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Laboratory Testing of a 2017 Ford F-150 3.5L V6 EcoBoost With a 10-Speed Transmission

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16. Abstract

The vehicle benchmarked in this report is a 2017 Ford F-150 with the 3.5 liter V6 EcoBoost engine coupled to a newly introduced 10-speed automatic transmission. This particular powertrain configuration provides favorable fuel economy results while providing significant vehicle performance. The focus of the benchmark is to understand the use of critical powertrain components and their impact on the vehicle efficiency. The vehicle is instrumented to provide data to support the model development and validation in conjunction to providing the data for the analysis in the report. The vehicle is tested on a chassis dynamometer in the controlled laboratory environment across a range of certification tests. Further tests are performed to map the different powertrain components.

The analysis in this report start by providing the fuel economy and efficiency results on the certification drive cycles along with of component operation on those tests. The maximum performance envelops of the powertrain are presented. A section is devoted to specific powertrain characterization. Some off-cycle testing, such as the thermal testing of 5-cycle label fuel economy and octane fuel testing, is explored. Finally, some vehicle specific test, such as the impact of different drive modes on the transmission operation, increased payload and active grille shutters, close out the analysis.

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Definitions and Abbreviations

° C	degrees Celsius
° F	degrees Fahrenheit
2WD	two-wheel drive
4WD	four-wheel drive
AC	air conditioning
AKI	anti-knock index
APRF	Advanced Powertrain Research Facility (Argonne)
Autonomie	Argonne full-vehicle simulation software (https://www.autonomie.net/)
Argonne	Argonne National Laboratory
ASR	absolute speed change rating
AVTE	Advanced Vehicle Testing Evaluation (U.S. DOE activity)
BEV	battery electric vehicle
BTU	British thermal unit
CAN	computer area network
CAFE	Corporate Average Fuel Economy
cc	cubic centimeter
ccps	cubic centimeters per second
CEd	positive driven cycle energy
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
DAQ	Data acquisition system
deg	degree
DFCO	deceleration fuel cutoff
DFI	Direct fuel injected
DI	Direct Injection
DOHC	double overhead cam
DR	distance rating
EGR	exhaust gas recirculation system
EPA	U.S. Environmental Protection Agency
ER	energy rating
EER	Energy Economy Rating
FTP	Federal test procedure (EPA defined)
gps	grams per second
HC	hydrocarbon
HEV	hybrid electric vehicle
hp	horsepower
Highway	EPA certification testing: Highway dynamometer driving cycle
Hz	Hertz
inH20	inches of water

inHg	inches of mercury
kPa	kilopascal
kph	kilometer per hour
kW	kilowatt
L	liter
LA92	California unified driving schedule
Lb / lbs	pound(s)
lb-ft	foot pounds
lbm	pound-mass
LHV	lower heating value
m	meter
MBT	maximum brake torque
mg	milligrams
mpg	miles per gallon
mph	miles per hour
N	Newton
NA	naturally aspirated
Nm	Newton-meters (torque)
NOx	oxides of nitrogen
PFI	Port fuel injected
RMS	root mean squared error
rpm	rotations per minute
RWD	rear wheel drive
s	second
SAE	Society of Automotive Engineers
SC03	EPA certification test (Air conditioning test)
scfm	standard cubic feet per minute
SSS	steady speed stairs
TCC	torque converter clutch
TCU	transmission control unit
UDDS	EPA certification test: urban dynamometer driving schedule
US06	EPA certification test: US06 dynamometer driving schedule
Volpe	Volpe National Transportation Systems Center
V	Volts

1. Executive summary

The National Highway Traffic Safety Administration (NHTSA) is an agency within the U.S. Department of Transportation (DOT), which sets Corporate Average Fuel Economy (CAFE) standards for passenger cars, light trucks and medium-duty passenger vehicles. NHTSA contracted Argonne to conduct full vehicle simulation using Autonomie (www.autonomie.net/), a vehicle system simulation tool, to provide input into the CAFE model to determine minimum average fuel economy. Autonomie relies on vehicle technology assumptions for model development and validation. Argonne's Advanced Powertrain Research Facility (APRF) provides the laboratory test data that informs that technology assumptions in Autonomie. NHTSA funded Argonne's APRF to perform a benchmark of a 2017 Ford F-150 pickup truck and to provide data to Autonomie and assess the fuel saving technologies of that powertrain.

The vehicle benchmarked in this report is a 2017 Ford F-150 with the 3.5 liter V6 EcoBoost engine coupled to a newly introduced 10-speed automatic transmission. This particular powertrain configuration provides favorable fuel economy results while providing significant vehicle performance. The focus of the benchmark is to understand the use of critical powertrain components and their impact on the vehicle efficiency. The vehicle is instrumented to provide data to support the model development and validation in conjunction to providing the data for the analysis in the report. The vehicle is tested on a chassis dynamometer in the controlled laboratory environment across a range of certification tests. Further tests are performed to map the different powertrain components.

The analysis in this report start by providing the fuel economy and efficiency results on the certification drive cycles along with of component operation on those tests. The maximum performance envelops of the powertrain are presented. A section is devoted to specific powertrain characterization. Some off-cycle testing, such as the thermal testing of 5-cycle label fuel economy and octane fuel testing, is explored. Finally, some vehicle specific test, such as the impact of different drive modes on the transmission operation, increased payload and active grille shutters, close out the analysis.

2. Introduction and background

2.1. Project background

Argonne is providing a benchmark report based on chassis dynamometer testing in laboratory conditions for a 2017 Ford F-150 EcoBoost. In order to complete this evaluation, the Vehicle System Research Group at Argonne National Laboratory conducted vehicle testing on a chassis dynamometer at its Advanced Powertrain Research Facility (www.anl.gov/d3). The vehicle was extensively instrumented to understand powertrain operation and the impact of specific advanced vehicle technologies on fuel consumption. In addition to this report, the hundreds of available time resolved vehicle signals generated by the testing are provided to Argonne's vehicle simulation group in order to inform the refinement of Autonomie software and enable validation of the vehicle specific technologies (www.autonomie.net).

This report provides a detailed analysis of the 2017 Ford F-150 equipped with the 3.5L turbocharged V6 EcoBoost engine and a 10-speed automatic transmission. This boosted V6 engine provides similar power to traditional V8 engines, but with claimed fuel efficiency benefits seen from smaller displacement engines with turbocharging. The 10-speed transmission can increase the average powertrain efficiency by providing greater flexibility in gear ratios to operate the engine at more efficient speed and load points.

2.2. Argonne's vehicle simulation and testing synergy

Argonne's vehicle benchmark and simulation efforts have grown in parallel since the early 2000s. The powertrain data generated from the vehicle testing in the laboratory has been used to develop component models and control strategies for simulations. The laboratory data is also used to validate the powertrain simulation results.

3. Argonne's vehicle system research capabilities

3.1. Laboratory description

Argonne National Laboratory has several research groups and facilities performing automotive research within the Center for Transportation Research. The testing and analysis in this report is performed by the Vehicle Systems Research group. The Advanced Powertrain Research Facility (APRF) provides resources for both vehicle instrumentation and testing, including two chassis dynamometer test cells. The testing for this report is performed using the APRF's 4WD chassis dynamometer test cell. This test cell is designed to handle light- to medium-duty vehicles and includes a thermal chamber that is EPA 5-cycle-capable. A vehicle speed-matching simulation fan fulfills the test regulations for the SC03 air-conditioning test. The cell also contains solar lamps to simulate real-world solar loading of 850 W/m^2. Figure 1 highlights some of the major capabilities of the test cell.

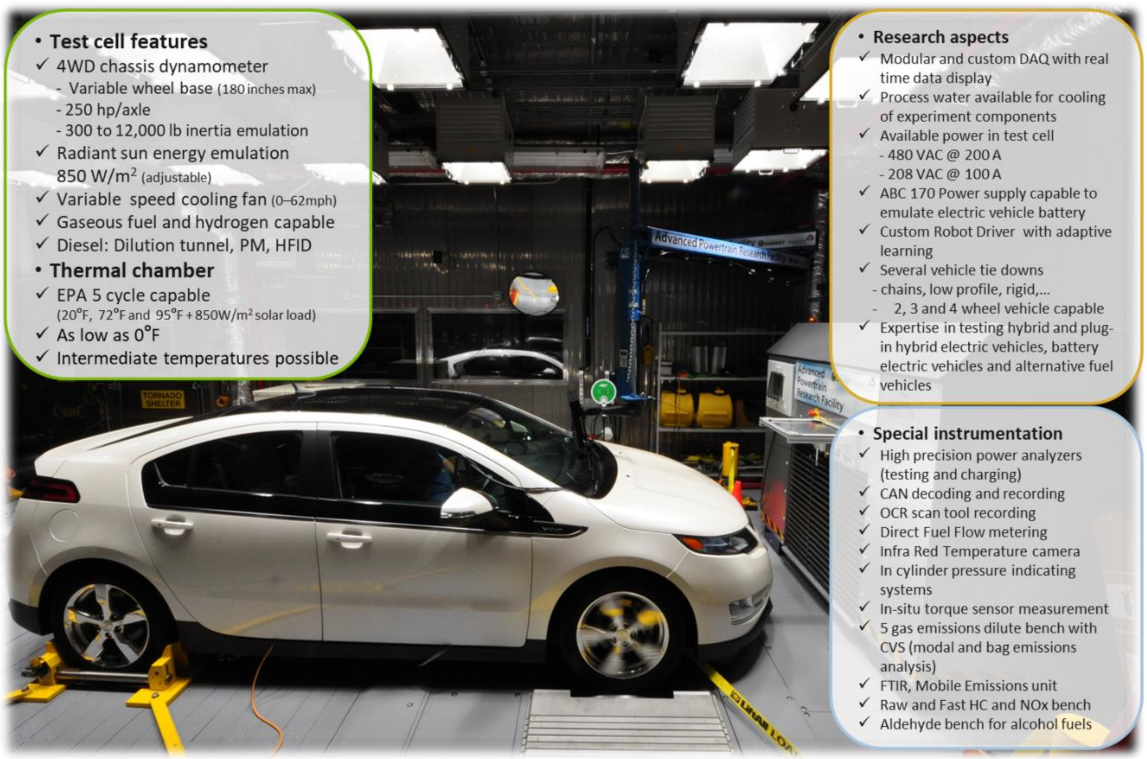

Figure 1: Major features of the 4WD chassis dynamometer and thermal chamber test cell.

The APRF is purpose-built for technology evaluations and powertrain research. Within this research focused facility, in-depth testing of a vehicle is best facilitated by leaving that vehicle mounted on the chassis dynamometer for the duration of the testing. A testing session usually lasts from a few days to a few weeks. This approach has been found to minimize test to test variability inherent to vehicle re-mounting, and was applied for the test vehicle in this report. Vehicle instrumentation in the facility includes a custom fully integrated data acquisition (DAQ) system that merges and time aligns data streams from many different selectable sources such as facility sensors, dynamometer feedback, analog vehicle sensors, vehicle communication messages, emissions analyzers, fuel flow meters and many others. The test cell contains a dilute emission bench that measure the criteria emissions of total hydrocarbons (HCs), oxides of nitrogen (NOx), and carbon monoxide (CO), as well as carbon dioxide (CO_2).

A particular benefit of the custom DAQ is the ability to display real time signals from any sensor in the instrumentation. This enables targeted component mapping as the testing staff can set and verify component operating points, vary test conditions, and ensure that all relevant signals have reached stability in real time that ensures quality data for component characterization and modeling.

The Argonne staff has been benchmarking advanced technology vehicles since the 1990s. The well-refined vehicle test process starts with instrumentation and testing and ends with detailed analysis of the results. The testing staff always aims to understand the power (fuel and electric) flows between the components in the vehicle, to establish transient efficiency and usage maps for components, and to characterize the behavior of the key components of the powertrain.

3.2. Difference in purpose between certification testing and the APRF testing

The major focus of certification testing is to provide robust, repeatable vehicle evaluations to ensure fuel economy and emission compliance within the regulatory framework. The testing that Argonne performs for the U.S. Department of Energy differs from standard certification testing in two specific dimensions: (1) the depth of instrumentation; and (2) the breadth of test types and testing conditions. While standard certification testing performed by the EPA focuses on certification drive cycles fuel economy and tailpipe emissions on a very large number of cars, Argonne targets a much smaller set of vehicles (and therefore of powertrains) with the intent to characterize the components in each powertrain across a wide range of conditions.

Similar to certification testing, Argonne measures fuel consumption and tailpipe emissions at the vehicle level for specific drive cycles. The Argonne testing provides additional value with in-depth information on specific powertrain components and characterization of component operational areas, efficiencies, and performance limits (where possible). The comprehensive instrumentation approach allows the research staff to determine the powertrain behavior and how each component contributes to the powertrain system efficiency on standard drive cycles.

In addition to EPA standard certification drive cycles, the testing covers many other drive transient cycles, performance tests, and component mapping tests across a range of ambient temperatures. The performance testing typically includes maximum accelerations, passing maneuvers, and grade testing. Additionally, component mapping often includes steady state speed testing with a focus on specific component operation areas.

3.3. Differences between certification test procedures and procedures at the APRF

The Argonne testing deviates from certification testing as Argonne's goal is research fidelity rather than regulatory compliance. Based on this intent, the staff often purposefully chose to change specific aspects of the test procedures to prioritize vehicle operation in real-world conditions. The next paragraphs describe some of the variations in vehicle testing that are unique to testing at the APRF.

Speed-matched fan: In order to provide results close to real world conditions, Argonne uses a fan in front of the vehicle in speed match mode and has the vehicle hood closed for all testing at any ambient temperature, unless otherwise specified. This deviates from certification testing requirements described in the Codes of Federal Regulations that requires the vehicle hood to be open and the fan to operate at a constant speed of 5,300 scfm for the standard UDDS and Highway drive cycles. Argonne has determined that there is a small, but measurable different in fuel consumption between these two vehicle configuration at 72° F and especially at 20° F and 95° F.

Emission bench set-up: The second test setup difference is that Argonne continuously runs a diluted exhaust sample through the emissions analyzers during the drive cycle testing in order to obtain modal (time resolved) emission data. Therefore the emission bags are not sampled immediately after the end of a test phase but they are sampled at the end of a full test. Argonne has run some experiments to compare both procedures and found statistically insignificant differences in fuel consumption results. Due to this result, the staff chose to sample to emissions bags at the end of the test in order to obtain the time resolved emission data.

Figure 2 details the vehicle and equipment setup used by Argonne for chassis dynamometer testing. The major differences are explained above. The vehicle cooling setup and the emissions bench sampling are the two major differences between Argonne testing and certification testing. The 20° F testing at Argonne is performed on the same certification fuel as the 72° F and 95° F tests. Furthermore the target road load coefficients are not readjusted for 20° F testing as they are for certification testing.

	20°F ambient temperature	72°F ambient temperature	95°F ambient temperature
Origin	• Cold CO and HC test	• UDDS, HWFET and US06	• SC03 test with air conditioning
Road load	• Listed EPA listed coefficients, unless otherwise provided • Target coefficients used are listed in the summary sheet for each vehicle		
Cooling fan	• Vehicle Speed match mode	• Vehicle Speed match mode	• Vehicle Speed match mode
Hood position	• Hood down	• Hood down	• Hood down
Window position	• Windows closed	• Windows open	• Windows closed
Climate control	• Automatic mode • 72°F target temp	• OFF	• Automatic mode • 72°F target temp
Solar lamps	• OFF	• OFF	• 850 W/m² radiant solar energy
Additional notes	• Target road load not necessarily readjusted • Cold temperature fuel not used for AVTE	• None	• None
	Valid at all temperatures • Modal and bag measurements simultaneously		

Figure 2: Vehicle test setup at Argonne

For the remainder of this report all data and test results are generated using the Argonne test setup and procedures as described in this section unless otherwise noted.

3.4. Instrumentation approach

The APRF was purpose built for automotive powertrain research and technology benchmarking. Based on that mission, the staff have developed unique expertise focused on the instrumentation of advanced technology powertrain components. This expertise includes, decoding and capture of vehicle broadcast CAN and diagnostic messages, in-situ component mapping, custom facility and the custom data acquisition system, and the development of special test procedures to produce desired high quality research results.

Figure 3 illustrates the general instrumentation of conventional vehicles. For the testing on conventional vehicles such as the 2017 Ford F-150, the testing integrates data streams from several sources. The facility data captures the test cell conditions (ambient test cell temperature and relative humidity), the dynamometer data (vehicle speed and the tractive effort) and emissions data (bag and modal bench data: HC, CO, NOx, and CO_2). The fuel consumption is measured in several different ways: (1) Carbon balance fuel economy results from the emissions bench (bag and modal) and (2) several fuel flow meters, providing both volumetric and mass measurements.

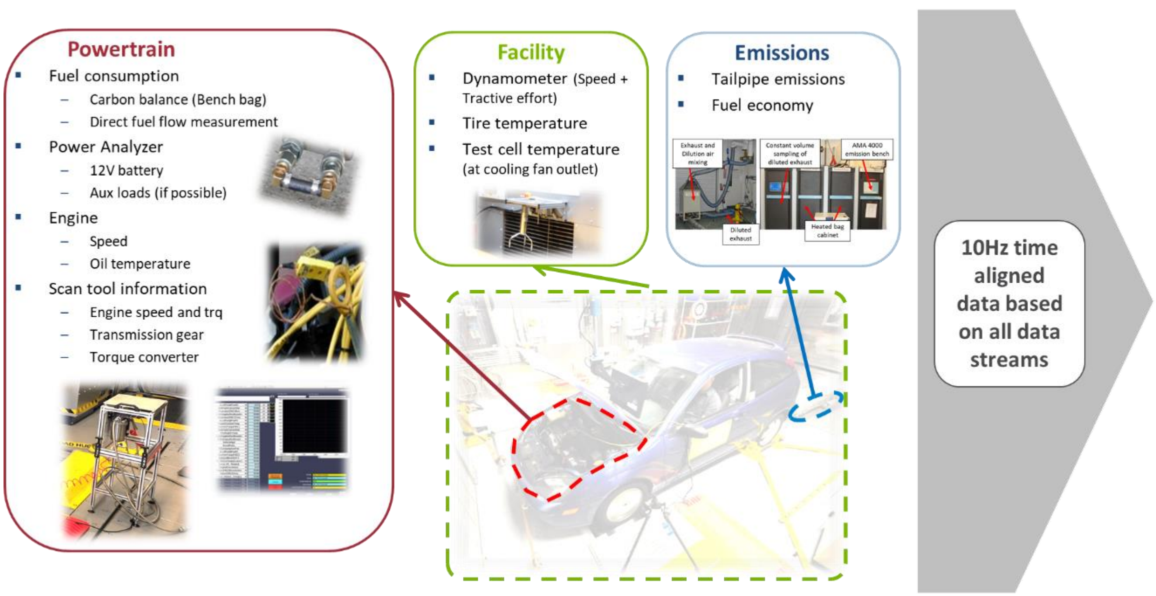

Figure 3: Overview of general instrumentation for conventional vehicle

The target drive schedule and phase information is also recorded with the results. The modal emissions data from the analyzers is the third data stream. General analog vehicle signals are part of the standard testing and typically include engine oil temperature, direct fuel flow measurements and electric power flow measurements (12V battery for conventional vehicles). The list of standard signals and data streams is shown in Table 1.

Table 1: Standard data streams collected for all vehicles tested at Argonne's Advanced Powertrain Research Facility

Facility data	Drive cycle input	Emissions data	Generic vehicle data
Dyno_Spd[mph]	Drive_Schedule_Time[s]	Dilute_CH4[mg/s]	Engine_Oil_Dipstick_Temp[C]
Dyno_TractiveForce[N]	Drive_Trace_Schedule[mph]	Dilute_NOx[mg/s]	Cabin_Temp[C]
Dyno_LoadCell[N]	Exhaust_Bag []	Dilute_COlow[mg/s]	Solar_Array_Ind_Temp[C]
DilAir_RH[%]		Dilute_COmid[mg/s]	Eng_FuelFlow_Direct[gps]
Tailpipe_Press[inH2O]		Dilute_CO2[mg/s]	Eng_FuelFlow_Direct[ccps]
Cell_Temp[C]		Dilute_HFID[mg/s]	12V Battery [V], [A] and [W]
Cell_RH[%]		Dilute_NMHC[mg/s]	
Cell_Press[inHg]		Dilute_Fuel[g/s]	
Fan_Air_Spd[mph]			
Tire_Rear_Temp[C]			
Tire_Front_Temp[C]			

A Re-Sol RS840-060 fuel measurement system is routed in the fuel line between the vehicle tank and the fuel rail. This device is suitable for all vehicles with return-less style fuel delivery systems. It is installed in-line with the vehicle fuel supply and makes use of a positive displacement flow meter to measure the volumetric flow rate of fuel consumed by the engine. The meter is able to measure flow rates between 0.3 and 60 liters per hour with an accuracy of ± 0.5% of the reading.

A core capability of the APRF staff is the ability to decode the vehicle and powertrain internal communication messages (CAN), which is relevant to this testing. Over the last few years, the APRF staff has developed powerful tools that enable the decoding of both broadcast and diagnostic CAN messages. These tools rely on the understanding of powertrain CAN structure, the correlation of changes in CAN messages to known scan tool or instrumentation signals, the ability to mimic scan tool message requests, and the dynamometer environment that can safely put the powertrain in specific planned scenarios to enable the decoding of certain signals. The team decoded a significant list of powertrain messages for the vehicle that are detailed in section 5.1.2.

3.5. General test plan approach for this study

The testing focus for this work is on the UDDS, the Highway and the US06 drive cycles at the 72° F ambient temperature. The test sequence includes a cold start UDDS, a hot start UDDS, a third UDDS, a Highway pair and a US06 pair. The preparation for the cold start test consists of completing a UDDS cycle at 72° F and leaving the vehicle to thermally soak at 72° F for over 12 hours. The overnight soak is done on the chassis dynamometer in the test cell since the vehicle stayed mounted on the rolls for the duration of the testing. The graph in Figure 4 shows the sequence of drive cycles executed for this testing. Note that a 10 minute soak period is held between the UDDS cycles as noted in the figure. The test sequence is repeated at least three times. The fuel economy numbers in this report are based on the test phases highlighted by the pink boxes. The phases for the US06 drive cycle are the split city and highway phases needed to calculate the EPA 5-cycle fuel economy label.

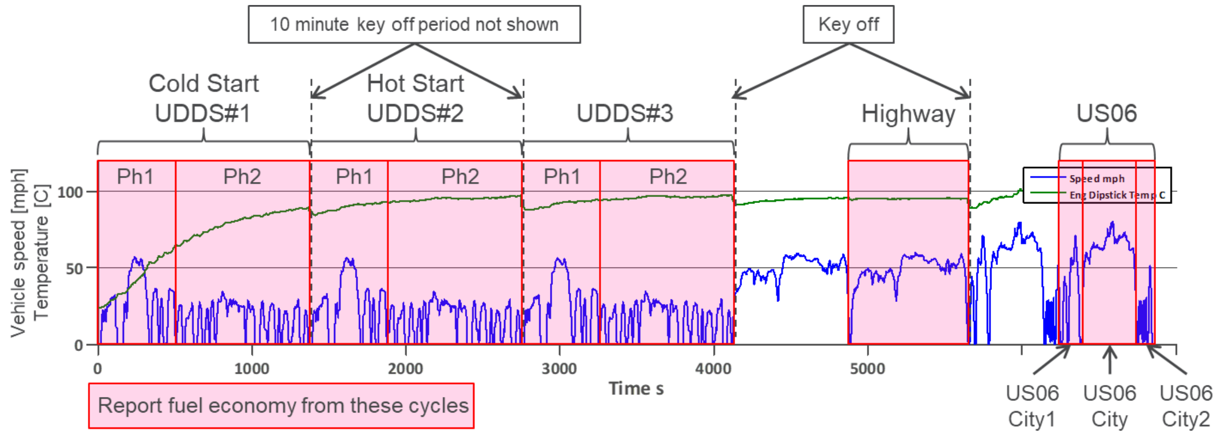

Figure 4: Daily drive cycle test sequence executed in the morning

Performance testing, component mapping and other drive cycle testing is performed in the afternoon. The performance testing includes maximum accelerations, several passing maneuvers, and steady state speed tests at different grades. The mapping focuses on specific engine features and transmission shifting.

Two additional investigations are performed. The impact of premium and regular fuel on performance and fuel economy is investigated. The vehicle is also tested at 20° F and 95° F with 850 W/m^2 of solar loading on the test sequence shown in Figure 4. A detailed test plan is described in section 5.1.3.

3.6. General vehicle preparation and chassis dynamometer setup

The test vehicle was purchased at a dealership by Argonne. The Ford F-150 with the EcoBoost engine and the 10-speed transmission had been launched at the beginning of the project and had to be purchased as a brand new vehicle. The vehicles was appropriately broken in through an on-road mileage accumulation of 4,000 miles as indicated by the vehicle odometer. The final tank of fuel during the on-road mileage accumulation was performed with certification test fuel.

The vehicle test weigh and road load coefficients are acquired from EPA (https://www.epa.gov/compliance-and-fuel-economy-data/data-cars-used-testing-fuel-economy). After the instrumented vehicle was mounted on the chassis dynamometer, the team performed some signal check out that served to warm up the powertrain and tires. The vehicle then completed a double Highway drive cycle (pair of Highways) as required by SAE J1263 ™ “Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques” before engaging the vehicle loss determination procedure on the chassis dynamometer interface. The derived vehicle dyno set coefficients were accepted, saved and applied to the road load emulation. The dyno set coefficients from the vehicle loss determination are used for the remainder of the chassis dynamometer testing for the vehicle. The dynamometer road load target coefficients (target and dyno set) are provided in the specific-vehicle section 5.1.1.

3.7. Professional driver vs robot driver

Argonne has experienced dynamometer drivers who have driven test cycles on chassis rolls for decades. Argonne has also developed and refined a custom robot driver. The robot driver was first developed for plug-in hybrids and battery electric vehicles. The powertrains in these vehicles require repetitive testing over the course of very long and uninterrupted test periods (up to 18 hours for electric vehicles with large battery packs). The high repeatability of the robot driver enables a determination of very small changes in fuel consumption in comparative technology testing such as testing the effect of a specific technology through A to B testing.

Argonne developed the robot hardware as well as the software. The robot driver is composed of two oversized linear actuators. The first actuator operates the accelerator pedal and the second actuates the brake pedal. The control software is implemented directly in the APRF custom data acquisition system. Several software features – such as look ahead, gain scheduling, and active feed-forward learning – enabled the staff to fine tune the robot driver to the powertrain and certification cycles.

Argonne considered using the robot driver for this testing but ended up using the professional chassis dynamometer drivers. The decision was driven by the facts that: (1) the test period was short and the training of the robot driver requires some time, and (2) that the testing was focused on technology assessment rather than comparing specific technology changes in a vehicle (such as different fuels or two separate powertrain warm up strategies).

Additionally, Argonne calculates, prints and verifies the SAE J 2951 drive quality metrics for each test in real time.

3.8. SAE J2951 drive quality metrics

The SAE J2951 "Drive Quality Evaluation for Chassis Dynamometer Testing" defines a set of parameters aimed at quantifying how close the driving speed trace followed the actual drive trace. The procedure clearly prescribes the different data processing and calculation steps to generate these parameters. Argonne staff members were actively involved in developing the drive quality metrics through mathematical concepts as well as target chassis dynamometer testing.

The J2951 metrics are the energy rating, the distance rating, the energy economy rating, absolute speed change rating and the root mean squared speed error. The standard clearly defines how to process the 10 Hz data from the drive schedule and the measured driven speed along with the vehicle characteristics (test weight and road load) to calculate the positive driven cycle energy (CEd) which is the foundation is the J2951 energy and economy ratings. The CEd can also be used for powertrain efficiency calculations. The energy rating is the percent difference between the positive driven cycle energy to the positive drive cycle energy. The distance rating is the percent difference between the total driven distance and the drive cycle distance. The energy economy rating combines the ER and DR into an economy rating. The absolute speed change rating compares the acceleration and deceleration rates between the driven trace and the drive trace. The RMS error provides the mathematical root mean square error between the driven trace and the drive trace. Figure 5 shows a few of the drive quality metrics that resulted from a past study focused on the how these parameters change with different drivers.

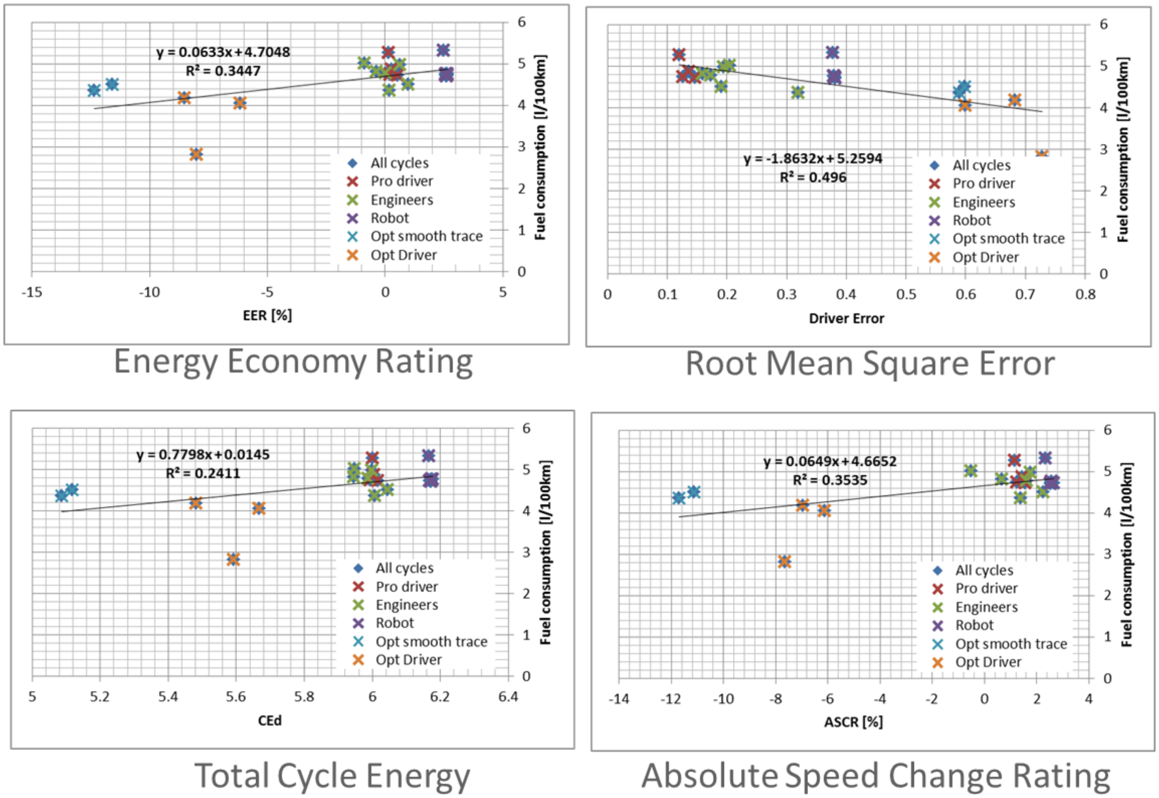

Figure 5: A few select SAE J2951 drive quality metrics from a study comparing different drivers from professional dyno drivers to the robot driver

The data in Figure 5 clearly shows that the robot driver and the professional dynamometer drivers repeat results are closely clustered into two groups. The 'Engineers' label represent a range of different engineers on staff who had less experience driving on the chassis dynamometer. Clearly the professional dynamometer drivers are very repeatable. It is notable the robot and professional driver clusters are close but that they rarely overlay. Usually the professional drivers perform better on these rating or are closer to the ideal rating compared to the robot driver. This information contributed to the decision to use the professional chassis dynamometer drivers for this testing rather than the robot driver.

