U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

FUELS TECHNOLOGIES

Less dependence on foreign oil, and eventual transition to an emissions-free, petroleum-free vehicle

Vehicle Technologies Program

2010 ANNUAL PROGRESS REPORT

21st CENTURY TRUCK PARTNERSHIP

FreedomCAR & Fuel Partnership

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FY 2010 PROGRESS REPORT FOR FUELS TECHNOLOGIES

Energy Efficiency and Renewable Energy
Vehicle Technologies Program

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IV.7 Mid-Level Ethanol Blends Vehicle Aging Program

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Objectives

- Determine effects of mid-level ethanol blends – blends up to 20% ethanol in gasoline – on legacy vehicle emissions and emissions durability when aged with a dedicated fuel blend.
- Enable informed decision-making regarding Clean Air Act waiver application for increased ethanol in gasoline.

Fiscal Year (FY) 2010 Accomplishments

- Conducted testing of 82 vehicles for emissions durability at three subcontractor laboratories.
- Completed mileage accumulation and emissions testing of 47 Tier 2 vehicles aged with gasoline (E0), and blends of 10, 15 or 20% ethanol in gasoline (E10, E15, E20).
- Completed mileage accumulation and emissions testing of 11 pre-Tier 2 vehicles aged with E0, E15, or E20.
- Completed powertrain component inspection on six pairs of Tier 2 vehicles aged on E0 and E15.
- Provided critical data to the Environmental Protection Agency (EPA) prior to September 30, 2010 to enable informed decision-making on a fuel waiver application.

Future Directions

Complete data collection and analysis and publish report in FY 2011.

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Introduction

The United States' Energy Independence and Security Act (EISA) of 2007 calls on the nation to significantly increase its production of renewable fuels to meet its transportation energy needs [1]. The law established a new renewable fuel standard (RFS) that requires 36 billion gallons of renewable fuel to be used in the on-road vehicle fleet by 2022. Given that ethanol is the most widely used renewable fuel in the United States, ethanol–both from corn and from cellulosic feedstocks–will likely make up a significant portion of the new renewable fuel requirements. The vast majority of ethanol currently used in the United States is blended with gasoline to create E10–gasoline with up to 10 volume percent (vol.%) ethanol.

In light of projected growth in ethanol production, as well as the new RFS, most analysts agree that the E10 market will be saturated within the next few years, possibly as soon as 2012. Although the U.S. Department of Energy (DOE) remains committed to expanding the flexible-fuel vehicle (FFV) fuel infrastructure, that market will not be able to absorb projected volumes of ethanol in the near term. Given this reality, DOE and others have been assessing the viability of using mid-level ethanol blends (blends of gasoline with up to 20 vol.% ethanol) in conventional vehicles as one way to potentially accommodate growing volumes of ethanol, thereby displacing petroleum and helping the country comply with EISA.

Approach

This work is a follow-on effort to previous DOE [2] and the Coordinating Research Council (CRC) [3] mid-level ethanol blend studies to investigate the effects of aging vehicles with mid-level ethanol blends. Vehicle testing has been conducted at three laboratories under subcontract to ORNL and NREL. Vehicles were aged using the Standard Road Cycle (SRC), the official EPA driving cycle used for aging whole motor vehicles for exhaust system durability [4], shown in Figure 1. Southwest Research Institute® (SwRI®, San Antonio, TX) and Environmental Testing Corporation (ETC, Aurora, CO) aged vehicles using the SRC on mileage accumulation dynamometers, while Transportation Research Center (TRC, East Liberty, OH) ran the SRC on their 7.5 mile test track[1]. Vehicles on the mileage accumulation dynamometers (MADs) are shown in Figure 2, while Figure 3 shows the TRC test track.

[1] All vehicles were aged using the SRC with the exception of the 2006 Nissan Quest vehicle set, which was switched to a series of steady-speed laps on the track part way through aging. DOE directed this change to accelerate mileage accumulation.

