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Gasoline engine and Fuels Offering Reduced fuel Consumption and Emissions (GEFORCE)

CRADA final report for CRADA number NFE-15-05485

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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Energy and Transportation Science Division

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1. ABSTRACT

The GEFORCE project resulted from a collaborative proposal submitted to a U.S. DOE funding opportunity announcement. The CRADA reported herein was put in place to support the GEFORCE project. The project objective was to establish key engine technologies and fuel characteristics that enable very high fuel efficiency with very low emissions in future vehicles. A matrix of study fuels was designed and produced to support engine experiments in an advanced engine. The advanced engine was constructed and prepared for operation in an engine test cell at a 3rd party laboratory. ORNL conducted engine experiments using a 2.0 LTG engine and used the resulting data to estimate fuel economy values for a mid-size sedan using a vehicle model established in Autonomie. The projected fuel economy trends versus driving schedule were consistent with those identified in a previous project conducted in partnership with the Coordinating Research Council (CRC), AVFL-20. Additional vehicle modeling is anticipated when data are available from the advanced engine.

2. STATEMENT OF OBJECTIVES

The project objective was to establish key engine technologies and fuel characteristics that enable very high fuel efficiency with very low emissions in future vehicles. The results are expected to demonstrate a minimum of 25% reduction in petroleum consumption for multiple combinations of fuel formulation and engine technology.

3. TECHNICAL DISCUSSION OF WORK PERFORMED BY ALL PARTIES

The focus of this CRADA was to support a study resulting from a funding opportunity announcement (FOA). The technical objective of the project was to investigate synergistic combinations of fuel formulation and engine technologies that may offer reduced fuel consumption and emissions in a spark-ignition engine. Developments during the course of the program dictated a change in the anticipated program plan and task assignments. The overall project will continue past the expiration of this CRADA. ORNL and CRC completed several steps towards the overall project objective during the period of performance of this CRADA; these completed tasks are described in the subsequent sections.

3.1 FUEL MATRIX DEVELOPMENT AND PRODUCTION

The fuel matrix for this project was designed to support investigation of the interaction between fuel formulation and engine technologies and the effect on engine efficiency and particulate emissions. Three variables were chosen for investigation: research octane number (RON), ethanol blend fraction, and final boiling point. Fuel anti-knock behavior (characterized by RON) is an important characteristic that impacts engine efficiency. [1-8] Three target RON levels were selected: 92, 97, and 102. The particulate matter index (PMI) of a fuel is an indicator of the particulate formation tendency of a given gasoline. [9] However, differences in blendstocks prevent PMI from being a workable target value during fuel production at this time. Final boiling point was selected as a single figure-of-merit that could substitute for PMI during fuel production as a directional indicator of particulate formation tendency. Two primary final boiling point levels were established: a low level of 360 – 385 °F and a high level of 380 – 420 °F. Ethanol can influence both engine efficiency and particulate formation and is the most prevalent biofuel in use. Ethanol content was targeted for levels of 0%, 10%, and 30% by volume. Additionally, fuels were added having intermediate levels of the target parameter values to represent blends currently available in the marketplace. The target fuel matrix was thus defined by a cubical design space, shown in Figure 1. Gage Products of Ferndale, Michigan was selected to produce the fuels (through a contract established with CRC). Six drums of each fuel were produced and held in storage for use in engine studies for this project.

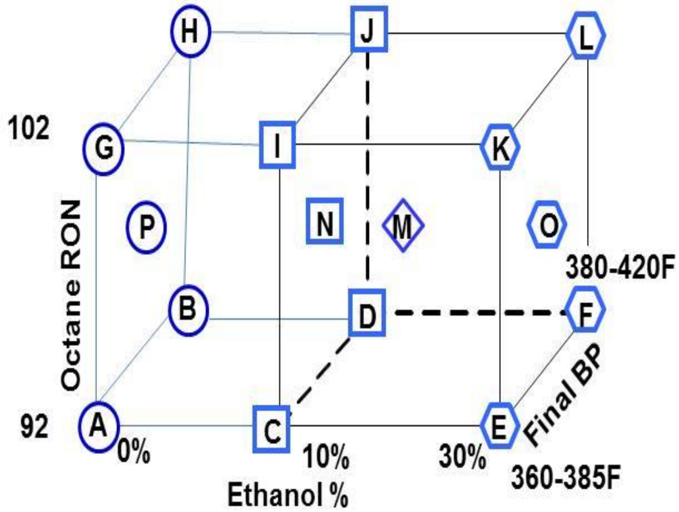

Figure 1. Study fuel matrix with characters denoting each of the 16 specific blends targeting combinations of fuel properties.

