the limits of the Megasquirt ECM. The ECM unit was designed to operate under the conditions we plan on putting it through so installation should be straightforward.

Each kit will comprise of instructions that will ease the installation process either by the end user or a recommended local professional. The initial design will function with a standalone ECM making installation more complicated than our competitor’s products. With further refinement, the stand alone ECM will eventually be redesigned as a piggy back unit, simplifying the installation process. Unlike the systems currently on the market this would be a true universal system. The piggy back system would function under the same programming constraints as the standalone unit, but will intercept and modify the fuel signal and ignition timing signal based on the input from the sensors used.

Tuning the system after it is installed on a vehicle will be a vital part for proper operation. The initial tune included with the kit will allow the vehicle to start and operate on roadways but will need to be “tweaked” by either the same user or a recommended professional. The benefits of further tuning can increase gas mileage, power output, and cleaner emissions. The higher octane rating of E85 can be taken advantage of by adjusting the timing. This should net in a higher power output, while not affecting emissions. Even tuning with straight gasoline should yield an increase in mileage or power output. If the user than decides to add modifications to increase airflow to the cylinder, extra fuel can be supplied with slight tweaking in the ECM.
COMPONENTS OF DESIGN

Table 4 List of Components needed

<table>
<thead>
<tr>
<th>Component</th>
<th>From</th>
<th>Price</th>
<th>Function</th>
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<tbody>
<tr>
<td>Megasquirt (ECM)</td>
<td>DIYAutotune.com</td>
<td>$436</td>
<td>Engine Control</td>
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<tr>
<td>Exhaust temperature</td>
<td>lethaldiesel.com</td>
<td>$78</td>
<td>Timing Control</td>
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<td>Oxygen Sensor</td>
<td>Summitracing.com</td>
<td>$200</td>
<td>Air/Fuel Ratio Control</td>
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<tr>
<td>Flex Fuel Sensor</td>
<td>Gmpartsdirect.com</td>
<td>$363</td>
<td>Fuel Composition</td>
</tr>
<tr>
<td>Engine</td>
<td>E-bay or other used parts marketplace</td>
<td>$1200</td>
<td>Testing</td>
</tr>
<tr>
<td>Dynamometer</td>
<td>Local performance shop</td>
<td>$80/test</td>
<td>Testing</td>
</tr>
<tr>
<td>Emissions</td>
<td>Local testing center</td>
<td>$80/test</td>
<td>Testing</td>
</tr>
<tr>
<td>E85 Fuel</td>
<td>Closest E85 Station</td>
<td>$2.75/Gallon</td>
<td>Fuel</td>
</tr>
</tbody>
</table>

*Prices do not include taxes and shipping fees.

For testing purposes and proof of concept an engine control unit called Megasquirt will be used. The unit is very easy to assemble and uses an open source code that can be modified for to account for different sensors and variations in readings. The open source code is very favorable because it will allow us to install various sensors and make program adjustments as needed. The unit will allow us to prove the concept of the daughterboard and create a code that will work the way that is needed. Once the Megasquirt is functioning and returning satisfactory results it will be time to think about creating a daughter computer to work directly with the factory engine management.

The daughter board, although not built for this project, will incorporate what is learned from the Megasquirt unit. Most of the code and algorithms will be extracted from the Megasquirt code and used to make adjustments to the factory computer. The adjustments will be made by trimming the factory values by a percentage based on the algorithm. The percentage will be calculated using numerous sensors that will be supplied with the kit. Most the sensors are off the shelf products, therefore allowing for easy replacement, repair, and development.

The most important sensor that will need to be installed is the flex fuel sensor. This sensor is needed due to variations in the blending of the fuel for winter and summer. Without the use of this sensor, it would have to be guaranteed that an exact blend of E85 was being distributed, which is nearly impossible to know on a tank to tank basis. The flex fuel sensor will also allow for the use of regular gasoline and any blend of E85 and gasoline created by mixing. Whether the mix is E85, E70, E15, or anything in between the flex fuel sensor will supply the algorithms with the required data to make the necessary adjustments. The sensor works on a 0-5V scale to determine oxygen content in the fuel. Pure gasoline contains no oxygen where as Ethanol does. See appendix D.1 for details.
Once the flex fuel sensor determines the fuel composition a wideband oxygen sensor will be used to correct fueling. The stoichiometric air to fuel ratio will vary with composition and be adjusted as needed based on the wideband feedback. The Wideband sensor works on a 0-5V scale which will be inputted into the daughter board to make the necessary adjustments. The amount of fuel burned will directly affect the emissions of the vehicle. Another item that will affect emissions is the combustion chamber temperature.