Finally, it is important to understand that neither SAE nor EPA has defined any targets or limits on these drive quality metrics to define "good" or valid testing versus "bad" or invalid tests. The Argonne staff uses its experience and judgement on these drive quality metrics to determine if a test was "bad" that rarely occurs. All the J2951 drive metrics are provided with each test as part of this work.

3.9. Test-to-test repeatability at Argonne's APRF

In a previous study using a conventional vehicle, Argonne determined that the fuel economy test-to-test variability on a UDDS drive cycle is 0.8 percent on cold start and 0.6 percent on a hot start with a 90 percent confidence interval in fuel consumption terms. The low test-to-test variability is achieved by: (1) keeping the vehicle mounted on the chassis dynamometer for the duration of the test period; (2) staying very consistent on the test plan and time of day to ensure consistent day-to-day thermal conditions; (3) the consistency in daily operation from a small staff in one test cell (including experienced professional dyno drivers); and (4) number of other small experimental details. Like many other test laboratories, Argonne follows a strict calibration schedule for all the measurement equipment used.

3.10. Test Fuel Specifications

EPA Tier 2 EEE certification fuel was used for the testing. The fuel was procured through Haltermann Solutions under the product code of HF0437. Table 2 provides the major specification for the Tier 2 certification fuel used. The full fuel specifications can be found in Appendix A.

Table 2: Main specifications of the EPA Tier 2 EEE fuel

Fuel Name:	**HF0437 EEE Tier 2**
Carbon weigh fraction	0.8656
Density	0.743 [g/ml]
Net heating value	18539 [BTU/lbm]
Research Octane Number	97.8
Motor Octane Number	88.7
R+M/2	93.2
Sensitivity	9.1

Premium gasoline is recommended by the manufacturer but not required. One of the goals of this assessment is to evaluate the impact of premium and regular fuel on fuel economy as well as vehicle performance. The EPA Tier 2 EEE certification fuel described above serves as a premium gasoline with its 93 AKI octane rating. The EPA Tier 3 EEE certification fuel has an 88 AKI octane rating and serves as the regular gasoline in the comparison.

Table 3 provides the major specification for the Tier 2 certification fuel used. The full fuel specifications can be found in Appendix A.

Table 3: Main specifications of the EPA Tier 3 EEE fuel

Fuel Name:	**HF2021 EEE Tier 3**
Carbon weigh fraction	0.8263
Density	0.7447 [g/ml]
Net heating value	17972 [BTU/lbm]
Research Octane Number	91.8
Motor Octane Number	84.2
R+M/2	88.0
Sensitivity	7.6

The Tier 2 fuel has a 3.1 percent lower energy content by mass compared to the Tier 3 fuel that does impact the volumetric fuel economy comparison. The vehicle efficiency calculations do use the actual energy content and fuel specifications.

4. 2017 Ford F-150 3.5L EcoBoost

4.1. Test vehicle specifications

The Ford F-150, like many other pickup trucks, has a very wide range of powertrain options, among which are a 3.5 liter V6 EcoBoost and a 5.0 liter V8 engine coupled to a newly introduced 10-speed automatic transmission. The 5.0 liter V8 engine produces 385 hp and 387 lb-ft of torque, but the boosted 3.5 liter V6 has 30 percent less displacement and produces 375 hp, only 10 hp less than the V8, and 470 lb-ft of torque, which is significantly higher and occurs at only 3500 rpm (compared to 5,750 rpm for the V8). Additionally, the 3.5 liter V6 4x4 has a combined EPA label fuel economy of 20 mpg, compared to 17 mpg for the V8 4x4 with the same 10-speed automatic transmission. These performance and fuel economy advantages of the V6 EcoBoost engine lead to interest in this particular powertrain configuration and it is the focus of this technology assessment work. The build sheet for the test vehicle can be found in Appendix D. Table 4 lists the technical specifications of the Ford F-150 test vehicle.

Table 4: Technical specification of the Ford F-150 test vehicle

Test vehicle	2017 Ford F-150 3.5L V6 EcoBoost with 10-speed automatic transmission and 4x4
VIN	1FTEW1EGXHKC32685
Engine	3.5 liter Turbo, V6, DOHC 24V, 375 hp @ 5,000 rpm, 87 octane, regular fuel 470 lb-ft @ 3,500 rpm Compression ratio 10.5.:1 Port-fuel Injection and Direct Injection
Transmission	Four wheel drive 10-speed automatic transmission 1st 4.69 2nd 2.98 3rd 2.14 4th 1.76 5th 1.52 6th 1.27 7th 1.00 8th 0.85 9th 0.68 10th 0.63 Final Drive 3.21 265/60 R18 all-season tires
Climate control	Belt driven air conditioning compressor Waste heat heating
EPA Label Fuel Economy (mpg) [1]	17 City / 23 Hwy / 20 Combined (4WD option)
Performance [2]	0-60 mph time: 6.1 seconds

[1] Data from fueleconomy.gov
[2] MotorTrend

4.2. Specific technology features of interest

The significant F-150 technologies that test data can provide more insight on are the following.

- 10-speed transmission
  - Skip shift operation
  - Shift strategy and torque converter operation
- EcoBoost engine
  - Direct injection system and port fuel injection system
  - Engine start-stop behavior
- Behavior under different payloads
  - Transmission behavior changes with added pay load
  - Fuel consumption impact with payload
- Grille shutter operation

4.3. Comparison vehicles in the APRF database

The Argonne team has tested 150 vehicles in the last two decades. The major focus of this testing was on fuel-efficient advanced technology vehicles, thus full-size pickup trucks represent only a small part of the existing database. The two pickups listed below from previous testing provide good reference points and will be used for comparison.

- 2013 Dodge RAM 1500 HFE
- 2012 Ford F-150 EcoBoost

Technical Specifications for the two vehicles used in the comparisons are provided in Table 5 and Table 6.

Table 5: Technical specification of the 2012 Ford F-150 Ecoboost historical test vehicle

Test vehicle	2012 Ford F-150 3.5L V6 EcoBoost with 6 speed automatic transmission
VIN	1FTFW1ET5CKD18562
Engine	3.5 liter Turbo, V6, DOHC 24V, 365 hp @ 5,000 rpm 420 lb-ft @ 2,500 rpm Compression ratio 10.0.:1 Direct Injection
Transmission	Four wheel drive 6 speed automatic transmission 1st 4.17 2nd 2.34 3rd 1.52 4th 1.14 5th 0.86 6th 0.69 Final Drive 3.15
Climate control	Belt driven air conditioning compressor Waste heat heating
EPA Label Fuel Economy (mpg) [(1)]	15 City / 21 Hwy / 17 Combined (4WD option)
Test Fuel Properties	Tier II EEE HF437
Test Configuration	2WD

Table 6: Technical specification of the 2013 Dodge Ram HFE test vehicle

Test vehicle	2013 Dodge Ram 1500 HFE with 8 speed automatic transmission
VIN	**3C6JR6RG0DG561319**
Engine	3.6 liter , V6, DOHC 24V, 305 hp @ 6,400 rpm 269 lb-ft @ 4,175 rpm Compression ratio 10.2.:1 Port-fuel Injection
Transmission	Four wheel drive 8 speed automatic transmission 1st 4.71 2nd 3.14 3rd 2.10 4th 1.67 5th 1.29 6th 1.00 7th 0.84 8th 0.67 Final Drive 3.21 265/70 R17 all-season tires
Climate control	Belt driven air conditioning compressor Waste heat heating
EPA Label Fuel Economy (mpg) (1)	18 City / 25 Hwy / 21 Combined in (2WD option only)
Test Fuel Properties	Tier II EEE HF437
Test Configuration	2WD

5. Ford F-150 test results and analysis

5.1. General observations from testing

5.1.1. Vehicle setup

Argonne used the test weight and road load coefficients published by the EPA for this vehicle. The team encountered some challenges in the initial setup of the vehicle on the chassis dynamometer. The vehicle was tested using both the front and the rear rolls in the test cell and was restrained on the chassis dynamometer using chains linked to towers at each corner of the vehicle. The team then performed the vehicle coast down and vehicle loss determination and started testing. The initial vehicle setup was to run the dyno in 4WD mode (all four wheel spinning) with the vehicle in normal 2WD mode. Unfortunately, this particular dynamometer and vehicle setup caused the vehicle's traction control and stability control systems to periodically engage, which in turn disabled the engine idle stop feature, thus rendering that test invalid. After three days of testing, the Argonne team decided that this setup was not practical and should be changed, because some number of tests would have been affected by this issue.

Thus, the team decided to utilize the vehicle's dynamometer test mode thus enabling normal vehicle operation with the dynamometer in 2WD mode. Although the front wheels were left on the front roll, during testing the front wheels did not spin. The test plan was then restarted from the beginning in this test configuration, including the vehicle coast down and vehicle loss determination. Table 7 provides the chassis dynamometer setup parameters for the Ford F-150. Figure 6 shows a picture of the test vehicle mounted to the chassis dynamometer.

Table 7: Chassis dynamometer parameters for the Ford F-150 test vehicle

Test weight	5,250 [lb]	
Chassis dyno setup	2WD/RWD on rolls with dyno mode	
	Target	Set
Road load A term	32.92 [lb]	-20.0431 [lb]
Road load B term	0.2164 [lb/mph]	0.0810 [lb/mph]
Road load C term	0.0371 [lb/mph^2]	0.0344 [lb/mph^2]

Figure 6: Ford F-150 test vehicle mounted to the chassis dynamometer inside of the test cell. Note that even though the front wheels are on the rolls in this picture, the front wheels were never spinning for duration of the testing.

A small number of the higher power mapping tests were completed in 4WD mode as this vehicle can overpower a single chassis dynamometer roll. The test plan in Appendix C details which tests were performed in the 4WD mode.

In order to reduce unrealistically high braking loads while running a dynamometer in 2WD mode (especially for RWD vehicles), chassis dynamometer controllers have an "augmented braking" feature that significantly reduces the vehicle inertia emulation at the chassis rolls during braking. This reduces the braking force that the brake pads have to apply on the rotor and prevents the brakes from overheating. Most test vehicles at Argonne are typically electrified (i.e. HEVs or BEVs), thus the correct inertia emulation is important to accurately capture regenerative braking. The regenerative braking system reduces the load on the mechanical brakes significantly. For these reasons Argonne does not typically use this feature. However, as the F-150 is a conventional vehicle with significant mass, the team decided to enable the augmented braking for the duration of the Ford F-150 testing.

5.1.2. Instrumentation description

This section describes the specific instrumentation installed on the F-150 in addition to the generic instrumentation detailed in Table 1. The additional analog signals include a thermocouple measuring the air temperature behind the radiator and a thermocouple measuring the engine bay temperature.

The following is a categorized list of important signals decoded on the vehicle communication bus.

- Driver input:
    - Accelerator pedal position (multiple signals)
    - Brake pedal (multiple signals)

    - Mode selection
    - Transmission PRNDL selection
- Engine:
    - Engine load
    - Engine speed
    - Engine boost
    - Engine turbo by pass valve
    - Waste gate position
    - Intake air temp
    - Exhaust and intake cam angle
    - Engine oil pressure
    - Knock feedback
    - Spark adjustment based on knock control spark adjustment
    - EGR sensor
    - Equivalence ratio
    - Engine DI commanded fueling ratio
    - Fuel rail pressure
- Cooling system
    - Engine cylinder head temperature
    - Engine cooling fan speed
    - Grille shutter position
- Transmission
    - Transmission temperature
    - Gear # desired & engaged
    - Trans intermediate speed A and B
    - Trans output speed and torque
    - Shift in progress
    - Torque converter slip

This list of signals is intended to be sufficiently comprehensive to provide the modeling and simulation team with enough detail to develop models, calibrate control strategies, and to validate simulation results. The complete list of the Ford F-150 test vehicle signals (recorded at 10 Hz) is in Appendix B. The vehicle messages have varying degrees of accuracy depending on the need for accuracy within the powertrain control.

The 3.5L V6 EcoBoost engine has two fuel injection systems: a direct injection system, and a port fuel injection (PFI) system. Each system uses two fuel rails with one fuel rail for each bank of 3 cylinders on the engine. The DI system also includes a high-pressure fuel pump on the engine that can store high-pressure fuel for the engine idle stop feature. The total fuel flow was measured between the low-pressure fuel pump in the tank and the junction that splits the fuel between the DI and PFI systems, using both a positive displacement fuel scale and a Coriolis fuel flow meter. A third fuel flow meter was used to measure the fuel flow going to the DI system and was added on the fuel line after the fuel junction and before the high-pressure fuel pump. Figure 7 illustrates the fuel system in the vehicle as well as the fuel flow measurement system. The DI fuel flow meter was only used for parts of the testing, until the team verified a decoded ECU signal that correctly defined the ratio of fuel flow between the PFI and DI system.

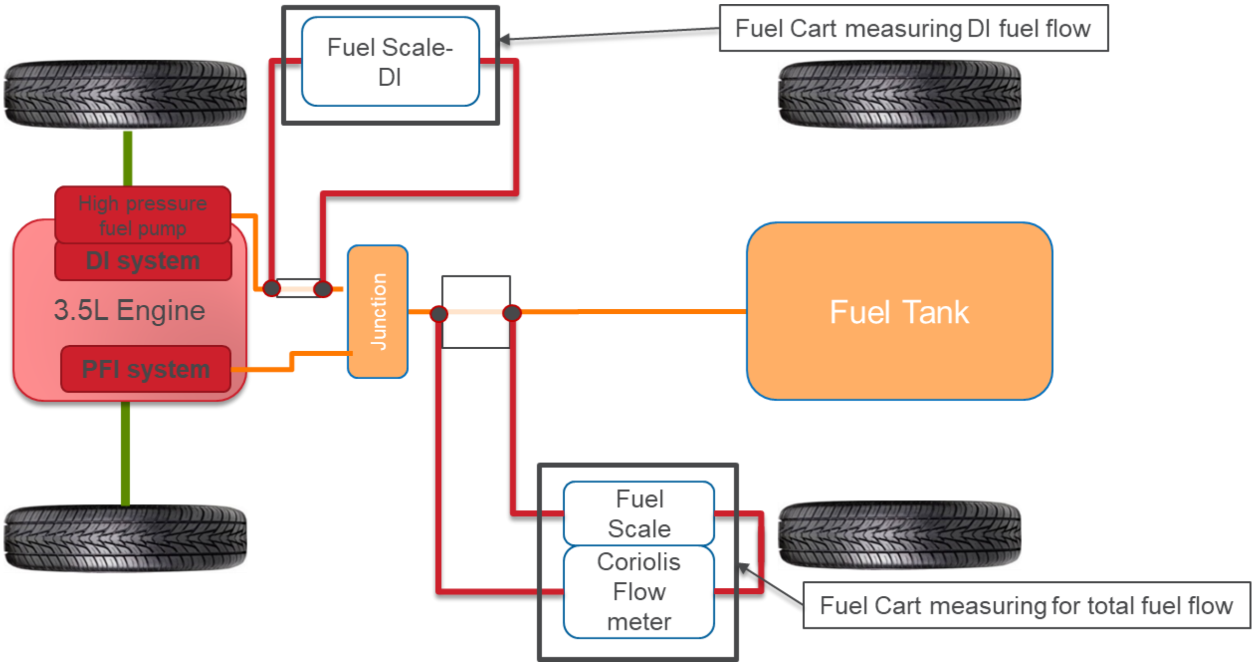

Figure 7: Fuel flow instrumentation diagram

5.1.3. Executed test plan

The general test plan for the vehicle is described in a previous section. Table 8 provides a summary of the tests that are executed as part of the general test plan. The test sequence introduced in Figure 4 is repeated three times at 72° F. The testing at 20° F and 95° F did not include any repeat testing. In addition, the drive cycle test sequence is repeated at 72° F with Tier 3 certification fuel for the premium versus regular gasoline comparison study.

Table 8: Summary of the executed general test plan

Test cycle/Test conditions	72° F	95° F + 850W/m^2	20° F	72° F Tier 3 fuel
UDDSx3 (including cold start)	3X	UDDSx2	X	3X
HWYx2	3X	2X	HWYx3	3X
US06x2 (4bag)	3X	2X	x	3X
SC03x2	N/A	2x	N/A	N/A
Steady state speed testing 0%, 3% 6% grade	X	X		X
Passing 0%, 3%, 6% grade	X			X
WOT'sx3	X			X

Some additional tests are the mapping of the powertrain operation. The additional testing includes the following.

- 72° F Cold start idle: to map out the idle fuel flow consumption as a function of powertrain temperature
- 72° F Cold start LA92
- 72° F Cold start US06
- Transmission mapping through:
  - constant accelerator tip-ins tests
  - accelerator tip ins with vehicle locked at constant speed
- High load engine and transmission mapping with dyno and the F-150 in 4WD mode
- Transmission shifting behavior with vehicle pay load.
  - Drive cycle based:
    - 10,000 lb total test weight: UDDS → Normal, Tow haul,
    - Standard weight: US06 → Normal, Tow haul, sport
    - Standard weight: SSS → Normal, Tow haul, sport

The total testing took several weeks including the instrumentation verification, the vehicle setup corrections and restarting the test program. The table in Appendix C summarizes all the final tests performed on the Ford F-150 test vehicle for this project.

Questions about the benefits of the engine idle stop feature arose during the analysis. These questions led Argonne to setup the vehicle on the dyno for a second 3-day test session focused on the engine idle stop feature. The results from the second test session are only used to compare results within that second test session.

5.2. Test results and analysis

5.2.1. Brief operation powertrain overview

The Ford F-150 engine idles after it is initially started. When the engine idles it is fueled through the PFI system. Once the engine warms past its cold start mode the idle stop feature is enabled. Once the driver lets his foot off the brake pedal the engine is cranked and the vehicle launches into creep mode. When the vehicle accelerates it shifts quickly through the gears to maintain a low engine speed. During deceleration the fuel to the engine is cut off while the engine is spun through the transmission and locked torque converter using the kinetic energy of the vehicle. The engine resumes fueling again before the vehicle comes to a full stop. The vehicle is stopped for about a second before the engine is shut off through the idle stop feature. Figure 8 provides an overview of this powertrain operation.

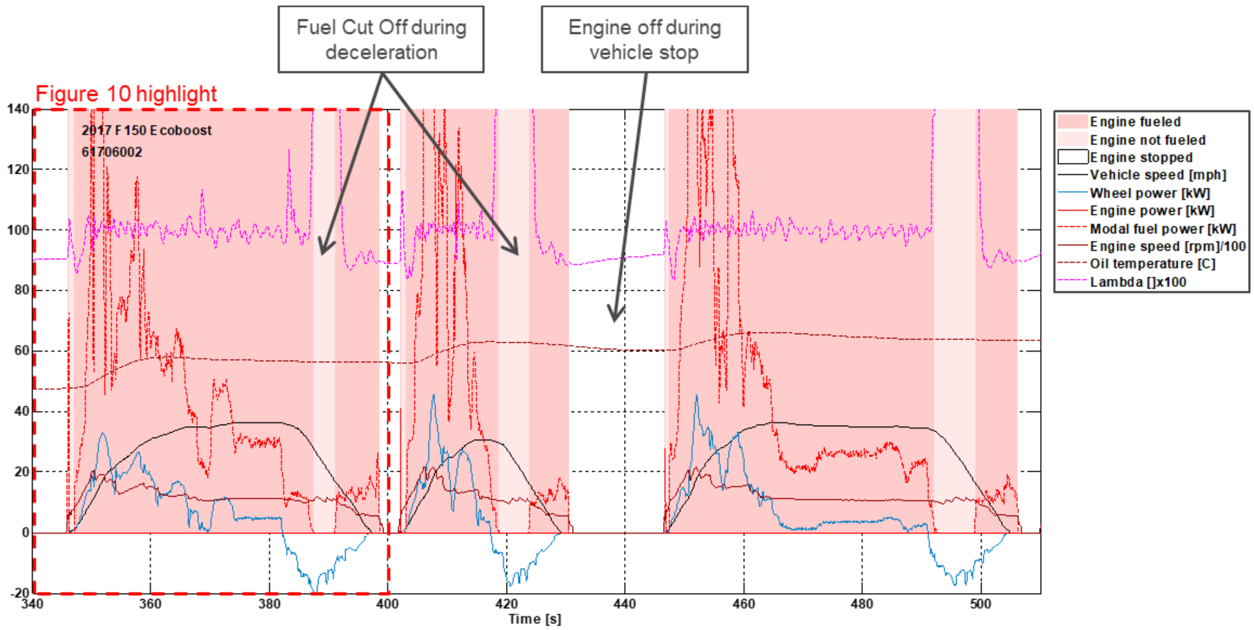

Figure 8: F-150 powertrain operation on cold start UDDS

Figure 9 provides a closer look at the transmission shifting behavior of the test vehicle. During launch and a mild acceleration, the transmission shifts from 1st to 3rd gear and 3rd to 5th gear while skipping 2nd and 4th gear. This skip shifting can result in some energy savings by lowering the engine speed that will result in higher engine loads and increase engine efficiency. The transmission shifts up to 8th gear above 30 mph on this third hill of the UDDS. During launch, during low gear accelerations and during gear shifts the torque converter slips whereas at higher gears it is locked. The torque converter also stays locked during downshifts in the decelerations that enables fuel cut off.

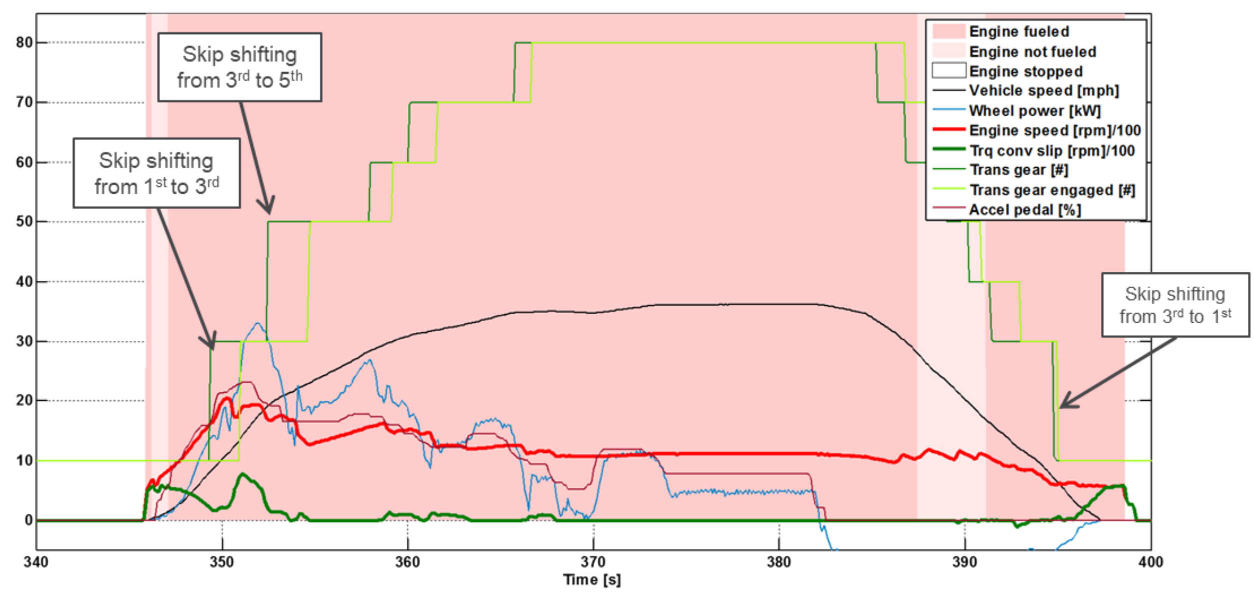

Figure 9: F-150 shift operation on cold start UDDS

The different powertrain components and operational features are investigated in much deeper detail in later sections. More details are provided on the shift strategy and skip shifting in section 5.4.4.1.

5.2.2. CAFE fuel economy results with EPA comparison

The fuel economy results from the testing at Argonne compare very closely to the fuel economy results published by EPA on www.fueleconomy.gov. The EPA publish unadjusted fuel economy results from the manufacturer as well as their own testing results for phases 1, 2 and 3 of the UDDS as well as the Highway cycle. Figure 10 and Table 9 compare the published fuel economy results to the three test sequences completed at the APRF. The average fuel economy of the Argonne testing falls within the range of values seen in the EPA and manufacturer results.

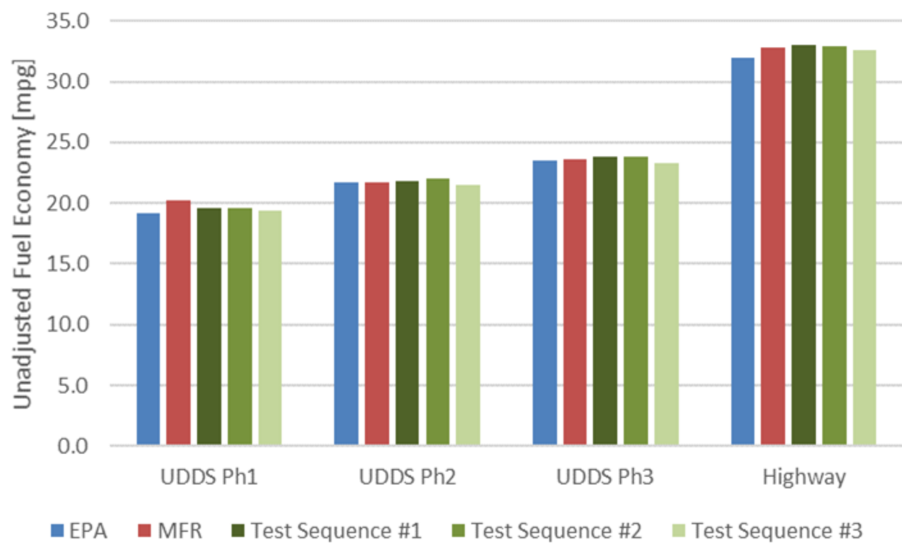

Figure 10: Raw fuel economy results for the UDDS and Highway certification cycles from EPA and Argonne

Table 9: Raw fuel economy results for the UDDS and Highway certification cycles from EPA and Argonne

FE [mpg]	EPA	MFR	Repeat#1	Repeat#2	Pepeat#3	ANL average
UDDS Ph1	**19.1**	**20.2**	19.6	19.5	19.4	**19.5**
UDDS Ph2	**21.7**	**21.8**	21.8	22.0	21.5	**21.8**
UDDS Ph3	**23.5**	**23.6**	23.9	23.8	23.3	**23.6**
Highway	**32.0**	**32.8**	33.0	32.9	32.6	**32.8**

5.2.3. Fuel economy results for standard drive cycles

The fuel economy results for standard drive cycles are presented in Table 10. The drive cycles include the cold start UDDS (Phase 1 and 2), the hot start UDDS (Phase 3 and 4), a third UDDS cycle, the Highway cycle and the US06 cycle. The third UDDS cycle is not part of the certification testing, however it is performed to understand the fuel economy changes as the powertrain temperature reaches higher operating temperatures as can be seen in Figure 4. Both of the Highway and US06 drive cycles were tested in phases and the fuel economy presented here is from the second cycle as described in Figure 4.

Table 10: Raw fuel economy results for drive cycle results

	Fuel economy [mpg]
UDDS #1 Cold Start	20.8
UDDS#1 Ph1	19.5
UDDS#1 Ph2	22.0
UDDS#2 Hot	22.9
UDDS#2 Ph1	23.8
UDDS#2 Ph2	22.1
UDDS#3	23.3
UDDS#3 Ph1	22.6
UDDS#3 Ph2	23.2
Highway	32.9
US06	19.0
US06 City	12.8
US06 Highway	22.1

5.2.4. Vehicle efficiency based on SAE J2951 positive cycle energy

The vehicle efficiency is calculated by dividing the CEd by the fuel energy used over the drive cycle. Table 11 provides the calculated vehicle efficiencies for the drive cycles in each test sequence.

Table 11: Powertrain efficiencies based on J2951 positive cycle energy

	Test Sequence #1	Test Sequence #2	Test Sequence #3	Average
UDDS #1 Cold Start	18.8%	18.5%	18.8%	18.7%
UDDS#2 Hot Start	20.6%	20.4%	20.8%	20.6%
UDDS#3	20.9%	20.6%	20.7%	20.8%
Highway	30.1%	29.4%	30.2%	29.9%
US06	28.5%	28.8%	28.7%	28.7%

The lowest average vehicle efficiency occurs on the UDDS cycle that is typical for conventional vehicles. The UDDS cycle is a stop-and-go drive cycle with very mild power requirements. On the UDDS cycle the engine operates at low load with a relatively low throttle opening that increases the pumping losses. The powertrain efficiency increases by 2 percent from the cold start cycle to the third cycle were the powertrain has reached its operating temperature. This efficiency increase is likely due to the lower friction that is a typical results of higher temperatures in all components within the powertrain.

The average powertrain efficiency is the highest on the Highway drive cycle. The powertrain can take full advantage of the 10-speed automatic transmission on the Highway cycle. 10^{th} gear is engaged about 65 percent of the time and 9th and 10th gears combined are engaged over 80 percent of the time that results in median speeds between 1,100 rpm to 1,300 rpm on the Highway cycle. This enables the vehicle to achieve almost 30 percent vehicle efficiency on the Highway cycle.

The average powertrain efficiency on the US06 drive cycle is close to 29 percent. This drive cycle requires high engine loads. These high loads along with the flexibility of the 10-speed automatic transmission enables the high vehicle efficiencies.

