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THE CREED PROJECT: 2003 Toyota Prius Hybrid Conversion to Ethanol

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ABSTRACT

A 2003 Toyota Prius Hybrid-Electric vehicle was tested for operation on E-85 (85% ethanol/ 15% gasoline). Tests were done to determine if the vehicle could be operated safely on E-85 without any alterations.

The vehicle was monitored, while slowly increasing the percentage of ethanol, for conditions, which would indicate it would require system modification to adapt the car to operate efficiently and reliably on E-85. Tests were also conducted to compare operating on 89-pump gasoline against E-85. The fuel's effects on emission levels, fuel economy, power output, and drivability were found

INTRODUCTION

According to Toyota, the Toyota Prius was designed primarily to improve emissions in urban driving and increase fuel economy. The Prius consists of a parallel hybrid power train, called the Toyota Hybrid System (THS). This system combines a 1.5 liter 4 cylinder gasoline engine, an electric motor, a generator, and a Power Split Device, that also acts as a Continuously Variable Transmission (CVT).

The Power Split Device is at the center of the Toyota Hybrid System. It is a gearbox that is connected to the gasoline engine, the generator, the electric motor, and the differential. This device makes it possible to operate the vehicle using as a power source either the electric motor, or the gasoline engine, or both power plants combined. The gasoline engine can also operate independently of the vehicle speed, allowing it to charge the batteries for the electric motor –

eliminating the need for external power source for charging the batteries.

When the batteries for the electric motor are fully charged and the engine temperature has reached the normal operating level, the Prius will use only the electric motor to get the vehicle going from start to approximately 15 mph before operating on the gasoline engine. Switching between the two power plants or operating on both is achieved seamlessly – again due to the Power Split Device that allows the generator to start the gasoline engine at any time without the need for a starter. Skid-control also utilizes the Power Split Device in conjunction with the electronic throttle of the gasoline engine.

In the center of the Prius dashboard is a multi-informational display screen that indicates energy consumption status, power-flow, trip information and consumption, audio system settings, navigation, and more.

The fuel tank in the Prius has an 11.9-gallon capacity, which Toyota estimates will provide a range of 500 miles between refills.

TESTING

Most tests were conducted at Minnesota State University's facilities in Mankato (MSU, M). Emission and highway fuel economy testing were conducted using the school's inertia dynamometer, constant sampling system and analytical exhaust gas analyzers as per U.S. EPA regulations. Drivability and real world mileage were determined on the road.

DYNAMOMETER TEST

The L.A.4 FTP 78 driver traces were used to determine exhaust emission characteristics, and EPA HWC.TRC was used to determine highway fuel economy.

Power output testing was also conducted at MSU, M using a Mustang 2000 Dynamometer.

Fuel was tested for ethanol concentration levels before and after every test. No tests were conducted to ascertain what long term effects high concentrations of ethanol would produce on the components that are exposed to it.

ROAD TEST

Road tests were conducted on a route depicting varying load conditions and drive-cycles representative of urban, highway, and short trips. During the road tests, the vehicle was monitored for drivability, and the fuel control system's adaptive capabilities.

While all the tests were conducted with as much control as possible to reduce variability, the road tests had to be repeated a greater amount of times. One driver was selected for all the tests to provide greater consistency and repeatability in the results.

During tests that required the use of a dynamometer, the skid-control had to be disabled to allow the front wheels to exceed 19 mph, while the rear wheels remained fixed. This was done by activating the Inspection Mode, which only utilizes the gasoline engine for driving the front wheels. Since this research was concerned with the comparison of fuels in the engine, the Inspection Mode also served to eliminate any effects from the electric motor. Evidence of this can be seen in the lower fuel economy results from the FTP HWC.TRC tests for both gasoline and ethanol, compared to the results from the on-board computer that were attained from road tests. The Inspection Mode was not used during the road tests; Toyota strongly advises against it due to safety concerns.

RESULTS

While the results from the exhaust emission tests showed a decrease in all levels of emissions, the levels of Hydrocarbons (HC) and Nitrogen Oxides (NOx) were significantly reduced. The reason for only a small reduction in Carbon Monoxide emissions was primarily caused by a high count during the first phase of the L.A.4 FTP 78 trace. The first phase of this trace begins with a cold start. One of the differences between the properties of ethanol and gasoline that plays a crucial role; in cold starting and operating conditions, is their respective Reid Vapor Pressure.

