Fall Technical Report

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ABSTRACT

As part of the Challenge X competition, Team Tennessee has developed a through the road (TTR) hybrid electric vehicle architecture to convert the 2005 Chevrolet Equinox into a more environmentally responsible vehicle. The competition has entered into the second year where the implementation of the conceptual design in hardware begins. An update of the Vehicle Technical Specification is presented. There have been changes to some of the major components in the vehicle architecture due to component availability. These changes and their influence on the overall performance and operation of the vehicle are described.

INTRODUCTION

There are three distinct design phases in the Challenge X program. Each year marks the beginning of a new phase. Year one was focused on the development of a vehicle architecture based on vehicle modeling and simulation. Year-two development is underway with a focus of implementing the vehicle design from year-one. The product for year-two will be a fully functional vehicle. Year three focuses on control system refinement and producing a near showroom ready vehicle.

A TTR HEV architecture has been developed. A compression ignition engine will provide power to the front wheels while a high voltage electric drive will power the rear wheels. A charge-sustaining control strategy has been adopted with emphasis on maintaining the integrity of the high voltage storage system.

This document covers the final vehicle design and VTS targets for the 2006 competition vehicle entry, focusing on substantial changes to the overall vehicle design. Originally, Team Tennessee planned to use the GM 1.3L High Feature (HF) diesel engine. Because of calibration issues with the GM 1.3 liter HF diesel engine the engine will not be available to Team Tennessee for the 2006 competition. Vehicle simulations of the High Value (HV) version of the GM 1.3L show that the VTS acceleration targets would not be met using this engine. Performance on the trailer towing event would also be greatly impacted. The decision was made to locate a suitable alternative engine that would meet the fuel economy and acceleration targets prescribed by the team. The only other viable option that would not substantially alter the implementation schedule was the GM 1.9 Liter diesel engine. Simulation of this engine in the UTK powertrain architecture shows that vehicle performance targets are satisfied, with a slight decrease in fuel economy.

Another change to the overall design is the high voltage battery pack. Our team was awarded a Cobasys 288 VDC NIMH battery pack. Notice was given at the Fall Workshop from Cobasys that some problems had been discovered with the pack. Cobasys advised to discontinue work on these packs, such as conditioning and deep cycling tests, until a software upgrade could be implemented. Cobasys is replacing the battery pack with a new version of the pack. The replacement pack will be a 336 volt NIMH pack, with a new metal enclosure instead of the original plastic one on the current 288 VDC pack. The dimensions of the new pack are slightly larger than the existing pack. There were not significant changes to the VTS with the use of 336V pack that would adversely affect the performance of the vehicle. In fact, the EV Ranger transaxle actually benefits from the higher voltage of the new pack. There will need to be some modification to the packaging design for the pack due to the difference in overall dimensions of the two packs.

VEHICLE TECHNICAL SPECIFICATION

Team Tennessee had the goal of designing an advanced powertrain vehicle capable of meeting a variety of metrics established by the demanding consumer and the internal objectives of the Tennessee Challenge X vehicle. Based on these metrics, the team proceeded to size components and to decide on appropriate powertrain configurations that best meet these goals.

During the conceptual design for a powertrain, a trade-off between acceleration performance and fuel economy objectives must be addressed. The VTS displayed in Table 1 represents the final iteration of this trade-off process. The team decided to relax the IVM to 60 MPH metric in order to attain higher fuel economy benefits. The VTS shown in Table 1 reflects vehicle level specification only and does not contain design validation planning and report (DVP&R) documentation or corresponding test specifications. The team will develop and internal DVP&R document and associated test methodologies in order to validate whether the powertrain/vehicle meets the VTS. Due to the change in vehicle components the VTS will be modified to reflect the changes in performance goal of the new vehicle architecture. Changes to the vehicle design are modeled and simulated to determine if the vehicle can still meet the VTS when changes are made. No change will be implemented if the VTS is violated.