3.2 2.0 LTG ENGINE CHARACTERIZATION

Initially, a GM 2.0 liter turbocharged LTG engine was anticipated as a baseline application against which the gains attained through differing fuel formulation and engine technology additions could be compared. This engine uses a direct fuel injection system, a single turbocharger, and has a compression ratio of 9.5. General Motors (a CRC member company) provided an LTG engine and suitable engine controller to ORNL for initial evaluations. ORNL installed the engine and conducted studies to determine the fuel consumption and emissions levels of the engine at a range of conditions using a premium-grade, ethanol-free emissions certification gasoline (Haltermann Solutions HF0437). The certification fuel had a lower heating value of 43.3 MJ/kg and density of 0.743 kg/l. Engine speeds selected for data collection were in keeping with the method outlined in the AVFL-20 project, which were targeted towards conditions typical of certification driving schedules. [7] Figure 2 shows the 53 combinations of engine speed and torque where emissions and fuel consumption data were collected. The engine was in a fully warmed state for all data collection, with coolant and oil temperature of nominally 90 °C. Figure 3 shows fuel consumption values for the LTG engine.

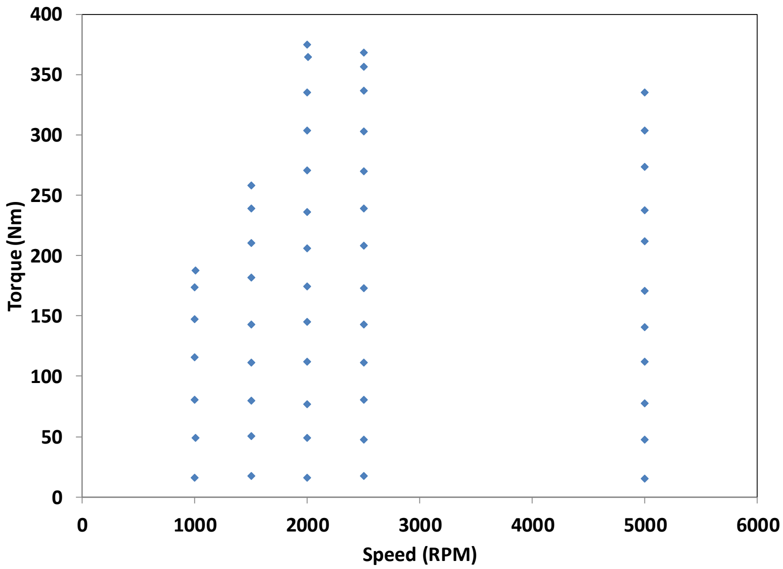

Figure 2. Engine speed and torque conditions where fuel consumption and emissions data were collected.