Reid Vapor Pressure a measure of a liquid's ability to evaporate. It is measured at 100ºF, and the higher pressure indicates easier evaporation. Gasoline is rated between 8 and 15psi, while ethanol is rated at 2.3psi.

A rich Air/Fuel ratio, high equivalence ratio, will produce higher levels of CO emissions, while leaner Air/Fuel ratios will produce the minimum CO emissions. During cold start and driving, the vehicles fuel management system provides a richer (lower) air/fuel ratio required for cold starts and then leans (increases) the air/fuel ratio gradually as the coolant temperature rises. It was seen that by the second phase of the trace, the CO levels produced by the use of ethanol were 48.8% less than those produced by gasoline. In the third phase of the trace the levels of CO were 39.2% less. Yet, the overall results only produced a reduction of 5.5%. During the first phase, ethanol produced higher levels of CO over gasoline with a 53.7% increase.

Similar results were obtained for Hydrocarbons emissions, except that in the second and third phases of the trace, ethanol showed greater reductions than

gasoline.
Drivability during the road tests also highlighted the difference in cold driving performance between the two fuels. When the engine was powered using ethanol it felt sluggish and the idle quality was rougher. After a time of between 9 to 15 minutes, the ethanol performance improved and there was no noticeable difference in drivability between the two fuels.

While using E-85, the check engine light came on. Upon inspection this produced a code indicating a lean condition was detected. During this testing, it was noted that the check engine light for the lean code would come on between 140-160 miles after clearing the code. The oxygen sensor output and the short-term fuel trim all indicated that the Air/Fuel ratio is stoichiometric, and that the fuel control module was maintaining the correct amount of fuel required. What is setting off the check engine light is that the system monitors the change in the base fuel map, which is indicated by the long-term fuel trim. If this change is outside of the set boundaries for an extended period of time, then a code is set to indicate that the fuel system is making greater adjustments to the fuel quantity to maintain the correct air/fuel mixture than is necessary under normal circumstances. The use of ethanol caused the fuel system to adapt the long-term fuel trim by an increase of 32.81%. ! This supports the lower average fuel economy of ethanol in the results. See figure 4. An added advantage of using E-85 showed gains in power output, as shown on table 1. Although ethanol has a lower energy density than gasoline, due to its lower air/fuel ratio, and effectively cooling the intake charge, it allows more fuel to be introduced to the combustion chamber thereby providing the power gains seen.

Since E-85 tests were not done at ambient temperature of 25ºF or less, it is not possible to comment on starting abilities in such conditions. While at 25ºF the vehicle started without difficulty.

Table 1: Maximum power and torque comparison

Fuel Type	**Maximum Power**	**Maximum Torque**
Gasoline	**64bhp @4500rpm**	**80lb-ft @4200rpm**
E-85	**77bhp @4700rpm**	**106lb-ft @4250rpm**

Results showed the benefits of using E-85 in the reduction of emission pollutants compared to gasoline, but fuel economy dropped. These results were obtained without any alterations to the stock vehicle for optimizing it to run on E-85. See figure 1 & 2