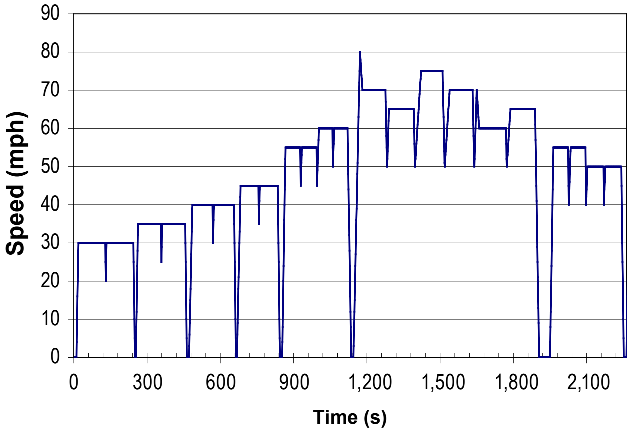

FIGURE 1. Standard Road Cycle for Vehicle Aging

FIGURE 2. Vehicles on Mileage Accumulation Dynamometers at ETC (top) and SwRI® (bottom)

Emissions tests on all vehicles were conducted using emissions certification gasoline (E0), and splash blends of this same fuel with denatured ASTM International D4806 ethanol to produce "certification grade" E10, E15, and E20. Vehicle aging was conducted with retail gasoline (RE0), and this same fuel splash blended with denatured ASTM D4806 ethanol to produce RE10, RE15, and RE20; the "R" denoting retail gasoline.

Vehicles were purchased in matched sets of two, three, or four vehicles with matching model year, engine family, evaporative emissions control family, powertrain control unit calibration, transmission, wheel and tire size, etc. For vehicle sets of two, one vehicle was aged with RE0, and the second vehicle was aged with RE15. For vehicle sets of three, a third matched vehicle was acquired and aged on RE20. For vehicle sets of four, a fourth vehicle was acquired and aged on RE10. Five vehicle sets were aged on all four fuels, eighteen vehicle sets on three fuels (RE0, RE15 and RE20), and four vehicle sets on two fuels (RE0 and RE15). Figure 4 shows a sample schematic for a four-vehicle set, in which each colored rectangle represents one vehicle. Both new and pre-owned vehicles were purchased for the program, with Tier 2 model years ranging from 2005-2009, and pre-Tier 2 model years ranging from 2000-2003, as shown in Table 1.

FIGURE 3. Test track at TRC

Vehicles were emissions tested using the Federal Test Procedure at three or four points during the aging program; at the start of mileage accumulation, at one or two mid-mileage points in the program, and at the end of mileage accumulation. All of the 2009 vehicles were purchased new and were driven 120,000 miles (120k) during the program. Eight new vehicles at ETC were emissions tested at 4k miles (start of test), and 60k and 90k (intermediate test points), and at 120k (end of test). Twelve new vehicles at TRC were tested at 4k, 60k, and 120k, omitting the 90k test point due to time and budget constraints. Mileage accumulation for the pre-