The combustion chamber temperature is measured in the exhaust housing using a thermocouple. The ignition timing will be adjusted based on the combustion temperature to either raise or lower the temperature to an acceptable limit. The combustion temperature will also directly affect some emissions outputs. For example, NOx forms much more at higher EGT levels. A sensitivity analysis will be performed during testing to find the appropriate EGT values to reduce NOx and other emissions.

An engine will also have to be purchased to perform the testing on. At the current time it is desired to install the engine into the Formula SAE race car so the vehicle can be taken to any local automotive facility. The testing costs will be less if the vehicle can be tested like on a standard automotive roller dynamometer. As a fallback option, the engine will be installed into an available motorcycle frame and tested on a motorcycle dynamometer.

The engine purchased must be fuel injected and have an electronic ignition. The conversion kit will not work properly in an engine that uses mechanical means of controlling ignition timing. Ignition timing must be adjusted to increase performance, reduce emissions, and maintain reliability. The engine chosen is from a motorcycle due to size and ease of use. A motorcycle engine also costs less than a car engine and should be easier to test.

The testing used will be a direct comparison without the use of a catalytic converter. A catalytic converter will not be used as pure emissions are desired. Once it can be shown that the un-catalyzed emissions are lower a catalytic converter can be installed to lessen the emissions even more. The test used will be IM240 which is the standard test used for automotive emissions. The engine will be tested both pre and post conversion using the same test to get a direct comparison. Once this is done and the results obtained are as expected, the system could be further scrutinized using a particle collection test to obtain EPA certifiable results. EPA testing, due to cost and time, will not be included as part of the project but will remain an option for future groups.

The dynamometer will be used to optimize power output from the vehicle on E85 as well. It is expected that the power output will increase, as the octane rating is higher for E85 than gasoline. The higher the octane rating, the less likely the fuel is to combust prior to spark ignition. E85 also burns at a lower temperature so the exhaust temperature is expected to drop slightly over gasoline. This will increase engine life and reliability while maintaining proper power and emissions.

Finally, fuel consumption will be measured. It is expected that there will be a slight drop in fuel economy due to the lower heating value of ethanol, but the cost per mile should be less because the cost of E85 is less than that of gasoline. The fuel economy will be measured by running the vehicle on a dynamometer under set conditions for an extended period of time. The distance traveled will be calculated using the dynamometer. The amount of fuel used will then be measured, based on weight, to obtain a fuel economy. This test will be repeated for both E85 and gasoline.
APPENDIX

APPENDIX A

Pressure plot at mfb50 at 80° CA

Figure 2 Pressure when mfb50 at 8 CA
APPENDIX B
Effect on pressure, temperature and work
SOC -5
Figure 3 Pressure, Work and Temperature when Theta SOC is -5 CA

SOC -2.5
Figure 4: Pressure, Work and Temperature when Theta SOC is -2.5 CA

SOC 0
Figure 5: Pressure, Work and Temperature when Theta SOC is 0 CA

SOC 2.5
Figure 6: Pressure, Work and Temperature when Theta SOC is +2.5 CA
Figure 7: Pressure, Work and Temperature when Theta SOC is +5 CA
State 5

Residual Mass
Residual Mass Mixing

Second run - State 1
Residual mass

Residual Mass Mixing

Figure 8 CEA-Otto first and second iteration
Appendix D

1. Oxygen Content in Ethanol – Gasoline Blends

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<th>%Ethanol</th>
<th>%Gasoline</th>
<th>H/C Ratio</th>
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<td>1.650</td>
<td>0</td>
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<td>0</td>
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<td>8.946</td>
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2. Emissions vs A/F Ratio
3. **Narrowband vs Wideband Oxygen Sensor**

Wideband, Voltage (Black Bars, 0-5V) vs Lambda

![Wideband Voltage vs Lambda](image)