5.2.5. Break down of fuel consumption based on drive mode

This section decomposes the fuel usage of the Ford F-150 into basic drive modes that are: (1) the vehicle being stopped, (2) the vehicle accelerating, (3) the vehicle cruising, and (4) the vehicle decelerating. The vehicle is considered stopped when the dynamometer speed is below 0.1 mph. Cruise is defined as an acceleration less than 0.05 m/s^2 for the purpose of this analysis. Figure 11 shows the contribution of these for drive modes to the fuel consumption on the certification drive cycles. Note that the total fuel used in each mode was found and divided by the total distance of the drive cycle.

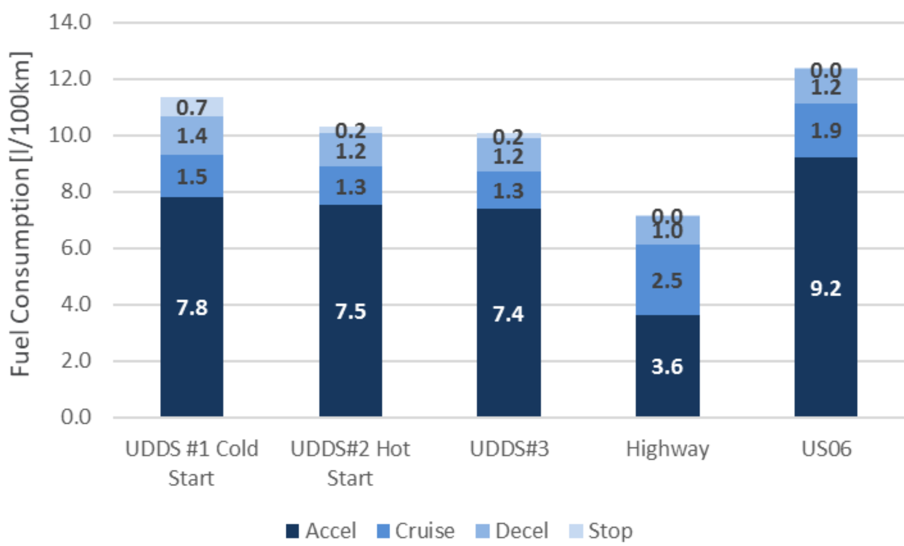

Figure 11: Drive cycle fuel consumption decomposed into drive modes

A comparison of the three UDDS cycles shows that the vehicle used more fuel in each drive mode when the powertrain was cold. The largest increase in fuel used occurs while the vehicle is stopped as the engine idle stop feature is disabled until the powertrain has reached a certain operating temperature. The majority of the fuel is used during acceleration on the city drive cycle. Note that Figure 11 show fuel used during decelerations that indicates that the powertrain has practical limitation that are discussed in 5.4.3.6.

Table 12 provides the percentage of fuel used in each drive mode for the different drive cycles. The Highway cycle has a high percentage of cruise driving compared to the other drive cycles. This relatively steady driving mode also helps increase the powertrain efficiency.

Table 12: Percentage of fuel used on drive cycles by drive mode

	Accel	Cruise	Decel	Stop
UDDS #1 Cold Start	68.9%	13.3%	12.0%	5.9%
UDDS#2 Hot Start	73.2%	13.1%	11.8%	1.9%
UDDS#3	73.2%	13.1%	11.7%	1.9%
Highway	50.8%	35.0%	14.1%	0.1%
US06	74.6%	15.6%	9.7%	0.2%

5.2.6. Cold start penalty on UDDS

This work also looked at the cold-start penalty on the UDDS. The cold start penalty is defined as the additional fuel used on the cold start drive cycle as compared to the fuel used on the hot start drive cycle. This cold-start penalty can be calculated by comparing phase 1 and phase 3 or by comparing the entire cold start UDDS drive cycle to the entire hot start UDDS drive cycle. Both cold start penalties are provided in Table 13.

Table 13: Cold start fuel penalty by phase and full cycle

	Test Sequence #1	Test Sequence #2	Test Sequence #3
Phase 1 vs Phase 3	21.8%	21.9%	19.8%
UDDS #1 vs UDDS #2	10.8%	10.3%	11.0%

Figure 12 compares the cold start and hot start behavior of the powertrain on the UDDS. The comparison includes fuel flow, engine speed and engine oil temperature. The difference in fuel flow is most apparent over the first 500 seconds. The majority of the increase fuel usage on the cold start cycle is typically a result of higher powertrain friction due to lower operating temperatures. The difference in the engine cold start behavior is most notable on the first 190 s, where the engine speed is higher as the transmission operates in a lower gear. The initial engine idle is higher for the first 20 seconds of the cycle likely due to after treatment warm up. The idle stop feature is not engaged until 360 seconds on the cold start cycle.

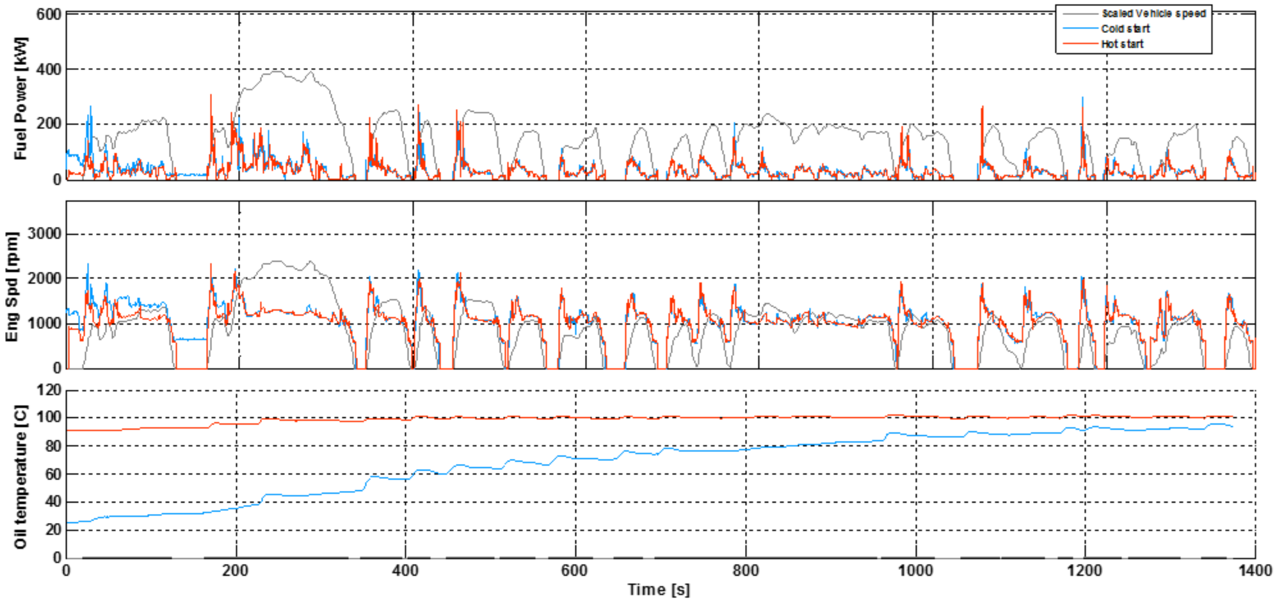

Figure 12: Comparison of powertrain operation on a cold start UDDS and a hot start UDDS

Figure 13 compares the cold start to the hot start fuel consumption by drive mode and includes a histogram of engine speeds for the cold start and hot start cycles. The elevated initial engine idle as well as the engine idle between hill one and two on the cold start test contributes to the increased fuel consumption. The powertrain also uses more fuel on the cold start cycle during the deceleration. On average the engine speed during the cold start test is slightly higher compared to the hot start test. The hot start test also shows a clear peak in the median engine speed at 1,000 rpm. The lower average engine speed on the hot start test also contributes to the increased efficiency.

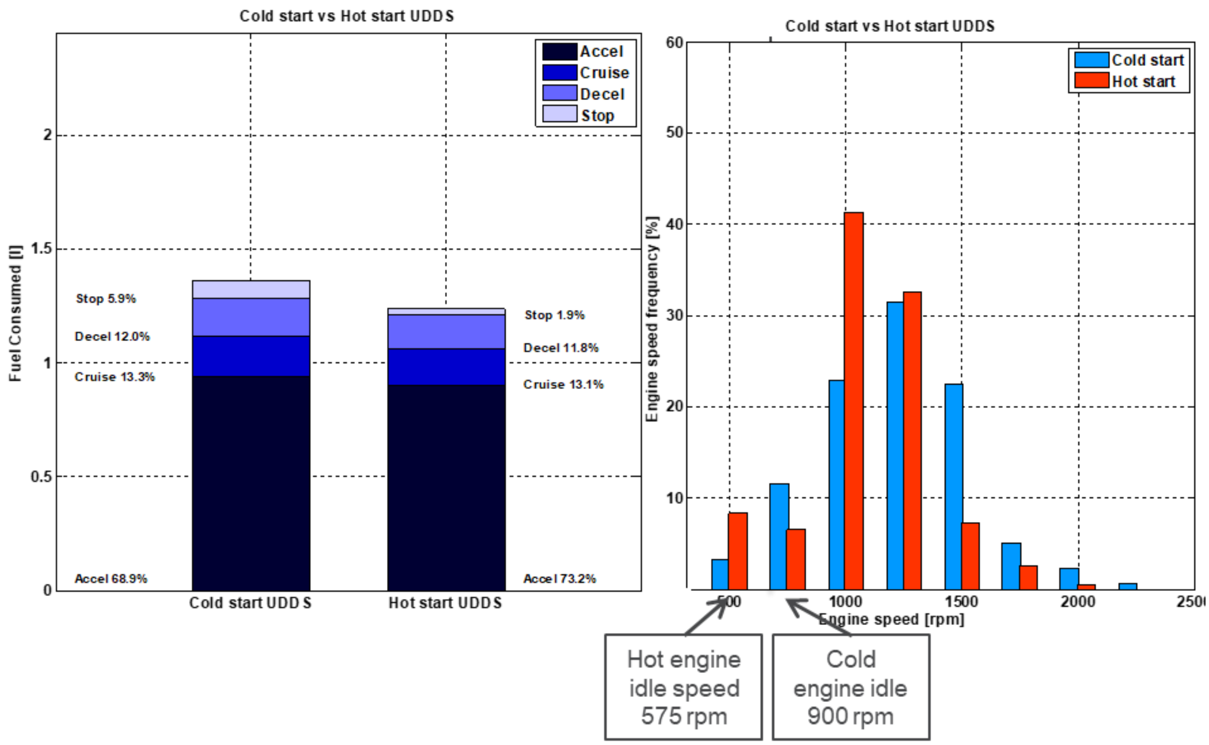

Figure 13: Fuel consumption inventory by drive mode and engine speed operation comparison between cold and hot start UDDS

5.2.7. Engine operating area on certification drive cycles

The 10-speed automatic transmission enables the vehicle to maintain a narrow range of low engine speeds. The majority of the engine operation is below 2,000 rpm for the UDDS the Highway cycles. Even on the more aggressive US06 cycle, the median engine speeds are around 1,500 rpm that is comparatively low. The maximum speed on the US06 cycle is below 3,500 rpm. Figure 14 shows the engine speed histograms for the three certification cycles (UDDS, Highway, and US06).

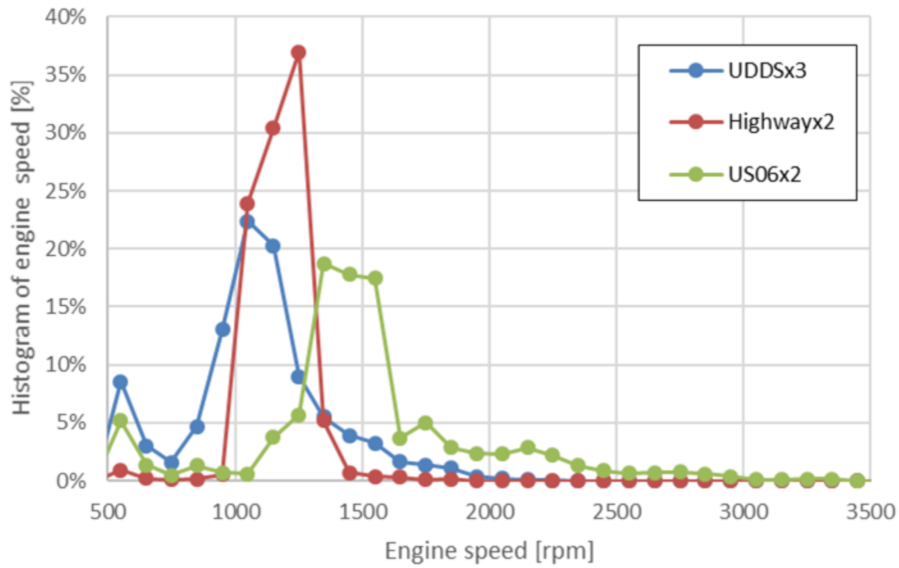

Figure 14: Engine speed histogram for certification cycles

Figure 15 shows an engine speed profile between the comparison vehicles. The gray points in the graph represents all of the 10 Hz data points from the test. The black line represents the maximum engine load envelope of the test. An engine speed histogram is in the background of the figure and is partially covered by some of the fuel energy data. The color map represents the integration of fuel energy in the engine load and speed domain. This figure shows the engine use for the three UDDS cycles, the two Highway cycles and the two US06 cycles separately.

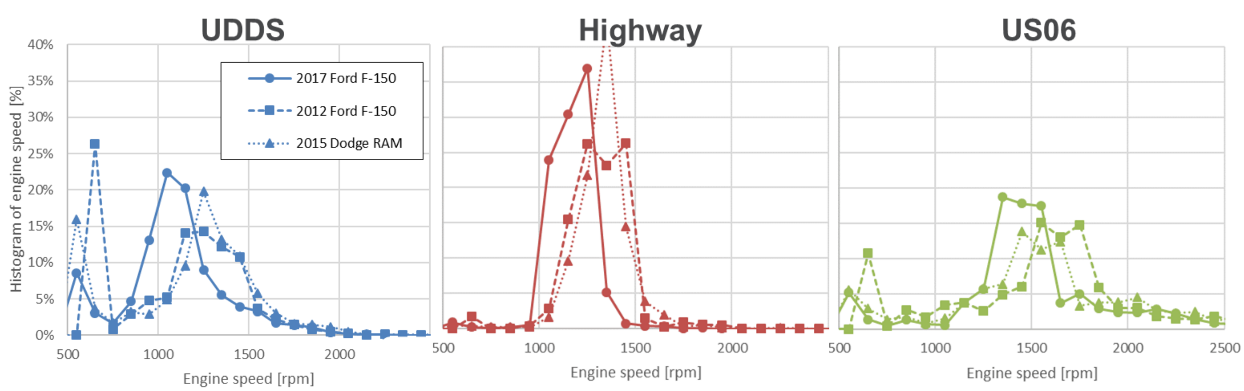

Figure 15:Engine speed histograms of comparison vehicles on certification cycles

Engine usage maps as a function of engine speed and absolute engine load are shown in Figure 16. The gray points in the graph represents all of the 10 Hz data points from the test. The black line represents the maximum engine load envelope of the test. An engine speed histogram is in the background of the figure. The color map represents the integration of fuel energy in the engine load and speed domain. Similarly the color map represents the amount of fuel energy used as a function of engine speed and load over the drive cycles. Note that an engine load above 100 percent indicates boosted operation. This figure shows the engine usage for the three UDDS cycles, the two Highway cycles and the two US06 cycles separately.

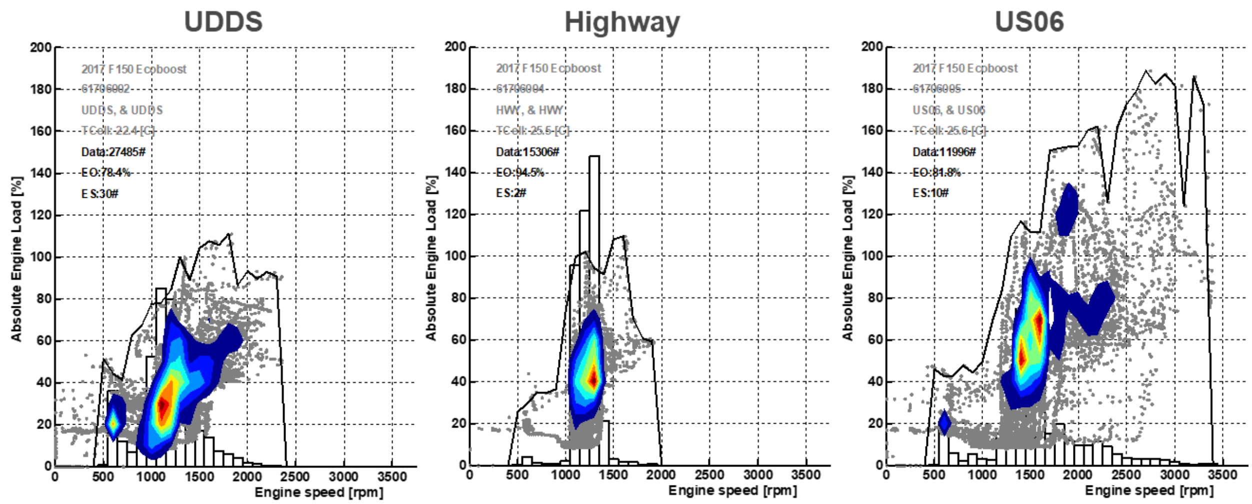

Figure 16: Engine operating area on certification drive cycles

On the UDDS cycle the engine spends most of its energy at around 1,200 rpm and 30 percent absolute engine load. The colormap shows a spread as the engine accelerates through the gears. A small idle fuel flow island is visible at 500 to 600 rpm. On the Highway cycle the engine is operated narrowly between 1,100 to 1,300 rpm at an average load of 40 percent absolute engine load. The operational envelop has significantly moved to higher loads on the US06 that has significantly more aggressive accelerations and vehicle speeds up to 80 mph. In general, the relatively low engine speeds are enabled by the 10-speed transmission as well as the high torque reserve available from the boosted engine.

5.2.8. Transmission operation on certification drive cycles

The engine operating area is directly linked to the transmission hardware and control strategy. Figure 17 shows the histogram of time spent in specific gears on the three certification cycles. A significant portion of time is spent in first gear on the UDDS cycle as this gear is engaged while the vehicle is stopped and during the initial vehicle lunch. On the UDDS, the transmission skip shifts from 1st to 3rd gear and spends significant time in 6th and 7th gears for cruising around 25 to 30 mph. On the Highway cycle 9th and 10th gear are engaged over 80 percent of the time. The gear usage is a bit more spread out on the US06, but it is still dominated by 10th gear that is engaged over the longer highway segment of the drive cycle.

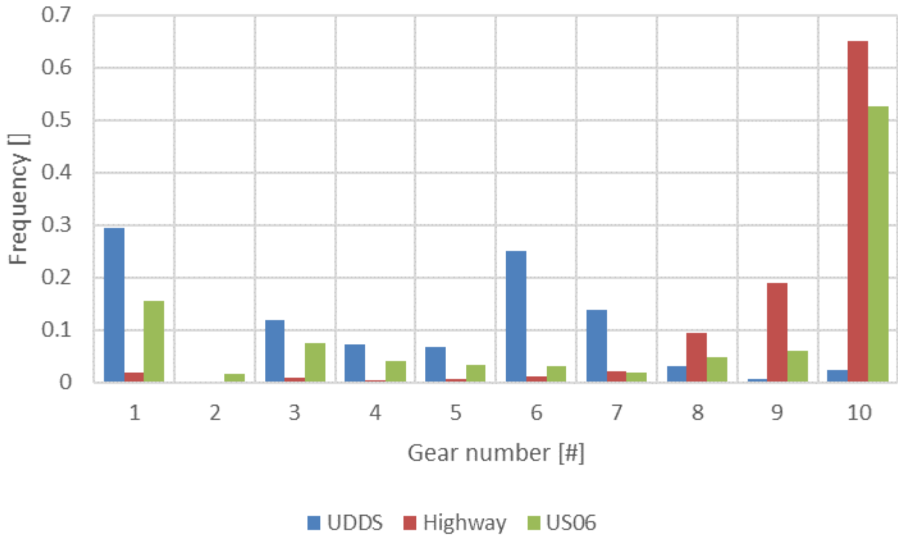

Figure 17: Histogram of gear usage on certification drive cycles

Figure 18 shows the gear usage of the comparison vehicles. The 2012 Ford F-150 launches in second gear from a stop and is more limited with only six available gears. The 2012 Ford F-150 does appear to favor 4th gear in city driving on the UDDS and US06. The 2015 Dodge Ram launches in 1st gear and does not appear to skip shift.

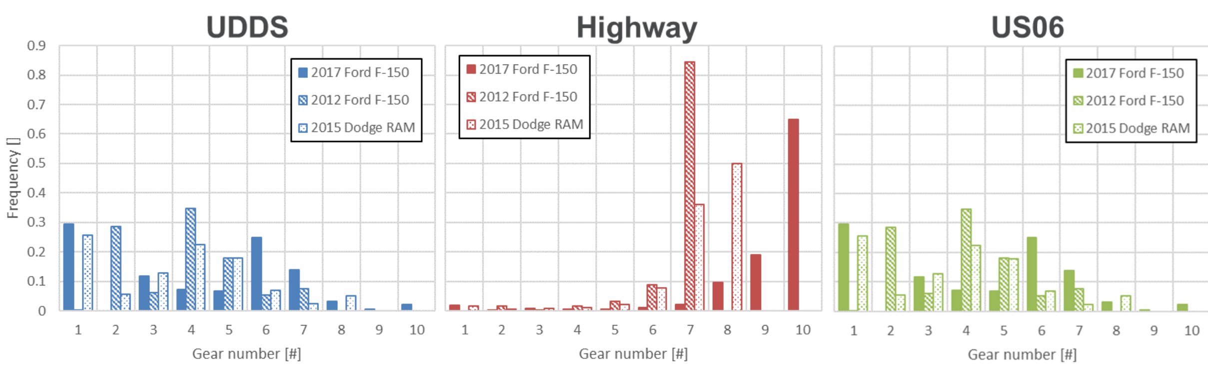

Figure 18: Histogram of gear usage for several vehicles across the certification drive cycles

Figure 19 illustrates the gear spread of the 10-speed automatic transmission in the F-150. The graph was assembled using the UDDS, the Highway and US06 drive cycles from the test sequence. The 10 gears are clearly visible in the figure. The upshifts at higher engine speeds and vehicle speeds are also clearly visible. Section 5.4.4.2 define the torque converter operation in this space as well. Note that across all these drive cycles, the median engine speed is maintained between 1,100 to 1,500 rpm that is relatively low.

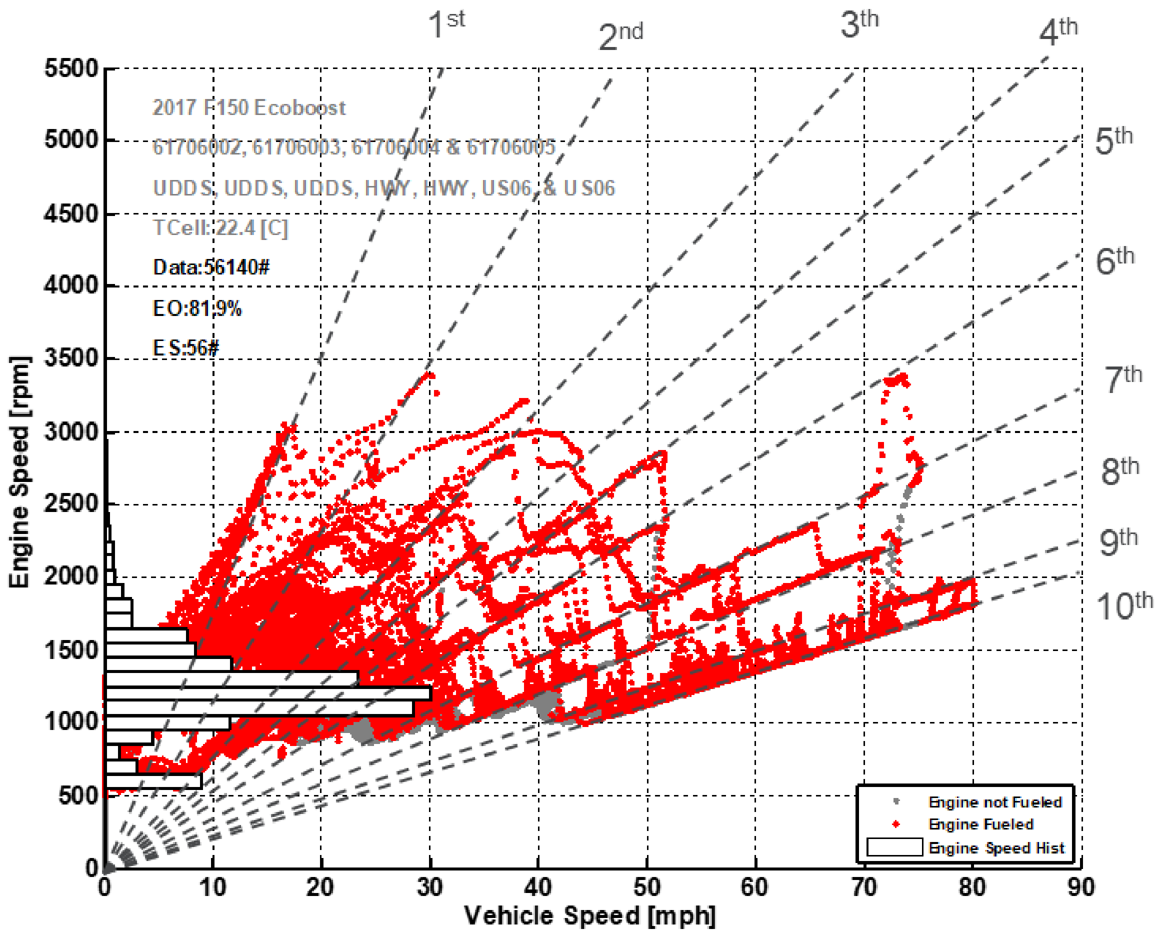

Figure 19: 10-speed transmission shift ratios and engine speed usage

Figure 20 correlates the gear up shifts to vehicle speed and accelerator pedal position. The accelerator pedal position rarely exceeds 20 percent on the UDDS and Highway cycles. A shifting trend related to vehicle speed emerges on the UDDS cycle. Note that the vehicle never shifts into second gear on the UDDS cycle. The Highway cycle contains relatively few shift points. The US06 data contained some higher load shift points and vehicle speeds. The US06 data shows a potential skip shift area at moderate loads from 1st to 3rd, 2nd to 4th and 3rd to 5th gear. The Argonne staff performed some specific transmission mapping tests to further define a clear shift map. Those results are discussed in section 5.4.4.

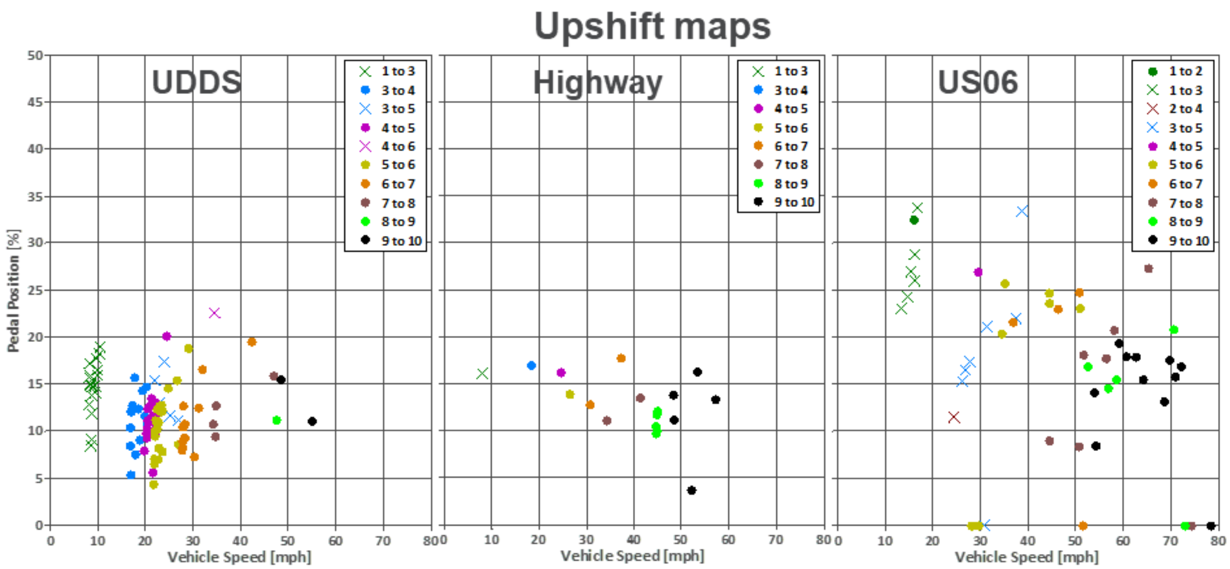

Figure 20: Transmission shift operation on certification drive cycles

Table 14 summarizes the number of upshifts per drive cycle. The orange columns represent shifts where the transmission skips one gear. Note that the second gear is always skipped on the UDDS and the Highway cycle. The 10-speed automatic transmission in this powertrain does shift frequently to enable the engine to operate at a narrow range of lower speeds and higher engine loads.

Table 14: Number of upshift per drive cycle (orange column highlight skip shifts)

# of shifts	1-2	1-3	2-3	2-4	3-4	3-5	4-5	4-6	5-6	6-7	7-8	8-9	9-10	Total
UDDS		18			14	5	16	1	21	12	4	1	2	**94**
Highway		1			1		1		1	2	2	5	5	**18**
US06	1	6		1		7	1		9	5	7	5	11	**53**

5.2.9. Engine idle stop feature on certification drive cycles

The F-150 powertrain includes an automatic engine idle stop (start-stop) feature. This feature automatically stops the engine while the vehicle is stopped in order to save the fuel required to idle the engine. When a driver starts the vehicle, the engine will crank and then idle for both cold and hot start tests. The engine will idle on the first and second stop on a cold start UDDS cycle at 72° F. The idle stop feature is enabled at the third stop (360 seconds into the cold start drive cycle) when the engine oil temperature has reached 50° C. When a vehicle comes to a complete stop the engine will still idle for a second and a half before it is stopped. Some of the stop periods on the UDDS cycle are too short for the engine to be stopped. Figure 21 shows the idle stop feature occurrences on a cold start UDDS and a portion of the hot start UDDS.