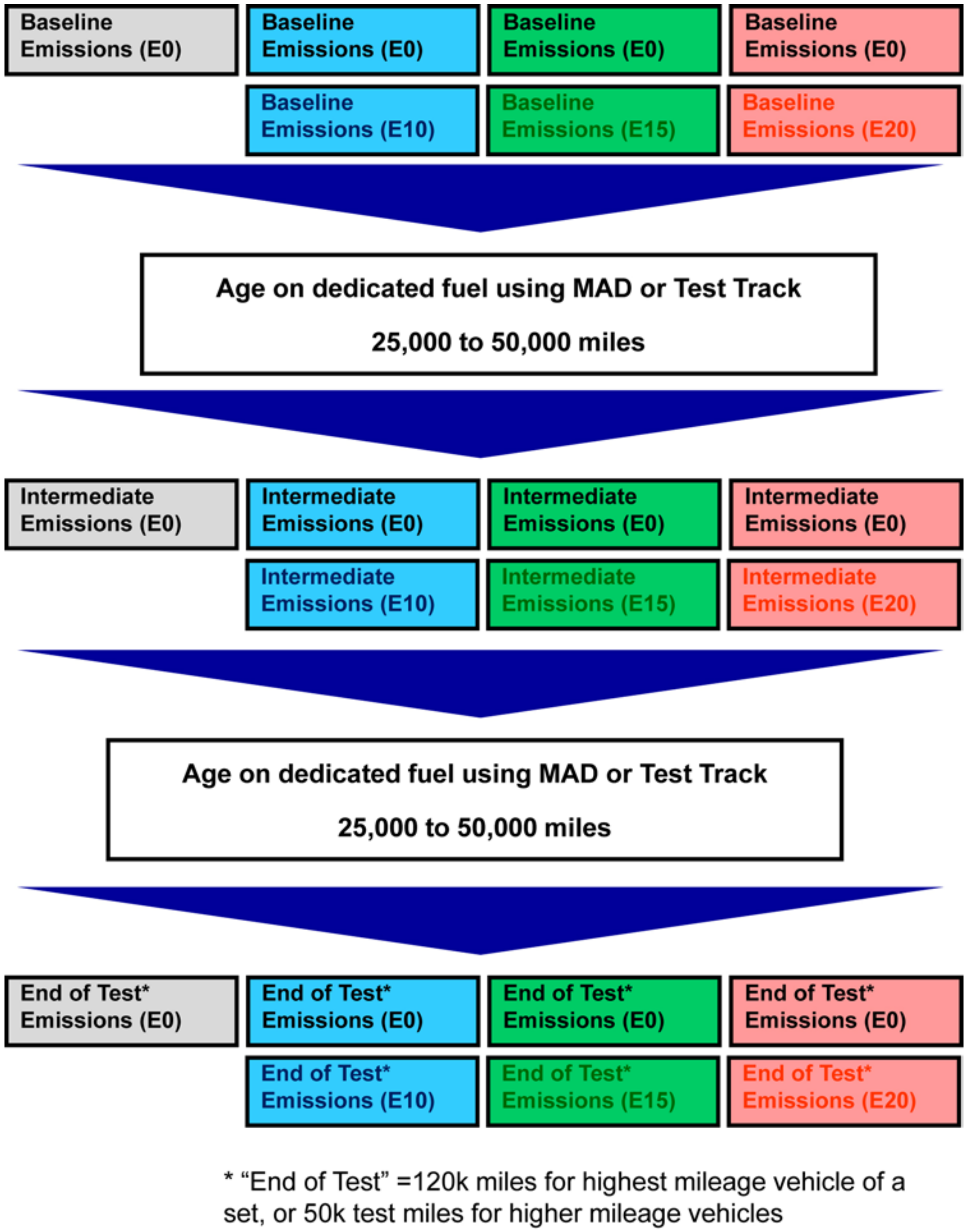

FIGURE 4. Vehicle Aging Program Schematic for One Matched Set of Four Vehicles

owned vehicles was determined based on actual vehicle odometers, ranging from 50k to 103k miles. All vehicles of a given set were driven the same distance in the test program.

Results

All Tier 2 vehicle results for the E0 and E15 vehicles were acquired before the end of FY 2010 and provided to EPA. Vehicle testing and data collection for the remaining vehicles are scheduled for completion by mid-January 2011. Results are being provided to EPA continuously throughout the program. A summary of the E0 and E15 vehicle results are shown in Table 2, taken from the Federal Register, which shows that three of the vehicle models aged with E0 exceeded their full useful life emissions standards at end of test (two for oxides of nitrogen [NOx], and one for non-methane organic gases), while two of the vehicle models aged with E15 failed for NOx emissions compliance. Emissions failures did not appear to be fuel-related. Based on these results and detailed statistical analysis, EPA determined that "E15 does not cause Tier 2 motor vehicles to exceed their exhaust emissions standards over their full useful life" [5].