Table 1 – University of Tennessee Vehicle Technical Specifications (VTS)

Description	Test Year	Modeling/ Inspection /Testing	VTS (Team Selected)
IVM -60 MPH	1,2,3	M,T	≤8.9s
50-70	1,2,3	M,T	≤6.8
Vehicle Mass	1,2,3	M,T	≤4200lbs
MPG Combined EPA	1,2,3	M,T	≥32.0 mpge
Highway Range	1,2,3	M,T	≥200 mi
Passenger Capacity	1,2,3	M,T	5 Passengers
Emissions Cert Level	2,3	T	Tier 2, Bin 5
Trailering Capacity	2,3	M,T	2500 LBS
Cargo Capacity	2,3	I	60 Cu. Ft. behind front seat
Starting Time	1,2,3	T	<5.0 s
Noise Emission	1,2,3	T	<75 dbA

POWERTRAIN DESIGN

Team Tennessee has elected to pursue a TTR powertrain configuration for its entry in the competition, which is shown graphically in Figure 1. The most compelling factors influencing this selection were cost, packaging, and other features such as complete subsystem isolation and redundancy. This concept is important to the team because the vehicle can operate independently from the high voltage system in a limited operating mode should problems arise. In addition, simulation of the system operating in the limited power mode shows that fuel economy would be minimally compromised while acceleration capability of the vehicle would be moderately affected. Separation of the high voltage system from the heat engine yields greater flexibility for the design in terms of control strategies, packaging, and overall implementation. In addition, this approach represents a completely redundant system should one source of tractive power fail.

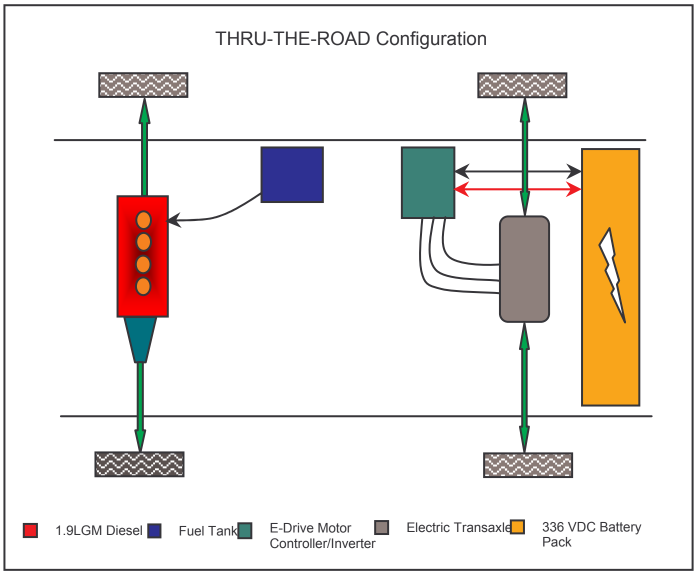


Figure 1 UTK powertrain configuration for 2006 competition

ENGINE ANALYSIS

Team Tennessee has chosen to utilize diesel engine technology as the heat engine for the vehicle. The original vehicle design used the GM 1.3 liter engine. There are two versions, the HV and the HF, versions of this engine. The HV version of the 1.3L is rated at approximately 70HP power output and the HF produces 90HP. The team first received the HV version of the engine in order to begin the initial subsystem development process. Later, the team was to receive the HF version to be used for 2006 competition. The team was informed the 1.3L HF engine would not be available in time for the 2006 competition. The HV engine does not produce enough power to allow the Equinox to meet the VTS targets for acceleration set by the team. This prompted the consideration of using the 1.9L GM diesel that was made available as one of the GM supported components during year one. A comparison of the IVM-60 MPH performance data is shown in Table 2. While the HF engine did not meet our initial VTS target, it was deemed acceptable when coupled with the high fuel economy that it afforded. The PSAT performance parameter would have been updated to reflect this in this document had the engine been made available. Although the PSAT predicted IVM-60 mph time is less than the current VTS value of 8.9s, the VTS target will remain as is – better than the stock vehicle.