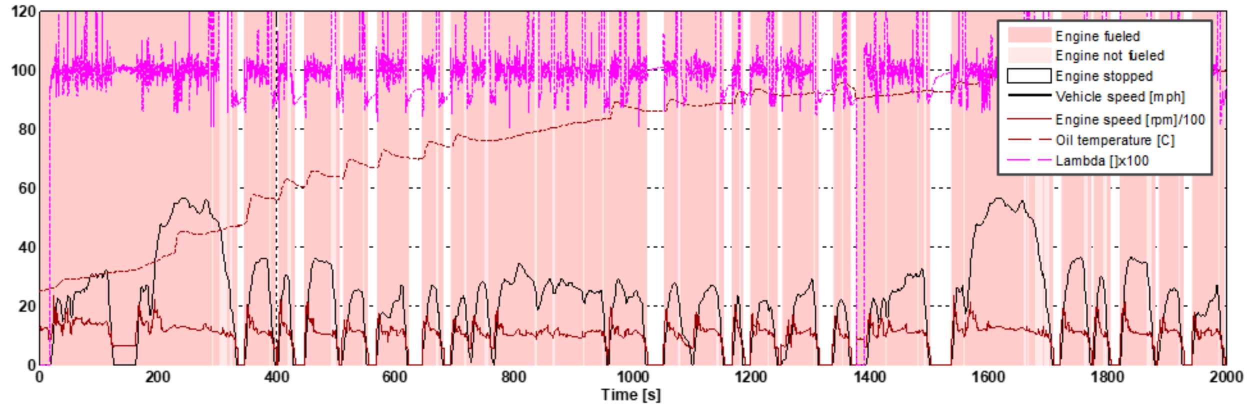

Figure 21: Engine start stop behavior on cold start UDDS

Table 15 show the fuel savings of the engine idle stop system. The fuel savings on the UDDDS drive cycle ranges from 4 to 7 percent on the UDDS drive cycle depending on the powertrain operating temperature. The powertrain temperature and the cabin climate control settings impact the engine idle stop engagement during the thermal testing. The heating request in cold ambient conditions and the cooling request in the hot ambient conditions will disable the engine idle stop feature.

Table 15: Fuel savings of the engine idle stop feature on certification drive cycles

Test	Start Stop enabled	Start Stop disabled	Fuel savings
	Fuel consumption [l/100km]		[%]
UDDS #1 CS	11.4	11.8	3.8%
UDDS #2	10.3	11.0	6.9%
UDDS #3	10.2	10.8	5.5%
US06	13.0	13.2	1.9%

The fuel savings from the engine idle stop feature will depend on the drive cycle and the proportion of time that vehicle is stopped during that drive cycle. The vehicle was tested on a number of drive cycles with the engine idle stop feature enabled and disabled. For each drive cycle, the drive cycle was completed to ensure thermal conditioning of the powertrain, the second cycle was completed with the engine idle system enabled as the baseline and the third cycle was completed with the engine idle system disabled for comparison. Table 16 shows the results from that testing. Notice that the vehicle stop time on the drive cycle correlated to the fuel savings from the engine idle stop feature. Section 5.4.1 provides more details.

Table 16: Fuel savings of the engine idle stop feature on a range of drive cycles

Drive cycle	Stop time proportion	Idle stop enabled	Idle stop disabled.	Fuel savings
	[%]	Fuel consumption [l/100km]		[%]
US06	7%	13.0	13.2	1.9%
LA92	15%	11.8	12.0	2.2%
UDDS Hot Start	18%	10.2	10.8	5.5%
JC08	29%	10.3	11.3	8.9%
NEDC	31%	9.5	10.1	6.5%
New York City Cycle	32%	19.9	22.1	10.6%

Section 5.4.2 details the mechanics involved to shutting down and restarting the engine.

5.3. Powertrain performance test results

5.3.1. Steady state speed fuel economy

One characterization test run on the F-150 is the steady state speed drive cycle that holds vehicle speed for 2 minutes from 10 mph to 80 mph in increments of 10 mph. The fuel economy results as well as some vehicle characterization parameters are presented in Figure 22 for the high octane fuel. For each steady state speed the vehicle efficiency, the power required at the wheel, and the engine speed are calculated.

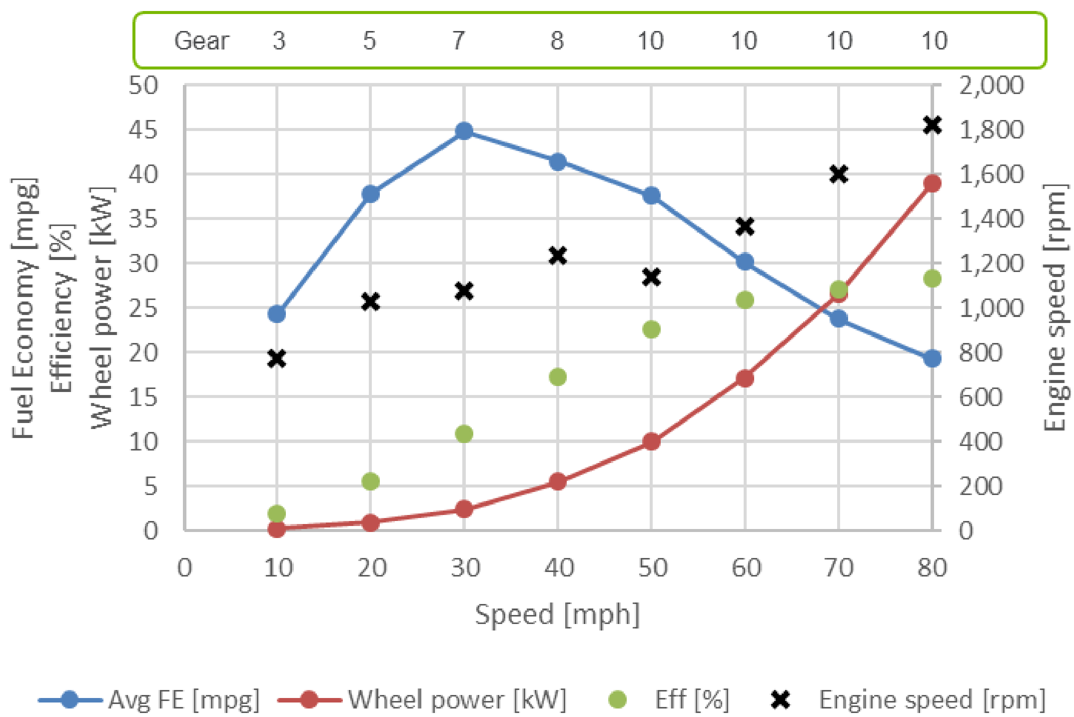

Figure 22: Steady state speed fuel economy with other powertrain measurements on Tier 2 – 93 AKI fuel

The best fuel economy of almost 45 mpg is achieved at 30 mph. Below 30 mph the vehicle efficiency is too low to offset the reduced power required at the wheel to move the vehicle. Above 30 mph the increased efficiency does not offset the increased power required at the wheel to move the vehicle. The peak efficiency of the vehicle is 29 percent at 80 mph. The 10th gear, which is the highest gear in the transmission, is engaged starting at 50 mph. Below 50 mph the engine is below 1,250 rpm.

Note that the steady state speed test is repeated on Tier 3 fuel and those results are presented in section 5.6.

Argonne has tested a 2012 Ford F-150 with a 3.5 L EcoBoost V6 engine and a 6-speed transmission. Figure 23 shows the steady state speed results of the 2012 Ford F-150 testing. The 2012 F-150 achieved a maximum fuel economy of 38 mpg at 30 mph. This fuel economy represents a significant improvement from one generation powertrain (2012) to the next (2017). Part of the increase in fuel economy comes from approximately 20 percent reduction in road load, including a weight reduction from 6,000 lb to 5,250 lb.

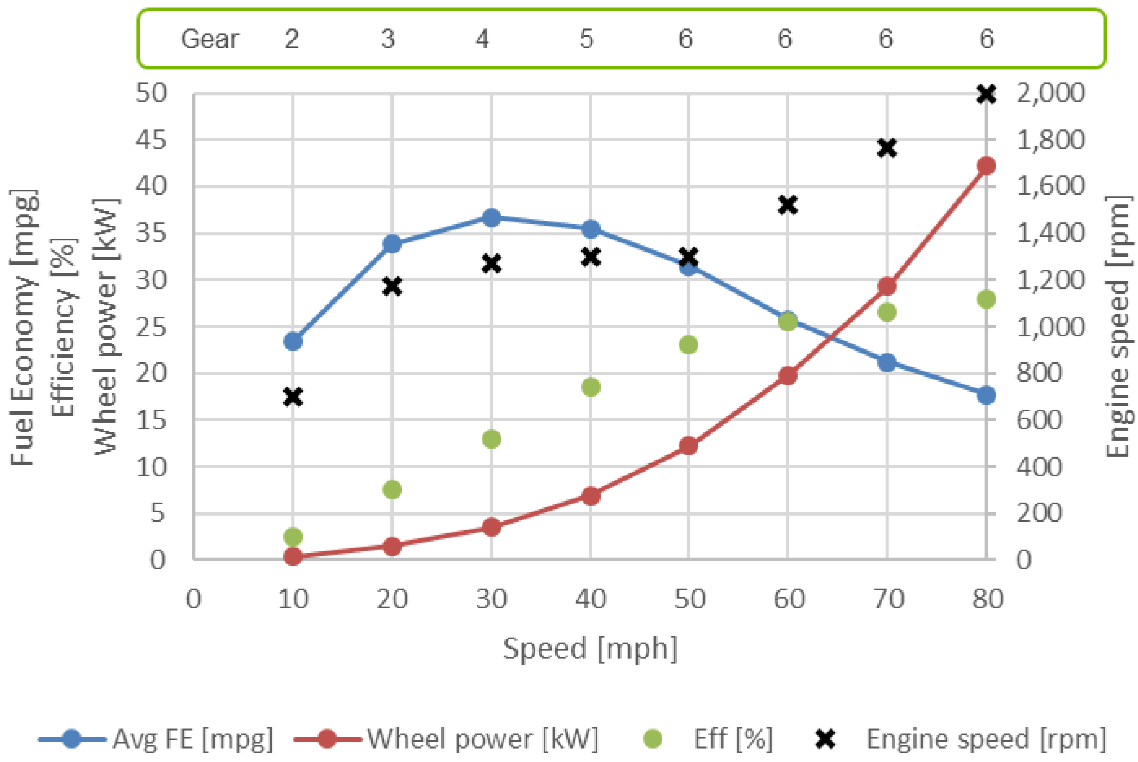

Figure 23: 2012 Ford F150 3.5L Ecoboost Steady state speed fuel economy with other powertrain measurements

5.3.2. Maximum acceleration

Maximum acceleration performance tests were performed on the chassis dynamometer. The test is performed from a rolling start to alleviate the traction issues of the tire on a steel roll. The vehicle accelerated to 60 mph in 6.7 seconds and to 80 mph in 10.6 seconds as shown in Table 17.

Table 17: Maximum performance results

	Time [s]
Start-60 mph	6.7
Start-80 mph	10.6

Figure 24 shows the details of the powertrain operation during the maximum acceleration test. As soon as the accelerator pedal is at 100 percent the intake air boost from the turbocharger starts to build. The fueling system switches from the PFI system to the DI system to quickly settle on 60 percent of the fuel provided by the DI system and 40 percent of the fuel provided by the PFI system. The air fuel ratio shows extra fuel in the air fuel mixture. The transmission shifts from 1st to 2nd, 2nd to 3rd, and 3rd to 4th gear when the engine speed reaches 5,300 rpm. The torque converter slips from launch through 1st and 2nd gear. The torque converter then locks in 3rd gear except for the shifts and slips 50 rpm in 4th gear.

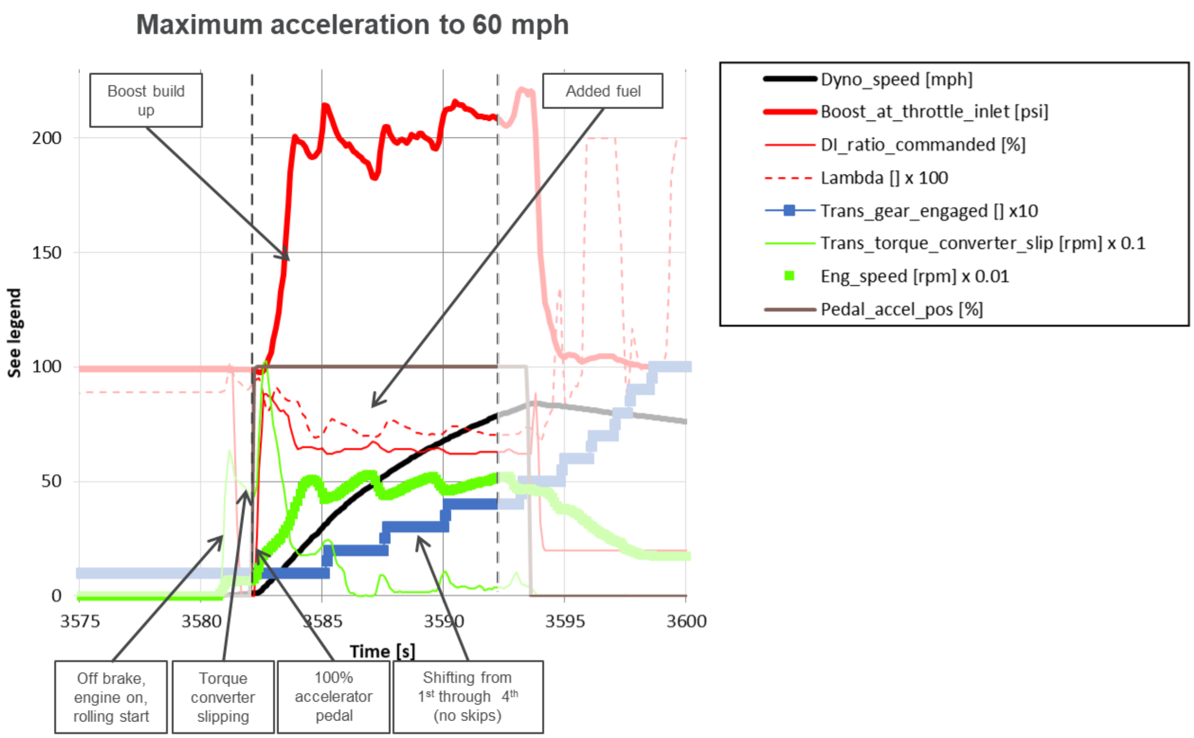

Figure 24: Powertrain operation during maximum acceleration

5.3.3. Passing maneuvers

The maximum performance tests also include some typical passing maneuvers. Argonne has devised a drive cycle that includes a number of passing maneuvers. For each passing maneuver the vehicle is held at an initial steady-state speed, then the driver applies 100 percent accelerator pedal until the vehicle passes the desired end speed. The passing maneuver drive cycle includes accelerations from 35 to 55 mph, 55 to 65 mph, 35 to 75 mph and 55 to 80 mph.

Table 18 summarizes the time it took the F-150 to complete each passing maneuver. A plot of the powertrain details for the passing maneuver from 55 mph to 80 mph is shown in Figure 25. In this case the powertrain required about a second after 100 percent application of the accelerator pedal to build up boost and downshift from 10th gear to fourth gear. Similar to the maximum acceleration test, the injection system switches to 90 percent DI initially and settles at 60 percent DI and 40 percent PFI once the intake air pressure is fully built up by the turbocharger. The fuel mixture is enriched. The torque converter slips up to 200 rpm for a second and a half after 4th gear is engaged.

Table 18: Passing maneuver performance results

	Time [s]
35-55 mph	3.8
55-65 mph	2.6
35-70 mph	6.1
55-80 mph	5.2

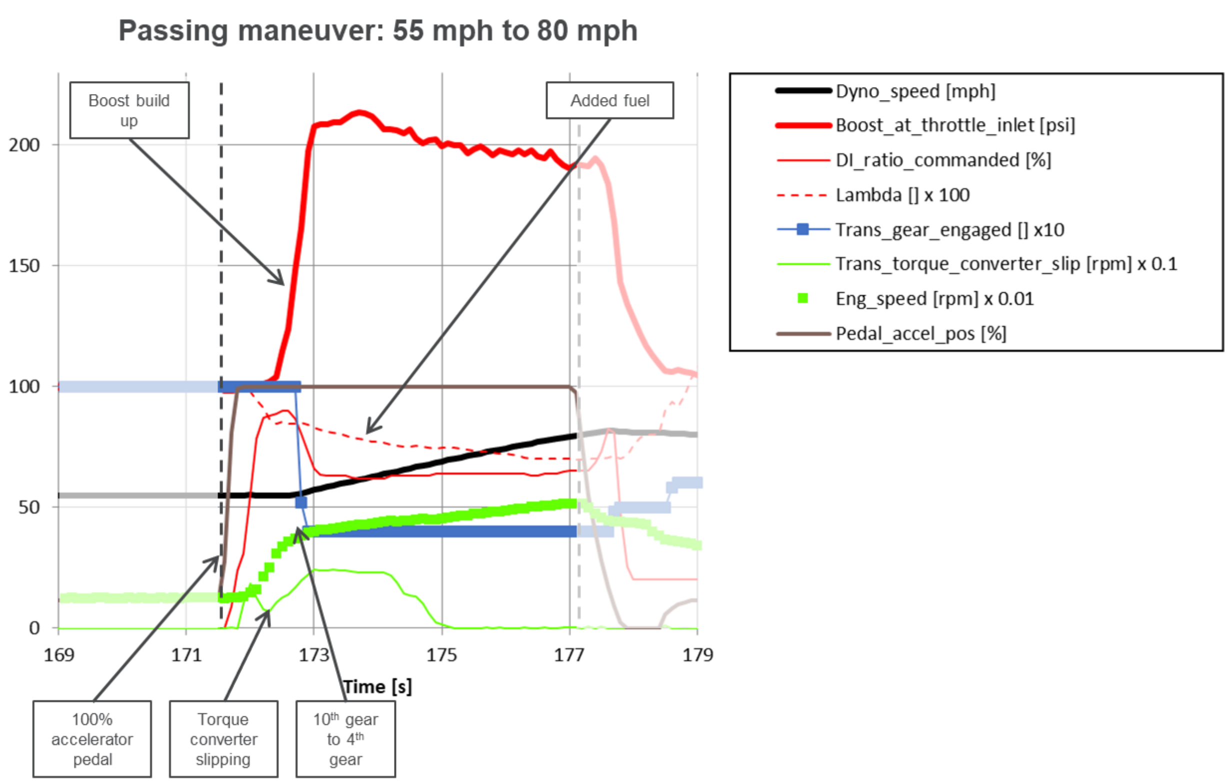

Figure 25: Powertrain operation during the 55 mph to 80 mph passing maneuver

5.4. Powertrain characterization

5.4.1. Idle fuel flow

The test plan includes a 25-minute engine idle test in cold start conditions. This idle test is performed with the transmission in park. The vehicle is soaked at 72° F overnight in the test cell. This test helps to characterize the engine behavior and fuel flow rate as the engine warms up.

Figure 26 shows the first 300 seconds of the cold start engine idle test. The initial engine idle speed is 1200 rpm that then switches to 900 rpm after 30 seconds and finally lowers to just above 600 rpm after 850 seconds. The fuel injection is 30 percent PFI and 60 percent DI during the first minute of the cold start idle. The ignition is also retarded for the first minutes to help with the warm-up of the exhaust aftertreatment system. After the initial warm-up phase the PFI system provides 100 percent of the idle fuel flow if the engine idles. The engine start stop mechanics are described in section 5.4.2.

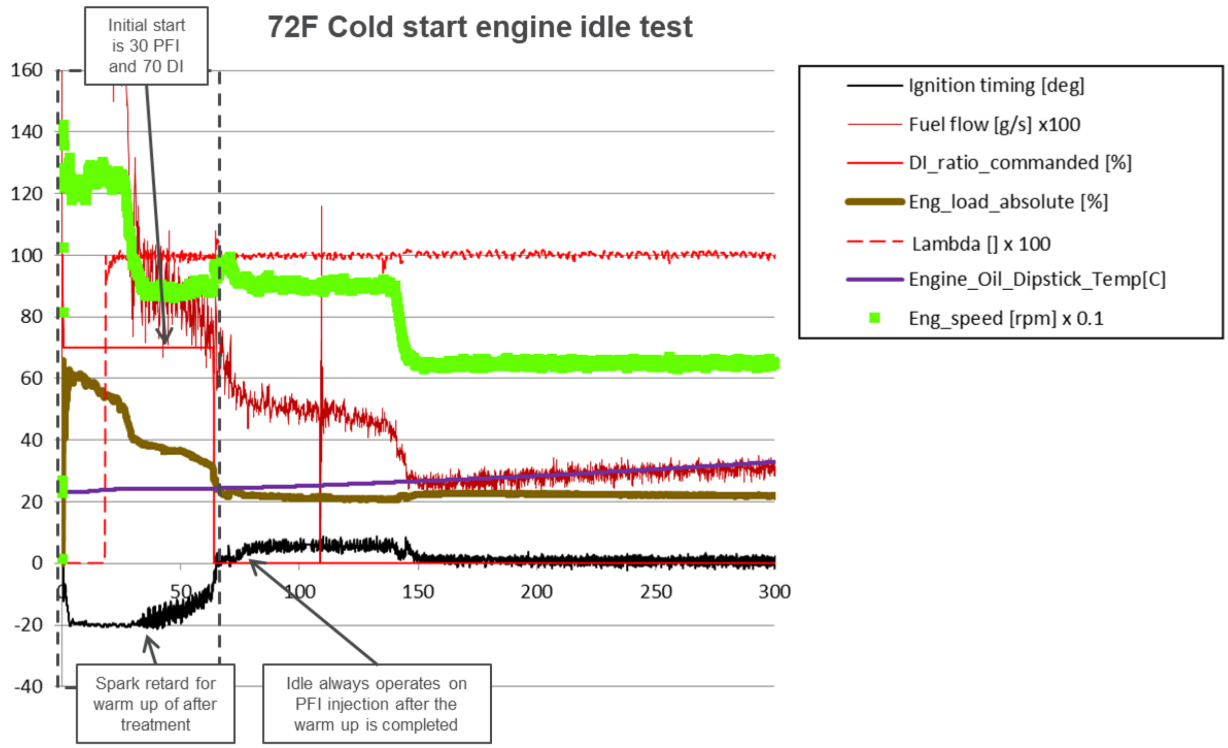

Figure 26: Analysis on a cold engine start and idle

The average idle fuel flow rate observed once the powertrain reaches operating temperatures on drive cycles is 0.368 cc/s (about 0.27 g/s). That flow is equivalent to a fuel power rate of 11.6 kW. Figure 27 compares the idle fuel flow rates of the 2017 Ford F-150 to some other test vehicles in the APRF database. The idle fuel flow rate of the 2017 Ford F-150 is similar to the idle fuel flow rate of the 2012 Ford F-150. In general, DI engines have lower idle fuel flow rates on a per displacement basis. The 2017 F-150 idles the engine with the PFI system compared to the 2012 F-150 that only has a DI system, yet their idle fuel flow rates are the same.

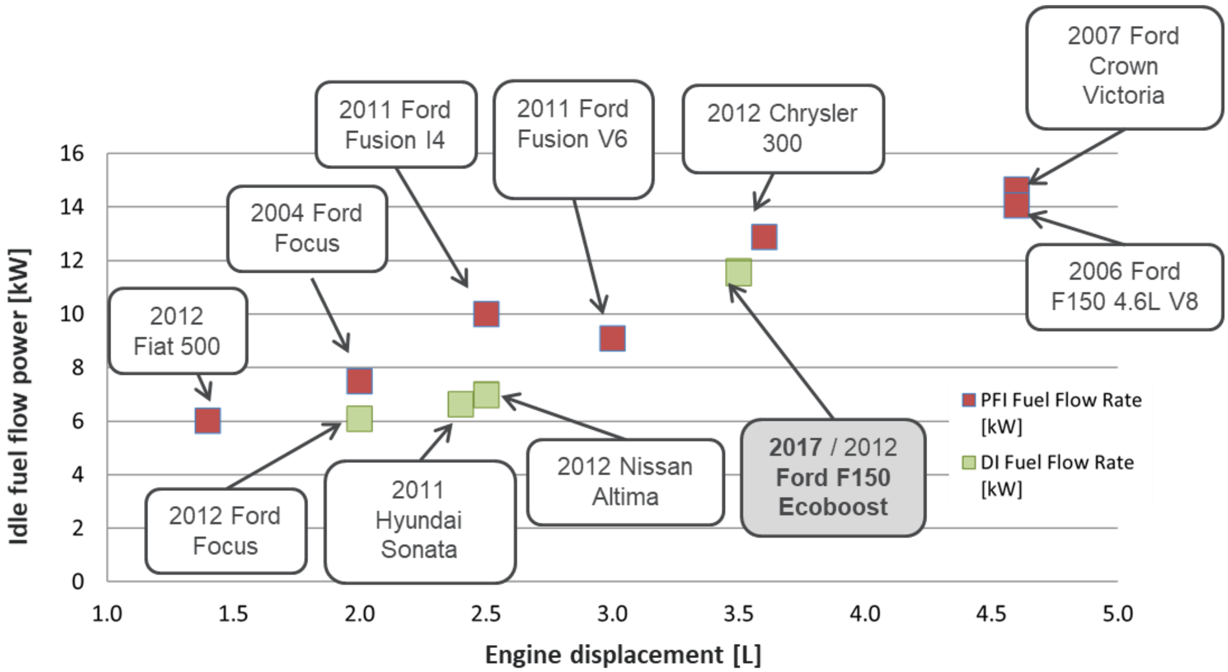

Figure 27: Idle fuel flow rate comparisons

5.4.2. Engine start stop operation

The test vehicle has an engine idle stop function that will stop the engine from idling while the vehicle is at a stop. Figure 28 illustrates the mechanics of the engine stopping and the engine re-starting. As the vehicle decelerates to come to a stop, the fuel injection is cut off until the vehicle drops below 17 mph. Below 17 mph the PFI system fuels the engine as the deceleration continues. When the vehicle comes to a complete stop the engine idles at 575 rpm for 1.3 to 1.5 seconds during which time the injection system transitions from PFI to DI before the engine is stopped. After the engine is stopped, the high pressure fuel pump and a fuel volume control valve accumulate approximately 2.3 ml of fuel. The low pressure fuel pump in the tank increases its duty cycle while the engine is stopped. When the driver stops pressing the brake pedal, the engine is restarted. The stored high pressure fuel volume is fed through the DI system to restart the engine. Once combustion is restarted, the injection switches from the DI to the PFI system.

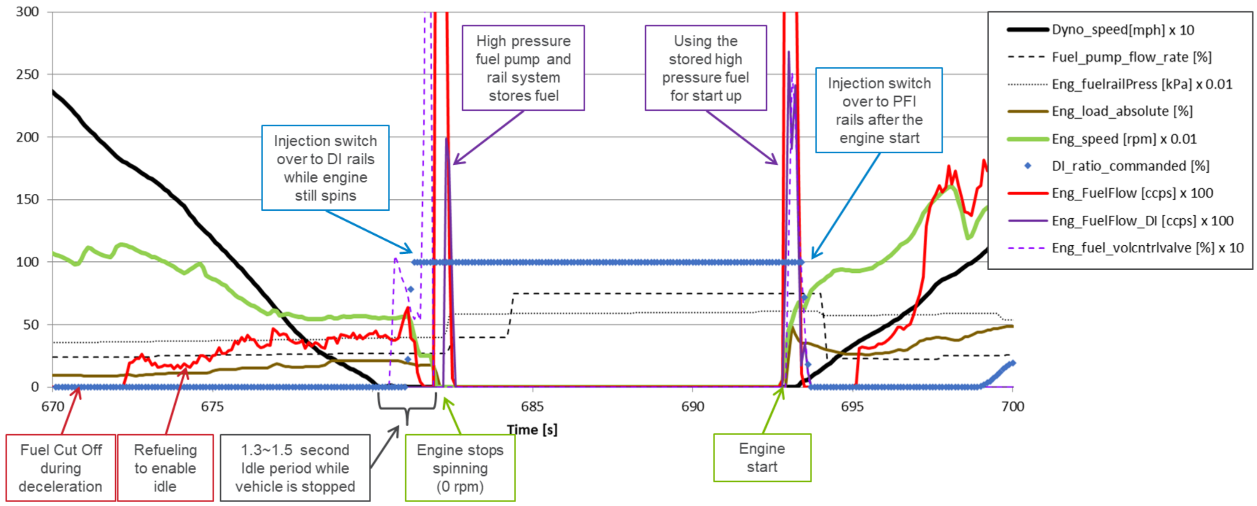

Figure 28: Mechanics of the engine start stop system

5.4.3. Specific engine technologies

5.4.3.1. Mapping methodology

This section focuses on some engine operation parameters across the engine load and engine speed domain. The graphs in the section were built by dividing the engine load and engine speed domain into a grid by defining engine load and engine speed bins. A large data set was built by combining many drive cycles, performance tests and component mapping tests into one data structure. The resulting data structure is composed of 10 Hz time-aligned data signals. Analysis software is used to distribute specific measurements or signals into the engine load and speed grid. The end results is a table with the averages values for each parameter of interest.

Figure 29 to Figure 32 were developed with this method using over 290,000 data points. Data from the 72° F testing on the Tier 2 certification fuel was used. The tests for this analysis were carefully selected to span the entire engine operating envelop. The engine maximum operating envelops for the UDDS, the highway and US06 cycles are overlaid on the figures to provide a visual guide to distinguish certification cycles from "off-cycle" operation.

5.4.3.2. DI vs PFI

The fuel can be fed to the engine through the PFI system or the DI system. Figure 29 shows the map of the PFI and DI strategy. The PFI system provides the fuel to the engine when the absolute engine load is below 40 percent. The DI system is quickly blended in above 40 percent absolute engine load. Between 60 percent to 140 percent absolute load, 80 percent to 70 percent of the fuel is delivered through the DI system. At absolute engine loads above 140 percent the PFI system provides an increase proportion of the fuel up to 40 percent. At the maximum absolute load above 2,000 rpm 60 percent of the fuel is provided by the DI system and 40 percent by the PFI system that corresponds to the values shown in the maximum acceleration test in Figure 24.