TABLE 1. Test Vehicle Summary

Tier 2 Vehicles						
Southwest Research Institute (TX), Mileage Accumulation Dynamometers						
Year	**Vehicle**	**# veh.**	**Fuels**			
2006	Chevrolet Silverado	4	E0	E10	E15	E20
2007	Honda Accord	4	E0	E10	E15	E20
2008	Nissan Altima	4	E0	E10	E15	E20
2008	Ford Taurus	4	E0	E10	E15	E20
2007	Chrysler Caravan	4	E0	E10	E15	E20
2006	Chevrolet Cobalt	3	E0		E15	E20
2007	Dodge Caliber	3	E0		E15	E20
Transportation Research Center (OH), Test Track Aging						
2009	Jeep Liberty	3	E0		E15	E20
2009	Ford Explorer	3	E0		E15	E20
2009	Honda Civic	3	E0		E15	E20
2009	Toyota Corolla	3	E0		E15	E20
2005	Toyota Tundra	3	E0		E15	E20
2006	Chevrolet Impala	3	E0		E15	E20
2005	Ford F150	3	E0		E15	E20
2006	Nissan Quest	3	E0		E15	E20
Environmental Testing Corp (CO), Mileage Accumulation Dynamometers						
2009	Saturn Outlook	2	E0		E15	
2009	Toyota Camry	2	E0		E15	
2009	Ford Focus	2	E0		E15	
2009	Honda Odyssey	2	E0		E15	
Pre-Tier 2 Vehicles						
Southwest Research Institute (TX), Mileage Accumulation Dynamometers						
Year	**Vehicle**	**# veh.**	**Fuels**			
2000	Chevrolet Silverado	3	E0		E15	E20
2002	Nissan Frontier	3	E0		E15	E20
2002	Dodge Durango	3	E0		E15	E20
Transportation Research Center (OH), Test Track Aging						
2003	Toyota Camry	3	E0		E15	E20
2003	Ford Taurus	3	E0		E15	E20
2003	Chevrolet Cavalier	3	E0		E15	E20
Environmental Testing Corp (CO), Mileage Accumulation Dynamometers						
2000	Honda Accord	3	E0		E15	E20
2000	Ford Focus	3	E0		E15	E20

In addition to the emissions testing throughout the program, powertrain component inspections were performed on six of the vehicle sets at SwRI® at end of test. Results for the E0 and E15 vehicles were completed by September 30, 2010 with results compiled in a draft report and pre-published in the EPA docket [6]. Additional results for the E20 vehicles from those same vehicle sets are expected before the end of the calendar year. Powertrain component inspection included an evaporative emissions system leak check, evaporative canister working capacity test, cam lobe measurement, valve seat width and valve surface contour, valve stem height, intake valve deposit mass, engine oil analysis, fuel injector flow measurements, fuel pump flow measurement and fuel pump disassembly and inspection.

There were no significant differences in the powertrain components from vehicles aged on gasoline versus those aged on ethanol blends, with the exception of intake valve deposit (IVD) weight. Many of the vehicles aged on E15 or E20 showed significantly higher IVD than their E0 counterparts; an example is shown in Figure 5 for the 2007 Honda Accord. The gasoline used for vehicle aging was top tier gasoline[2], and this gasoline was splash-blended with ethanol to make the RE15 and RE20 blends. Dilution of the additive package would be expected to increase IVD formation, so these results are not surprising. In addition, E10 has been shown to be a more severe test fuel for intake valve deposits [5]. While the IVD was higher for the E15 vehicles, it does not appear to have lead to emissions increases on these vehicles.

About half of the 24 pre-Tier 2 vehicles completed testing in FY 2010, and the remainder will be completed early in FY 2011. Data analysis on the full suite of vehicle data will continue into FY 2011 and be detailed in a comprehensive report.

Conclusions

- Tier 2 vehicles aged 63k to 120k miles did not show any increased exhaust emission deterioration due to aging with E15 fuel.
- Examination of powertrain components from Tier 2 vehicles aged with E15 and E20 showed no signs of increased corrosion or wear from the use of ethanol blends. Vehicles aged with ethanol blends did have higher intake valve deposit mass, however detergent additive concentrations were not adjusted in consideration of adding ethanol to the fuel.

[2] Top tier gasoline is formulated to meet a particular level of deposit control per ASTM D 6201, "Standard Test Method for Dynamometer Evaluation of Unleaded Spark-Ignition Engine Fuel for Intake Valve Deposit Formation."