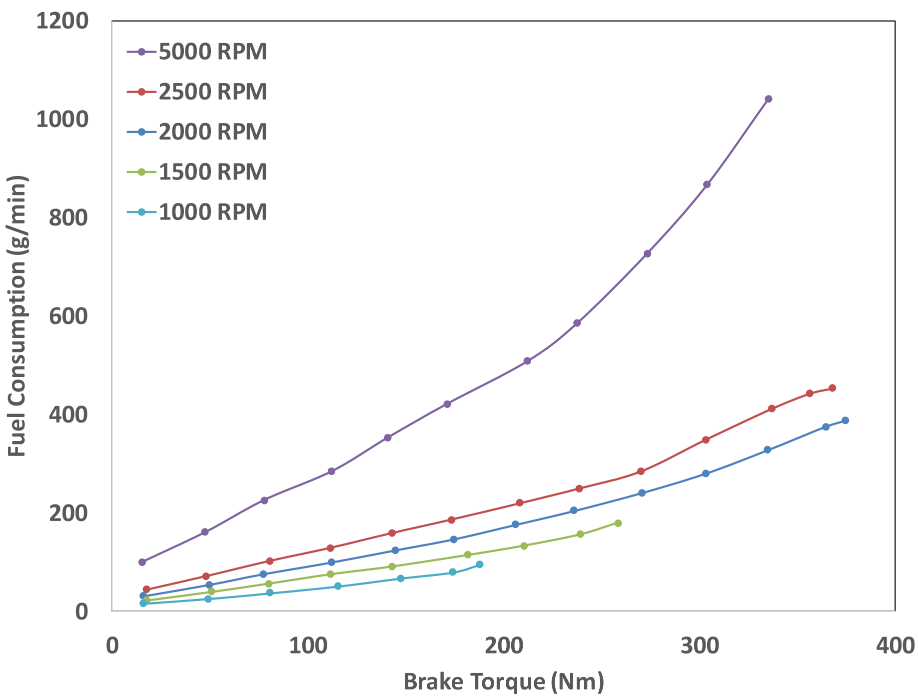

Figure 3. Measured fuel consumption values for the 2.0 liter LTG engine using certification gasoline.

3.3 VEHICLE MODEL DEVELOPMENT

Data gathered in the laboratory can be used to provide guidance on impacts of fuel formulation and engine technologies on engine efficiency, but to estimate their effects on vehicle fuel economy requires coupling the engine data with a suitable vehicle model. The Autonomie model is a well-known software environment for conducting vehicle modeling and has been successfully used for a related study and was used for this study as well. [7]

3.3.1 EPA Certification Database Mining

A data mining campaign was conducted using the Environmental Protection Agency (EPA) certification database for model year 2014 to determine values of aerodynamic and mass parameters needed to support vehicle modeling. Dynamometer target coefficients A, B, and C define the aerodynamic and friction loads on the vehicle during a certification test on a chassis dynamometer. Engineering test weight (ETW) defines the inertial loads on the vehicle during dynamometer tests. These parameters are collected for the certification tests in a given model year in the EPA certification database. Distributions of these parameters for mid-size sedans and small SUVs were analyzed to determine an appropriate value of each parameter to represent an "industry-average" vehicle. In each case, the distribution was created by examining the parameter of interest according to the vehicle power density in horsepower per ton of vehicle weight. An example of this distribution is shown in Figure 4 for target coefficient C. The large symbols at the center of the dark shaded areas show the median values of the distribution. The dark shaded areas denote the region where 25% of the data on either side of the median occur, with the light regions denoting the outer quartiles of the distribution of the data. The median values as determined by this analysis were used for modeling a mid-size sedan. The values for the small SUV were used in a different study and may additionally be used in this study for future analyses. Transmission gear ratios for a 6-speed transmission and final drive ratio were also selected by examining the actual gear ratios for vehicles of similar power density. The parameters identified for modeling vehicles in Autonomie are summarized in Table 1.

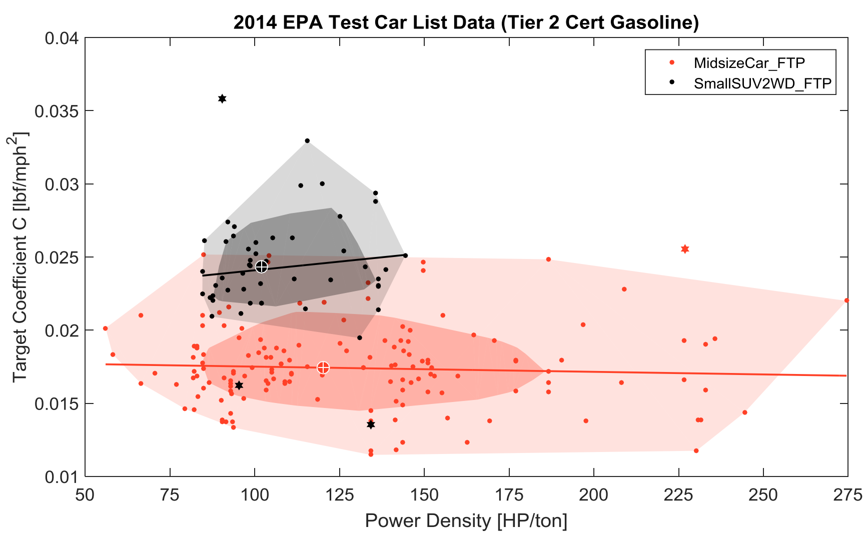

Figure 4. Distribution of target coefficient C values in the 2014 EPA test car certification database.