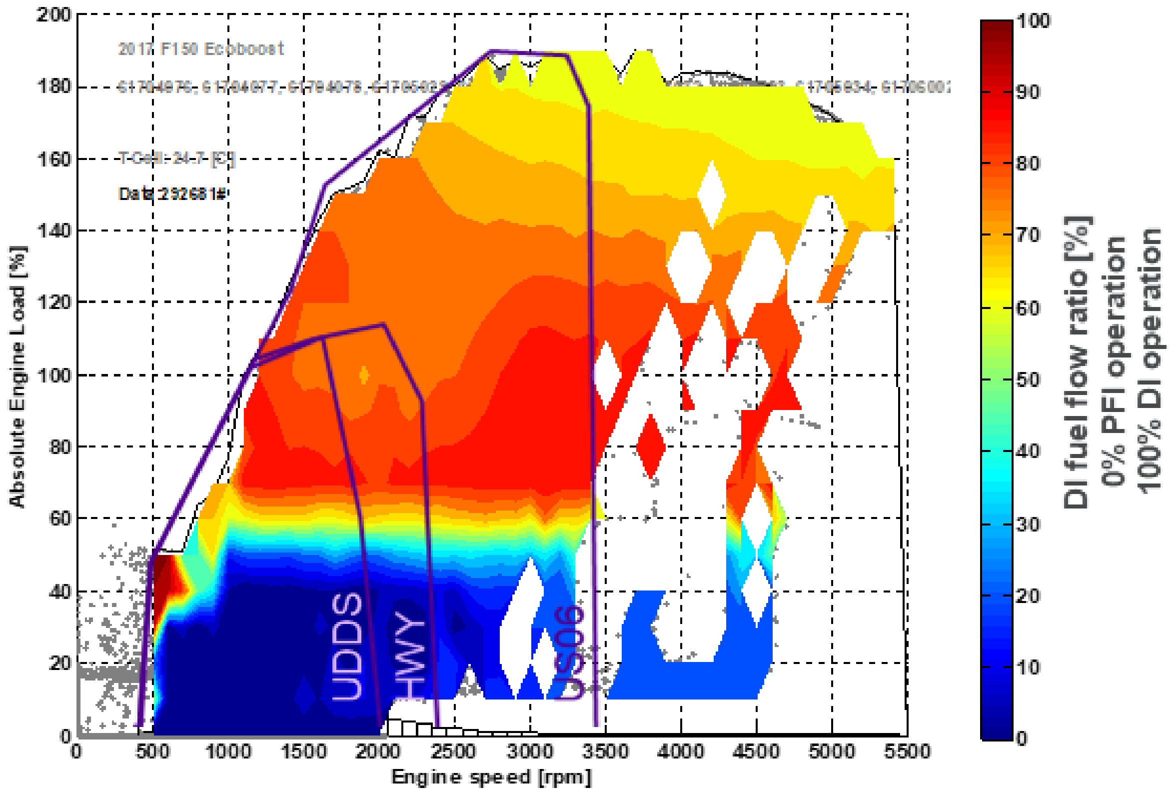

Figure 29: DI and PFI usage map as a function of the engine speed and load

The island of 100 percent DI operation at 575 rpm and 40 percent absolute load corresponds to the engine starting on the DI system before switching to the PFI system as described in the previous section.

5.4.3.3. Ignition timing

Figure 30 shows the spark ignition timing map for the engine. The most advance is observed at 20-40 percent load (low load cruise) and from 1,000-2,750 rpm.

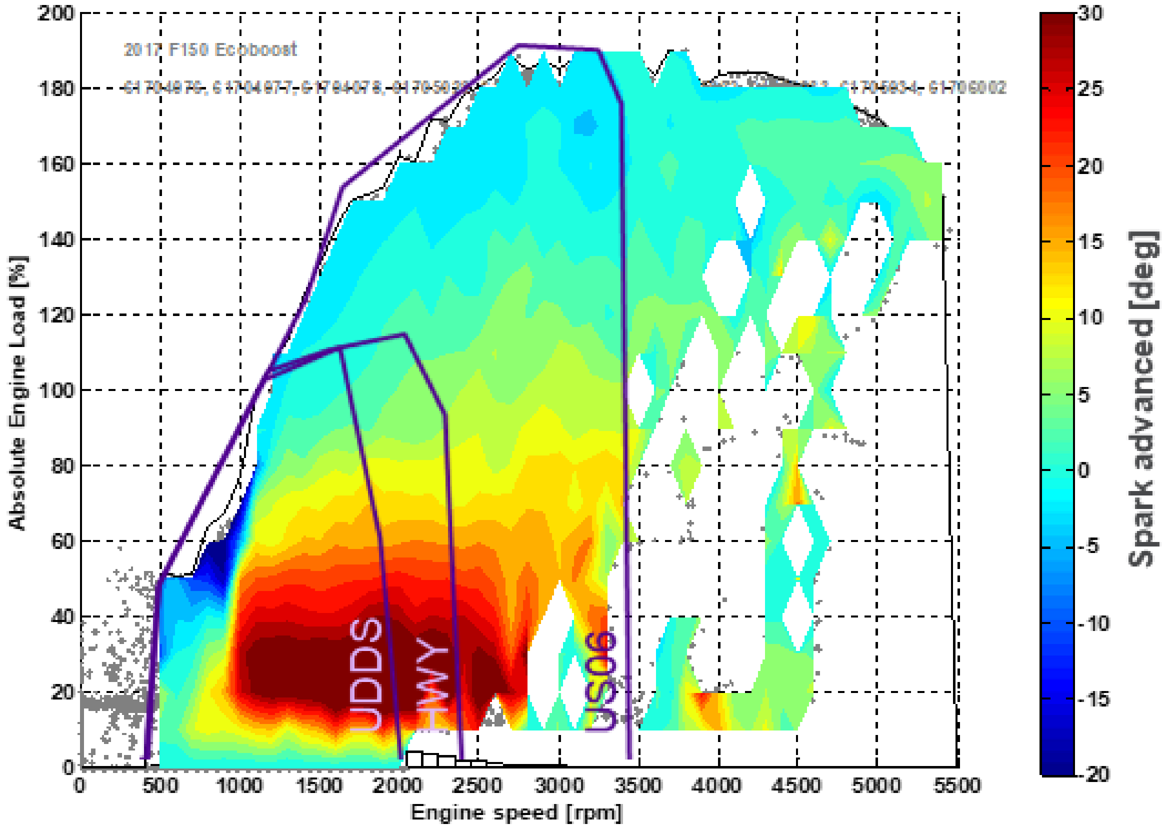

Figure 30: Spark advance map as a function of the engine speed and load

5.4.3.4. Engine boost strategy

Figure 31 shows the engine boost map. Note that the engine intake pressures on the UDDS and highway cycles do not require the turbocharger to provide boost. On the US06 cycle the power-train achieves required power by taking full advantage of the boost from the turbocharger rather than increasing engine speed.

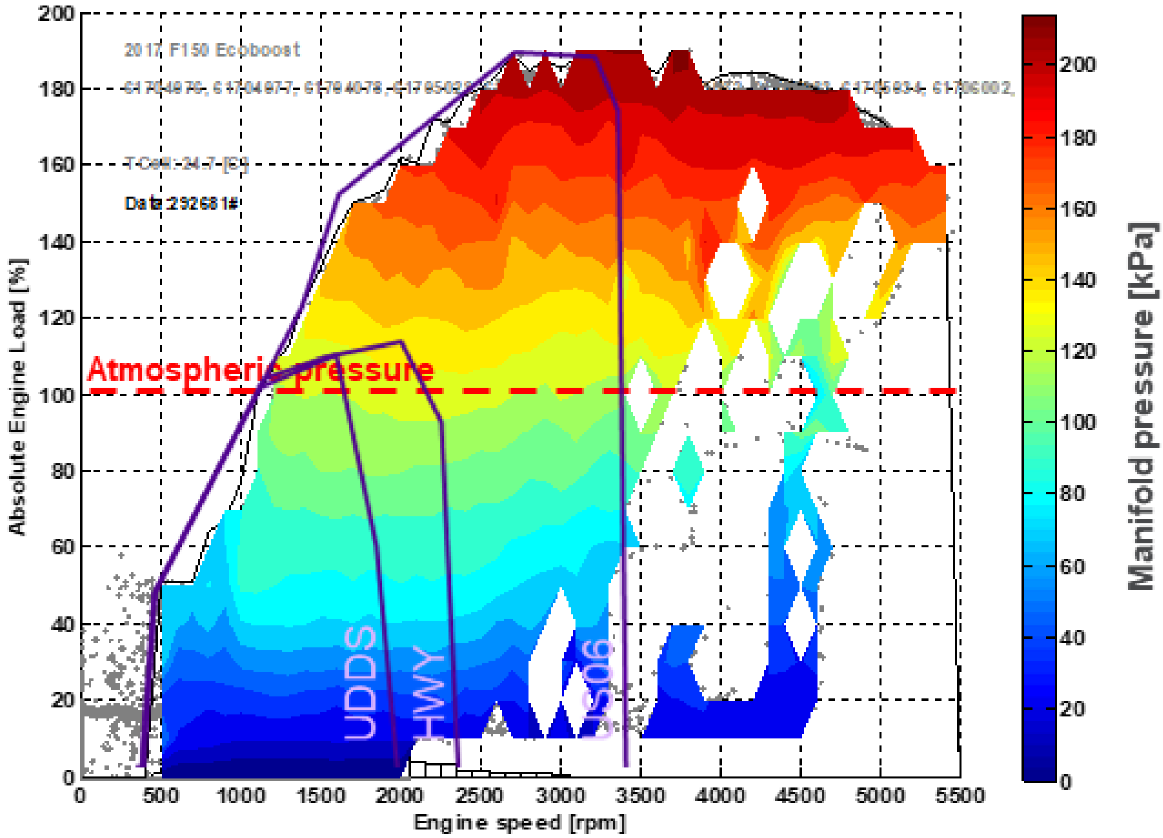

Figure 31: Manifold pressure and boost map as a function of the engine speed and load

5.4.3.5. Engine fueling map

Figure 32 provides the fuel flow map of the engine. This graph again shows the difference in power requirements between the relatively low power UDDS cycle and highway cycle compared to the US06 cycle.

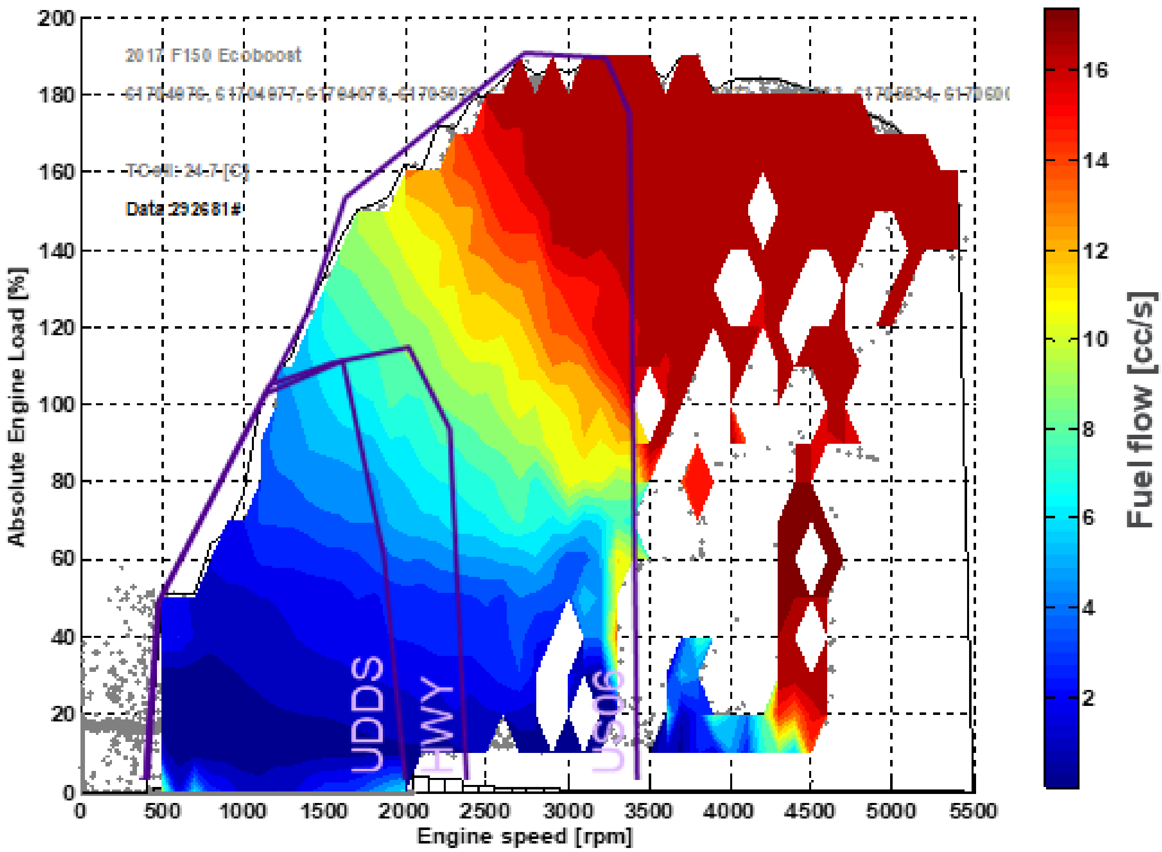

Figure 32: Fuel flow map as a function of the engine speed and load

5.4.3.6. Deceleration fuel cut off

Like other modern vehicles, the F-150 uses a deceleration fuel cut-off (DFCO) strategy to improve fuel economy. Recall Figure 8 and Figure 28 that show the deceleration fuel cut off mechanics as a function of time. Typically, the PFI system is providing the fuel to the engine before the fuel flow is cut off during the decelerations. The engine is fueled again as the vehicle reaches a lower speed.

Figure 33 shows the deceleration fuel cut off area in the vehicle speed and tractive effort space. This data is derived from 10 Hz drive cycle data that explains some of the noise in the data. The fuel is cut off at decelerations greater than 450 N at the wheel, which translates to a deceleration rate of 0.2 m/s^2. The engine is fueled again once the vehicle speed drops below roughly 17 mph.

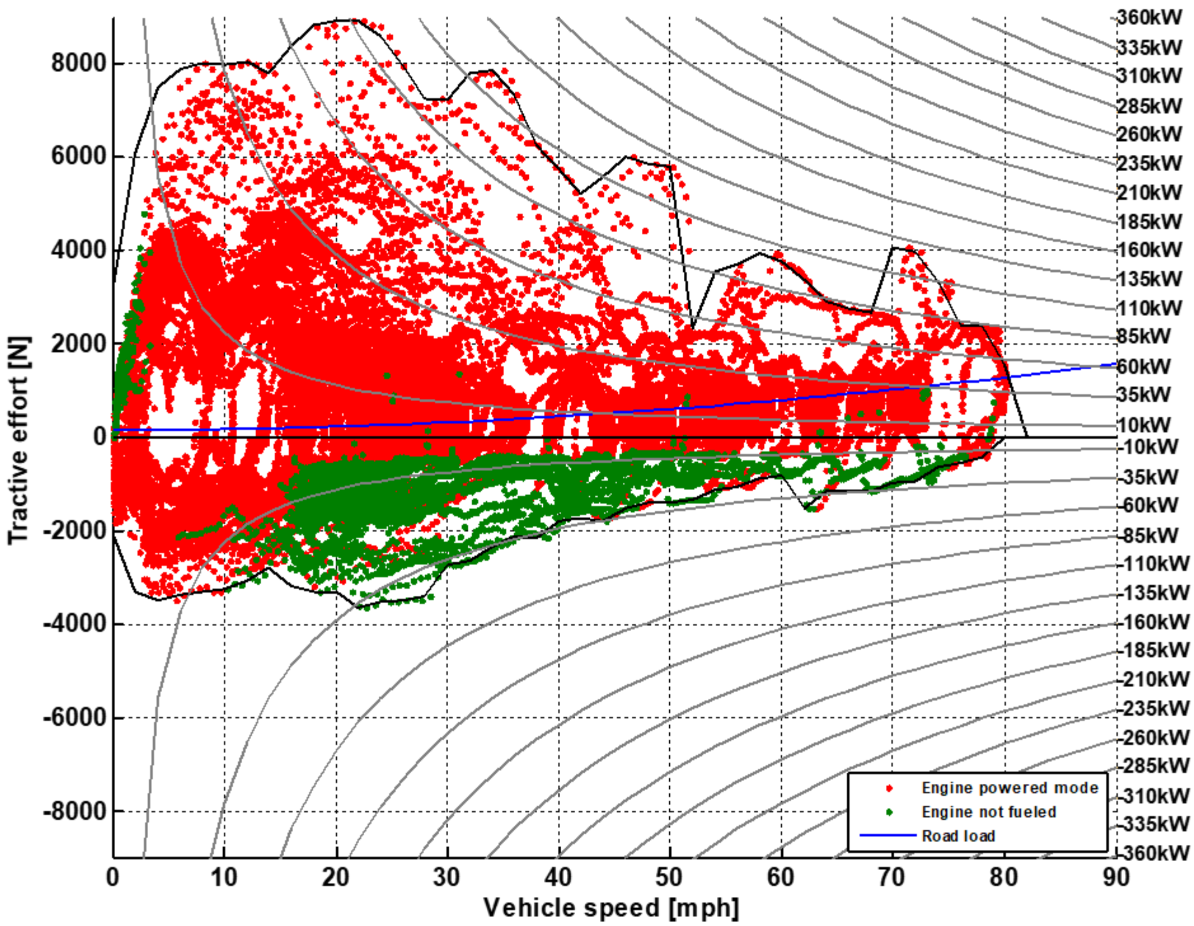

Figure 33: Deceleration fuel cut off strategy

The small islands of un-fueled engine operation at vehicle launch can be explained by how the vehicle operates and how the instrumentation is configured. This island is located at 0 to 4 mph and 0 to 4,000N that corresponds to the vehicle accelerating from a stop. As described in the engine idle stop section, the powertrain system stores fuel through the high pressure fuel pump when the engine is stopped and uses that stored fuel to restart the engine to help with launch. Figure 33 is generated from the total fuel flow measurement that does not include the stored fuel in the high pressure system. Therefore this island shows un-fueled operation at launch where the fuel comes from storage.

5.4.4. Transmission use

5.4.4.1. Shifting strategy

As mentioned in the drive cycle section in Figure 20, a potential skip shift island is observed in the shift map for the 10-speed transmission. The dynamic 10 Hz data from drive cycles can be a too noisy, therefore special transmission mapping tests were performed, consisting of constant pedal tip ins from zero to maximum speed for multiple pedal positions between zero and 100 percent. The maximum speed for any pedal position is limited to 85 mph. The chassis dynamometer is setup to emulate the proper road load and inertia just like for fuel economy testing. The resulting upshift map from this transmission mapping test is shown in Figure 34. The map shows clear trends in the shift strategy. In the low load area represented by accelerator pedal position below 15 percent the transmission shifts as soon as possible. In the medium load area represented by accelerator pedal positions between 15 percent to 70 percent the transmission starts to hold the gears longer to enable the engine to make enough power for the driver demand. In the high load areas represented by accelerator pedal positions above 70 percent, the transmission waits to shift the engine until the engine has reached its maximum allowable operating speed. The aforementioned skip shift island appears to lay at low to moderate pedal positions at speeds going up to 50 mph. The skip shift island includes gear shifts from 1st to 3rd, 2nd to 4th, 3rd to 5th, and 4th to 6th gears.

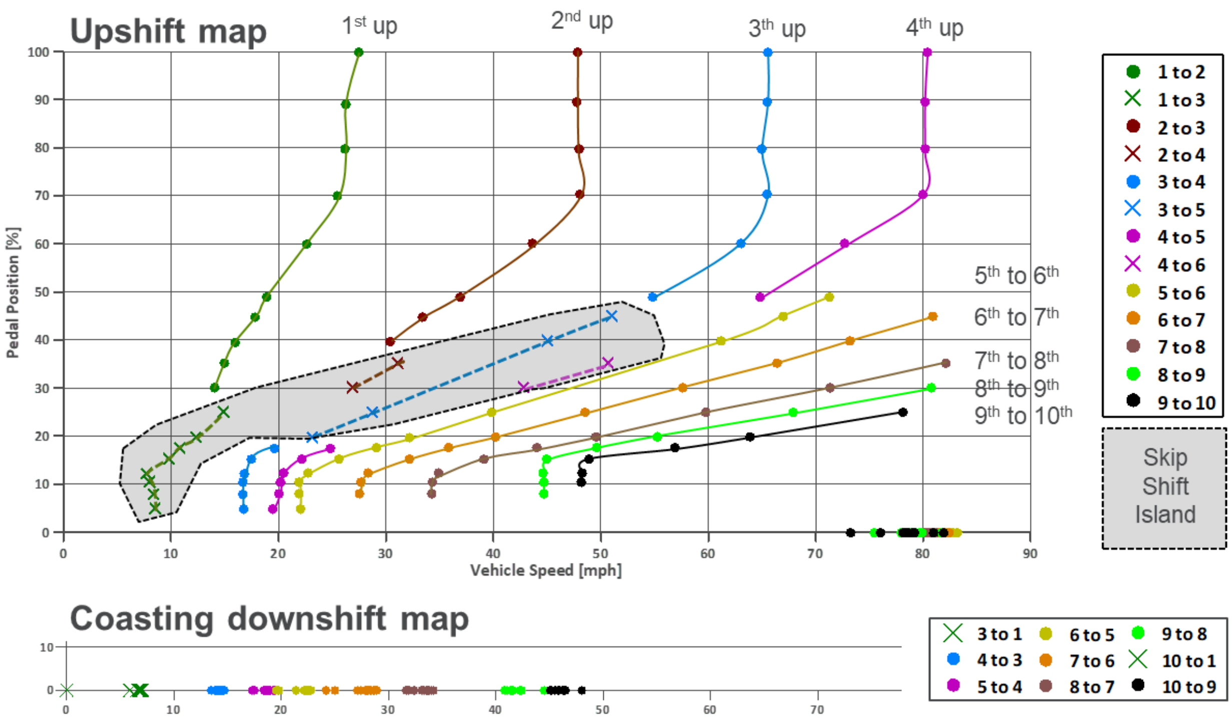

Figure 34: Shift strategy for the 10-speed automatic transmission (including skip-shifting)

5.4.4.2. Torque converter locking

The torque converter clutch (TCC) of the 10-speed transmission has three distinct operating modes: open, slipping, and locked. In the TCC open operation, the impeller and the turbine of torque converter are allowed to have the maximum possible speed differential. In the TCC slip operation, the difference in speed between the impeller and turbine of the torque converter is controlled to a desired value from the transmission controller. Finally, in the TCC locked operation, the impeller and turbine speeds are locked together and spin at the same speed. The TCC operation on the UDDS, Highway, and US06 drive cycles is summarized in Figure 35. The TCC is mostly open with a limited number of slipping points for 1st through 3rd gear. This is used for vehicle launch and idling. For 4th through 10th gear, the TCC is only locked or slipping. It is important to note that small variations from the gear ratio lines for the TCC locked mode appear because Figure 35 is based on the TCC desired slip and not the actual TCC slip, so some points show the TCC slipping while the transmission controller was commanding it to be locked. Additionally, any points where a shift was in progress have been removed.

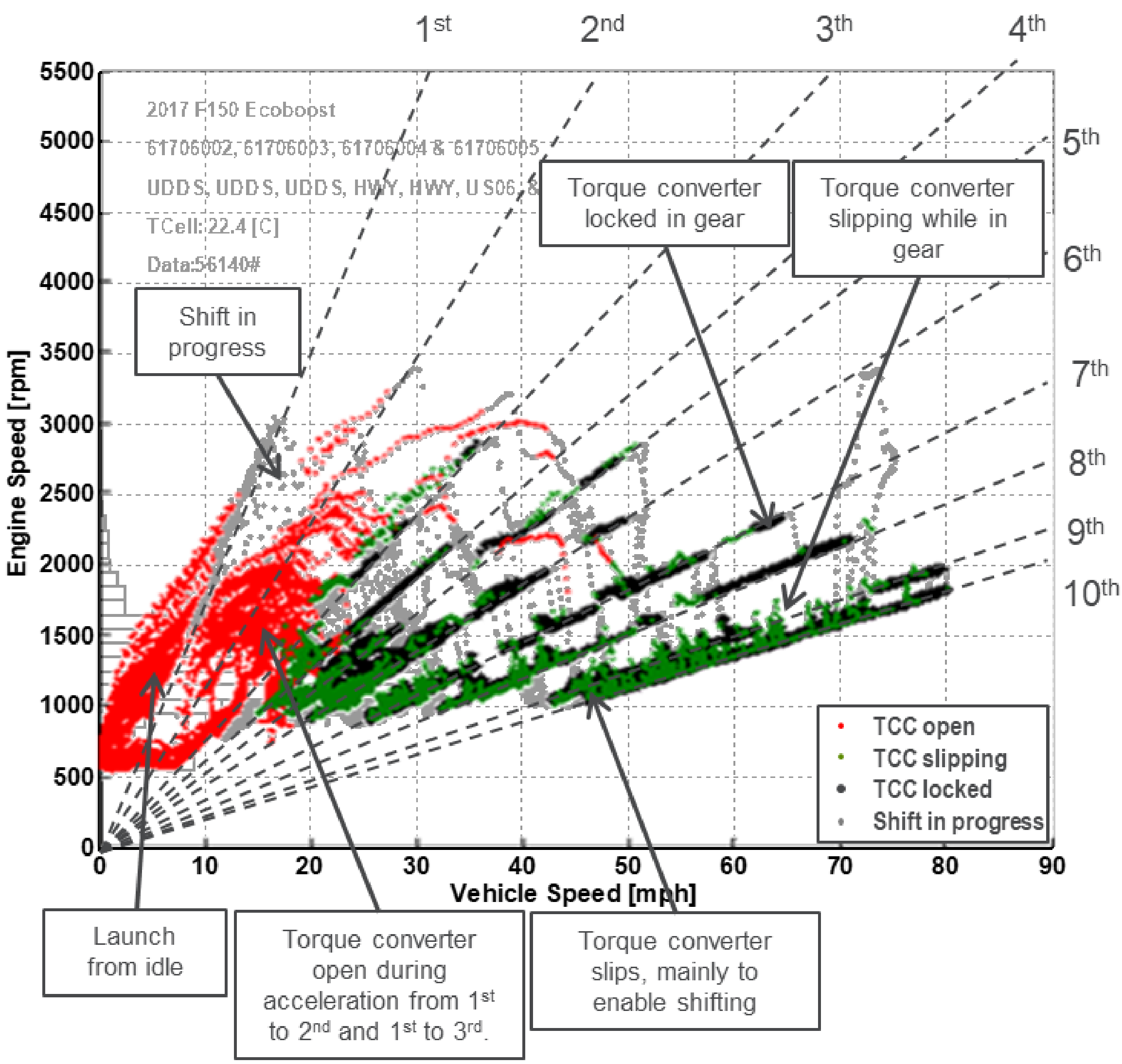

Figure 35: Torque converter operation on certification drive cycles (UDDS, Highway and US06)

The time spent in each TCC operating condition for each gear is summarized for the UDDS, Highway, and US06 cycles in Table 19, Table 20, and Table 21 respectively. For all drive cycles, the TCC is open 100 percent of the time in 1st and 2nd gear. The TCC is also open more than 85 percent of the time in 3rd gear. For gears 4 through 10, the TCC is generally locked for increasingly higher percentage of time as the gear number goes up. The TCC is open 100 percent of the time up through 4th gear on the US06 cycle, but is nearly locked for all other gears on the UDDS, Highway, and US06 cycles.

Table 19: Torque converter operation on UDDS (% time in mode)

Gear	TCC locked	TCC slipping	TCC open
1	0.0 % 1.0	0.0 %	100.0 %
2	N/A	N/A	N/A
3	0.4 %	1.8 %	97.9 %
4	20.8 %	38.7 %	40.5 %
5	43.6 %	53.0 %	3.4 %
6	74.6 %	25.1 %	0.3 %
7	68.6 %	31.4 %	0.0 %
8	77.1 %	22.9 %	0.0 %
9	77.8 %	22.2 %	0.0 %
10	92.0 %	8.0 %	0.0 %
% time on cycle			

Table 20: Torque converter operation on Highway cycle (% time in mode)

Gear	TCC locked	TCC slipping	TCC open
1	0.0 %	0.0 %	100.0 %
2	N/A	N/A	N/A
3	0.0 %	0.0 %	100.0 %
4	37.0 %	63.0 %	0.0 %
5	48.6 %	51.4 %	0.0 %
6	51.0 %	49.0 %	0.0 %
7	56.5 %	43.5 %	0.0 %
8	77.3 %	22.7 %	0.0 %
9	93.8 %	6.2 %	0.0 %
10	94.1 %	5.9 %	0.0 %
% time on cycle			

Table 21: Torque converter operation on US06 cycle (% time in mode)

Gear	TCC locked	TCC slip-ping	TCC open
1	0.0 %	0.0 %	100.0 %
2	0.0 %	0.0 %	100.0 %
3	1.4 %	11.2 %	87.4 %
4	0.0 %	0.0 %	100.0 %
5	43.1 %	41.5 %	15.4 %
6	64.0 %	36.0 %	0.0 %
7	53.5 %	27.6 %	18.9 %
8	40.3 %	59.7 %	0.0 %
9	66.9 %	33.1 %	0.0 %
10	86.7 %	13.3 %	0.0 %
% time on cycle			

This testing did not include torque and speed measurements at the input of the transmission in order to determine the torque converter and gearbox efficiency. In general the torque converter efficiency is at its highest when locked and at its lowest when open. Lower gears are typically transient gears in which the vehicle accelerates and therefore the torque converter tends to be open. When the vehicle is cruising at higher speeds, it is typically cruising at relatively steady speeds that allows the powertrain to lock the torque converter to maximize the powertrain efficiency.

5.5. "5-Cycle" thermal test conditions

The UDDS cycles, the Highway cycles and the US06 cycles were also tested at 20° F and at 95° F with 850 W/m^2 of solar load, which are the two extreme temperature conditions for the EPA 5-cycle fuel economy label. Figure 36 provides the test results for all of those conditions and drive cycles.