Narrowband, Voltage (0-1V) vs Lambda

![Narrowband Voltage vs Lambda](image)

4. **Maximum Power based on Air to Fuel Ratio**

<table>
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<tr>
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<td>Gasoline</td>
<td>12.5-13.2:1</td>
<td>14.7:1</td>
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<tr>
<td>E85</td>
<td>6.9-8.4:1</td>
<td>9.7:1</td>
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Appendix E  
Emissions test procedure, IM240

The IM240 test is a chassis dynamometer schedule used for emission testing of in-use light duty vehicles in inspection & maintenance programs implemented in a number of states.

It is a short, 240 second test representing a 1.96 mile (3.1 km) route with an average speed of 29.4 mile/h (47.3 km/h) and a maximum speed of 56.7 mile/h (91.2 km/h).

*Figure 1. Inspection & Maintenance Driving Cycle IM240*
Appendix F
Conceptual design and flow chart

Injectors ➔ ECM ➔ Fuel
Ignition ➔ O2 ➔ EGT

Exhaust Gases

Diagram showing the flowchart with nodes for ECM, FFS, Fuel, Injectors, Ignition, O2, EGT, and Exhaust Gases.
ME 423 Phase II Nugget Chart - Proposal & Conceptual Design

Title: E85 Conversion Kit
Team Members: Matt Grywalski, Josh Guerra, Jerry Dutreil, Bill Mehnert
Advisor: Prof. Frank Fisher

PHASE III Engineering Design

**Project Objectives**

Our project objectives include developing an E85 Flex Fuel conversion kit meeting EPA certified emissions testing while maximizing the fuel efficiency and horsepower of the engine compared to that of an engine run primarily on gasoline. The conversion kit will consist of a piggy back system that works with the ECU utilizing three sensors installed in various locations of the car to monitor certain performance parameters.

**From Technical Analysis to Engineering Design**

1. Ignition Timing
2. Explosion Limits
3. Emissions
4. Power/Torque

The results of the technical analysis was used to optimize the final design. The technical analysis was also useful to determine the exact part specifications needed to create a successful design. Design parameters were chosen and the needed materials will be ordered before the beginning of next semester.

**Prototype Plan and Purchase Requisition**

<table>
<thead>
<tr>
<th>Component</th>
<th>From</th>
<th>Price</th>
<th>Function</th>
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<tbody>
<tr>
<td>Megaquart (ECM)</td>
<td>DIYAutotune.com</td>
<td>$436</td>
<td>Engine Control</td>
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<tr>
<td>Exhaust Temp.</td>
<td>lethaldiesel.com</td>
<td>$78</td>
<td>Timing Control</td>
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<tr>
<td>Oxygen Sensor</td>
<td>Summit Racing.com</td>
<td>$200</td>
<td>Air/Fuel Ratio Control</td>
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<td>Flex Fuel Sensor</td>
<td>Go Parts Direct.com</td>
<td>$363</td>
<td>Fuel Composition</td>
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<td>Engine</td>
<td>E-bay or other used parts</td>
<td>$1200</td>
<td>Testing</td>
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<td>Dynamometer</td>
<td>Local performance shop</td>
<td>$90/tst</td>
<td>Testing</td>
</tr>
<tr>
<td>Emissions</td>
<td>Local testing center</td>
<td>$80/tst</td>
<td>Testing</td>
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<tr>
<td>E85 Fuel</td>
<td>Chevron E85 Station</td>
<td>$2.75/gallon</td>
<td>Fuel</td>
</tr>
</tbody>
</table>

*Prices do not include taxes and shipping fees.

**Major Results Obtained in the Semester**

Ignition timing trend, variation of timing will affect temperature, pressure, work, and many other parameters. Local emissions testing procedure was obtained. This will allow for adequate comparison between the two fuels. Torque will be affected by ignition timing. A 5% increase of power is expected while running on E85. The goal is to compare the performance of the engine next semester using various testing procedures. Other major results obtained so far include a simulation designed to shown the theoretical results of the vehicle's performance. This simulation is very useful to determine to effects of ignition timing.

**Drawing and Illustration of Final Design**
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<td>Fri 12/28/07</td>
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Books


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