Table 1. Parameters used in Autonomie models.

Parameter	Midsize Car	Small SUV
ETW (lbs)	4000	4000
A (lbf)	34.0501	31.3622
B (lbf/mph)	0.2061	0.3408
C (lbf/mph^2)	0.0178	0.0235
1st Gear Ratio	3.73	4.584
2nd Gear Ratio	2.05	2.964
3rd Gear Ratio	1.36	1.912
4th Gear Ratio	1.03	1.446

5th Gear Ratio	0.82	1.000
6th Gear Ratio	0.69	0.746
Final Drive Ratio	4.07	3.21

3.3.2 Vehicle Model with LTG Engine Data

The data collected on the 2.0 liter LTG engine at ORNL was used with the Automomie models as outlined above to estimate the fuel economy of a vehicle using the LTG engine in combination with the premium-grade certification fuel used to collect the engine data. For this purpose, the urban dynamometer driving schedule (UDDS), the highway fuel economy test (HWFET), and the city and highway portions of the US06 cycles (US06_city and US06_hwy) were adopted, as they are used in emissions and fuel economy certification for new vehicles in the U.S. A more in-depth discussion of these cycles is available in the AVFL-20 report. [7] The modeling exercise focuses on fully-warmed conditions, consistent with the data acquired in the experimental portion of the study. As a result, cold-start conditions are not included in estimates of fuel economy provided by the vehicle model. The fuel economy values resulting from the vehicle modeling for a mid-size sedan are shown in Figure 5. The trend in fuel economy with driving schedule is consistent with results determined during the AVFL-20 study. [7]