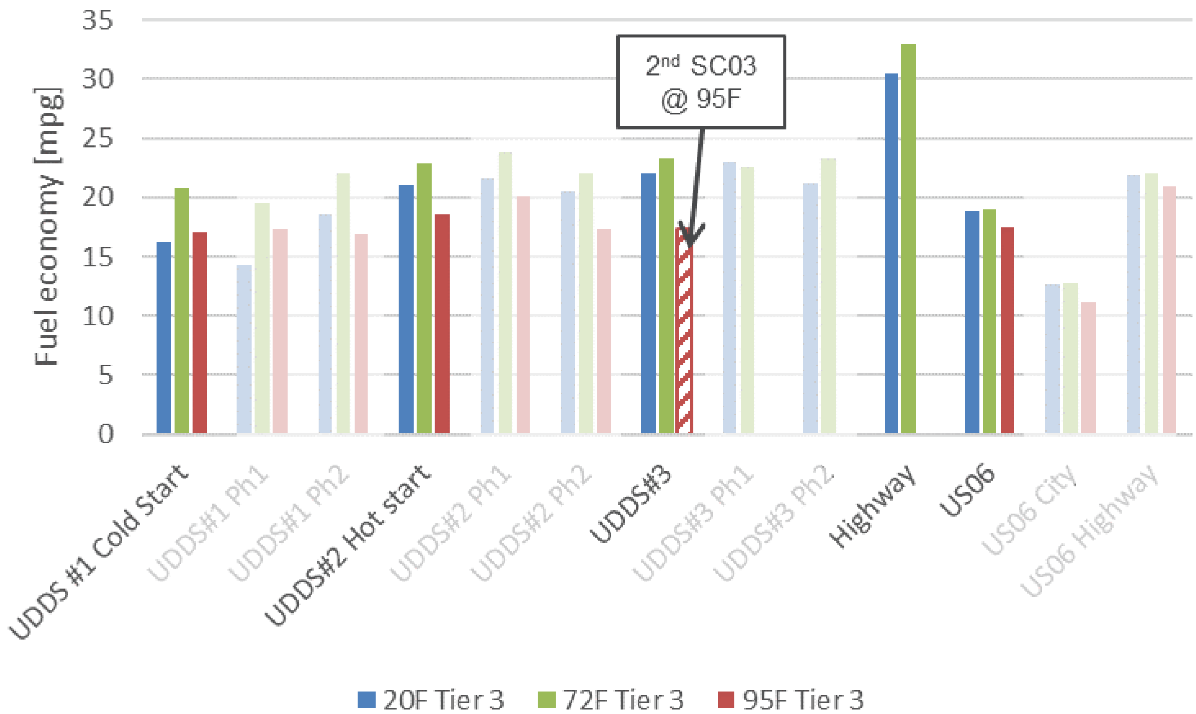

Figure 36: Raw fuel economy results for certification cycles across different temperature conditions

The fuel economy for the cold start UDDS at 20° F is decreased by 22 percent compared to the same test at 72° F, yet the fuel economy for the second urban cycle at 20° F is only 8 percent lower compared to the same test at 72° F. The powertrain has to overcome significantly increased friction losses throughout the drive train on the cold start at 20° F, but once the powertrain reaches a steady operating temperature those friction losses become less significant. The fuel economy penalty at 20° F compared to 72° F become smaller as the powertrain temperature increases.

The fuel economy at the 95° F test condition is also reduced compared to the 72° F test condition. At 95° F the fuel economy decreases by 17 percent and 19 percent for the cold start UDDS and the hot start UDDS respectively compared to the 72° F test condition. The fuel economy reduction is driven by the additional power required to operate the air conditioning system to cool down the cabin. Contrary to the cold temperature testing, this compressor load is a permanent energy penalty needed to maintain the comfort of the occupants in the vehicle. Note that for the 95° F testing the third UDDS was replaced by a pair of SCO3 drive cycles that is the fuel economy reported in Figure 36 instead of the third UDDS cycle.

Table 22 provides the calculated vehicle efficiencies for the different ambient test conditions. The impact of the cold powertrain temperatures is apparent in the 20° F cold start efficiency. As the powertrain temperatures rise throughout the tests in the test sequence, the vehicle efficiencies at 20° F start to approach the vehicle efficiencies at 72° F ambient temperature. The impact of the auxiliary load from the air conditioning compressor at 95° F is also apparent in this table. It is noteworthy that the efficiency impact of the air conditioning compressor is lower on the high power US06 drive cycle as the ratio between the air conditioning power to the average wheel power is lower compared to the same ratio for lower power UDDS cycle.

Table 22: Powertrain efficiencies across different ambient test conditions

	20° F	72° F	95° F
UDDS #1 Cold Start	14.7%	18.7%	15.5%
UDDS#2 Hot Start	19.0%	20.6%	16.7%
UDDS#3	19.7%	20.8%	17.6%
Highway	27.6%	29.9%	
US06	28.1%	28.7%	26.1%

Figure 37 shows the engine operating areas for the cold start and hot start UDDS at each of the three ambient temperature conditions. The 72° F plot in the middle serves as the reference. At 20° F the idle fuel flow island is significantly higher as the engine idle stop function is disabled; the engine idles all the time while the vehicle is stopped on both the cold start and hot start UDDS cycles. This may be related to the need for heat to warm up to the cabin as well as the need to warm up the exhaust after-treatment system. It also appears that the transmission holds gears slightly longer, therefore increasing the average engine speed at 20° F. At 95° F the engine idle island is also significantly increased with the average absolute engine load shifted upwards from 20 percent to 30 percent. This is explained by the power needed by the belted air conditioning compressor. The overall absolute engine load envelop is increased, which is also due to the additional power required for the air conditioning compressor.

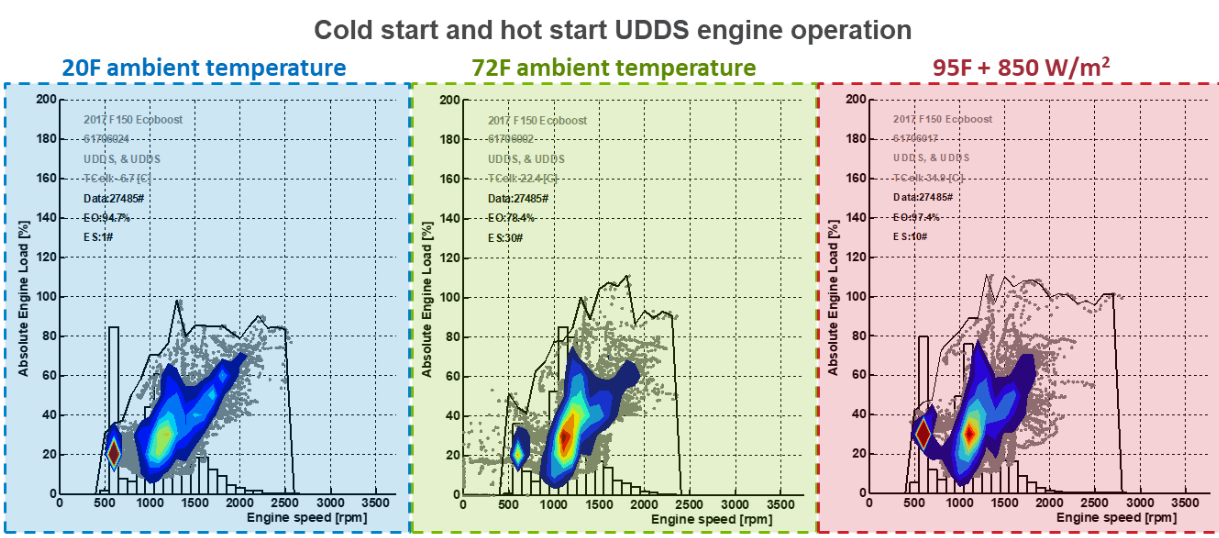

Figure 37: Engine operation on the UDDS across different temperatures

Figure 38 shows some relevant powertrain and ambient temperature profiles over the completion of the test sequence. Note that at 20° F the Highway cycles were tested as a cold start test. In order to obtain a thermally stable results three pairs of Highway drive cycles were tested. These graphs also show the targeted 72° F cabin temperature that the climate control system tries to achieve in the 20° F and 95° F test condition.

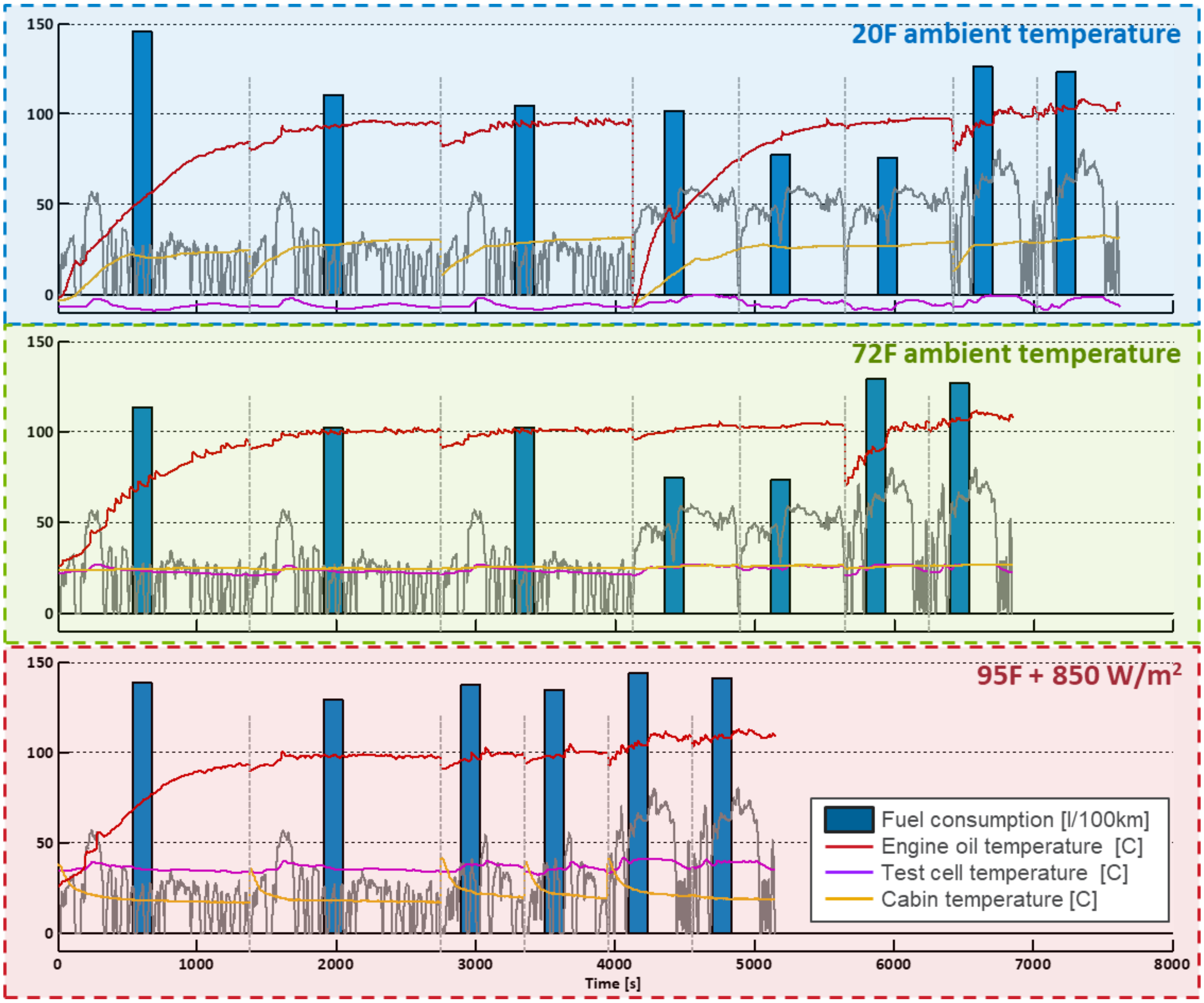

Figure 38: Powertrain and cabin temperature profits across different temperature

The engine oil temperature is representative of the powertrain temperature. For all three ambient temperature conditions the final engine oil temperature for the US06 is around 100° C to 110° C. In past testing of light duty vehicles, Argonne has observed that in a number of these vehicles the average powertrain temperatures in the 20° F testing never rise to the average powertrain temperatures at 72° F.

5.6. 93 to 88 AKI octane fuel comparison

The owner's manual of the Ford F-150 recommends the usage of premium fuel but does not require it. Argonne tested the vehicle on Tier 2 and Tier 3 certification fuel to investigate the impact of octane rating on fuel economy and performance. The Tier 2 certification fuel has an octane rating of 93 AKI and the Tier 3 certification fuel has an octane rating of 88 AKI. The Tier 2 fuel represents the premium fuel and the Tier 3 fuel represents the regular fuel in this investigation.

Argonne drained the Tier 2 certification fuel used for the vehicle technology work presented thus far in the report and replaced it with Tier 3 certification fuel. The vehicle was then driven on mild and aggressive drive cycles to enable the engine controller to adjust ignition calibration and fuel trims to the new fuel. The octane adjustments CAN message was monitored during of the conditioning tests and used to determine that powertrain had adjusted to the new fuel.

Once the staff confirmed that the powertrain controller had adapted to the new lower octane fuel, the test sequence of three UDDS cycles, a pair of Highway cycles and a pair of US06 cycles was repeated three times. The average drive cycle fuel economies based on the three repeats are presented in Table 23 and Figure 39. As pointed out in section 3.10., the Tier 2 fuel has a 3.1 percent lower energy content by mass compared to the Tier 3 fuel, which does impact the volumetric fuel economy comparison. The fuel economy results here are presented in terms of volumetric fuel economy based on each individual fuel. Considering that only three repeats were completed, the fuel economy results for the UDDS drive cycles and the Highway drive cycles between the different fuels are within test to test variabilities.

Table 23: Average fuel economy results for the Tier 2 and Tier 3 fuels

	Tier 2 93 AKI [mgp]	Tier 3 88 AKI [mpg]
UDDS #1 Cold Start	20.6	20.8
UDDS#2 Hot Start	22.8	23.1
UDDS#3	22.7	23.1
Highway	32.8	32.5
US06	19.1	18.1

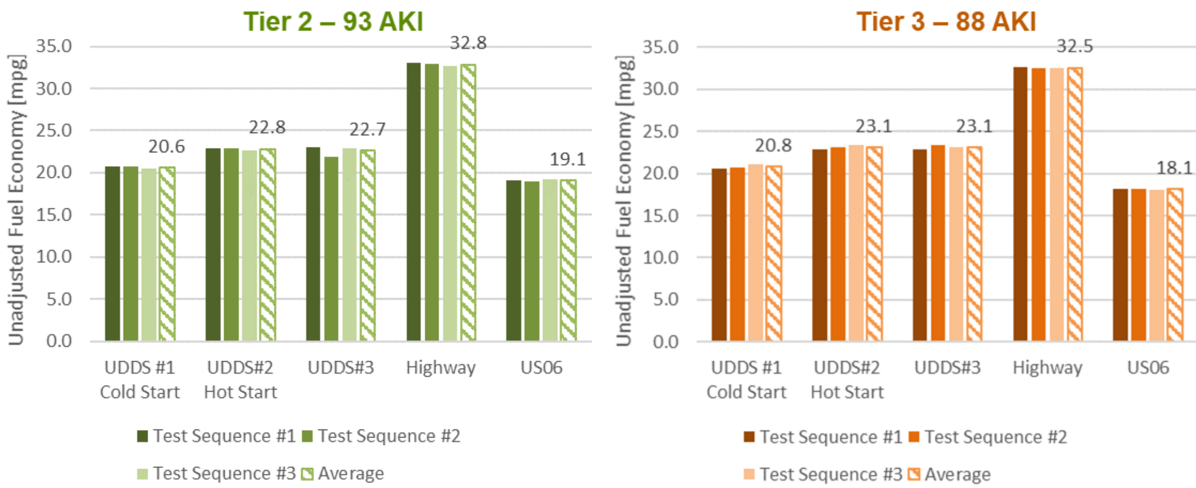

Figure 39: Drive cycle fuel economy results for the Tier 2 and Tier 3 fuels

The vehicle efficiencies calculations are based on the actual energy content of the fuels as provided in Table 2 and Table 3. The vehicle efficiencies were calculated for each drive cycle and averaged together based on the three repeats of the test sequence. They are shown for each drive cycle and test fuel in Figure 40. Again the average vehicle efficiencies for the UDDS cycle and the Highway cycle are very similar. The vehicle efficiency for the US06 has decreased by 1 percent when switching from the 93 AKI fuel to the 88 AKI fuel.

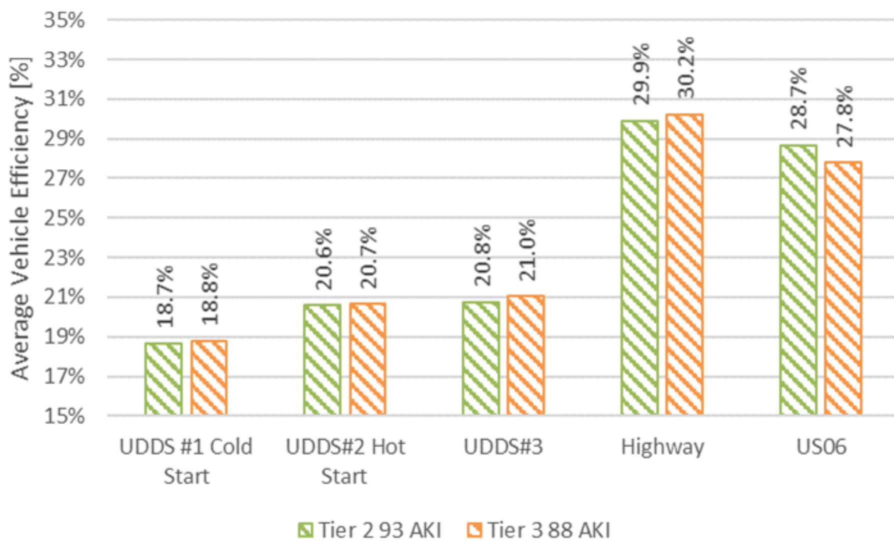

Figure 40: Average powertrain efficiencies for Tier 2 and Tier 3 fuels

Table 24 and Table 25 summarize the results from the performance testing with the different fuels. The vehicle performance is better for the 93 AKI fuel compared to the 88 AKI fuel. The vehicle accelerates 0.7 seconds faster to 80 mph under maximum acceleration with the 93 AKI fuel. The passing maneuvers are also executed faster with the 93 AKI fuel, except for the 35 mph to 55 mph test. It appears that the powertrain experienced a longer hesitation to build boost and switch gears for the 93 AKI fuel condition on that passing test. The performance tests suggested that the engine torque is increased with the higher octane fuel due to spark advance.

Table 24: Maximum acceleration performance results for Tier 2 and Tier 3 fuels

WOT [s]	Tier 2 93 AKI	Tier 3 88 AKI
0-60	6.7	7
0-80	10.6	11.3

Table 25: Passing maneuvers results for Tier 2 and Tier 3 fuels

Passing [s]	Tier 2 93 AKI	Tier 3 88 AKI
35-55	3.8	3.7
55-65	2.6	2.9
35-70	6.1	6.3
55-80	5.2	5.9

Figure 41 shows the ignition timing for both fuels for the UDDS, the Highway and the US06 cycles. At higher absolute engine loads the spark timing for the 93 AKI fuel is more advanced enabling the engine to operate closer to the maximum brake torque combustion conditions. For the lower octane fuel the spark ignition timing is retarded at these higher loads to prevent engine knocking from occurring. The vertical axis in these figures is absolute engine load as reported by the powertrain controller that is different than mechanical torque output from the engine. Overall the lower octane fuel resulted in higher engine speeds and higher boost levels to compensate for the lower mechanical torque.

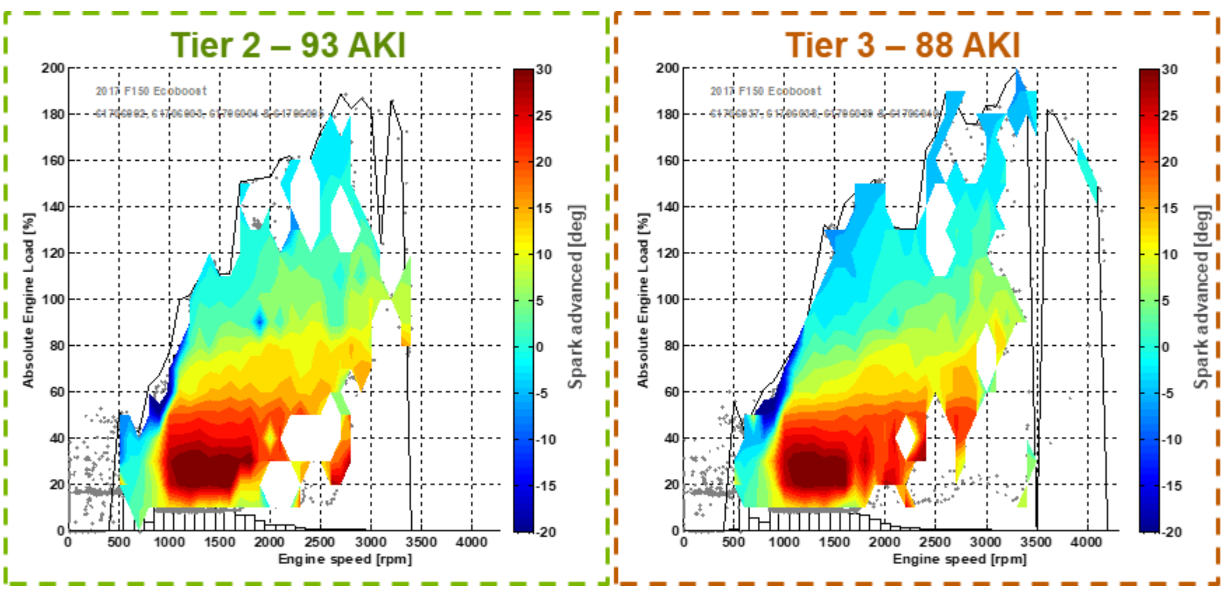

Figure 41: Spark advance comparison between Tier 2 and Tier 3 fuels

Figure 42 shows the steady state fuel economy results for the Tier 3 – 88 AKI fuel along with some powertrain characterizations. Figure 22 previously shows the same results for the Tier 2 –

93 AKI fuel. The fuel economy and powertrain efficiency are slightly higher for the high octane fuel. Again, the Tier 2 fuel has a 3.1 percent lower energy content by mass compared to the Tier 3 fuel that does impact the volumetric fuel economy comparison.

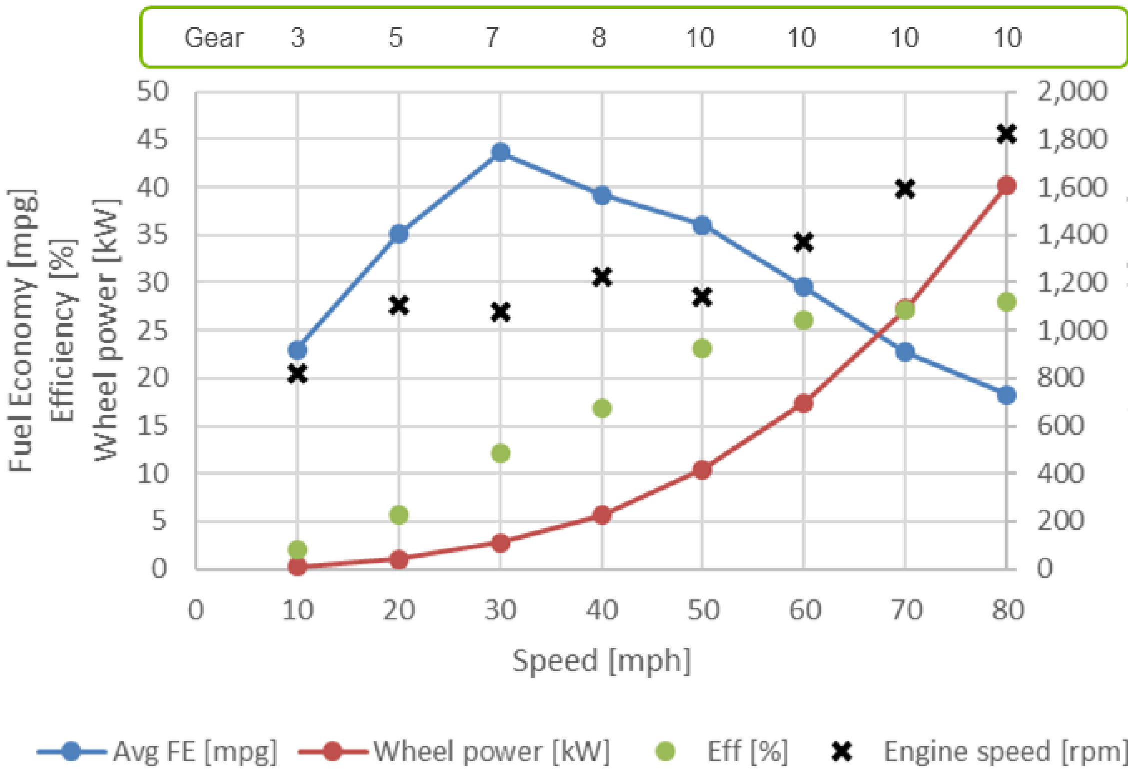

Figure 42: Steady state speed fuel economy with other powertrain measurements on Tier 3 – 88AKI

5.7. Vehicle specific testing

5.7.1. Transmission testing in normal mode, sport mode, and tow mode

Many manufactures now provide several driver selection modes that adjust vehicle operation from accelerator pedal mapping, engine and transmission operation. In the Ford F-150, three separate modes can be selected: *Normal* (default), *Tow/Haul*, and Sport. Specific testing is performed to determine vehicle operation and fuel consumption impact in each mode.

Manufacturer supplied service documentation lists the operation of the *Tow/Haul* as providing the following functionality:

"The tow mode feature:

- *Moves upshifts to higher engine speeds to reduce the frequency of transmission shifting.*
- *Provides engine braking in all forward gears, which will slow your vehicle and assist you in controlling your vehicle when descending a grade.*
- *Depending on driving conditions and load conditions, may downshift the transmission, slow your vehicle and control your vehicle speed when descending a hill,*

without pressing the accelerator pedal. The amount of downshift braking provided will vary based upon the amount the brake pedal is pressed.

The tow mode feature improves transmission operation when towing a trailer or a heavy load. All transmission gear ranges are available when using tow mode."

In addition, the vehicle owner's manual describes *Sport* mode as:

"The sport mode feature:

- *Provides additional grade (engine) braking and extends lower gear operation to enhance performance for uphill climbs, hilly terrain, or mountainous areas. This will increase engine rpm during engine braking.*
- *Provides additional lower gear operation through the automatic transmission shift strategy.*
- *Selects gears more quickly and at higher engine speeds."*

Both modes impact the transmission shift strategies. To measure the impact of the driver-selected mode the vehicle was tested in each mode on the US06 cycle that is the most aggressive and high-speed drive cycle used for certification purposes. The staff ran four consecutive US06 cycles. The first US06 cycle served to prepare the vehicle thermal state. The three subsequent US06 cycles were performed in normal, tow/haul, and sport mode respectively. Fuel Economy results and transmission operation from this testing are shown in Figure 43. Note that the road load curve was not adjusted for the added weight.

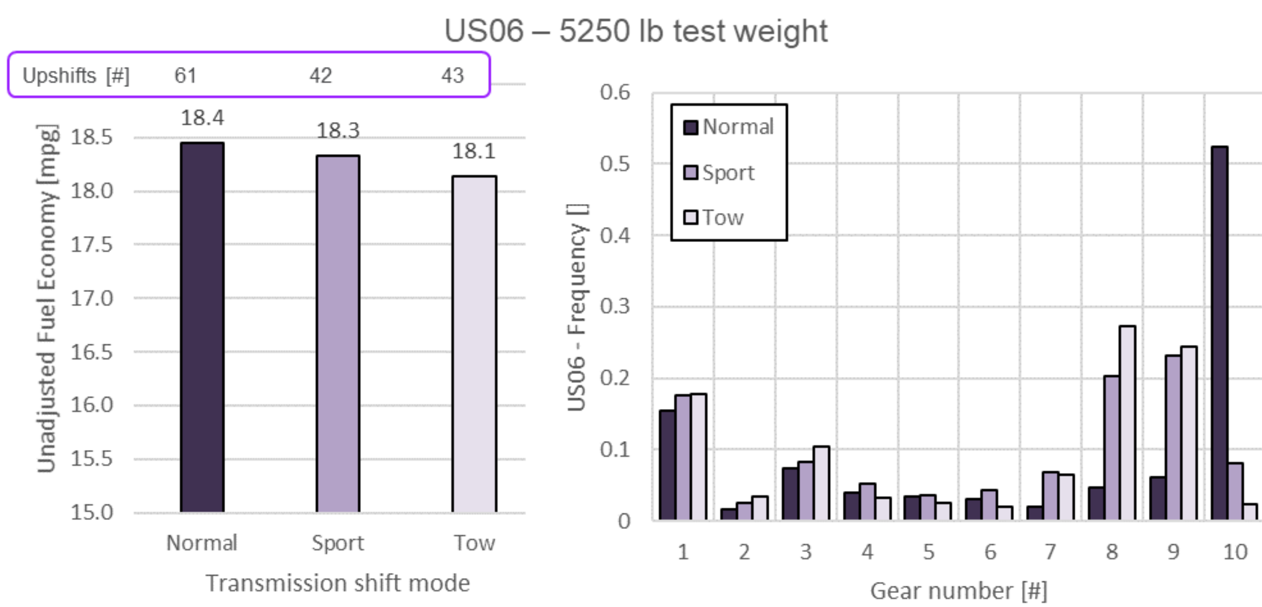

Figure 43: Fuel economy results and transmission gear histogram for different transmission shift modes on US06

The *Sport* and *Tow/Haul* modes reduce the fuel economy by 1 percent and 2 percent, respectively. Even though the fuel economy difference between the different modes is minimal, the gear usage by the transmission varies significantly between the modes. Tenth gear is engaged over 50 percent of the time on the US06 cycle in normal mode, whereas 10th gear is engaged less than 8 percent and 3 percent in the sport and tow mode respectively. In general, the lower gears are engaged longer and in both *Sport* and *Tow/Haul* modes, 8th and 9th gear are used the most frequently on the US06 cycle. In *Tow/Haul* mode, as compared to *Sport* mode, the transmission holds lower gears longer that increases torque reserve and improves drivability.

The effect on engine speed of these three modes is shown in Figure 44. The difference in engine speed on the highway section of the cycle is apparent. In normal mode 10th gear is engaged for the majority of the highway portion of the cycle that keeps the engine speed around or below 1,500 rpm whereas 9th or 8th gear are engaged in the sport and tow mode, which keeps the engine speed between 1,600 and 2,000 rpm. The up shifting into lower gears during decelerations is also apparent. While the transmission keeps the tallest gear engaged in normal mode, the transmission upshifts much earlier to provide the engine braking during decelerations in the sport and tow mode.