Figure 1: Emission comparison on federal, stock & E-85

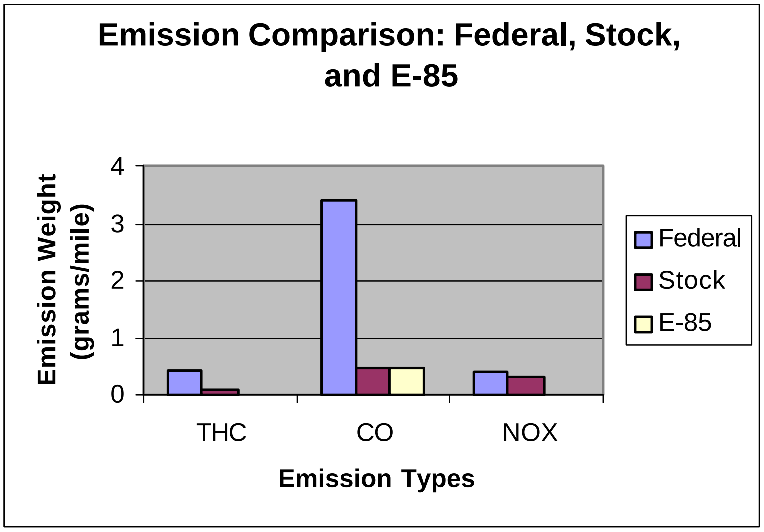

Figure 2: Emission comparison focusing on THC & NOx

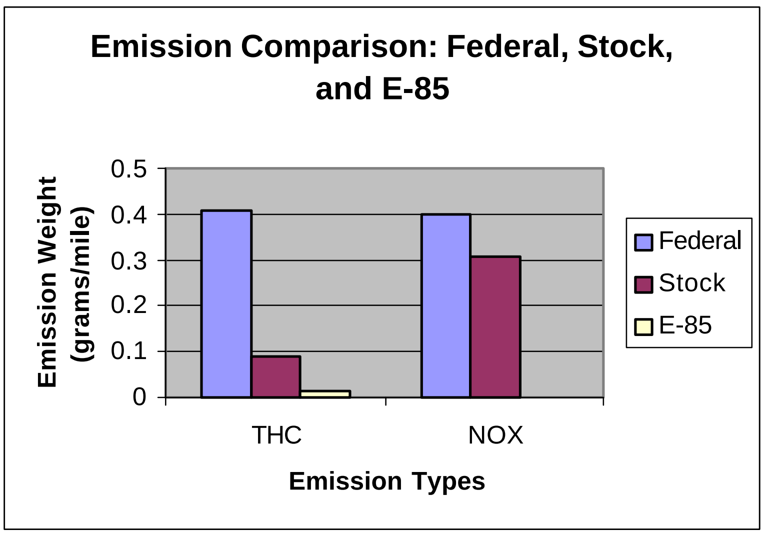

Figure 3: Horsepower comparison output at wheel

Figure 4: Highway fuel economy comparison

CONCLUSIONS

This research showed that it is possible to operate the Toyota Prius Hybrid using an E-85 fuel blend, weather conditions permitting, to provide further reductions in exhaust gas emissions. There are some issues of concern.

Further research must be done to assess the impact of E-85 on the components of the fuel system, such as the fuel lines, injectors, fuel pump, catalytic converter, oxygen sensor, and the fuel tank. The fuel map and control program needs to be developed to deal with the increased fuel requirement of E-85 compared to gasoline; otherwise a check engine light will be activated. Since cold-running operations provided the least reductions, in some case increases in exhaust emissions, short trips from cold starts may actually increase the levels of emissions. Developments must be made to improve cold starting performance. It could be done through pre-heating of the fuel, and/or pre-heating of the catalytic converter, or increasing the Reid Vapor Pressure of E-85.

As a research project, it was felt that all those involved have benefited through the knowledge acquired in dealing with the involvements of a team research project. The students gained the experiences of dealing with technical, automotive, management, communication, and financial aspects of a research project involving teamwork. In this respect, this was a successful project.

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DEFINITIONS / ACRONYMS/ABBREVIATIONS

AMET – Automotive and Manufacturing Engineering Technology
API – American Petroleum Institute
CO – Carbon Monoxide
CREED - Communities for Responsible Energy and Environmental Demonstration
E-85 – 85% of ethanol and 15% of gasoline
EPA – Environmental Protection Agency
FTP – Federal Test Procedure
Fuel trim – The correction factor to command fuel injectors. Based on learned values between maps in the ECU, and signals to the fuel injectors to compensate for required fuel.
HP – Horsepower
HWC .TRC – Highway trace for fuel economy
LA4 – A name of drive cycles used in superflow emission dynamometer
MSU,M – Minnesota State University, Mankato
NOx – Oxides of Nitrogen
PSI – Pound per square inch
Reid Vapor Pressure – Vapor Pressure at 100ºF
Stoichiometric – The correct amount of fuel and air mixture for complete combustion
THC – Total Hydrocarbon