Table 2 Performance comparison for candidate engines

Engine	1.3L HV	1.3L HF	1.9L
IVM – 60 MPH (s)	10.8	9.7	6.6

In order to quantify the effects on an engine change to the overall design and VTS targets, the new engine was modeled in a vehicle context. The 1.9L GM diesel model was inserted into the PSAT vehicle model for the UT version of the TTR configuration hybrid Equinox. The vehicle was exercised on various driving cycles to determine what impact the use of this engine would have on the fuel economy and acceleration of the vehicle. The team is considering two (2) methods for controlling the engine. The first approach forces the engine to run 100% pf the time, just as a conventional vehicle would. The second strategy allows the engine to shutdown during periods of prolonged vehicle idle conditions, such as at stop signs. Figure XX represents a summary of this analysis compared with both the original 1.3L HF design as well as the conventional vehicle. The results of this analysis are illustrated in Figure 2.

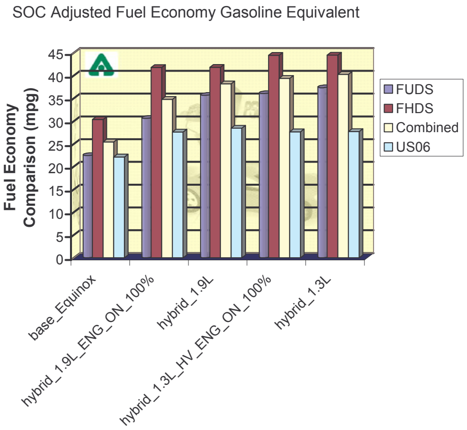


Figure 2 Vehicle comparison of the 1.3L and the 1.9L diesel engines

An important observation made during this analysis hinged on the fact that while the 1.3L HF engine provided high fuel economy estimates for most drive cycles, the 1.9L engine gave higher results for the US06 driving schedule. This is extremely significant due to the fact that the UDDS cycle is somewhat lax in evaluating a vehicle's real-world fuel economy numbers. The US06 is much more aggressive in terms of acceleration requirements and vehicle speeds, and can be considered *more* representative of how a vehicle might actually operate in real situations. The reason for this variation in fuel economy between the two candidate engine is the fact that the 1.3L HF cannot provide the necessary power for the hard accelerations required by the US06 cycle, and therefore must rely more upon the high voltage system to supplement the power requirement. This can be shown graphically in Figure 3, where a portion of the US06 is shown comparing the energy storage power use for the two 1.3L and the 1.9L vehicle simulations. The extra electrical energy used during maneuvers such as these must be accounted for when calculating fuel economy (through charge balancing, etc.). This results in the engine being run more to make up for the electrical energy loss.

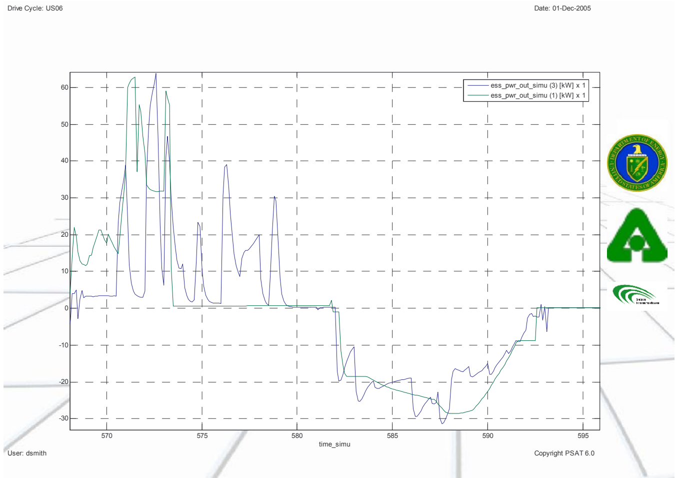


Figure 3 Comparison of 1.3L HF and 1.9L engines during US06 cycle

BALANCING FUEL ECONOMY AND CONSUMER ACCEPTABILITY THROUGH VEHICLECONTROL

The original control strategy for the UTK vehicle employed vehicle idle engine off strategies to boost fuel economy. The team has since decided that this approach is not a sound choice when considering all factors. Most notably, consumer acceptability and drivability concerns prompted the team to look more closely at what the impacts on fuel consumption might be for running the engine 100% of the time.