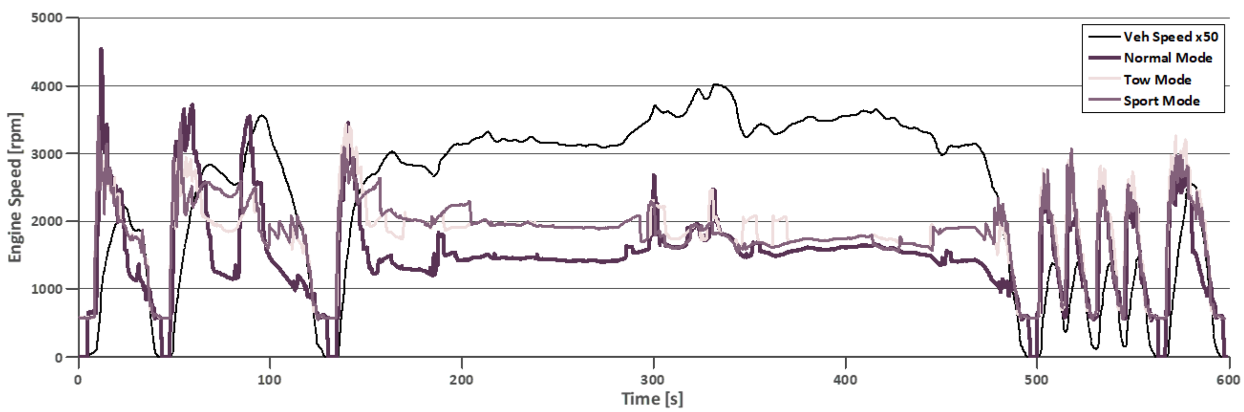

Figure 44: Engine speed differences on US06 for different transmission shift modes

5.7.2. Increase pay load testing for transmission mapping

Further testing of the F-150 was done with increased road load emulation to simulate a higher payload. The chassis dynamometer road load coefficients were kept constant but the test weight was increased to 10,000 lb for the high payload testing. The increased payload test was performed for a UDDS drive cycle and included three different cases: (1) standard vehicle weight of 5250 lb with transmission in normal shift mode, (2) 10,000 lb vehicle weight with transmission in normal shift mode, and (3) 10,000 lb vehicle weight with transmission in tow mode. Note that the vehicle owner's manual states that if equipped, the vehicle should be placed into *Tow/Haul* mode as described below:

> *If your transmission is equipped with a Grade Assist or Tow/Haul feature, use this feature when towing. This provides engine braking and helps eliminate excessive transmission shifting for optimum fuel economy and transmission cooling."*

The fuel economy results and transmission gear histogram for the three test cases are shown in Figure 45. The additional payload of 4,750 lb reduced the fuel economy by 29 percent in normal shift mode and by 36 percent in the *Tow/Haul* mode. With the additional payload, the fuel economy is higher in normal shift mode compared to the *Tow/Haul* mode. The reason for this can be seen in the transmission gear histogram in Figure 45. In the test with the 10,000 lb vehicle weight and normal shift mode, the transmission operates in significantly higher gears that results in lower engine speed and higher torque with increased powertrain efficiency. Conversely, the lower gears selected in the tow mode result in higher engine speeds and lower engine loads, thus reducing the powertrain efficiency. The lower gear selection in tow mode reduces the mechanical and thermal loads on the powertrain due to lower torque output necessary from the engine. Even though the tow mode for the transmission reduces the vehicle efficiency, the tow mode provides a number of benefits:

- increased vehicle responsiveness due to higher torque availability;
- higher engine braking to reduce brake system load and prevent brakes from overheating that is a critical safety factor;
- lower heat generation in transmission to prevent overheating;
- Increased powertrain durability;

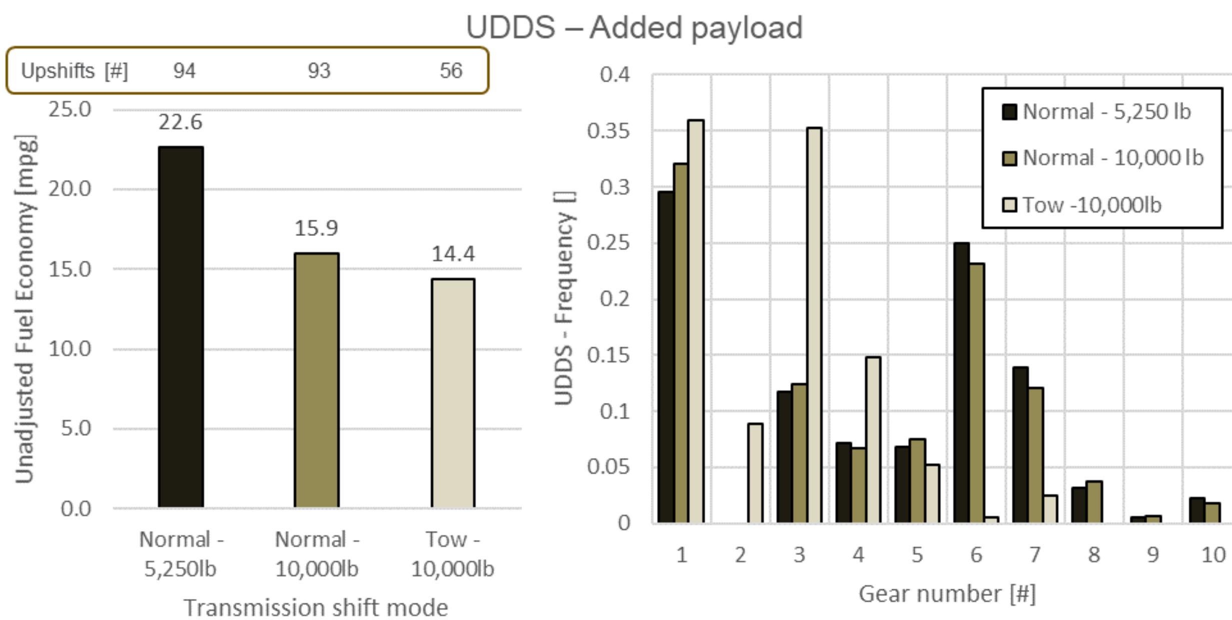

Figure 45: Fuel economy results and transmission gear histogram for different payloads and shift modes on US06

The engine operation shifts dramatically between the three test cases as shown in Figure 46. At normal vehicle weight of 5,250 lb, the engine operates in a narrow region with a mean engine speed around 1,200 rpm and absolute engine load from 10 percent to 30 percent. Maximum absolute engine load is less than 100 percent and maximum engine speed is around 2,000 rpm on the UDDS drive cycle with no payload. With the additional 4,750 lb payload and the transmission in normal shift mode, the engine operational region increases significantly, with maximum absolute engine load over 160 percent and maximum engine speed over 2,500 rpm. Finally, with the additional payload and the transmission in tow mode, the engine operation region shifts to significantly higher engine speed at lower loads where the maximum absolute engine load is about 110 percent and the maximum engine speed is 3,000 rpm. Additionally, when tow mode is selected, the engine idle stop function is disabled so that the powertrain is ready to pull a heavy load from a stop.

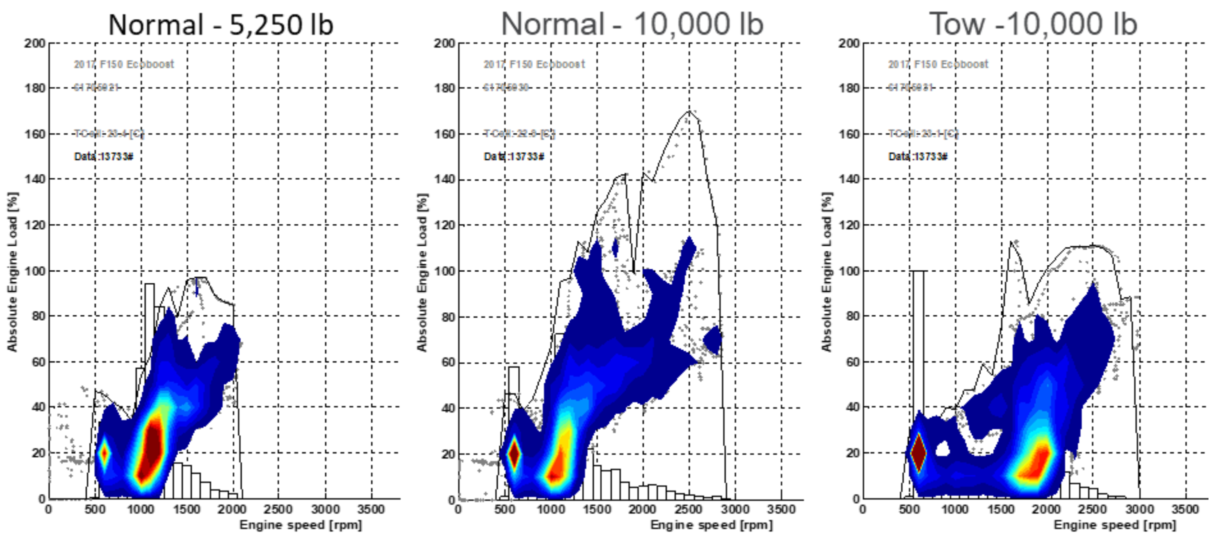

Figure 46: Engine operation for the different payload conditions

5.7.3. Active Grille Shutter Operation

The 2017 Ford F-150 is equipped with an active grille shutter system consisting of two separate arrays of shutters. As described in the vehicle owner's manual, the active grille shutter system has several benefits.

> *"The active grille shutter system is primarily used to maximize fuel economy by reducing aerodynamic drag on the vehicle. It is also used to shorten engine warm-up time, increasing engine efficiency and providing heat to the vehicle occupants in a timely manner."*

The F-150 active grille shutter system is separated into two arrays, with each array acting independently to control airflow into the front of the vehicle. The upper array controls airflow to the radiator, transmission cooler, and air conditioning evaporator core, while the lower array, located behind an inlet in the center of the bumper, controls airflow to the charge air cooler. Both active shutter systems are shown in Figure 46 .

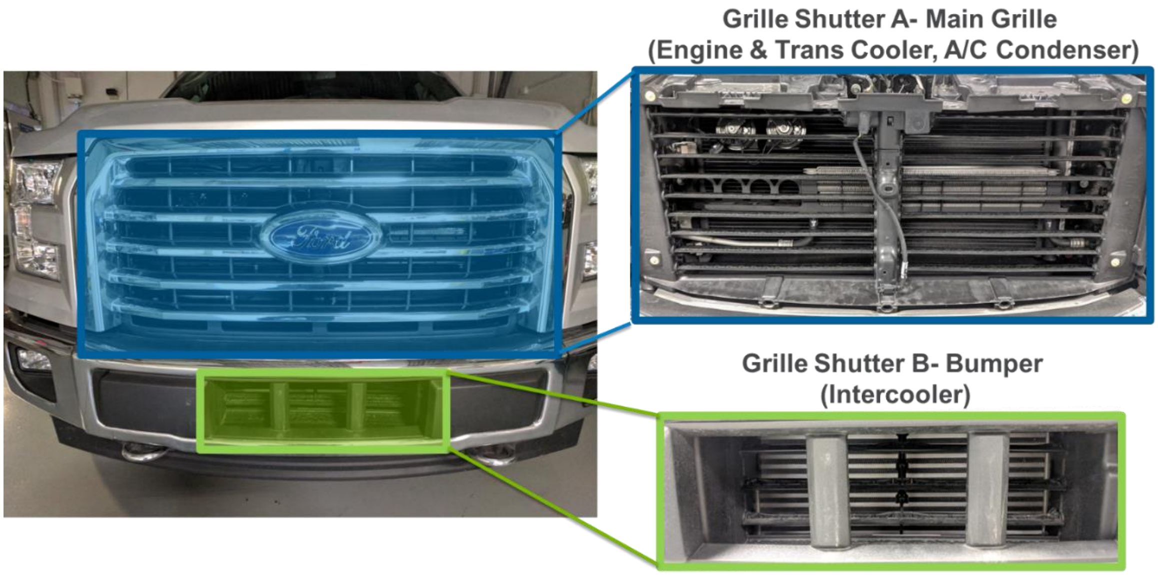

Figure 47: 2017 Ford F-150 Active Grille Shutter Component Overview

Diagnostic messages related to the active grille shutter system are decoded and subsequently logged during vehicle testing at a frequency of approximately 1 Hz. These messages consist of both the desired and actual positions of each array. Both sets of signals display the relative position with 0 percent corresponding to shutters fully closed and 100 percent to fully open shutters.

Chassis dynamometer testing is unable to quantify the impacts on aerodynamics from an active grille shutter system. Any impact from this system would show up in the vehicle road load coefficients that would be derived from coast down testing at a track. This report will only focus on the operation and relative position of the active shutter systems.

Figure 48 displays shutter operation during the vehicle coastdowns performed on the chassis dynamometer for the vehicle loss determination. A pair of Highway cycles are completed before the coast down section to bring the vehicle to thermal stability. During the coast downs, the upper grille shutter opens from 10 percent to 20 percent at speeds above 62 mph. Below 62 mph the upper grille shutter closes to 10 percent until 12 mph, at which point the shutter slowly opens to 50 percent at a rest. The lower grille shutter ranged from closed to 20 percent on the first coast down cycle from 80 mph to 40 mph, varying to 10 percent open at speeds under 40 mph. The lower grille shutter remained closed the duration of the second coastdown cycle.

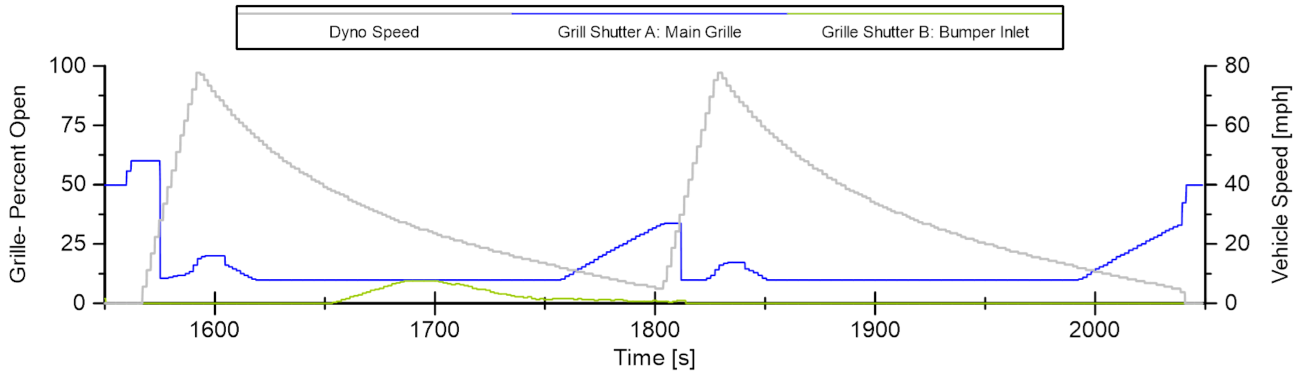

Figure 48: Grille Shutter operation on the dynamometer coast downs

An overview of the system operation on the UDDS cold start is shown in the Figure 49. Following every key-on event, the vehicle performs a test of operation of both active grille shutters by cycling both shutters from completely close to completely open. Following that self-test, the lower grille shutter located at the inlet to the intercooler remained closed through the duration of the test, whereas the upper grille shutter cycles between 10 percent and 50 percent based on vehicle speed. The upper shutter is open 50 percent when the vehicle comes to a stop. A histogram of grille shutter positions can be seen in Figure 50.

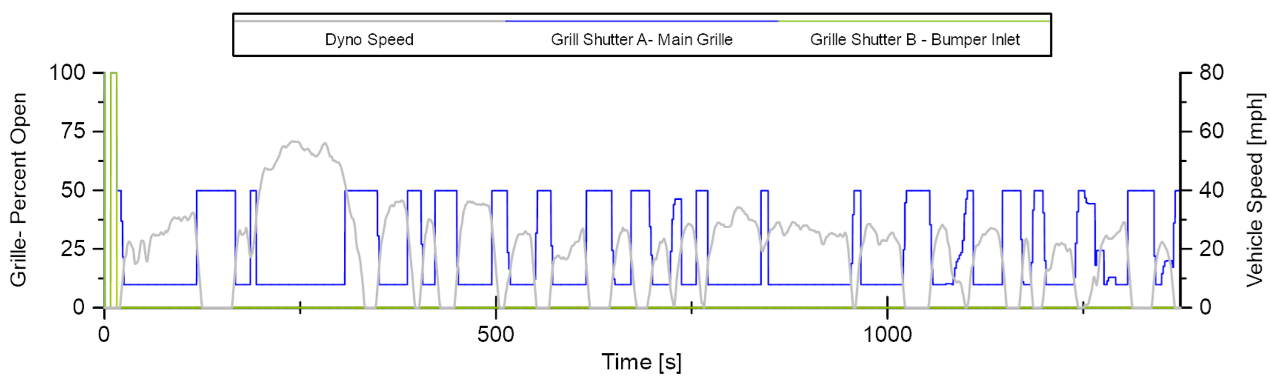

Figure 49: UDDS Cold Start Grille Shutter Commanded Operation

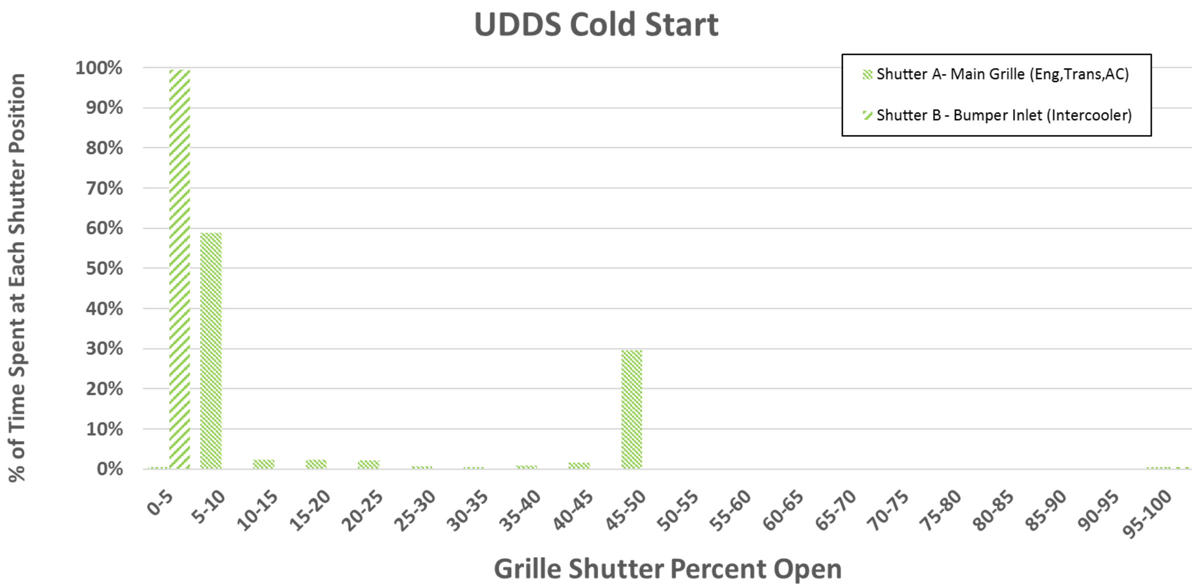

Figure 50: Histogram of Active Grille Shutter Operation on a UDDS Cold Start Test

Following the UDDS cold start test, the vehicle is keyed off, and soaked for 10 minutes. After which, the vehicle is restarted to complete the hot start UDDS cycle. The operation of the active grille shutter systems can be seen in Figure 51 for the hot start UDDS, with the corresponding histogram in Figure 52. The active grille shutter operation on the hot start UDDS is more dynamic compared to the cold start UDDS. The lower grille shutter is fully closed when the vehicle moves and fully open when the vehicle is stopped as long as the charge air cooler temperature is below 40° C. At 2,500 seconds into the cycle the charge air reached 40° C at which point the lower grille shutter is dynamically modulated between 0 percent and 50 percent opening when the vehicle is moving. Over the hot start UDDS cycle, the lower grille shutter is fully open for 17 percent of the cycle mainly while the vehicle is stopped. The lower grille shutter is fully closed about 50 percent of the time. The operation of the upper grille shutter is also more dynamic on the hot start UDDS. The upper grille is modulated between 10 percent to 30 percent while the vehicle is moving and open to 50 percent when the vehicle is stopped.

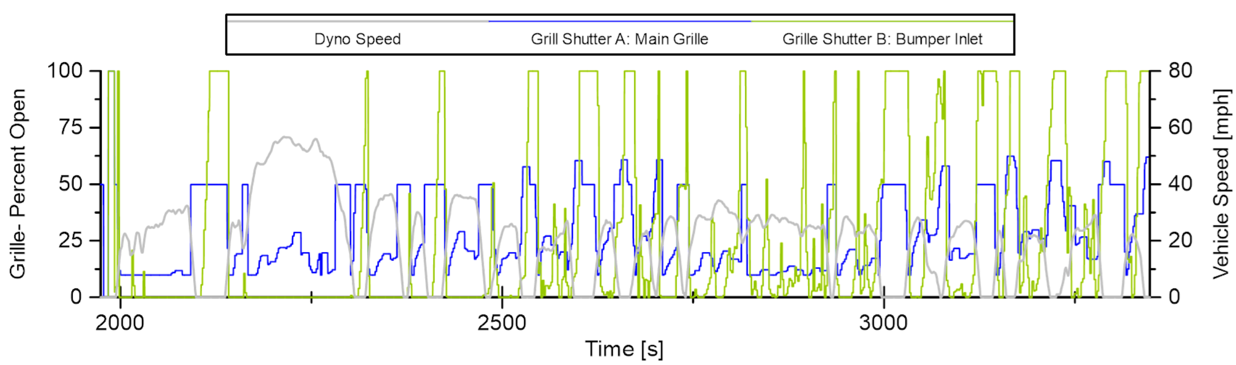

Figure 51: UDDS Hot Start Cycle Active Grille Shutter Commanded Operation

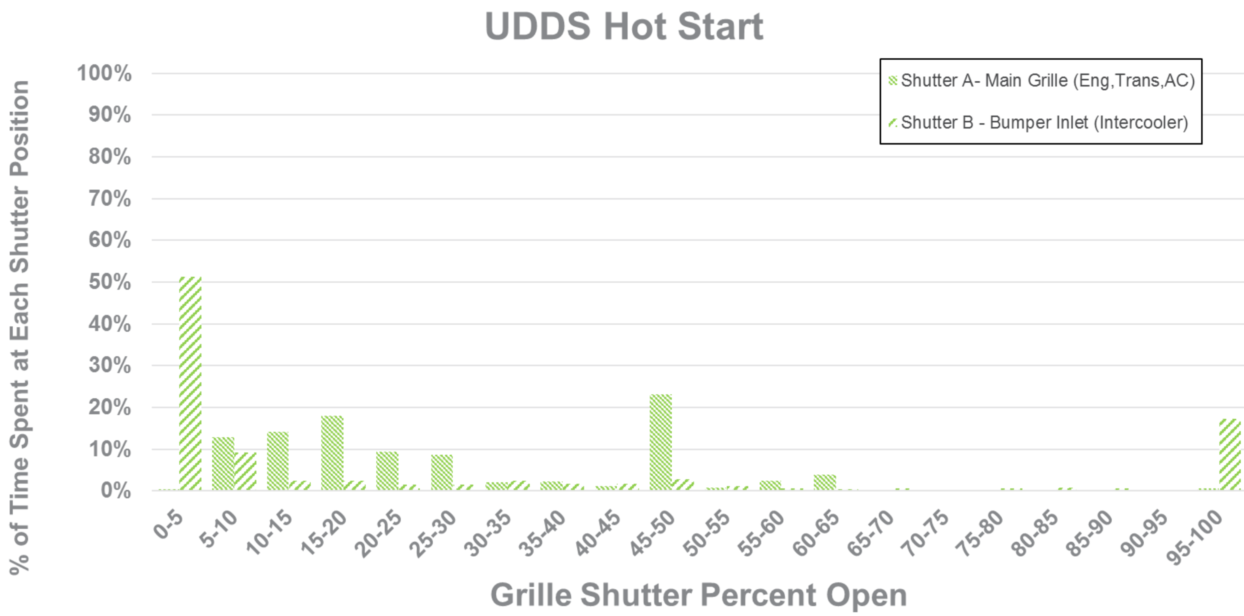

Figure 52: Active grille shutter operation on the UDDS Hot Start test

The aerodynamic benefits from the active grille shutter system would have a greater effect on the Highway cycle compared to the UDDS cycle. The active grille shutter operations on the Highway cycle are presented in Figure 53 and Figure 54. On the Highway cycle the lower grille shutter remained closed at all times with the exception of the large deceleration event in the middle of the cycle. The upper active grille shutter is modulated dynamically between 5 percent to 30 percent open, except for larger deceleration events where it opens to 50 percent (aerodynamics are unimportant for fuel consumption during braking).

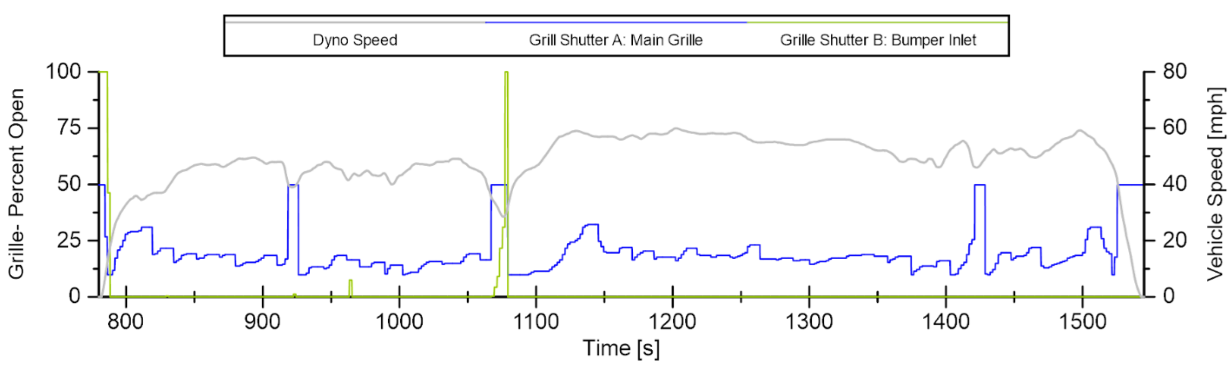

Figure 53: Highway Cycle Active Grille Shutter Commanded Operation

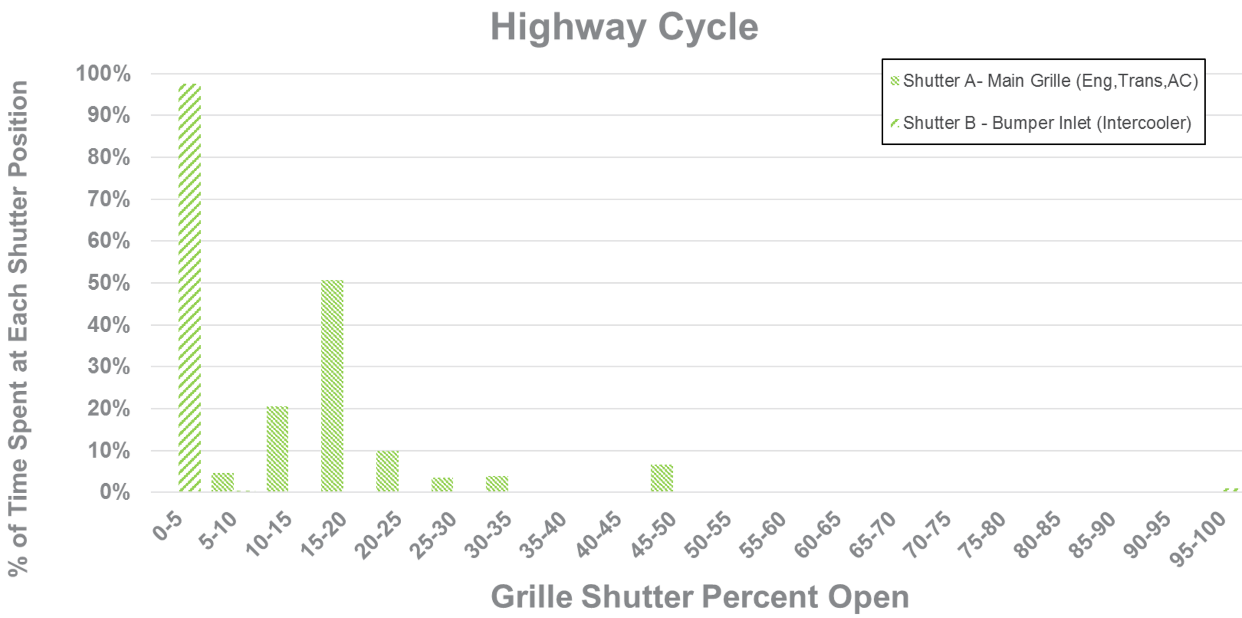

Figure 54: Active grille shutter operation on the HWY cycle

The Ford F-150 is tested at 20° F ambient temperature as well as 95° F with 850 W/m^2 solar load. On the cold start UDDS at 20° F, the upper grille shutter remains locked 30 percent open and the lower grille shutter is fully closed except for the self-test after a key cycle as can be seen in Figure 55. On the cold start UDDS at 95° F, the lower grille shutter is fully closed until the charge air reached 40° C at which point the lower grille shutter is modulated between fully closed and fully open. At 95° the upper grille shutter defaults to fully open and modulates between 60 percent to 100 percent open while the vehicle is moving on the UDDS cycle.