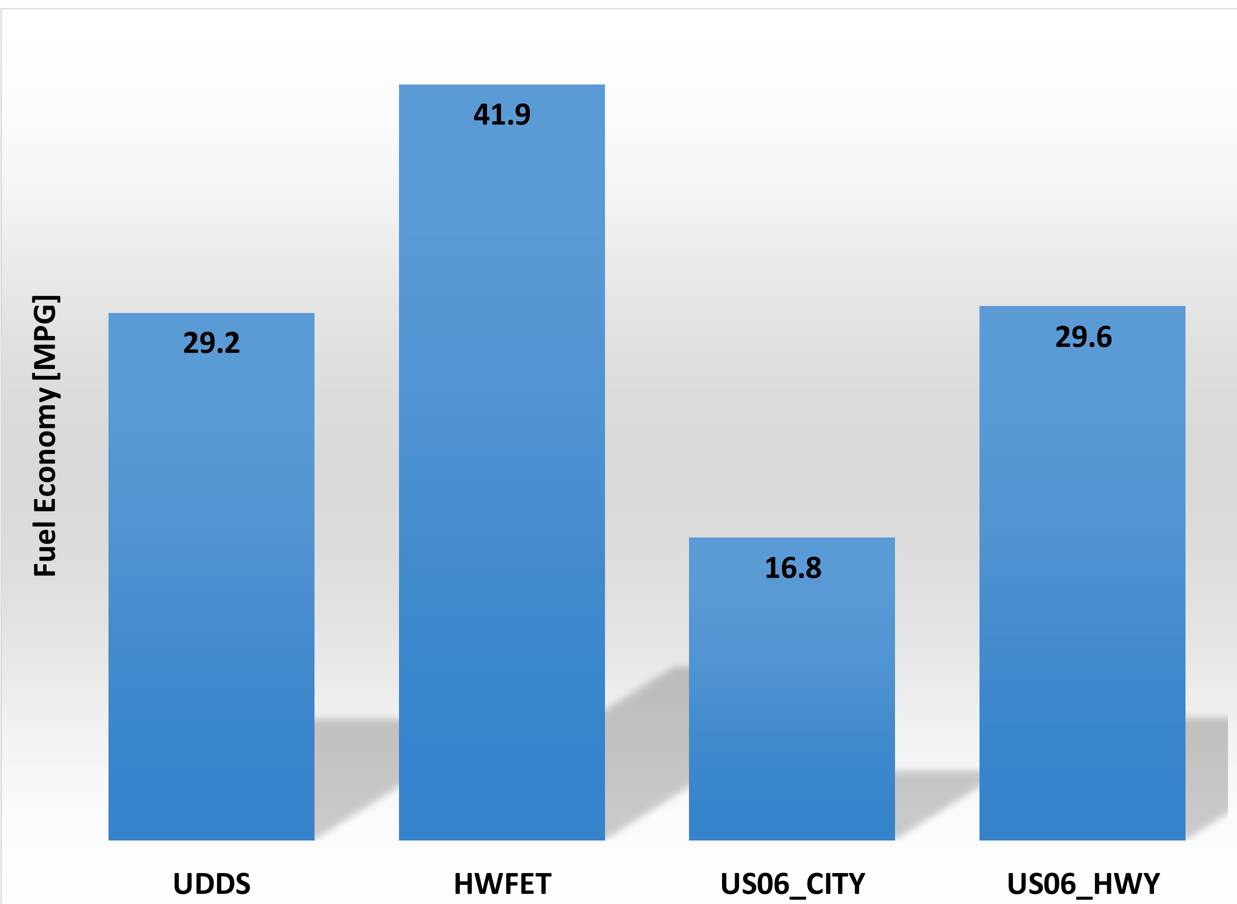

Figure 5. Modeled fuel economy results for an industry-average mid-size sedan using the 2.0 LTG engine and a premium-grade certification gasoline.

3.4 ADVANCED ENGINE DEVELOPMENT

An advanced engine was developed to evaluate the interactions between potential fuel formulations and engine technology that is anticipated to become mainstream in the next decade. The advanced engine uses the head, block, and other components of a 2.0 liter LTG, but also integrates a new crank to increase the stroke/bore ratio. Custom connecting rods were also incorporated to accommodate the new crank and to increase the engine compression ratio from 9.5 to 11.5. A two-stage turbocharger and a cooled exhaust gas recirculation (EGR) system were also incorporated in the advanced engine. The extensive modifications to the engine mandated much more engine control development than had been initially planned and required a change in direction for the project to reach a successful conclusion. Thus, the advanced engine optimization for each candidate fuel from the test matrix was undertaken by CRC at a 3rd party laboratory. ORNL will continue to provide vehicle modeling support as data from the advanced engine become available. Figure 6 shows a photograph of the advanced engine.

Figure 6. Photograph of the advanced engine.

4. SUBJECT INVENTIONS

There have been no invention disclosures or patent applications filed in association with this CRADA, and none are anticipated.

5. COMMERCIALIZATION POSSIBILITIES

Many of the CRC member companies are pursuing downsized, boosted spark ignition engines in their future product planning. The fuel and engine technologies investigated in this project are potential future technologies applicable to this engine design direction. The output of this project is scientific knowledge about the relationship between engine performance and fuel formulation. This knowledge is being actively shared with the member companies through their participation in CRC committees to aid them in developing their future product plans. As such, this information will be commercialized in that it helps inform the product planning within the member companies on potential interactions between engines and fuels that may influence engine efficiency and emissions characteristics.

6. PLANS FOR FUTURE COLLABORATION

ORNL and CRC often have similar or synergistic research interests and communicate frequently. We anticipate that this communication may lead to other opportunities for collaboration in the future and would explore opportunities for collaboration as they arise.

7. CONCLUSIONS

- A fuel matrix was designed to enable investigation of the connections between fuel properties in potential future fuel blends and engine technologies that are anticipated to be mainstream in the next decade.
- A vehicle model was established to aid in evaluating fuel efficiency impacts resulting from fuel and engine technologies at the vehicle level based on engine data gathered in the laboratory. Engine data collected at ORNL was used in combination with the model to project fuel economy values for common certification drive cycles for a mid-size sedan using a 2.0 liter LTG engine and a premium-grade certification gasoline.
- An advanced engine was constructed to incorporate engine technologies anticipated to be mainstream in the next decade and was readied for study in a 3rd part engine laboratory.

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