The UDDS, HWFET, and US06 cycle data generated during the engine analysis in the previous section provided the basis for evaluating the engine ON/OFF strategy. Clearly, running the engine 100% of the time increases fuel consumption more dramatically for the urban cycles, such as the UDDS. However, the combined city and highway fuel economy target is still maintained for the engine on 100% of the time case. This small reduction in fuel economy is acceptable when coupled with the following added benefits for running the engine 100% of the time.

In addition to allowing for a more simplified control strategy, there are also other substantial benefits to running the engine all of the time. By running the engine as a conventional vehicle would, there would be no need for a high to low voltage DC to DC converter in the vehicle. The normal alternator can be retained and run off the accessory drive of the engine to provide 12VDC nominal to the low voltage bus of the vehicle. There also creates a slight weight saving benefit due to not having a DC-DC converter, the corresponding thermal control system, or the additional wiring.

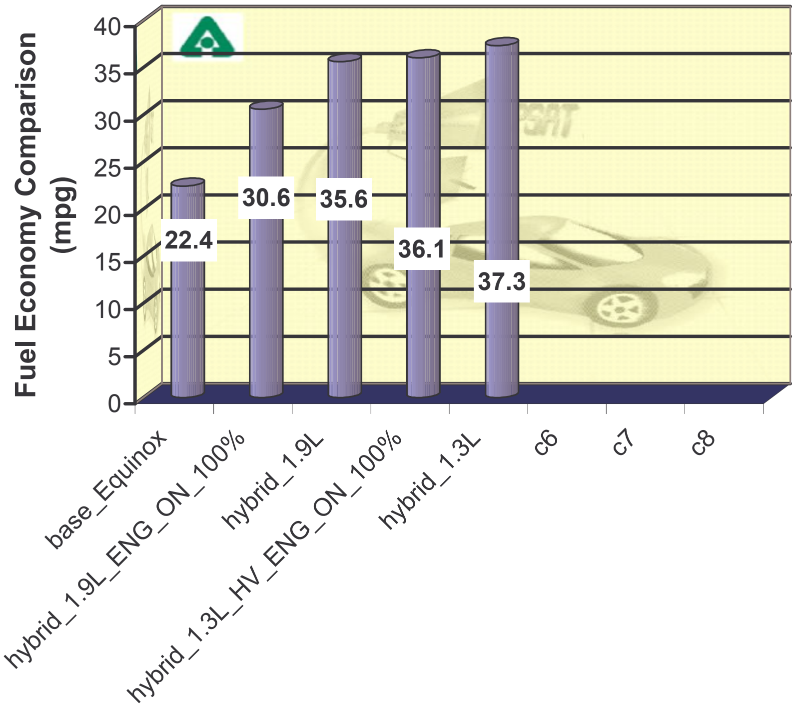
Another benefit for not allowing the engine to shut off is that there are no harsh engine stops that are unwanted by the driver. The vehicle would drive just like a conventional vehicle and not be ambiguous to the operator. The problems incurred with having the electric motor on the rear axle and ZEV operation would be non-trivial. The driver could potentially have the clutch disengaged and step on the accelerator pedal and the vehicle would move – this is not intuitive and is not desired from a consumer acceptability point-of-view.