TABLE 2. Tier 2 E0/E15 Vehicle Pass/Fail Summary

Reproduced from Federal Register/Vol. 75, No. 213/ November 4, 2010/Notices				
RE0 End of Test results Compared to Tier 2 Standards (Vehicles aged on RE0)				
Year	**Vehicle**	**NOx**	**NMOG**	**CO**
2007	Honda Accord	Pass	Pass	Pass
2006	Chevrolet Silverado	Pass	Pass	Pass
2008	Nissan Altima	Pass	Fail	Pass
2008	Ford Taurus	Pass	Pass	Pass
2007	Chrysler Caravan	Pass	Pass	Pass
2006	Chevrolet Cobalt	Pass	Pass	Pass
2007	Dodge Caliber	Fail	Pass	Pass
2009	Honda Civic	Pass	Pass	Pass
2009	Ford Explorer	Pass	Pass	Pass
2009	Toyota Corolla	Pass	Pass	Pass
2009	Jeep Liberty	Pass	Pass	Pass
2005	Toyota Tundra	Pass	Pass	Pass
2006	Chevrolet Impala	Pass	Pass	Pass
2005	Ford F150	Pass	Pass	Pass
2006	Nissan Quest	N/A	N/A	N/A
2009	Saturn Outlook	Pass	Pass	Pass
2009	Toyota Camry	Pass	Pass	Pass
2009	Ford Focus	Fail	Pass	Pass
2009	Honda Odyssey	Pass*	Pass	Pass
Total Fails, RE0		**2**	**1**	**0**

RE15 End of Test results Compared to Tier 2 Standards (Vehicles aged on RE15)				
Year	**Vehicle**	**NOx**	**NMOG**	**CO**
2007	Honda Accord	Pass	Pass	Pass
2006	Chevrolet Silverado	Pass	Pass	Pass
2008	Nissan Altima	Pass	Pass	Pass
2008	Ford Taurus	Pass	Pass	Pass
2007	Chrysler Caravan	Pass	Pass	Pass
2006	Chevrolet Cobalt	Pass	Pass	Pass
2007	Dodge Caliber	Pass	Pass	Pass
2009	Honda Civic	Pass	Pass	Pass
2009	Ford Explorer	Pass	Pass	Pass
2009	Toyota Corolla	Pass	Pass	Pass
2009	Jeep Liberty	Pass	Pass	Pass
2005	Toyota Tundra	Pass	Pass	Pass
2006	Chevrolet Impala	Pass	Pass	Pass
2005	Ford F150	Pass	Pass	Pass
2006	Nissan Quest	Fail	Pass	Pass
2009	Saturn Outlook	Pass	Pass	Pass
2009	Toyota Camry	Pass	Pass	Pass
2009	Ford Focus	Fail	Pass	Pass
2009	Honda Odyssey	Pass	Pass	Pass
Total Fails, RE15		**2**	**0**	**0**

*Denotes that average of emissions tests were below the applicable full useful life standard, but had at least one test value above the applicable standard

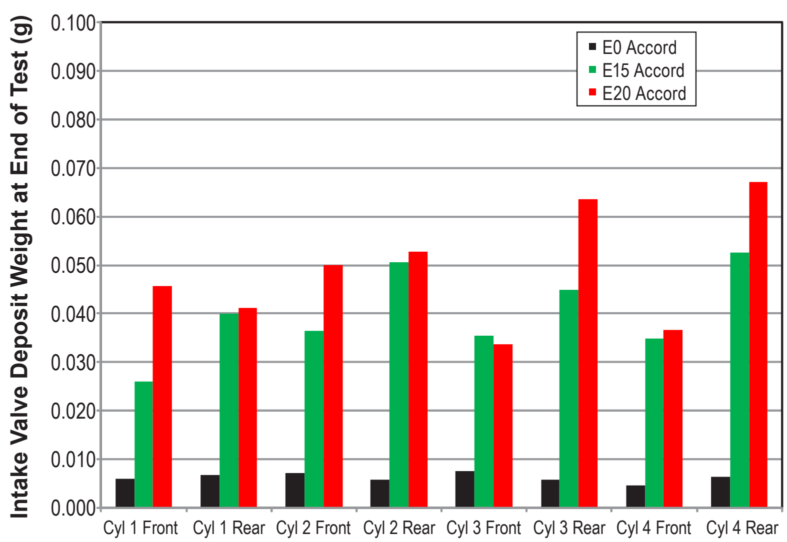

FIGURE 5. Intake Valve Deposit Weight for 2007 Honda Accords at End of Test

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