CONCLUSION

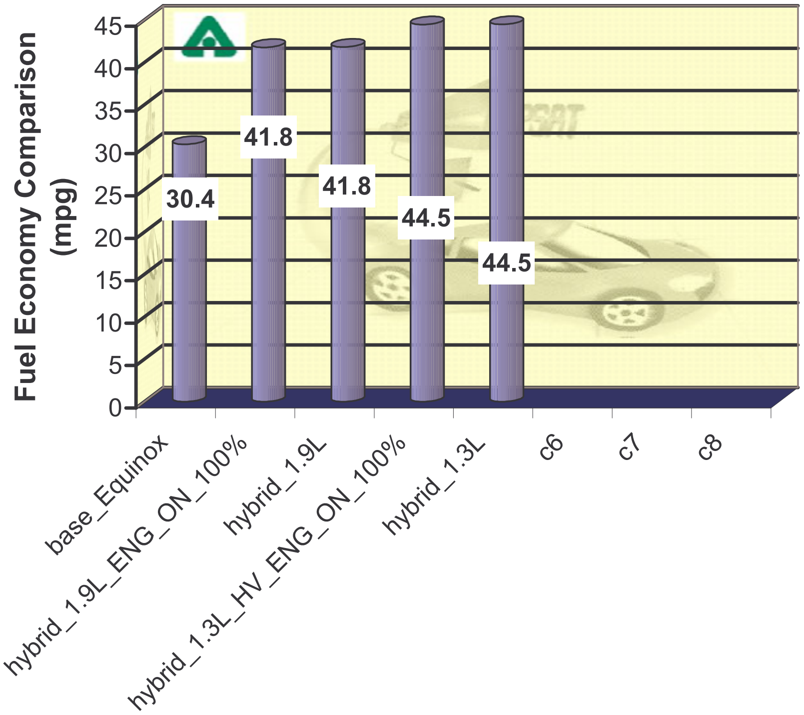
The design for the conversion of the 2005 Chevrolet Equinox into a more environmentally friendly vehicle has been achieved. Changes to subsystem component have been analyzed and their impact on the performance of the vehicle has been completed. The final engine choice is the 1.9 liter GM diesel and energy storage system will be the 336 VDC NIMH Cobasys battery pack. Subsystem integration is now the focus in the development process of the vehicle. It is the task of the team implement the vehicle design and to begin system level testing.

APPENDIX

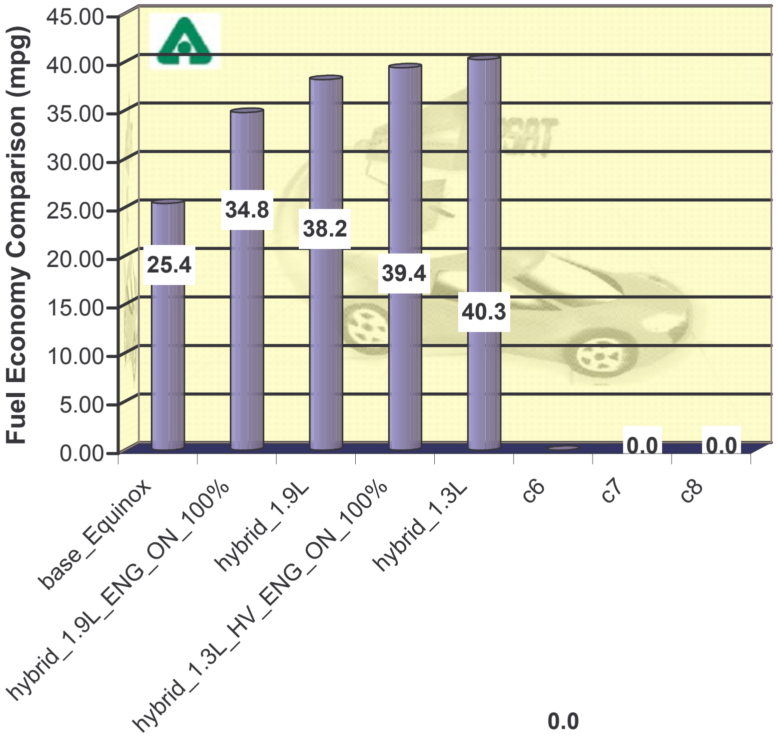
SOC Adjusted Fuel Economy Gasoline Equivalent - FUDS Cycle



SOC Adjusted Fuel Economy Gasoline Equivalent - FHDS Cycle



SOC Adjusted Fuel Economy Gasoline Equivalent - Combined Cycle



SOC Adjusted Fuel Economy Gasoline Equivalent - US06 Cycle