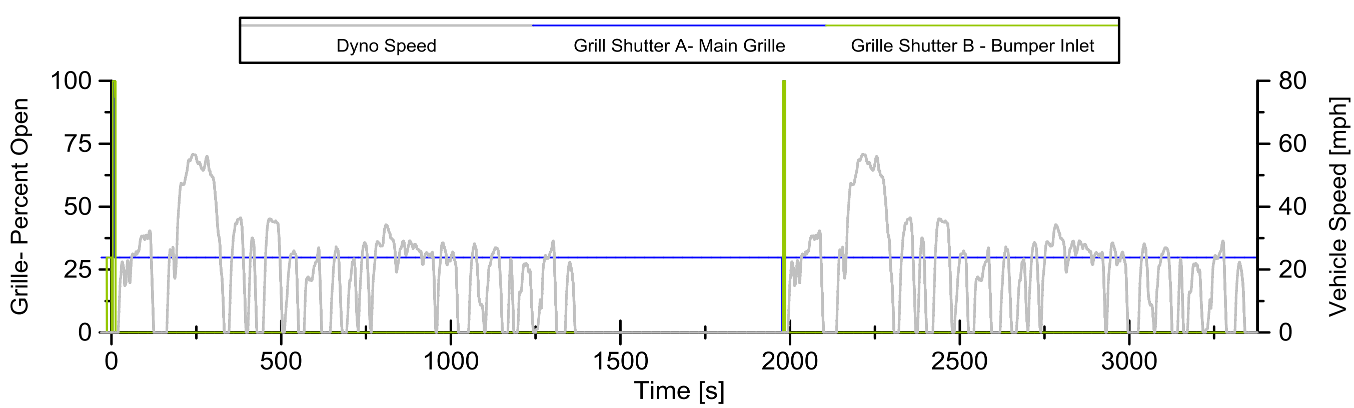

Figure 55: Active grille shutter operation on the UDDS at 20° F

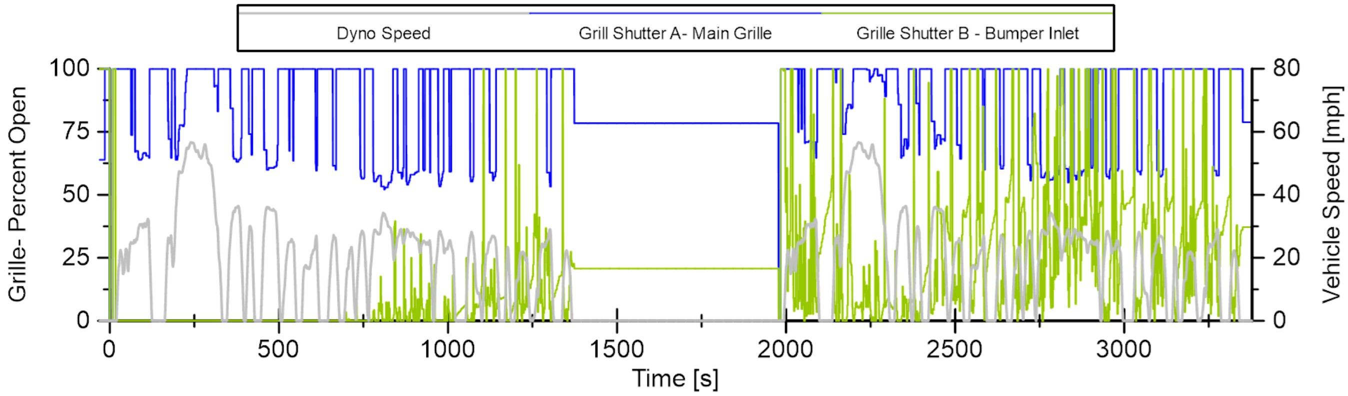

Figure 56: Active grille shutter operation on the UDDS test at 95° F with solar emulation

6. Public access to the data

The 10Hz data files used for the analysis in this report are available at www.anl.gov/d3.

If the data is not available at that location please e-mail d3@anl.gov to notify Argonne.

7. Conclusion

The vehicle benchmarked in this report is a 2017 Ford F-150 with the 3.5 liter V6 EcoBoost engine coupled to a newly introduced 10-speed automatic transmission. This particular powertrain configuration provides favorable fuel economy results while providing significant vehicle performance. The focus of the benchmark is to understand the usage of the critical powertrain components and their impact on the vehicle efficiency. The vehicle is instrumented to provide data to support the model development and validation in conjunction to providing the data for the analysis in the report. The vehicle is tested on a chassis dynamometer in the controlled laboratory environment across a range of certification tests. Further tests are performed to map the different powertrain components.

The analysis in this report started by providing the fuel economy and efficiency results on the certification drive cycles along with of component operation on those tests. The maximum performance envelops of the powertrain were presented. A section was devoted to specific powertrain characterization. Some off-cycle testing, such as the thermal testing of 5-cycle label fuel economy and octane fuel testing, was explored. Finally, some vehicle specific test, such as the impact of different drive modes on the transmission operation, increased payload and active grille shutters, close out the analysis.

8. Acknowledgements:

This work has been funded by NHTSA. Special thanks go to Seiar Zia for his technical guidance. The authors appreciate the opportunity to perform the laboratory testing and the data analysis of this vehicle.

The authors are also very grateful to Professor Douglas Nelson (Virginia Tech), Professor Giorgio Rizzoni (Ohio State University) and Professor David Foster (University of Wisconsin) for their peer-review of the work. Their diligent and detail oriented work improved the quality of the analysis and the reporting.

Finally, the authors want to acknowledge that this work would not have been possible without the entire team at the Advanced Powertrain Research Facility. Special thanks go to Mike Kern, Geoffrey Amann, and George Tsigolis.

Appendix A: Certification fuel specifications

haltermannsolutions

Telephone: (800) 969-2542

Product Information

FAX: (281) 457-1469

PRODUCT: EPA TIER II EEE FEDERAL REGISTER

PRODUCT CODE: HF0437

Batch No.: EK2821GP10

Tank No.: Drums

Date: 11/29/2016

TEST	METHOD	UNITS	HALTERMANN Specs			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86[2]	°F	75		95	89
5%		°F				110
10%		°F	120		135	124
20%		°F				142
30%		°F				163
40%		°F				191
50%		°F	200		230	217
60%		°F				231
70%		°F				242
80%		°F				260
90%		°F	305		325	317
95%		°F				339
Distillation - EP		°F			415	395
Recovery		vol %		Report		97.2
Residue		vol %		Report		1.1
Loss		vol %		Report		1.7
Gravity	ASTM D4052[1]	°API	58.7		61.2	59.4
Density	ASTM D4052[1]	kg/l	0.734		0.744	0.741
Reid Vapor Pressure	ASTM D5191[1]	psi	8.7		9.2	9.1
Carbon	ASTM D3343[2]	wt fraction		Report		0.8648
Carbon	ASTM D5291[2]	wt fraction		Report		0.8678
Hydrogen	ASTM D5291[2]	wt fraction		Report		0.1322
Hydrogen/Carbon ratio	ASTM D5291[2]	mole/mole		Report		1.815
Stoichiometric Air/Fuel Ratio				Report		14.533
Oxygen	ASTM D4815[2]	wt %			0.05	None Detected
Sulfur	ASTM D5453[2]	wt %	0.0025		0.0035	0.0034
Lead	ASTM D3237[2]	g/gal			0.01	None Detected
Phosphorous	ASTM D3231[2]	g/gal			0.005	None Detected
Silicon	ASTM 5184	mg/kg			4	None Detected
Composition, aromatics	ASTM D1319[2]	vol %			35	28
Composition, olefins	ASTM D1319[2]	vol %			10	1
Composition, saturates	ASTM D1319[2]	vol %		Report		72
Particulate matter	ASTM D5452[2]	mg/l			1	0
Oxidation Stability	ASTM D525[2]	minutes	240			1000+
Copper Corrosion	ASTM D130[2]				1	1a
Gum content, washed	ASTM D381[2]	mg/100mls			5	0.5
Fuel Economy Numerator/C Density	ASTM D5291[2]		2401		2441	2429
C Factor	ASTM D5291[2]			Report		0.9982
Research Octane Number	ASTM D2699[2]		96.0			96.5
Motor Octane Number	ASTM D2700[2]			Report		88.4
Sensitivity	D2699/2700[2]		7.5			8.1
Net Heating Value, btu/lb	ASTM D3338[1]	btu/lb		Report		18485
Net Heating Value, btu/lb	ASTM D240[2]	btu/lb		Report		18659
Color	VISUAL			Report		Undyed

APPROVED BY: [signature]

[1] Haltermann Solutions is accredited to ISO/IEC 17025 by A2LA for the tests referred to with this footnote.
[2] Tested by ISO/IEC 17025 accredited subcontractor.

Gasoline and diesel specialty fuels from Haltermann Solutions shall remain within specifications for a minimum of 3 years from the date on the COA so long as the drums are sealed and unopened in their original container and stored in a warehouse at ambient conditions. Specialty fuels that have been intentionally modified for aggressive or corrosive properties are excluded.

Main Lab, 15600 West Hardy, Houston TX 77060 haltermannsolutions

Telephone: (800) 969-2542

Certificate of Analysis

FAX: (281) 457-1469

PRODUCT: EPA TIER II EEE FEDERAL REGISTER

Batch No.: FD2421GP10

PRODUCT CODE: HF0437

Tank No.: Drums

Date: 4/26/2017

TEST	METHOD	UNITS	HALTERMANN Specs MIN	TARGET	MAX	RESULTS
Distillation - IBP	ASTM D86[2]	°F	75		95	88
5%		°F				110
10%		°F	120		135	123
20%		°F				141
30%		°F				161
40%		°F				188
50%		°F	200		230	216
60%		°F				230
70%		°F				241
80%		°F				258
90%		°F	305		325	316
95%		°F				340
Distillation - EP		°F			415	402
Recovery		vol %		Report		97.4
Residue		vol %		Report		1.0
Loss		vol %		Report		1.6
Gravity	ASTM D4052[1]	°API	58.7		61.2	59.0
Density	ASTM D4052[1]	kg/l	0.734		0.744	0.743
Reid Vapor Pressure	ASTM D5191[1]	psi	8.7		9.2	9.1
Carbon	ASTM D3343[2]	wt fraction		Report		0.8656
Carbon	ASTM D5291[2]	wt fraction		Report		0.8616
Hydrogen	ASTM D5291[2]	wt fraction		Report		0.1384
Hydrogen/Carbon ratio	ASTM D5291[2]	mole/mole		Report		1.914
Stoichiometric Air/Fuel Ratio				Report		14.674
Oxygen	ASTM D4815[2]	wt %			0.05	None Detected
Sulfur	ASTM D5453[2]	wt %	0.0025		0.0035	0.0029
Lead	ASTM D3237[2]	g/gal			0.01	None Detected
Phosphorous	ASTM D3231[2]	g/gal			0.005	None Detected
Silicon	ASTM 5184	mg/kg			4	None Detected
Composition, aromatics	ASTM D1319[2]	vol %			35	29
Composition, olefins	ASTM D1319[2]	vol %			10	0
Composition, saturates	ASTM D1319[2]	vol %		Report		71
Particulate matter	ASTM D5452[2]	mg/l			1	0
Oxidation Stability	ASTM D525[2]	minutes	240			1000+
Copper Corrosion	ASTM D130[2]				1	1a
Gum content, washed	ASTM D381[2]	mg/100mls			5	<0.5
Fuel Economy Numerator/C Density	ASTM D5291[2]		2401		2441	2418
C Factor	ASTM D5291[2]			Report		0.9959
Research Octane Number	ASTM D2699[2]		96.0			97.8
Motor Octane Number	ASTM D2700[2]			Report		88.7
Sensitivity	D2699/2700[2]		7.5			9.1
Net Heating Value, btu/lb	ASTM D3338[1]	btu/lb		Report		18466
Net Heating Value, btu/lb	ASTM D240[2]	btu/lb		Report		18539
Color	VISUAL			Report		Undyed

APPROVED BY: [signature]

[1] Haltermann Solutions is accredited to ISO/IEC 17025 by A2LA for the tests referred to with this footnote.

[2] Tested by ISO/IEC 17025 accredited subcontractor.

Gasoline and diesel specialty fuels from Haltermann Solutions shall remain within specifications for a minimum of 3 years from the date on the COA so long as the drums are sealed and unopened in their original container and stored in a warehouse at ambient conditions. Specialty fuels that have been intentionally modified for aggressive or corrosive properties are excluded.

haltermannsolutions

Product Information

Telephone: (800) 969-2542 FAX: (281) 457-1469

PRODUCT: EPA Tier 3 EEE Emission Certification Fuel, General Testing - Regular

Specification No.: HF2021

Batch No.: EH1021LT10-HW

Tank No.: Drums

Date: 9/26/2016

TEST	METHOD	UNITS	SPECIFICATIONS MIN	SPECIFICATIONS TARGET	SPECIFICATIONS MAX	RESULTS
Distillation - IBP	ASTM D86[2]	°F				94.8
5%		°F				123.0
10%		°F	120		140	130.6
20%		°F				140.0
30%		°F				147.5
40%		°F				154.1
50%		°F	190		210	200.2
60%		°F				229.3
70%		°F				253.1
80%		°F				278.4
90%		°F	315		335	318.0
95%		°F				339.4
Distillation - EP		°F	380		420	381.1
Recovery		ml		Report		98.1
Residue		ml			2.0	0.8
Loss		ml		Report		1.2
Gravity @ 60° F	ASTM D4052[1]	°API		Report		58.30
Density @ 15.56° C	ASTM D4052[1]	-		Report		0.7447
Reid Vapor Pressure EPA Equation	ASTM D5191[1]	psi	8.7		9.2	9.2
Carbon	ASTM D5291[2]	wt fraction		Report		0.8263
Hydrogen	ASTM D5291[2]	wt fraction		Report		0.1366
Hydrogen/Carbon ratio	ASTM D5291[2]	mole/mole		Report		1.970
Oxygen	ASTM D4815[2]	wt %		Report		3.71
Ethanol content	ASTM D5599-00	vol %	9.6		10.0	9.8
Total oxygentates other than ethanol	ASTM D4815[2]	vol %			0.1	None Detected
Sulfur	ASTM D5453[2]	mg/kg	8.0		11.0	10.2
Phosphorus	ASTM D3231[2]	g/l			0.0013	None Detected
Lead	ASTM D3237[2]	g/l			0.0026	None Detected
Composition, aromatics	ASTM D5769[2]	vol %	21.0		25.0	22.6
C6 aromatics (benzene)	ASTM D5769[2]	vol %	0.5		0.7	0.5
C7 aromatics (toluene)	ASTM D5769[2]	vol %	5.2		6.4	5.9
C8 aromatics	ASTM D5769[2]	vol %	5.2		6.4	5.9
C9 aromatics	ASTM D5769[2]	vol %	5.2		6.4	5.7
C10+ aromatics	ASTM D5769[2]	vol %	4.4		5.6	4.7
Composition, olefins	ASTM D6550	wt %	4.0		10.0	5.2
Oxidation Stability	ASTM D525[2]	minutes	1000			1000+
Copper Corrosion	ASTM D130[2]				1	1a
Existent gum, washed	ASTM D381[2]	mg/100mls			3.0	1.0
Existent gum, unwashed	ASTM D381[2]	mg/100mls		Report		1.0
Research Octane Number	ASTM D2699[2]			Report		91.8
Motor Octane Number	ASTM D2700[2]			Report		84.2
R+M/2	D2699/2700[2]		87.0		88.4	88.0
Sensitivity	D2699/2700[2]		7.5			7.6
Net Heat of Combustion	ASTM D240[2]	BTU/lb		Report		17972

APPROVED BY: [signature]

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Appendix B: Ford F-150 3.5L V6 EcoBoost Test Signals

The following signals were collected at 10Hz for each test.

B.1. Facility and Vehicle Signal list

Facility, dyno and cell data	Analog data from vehicle	Modal tailpipe emissions
DAQ_Time[s]	DAQ_Time[s]_RawVehicleDAQ	AMA_Dilute_THC[mg/s]
Time[s]_RawFacilities	Time[s]_RawVehicleDAQ	AMA_Dilute_CH4[mg/s]
Dyno_Spd[mph]	Engine_Oil_Dipstick_Temp[C]	AMA_Dilute_NOx[mg/s]
Dyno_TractiveForce[N]	Radiator_Air_Outlet_Temp[C]	AMA_Dilute_COlow[mg/s]
Dyno_LoadCell[N]	Engine_Bay_Temp[C]	AMA_Dilute_COmid[mg/s]
Distance[mi]	Cabin_Temp[C]	AMA_Dilute_CO2[mg/s]
Dyno_Spd_Front[mph]	Cabin_Upper_Vent_Temp[C]	AMA_Dilute_HFID[mg/s]
Dyno_TractiveForce_Front[N]	Cabin_Lower_Vent_Temp[C]	AMA_Dilute_NMHC[mg/s]
Dyno_LoadCell_Front[N]	Solar_Array_Ind_Temp[C]	AMA_Dilute_Fuel[g/s]
Dyno_Spd_Rear[mph]	Eng_FuelFlow_Direct2[gps]	
Dyno_LoadCell_Rear[N]	12VBatt_Volt_Hioki_U1[V]	
Dyno_TractiveForce_Rear[N]	12VBatt_Curr_Hioki_I1[A]	
DilAir_RH[%]	12VBatt_Power_Hioki_P1[W]	
Tailpipe_Press[inH2O]	Alternator_Curr_Hioki_I2[A]	
Cell_Temp[C]	Alternator_Power_Hioki_P2[W]	
Cell_RH[%]	12VBatt_Curr_Hi_Hioki_I3[A]	
Cell_Press[inHg]	12VBatt_Power_Hi_Hioki_P3[W]	
Tire_Front_Temp[C]	Eng_FuelFlow_Direct[ccps]	
Tire_Rear_Temp[C]	Eng_Fuel_Temp_Direct[C]	
Drive_Schedule_Time[s]		
Drive_Trace_Schedule[mph]		
Exhaust_Bag		

B.2. CAN Signal list

Broad cast data	Scantool data stream 1	Scantool data stream 2
Eng_load_PCM[per]	Trans_gear_CAN[]	Trans_gear_CAN[]_Scantool
Eng_speed_PCM[rpm]	Trans_shift_inpro-gress_CAN[]	Trans_shift_inpro-gress_CAN[]_Scantool
Veh_speed_PCM[mph]	Trans_PRNDL_pos_CAN[]	Trans_PRNDL_pos_CAN[]_Scantool
Eng_cylinder_head_temperature_PCM[C]	Vehi-cle_drive_mode_CAN[]	Vehi-cle_drive_mode_CAN[]_Scantool
Veh_barometric_press_PCM[kPa]	Pedal_ac-cel_pos_CAN[per]	Pedal_ac-cel_pos_CAN[per]_Scantool
Eng_misfire_detected_PCM[]	Trans_gear_de-sired_CAN[]	Eng_speed_CAN[rpm]

Broad cast data	Scantool data stream 1	Scantool data stream 2
Eng_knock_sensor1_PCM[]	Trans_gear_engaged_CAN[]	Trans_gear_desired_CAN[]_Scantool
Eng_knock_sensor2_PCM[]	Veh_ignition_switch_position_CAN[]	Trans_gear_engaged_CAN[]_Scantool
Eng_spark_advance_PCM[deg]	Pedal_brake_pos_CAN[]	Veh_ignition_switch_position_CAN[]_Scantool
Veh_ambient_air_temp_PCM[C]	Veh_steering_wheel_pos_CAN[]	Pedal_brake_pos_CAN[]_Scantool
Eng_o2s11_active_status_PCM[]	Veh_4WD_engaged_CAN[]	Veh_steering_wheel_pos_CAN[]_Scantool
Eng_air_fuel_ratio_commanded_bank1_PCM[]	Veh_wheel_spd_R1_CAN[]	Pedal_accel_position_PCM[per]
Eng_equivalance_ratio_o2s11_PCM[lambda]	Veh_wheel_spd_R2_CAN[]	Trans_in_gear_PCM[]
Eng_evap_canister_purge_valve_dutycycle_PCM[per]	Veh_wheel_spd_F1_CAN[]	Veh_4WD_engaged_CAN[]_Scantool
Eng_evap_canister_vent_valve_dutycycle_PCM[per]	Veh_wheel_spd_F2_CAN[]	
Eng_evap_commanded_purge_PCM[per]	HVAC_AC_compressor_engaged_CAN[]	
Eng_evap_system_monitor_evaluated_PCM[]	Veh_traction_control_off_CAN[]	
Eng_egr_evaluated_PCM[]	Eng_start_stop_active_CAN[]	
Eng_intake_air_temp_PCM[C]	Eng_start_stop_state_CAN[]	
Eng_load_absolute_PCM[per]		
Eng_misfire_count_PCM[]		
Eng_generator_current_corrected_PCM[A]		
Brake_pressure_applied_PCM[]		
Brake_pedal_applied_PCM[]		
Eng_throttle_electronic_control_actual_PCM[deg]		
Eng_throttle_position_PCM[per]		
Eng_rear_O2_fuel_trim_bank1_PCM[per]		
Eng_knock_control_spark_adjustment_PCM[deg]		
Eng_learned_relative_octane_adjustment_PCM[per]		
Eng_manifold_absolute_pressure_PCM[kPa]		
Eng_adaptive_fuel_table_status_PCM[]		
Eng_charge_air_cooler_temp_PCM[C]		
Eng_fuel_rail_press_PCM[kPa]		
Eng_long_term_fuel_trim_bank1_PCM[per]		
Eng_short_term_fuel_trim_bank1_PCM[per]		
Eng_measured_boost_at_throttle_inlet_press_sensor_PCM[psi]		
Eng_camshaft_exhaust_position_actual_bank1_PCM[deg]		
Eng_camshaft_intake_position_actual_bank1_PCM[deg]		
Eng_camshaft_intake_position_actual_bank2_PCM[deg]		

Broad cast data	Scantool data stream 1	Scantool data stream 2
Eng_camshaft_exhaust_position_actual_bank2_PCM[deg]		
Eng_short_term_fuel_trim_bank2_PCM[per]		
Eng_long_term_fuel_trim_bank2_PCM[per]		
Fuel_pump_flow_rate_PCM[per]		
HVAC_air_conditioning_compressor_commanded_state_PCM[]		
HVAC_air_conditioning_request_signal_PCM[]		
Eng_charge_air_cooler_cooling_fan_speed_commanded_PCM[per]		
Eng_oil_pressure_PCM[kPa]		
Eng_air_fuel_ratio_commanded_bank2_PCM[]		
Eng_equivalance_ratio_o2s21_PCM[lambda]		
HVAC_air_conditioning_variable_comp_current_PCM[A]		
Eng_cooling_fan_speed_desired_PCM[per]		
Fuel_level_PCM[per]		
Eng_electronic_variable_air_compressor_PCM[per]		
HVAC_AC_pressure_PCM[kPa]		
Eng_fuel_percent_to_DI_commanded_PCM[per]		
Eng_fuel_volume_control_valve_PCM[per]]		
Eng_gen_current_max_PCM[A]		
Eng_gen_monitor_PCM[per]		
Eng_gen_desired_voltage_PCM[V]		
Grille_shutter_A_pos_commanded_PCM[per]		
Grillee_shutter_A_pos_inferred_PCM[per]		
Grillee_shutter_B_pos_commanded_PCM[per]		
Grillee_shutter_B_pos_measured_PCM[per]		
Eng_cyl_1_knock_perf_counter_PCM[]		
Eng_cyl_2_knock_perf_counter_PCM[]		
Eng_cyl_3_knock_perf_counter_PCM[]		
Eng_cyl_4_knock_perf_counter_PCM[]		
Eng_cyl_5_knock_perf_counter_PCM[]		
Eng_cyl_6_knock_perf_counter_PCM[]		
Eng_learned_knock_comb_performance_detection_rate_PCM[per]		
Eng_powertrain_drive_mode_actual_PCM[]		
Eng_speed_desired_PCM[rpm]		
Eng_start_stop_out_of_op_PCM[]		
Eng_boost_pressure_desired_PCM[kPa]		
Eng_throttle_position_relative_PCM[]		
Eng_torque_control_state_PCM[]		
Eng_VCT_sys_PCM[]		
Eng_wastegate_pos_sensor_A_position_corrected_PCM[per]		

Broad cast data	Scantool data stream 1	Scantool data stream 2
Eng_wastegate_pos_sensor_B_position_corrected_PCM[per]		
Eng_camshaft_exhaust_angle_desired_PCM[deg]		
Eng_camshaft_intake_angle_desired_PCM[deg]		
Trans_torque_converter_clutch_solenoid_press_TCM[kPa]		
Trans_torque_converter_slip_ratio_TCM[]		
Trans_torque_converter_slip_actual_TCM[rpm]		
Trans_torque_converter_slip_desired_TCM[rpm]		
Trans_line_pressure_control_TCM[kPa]		
Trans_gear_ratio_measured_TCM[]		
Trans_turbine_shaft_speed_raw_TCM[rpm]		
Trans_shift_time_cmd_to_10_TCM[s]		
Trans_gear_commanded_output_state_control_TCM[]		
Trans_line_pressure_desired_TCM[kPa]		
Trans_gear_engaged_output_state_control_TCM[]		
Trans_gear_commanded by_output_state_control_TCM[]		
Trans_intermediate_shaft_A_speed_raw_TCM[rpm]		
Trans_intermediate_shaft_B_speed_raw_TCM[rpm]		
Trans_output_shaft_speed_raw_TCM[rpm]		
Engine_speed_TCM[rpm]		
Trans_shift_time_10_to_90_TCM[s]		
Trans_shift_solenoid_pressure_A_TCM[kPa]		
Trans_shift_solenoid_pressure_B_TCM[kPa]		
Trans_shift_solenoid_pressure_C_TCM[kPa]		
Trans_shift_solenoid_pressure_D_TCM[kPa]		
Trans_shift_solenoid_pressure_E_TCM[kPa]		
Trans_shift_solenoid_pressure_F_TCM[kPa]		
Eng_start_stop_main_control_state_TCM[]		
Eng_start_stop_monitor_state_TCM[]		
Trans_fluid_temp_TCM[C]		
Veh_speed_high_res_TCM[kph]		
Veh_total_distance_TCM[km]		
Eng_fuel_low_side_press_PCM[kpa]		
Veh_4WD_L_engaged_CAN[]		
Veh_wheel_spd_R1_CAN[]_Scantool		
Veh_wheel_spd_R2_CAN[]_Scantool		
Veh_wheel_spd_F1_CAN[]_Scantool		
Veh_wheel_spd_F2_CAN[]_Scantool		
HVAC_AC_compressor_engaged_CAN[]_Scantool		

Appendix C: Summary of the tests performed

Test ID [#]	Cycle	Date	Test Cell Temp [C]	Test weight [lb]	Test fuel	Test mode	Cycle Distance [mi]	Cycle Fuel economy [mpg] (Emiss Bag)	Fuel Economy Modal [mpg]	Fuel Economy Scale [mpg]	Test Driver	APCtime	ASCR	ASC_d	ASC_t	CE_d	CE_t	DR	D_d	D_t	EER	ER	IWR
Day 0 Coastdowns, Channel Check and Prep																							
61704073	Hwyx3 w/ coastdowns, Ph 1	04/28/17	26	5250	EK2821GP10	4WD	10.22	26.4	26.2	25.43	MK	1573.16	109.64	8219.00	3920.59	44.32	33.86	32.25	40.62	30.72	-1.06	30.86	0.25
61704073	Hwyx3 w/ coastdowns, Ph 2	04/28/17	25	5250	EK2821GP10	4WD	10.22	28.2	27.9	27.50	MK	1573.16	109.64	8219.00	3920.59	44.32	33.86	32.25	40.62	30.72	-1.06	30.86	0.25
61704073	Hwyx3 w/ coastdowns, Ph 3	04/28/17	25	5250	EK2821GP10	4WD	10.22	28.7	28.4	27.49	MK	1573.16	109.64	8219.00	3920.59	44.32	33.86	32.25	40.62	30.72	-1.06	30.86	0.25
61704077	WOTs	04/28/17	24	5250	EK2821GP10	4WD	3.37	0.0	0.0	17.18	MK	35869.02	0.88	2300.08	2279.90	6.22	11.58	-23.25	3.37	4.39	-42.76	-46.24	0.45
61704078	Tip ins	04/28/17	24	5250	EK2821GP10	4WD	9.84	0.0	0.0	19.82	GA	17823.75	13.22	3796.04	3352.80	17.32	19.64	-4.02	9.84	10.26	-8.84	-11.82	0.42
Day 1, 2, 3: Testing with stability track disabling the idle stop system																							
Switch to 2WD with Dyno mode active																							
61705011	Hwyx3 w/ coastdowns, Ph 1	05/03/17	25	5250	EK2821GP10	2WD	10.24	32.1	32.1	30.95	GA	1573.51	88.91	7406.23	3920.61	43.18	33.86	32.96	40.84	30.72	-4.27	27.52	0.25
61705011	Hwyx3 w/ coastdowns, Ph 2	05/03/17	23	5250	EK2821GP10	2WD	10.25	32.9	32.9	31.90	GA	1573.51	88.91	7406.23	3920.61	43.18	33.86	32.96	40.84	30.72	-4.27	27.52	0.25
61705011	Hwyx3 w/ coastdowns, Ph 3	05/03/17	22	5250	EK2821GP10	2WD	10.24	33.1	32.9	31.94	GA	1573.51	88.91	7406.23	3920.61	43.18	33.86	32.96	40.84	30.72	-4.27	27.52	0.25
61705012	US06x2, Ph 1	05/03/17	24	5250	EK2821GP10	2WD	1.79	12.7	12.7		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705012	US06x2, Ph 2	05/03/17	28	5250	EK2821GP10	2WD	6.23	21.6	21.6		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705012	US06x2, Ph 1+2	05/03/17	**26**	5250	EK2821GP10	2WD	**8.02**	**18.71**	**18.71**		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705012	US06x2, Ph 3	05/03/17	23	5250	EK2821GP10	2WD	1.77	12.9	12.8		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705012	US06x2, Ph 4	05/03/17	26	5250	EK2821GP10	2WD	6.23	21.8	21.6		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705012	**US06x2, Ph 3+4**	05/03/17	**25**	5250	EK2821GP10	2WD	**8.01**	**18.88**	**18.78**		MK	10691.30	-0.48	7164.96	7199.45	28.79	28.92	0.08	16.03	16.01	-0.51	-0.43	0.43
61705013	UDDS #1, Ph 1	05/03/17	21	5250	EK2821GP10	2WD	3.60	23.9	23.9	23.18	GA	2180.83	0.63	5499.81	5465.59	8.11	7.97	0.38	7.48	7.45	1.38	1.79	0.63
61705013	UDDS #2, Ph 2	05/03/17	21	5250	EK2821GP10	2WD	3.88	22.0	21.9	21.54	GA	2180.83	0.63	5499.81	5465.59	8.11	7.97	0.38	7.48	7.45	1.38	1.79	0.63
Day 4																							
61705016	Hwyx2, Ph 1	05/04/17	24	5250	EK2821GP10	2WD	10.25	31.8	31.7	31.26	GA	2355.12	1.11	2642.83	2613.73	22.60	22.60	-0.01	20.51	20.51	0.01	0.00	0.25
61705016	Hwyx2, Ph 2	05/04/17	23	5250	EK2821GP10	2WD	10.26	33.1	32.9	32.27	GA	2355.12	1.11	2642.83	2613.73	22.60	22.60	-0.01	20.51	20.51	0.01	0.00	0.25
61705017	US06x2, Ph 1+2	05/04/17	**23**	5250	EK2821GP10	2WD	**8.03**	**19.23**	**19.20**	**18.54**	GA	10691.68	-1.84	7067.16	7199.48	28.87	28.92	0.22	16.05	16.01	-0.39	-0.17	0.43
61705017	**US06x2, Ph 3+4**	05/04/17	**24**	5250	EK2821GP10	2WD	**8.02**	**19.08**	**19.04**	**18.50**	GA	10691.68	-1.84	7067.16	7199.48	28.87	28.92	0.22	16.05	16.01	-0.39	-0.17	0.43
61705018	Steady State Stairs	05/04/17	23	5250	EK2821GP10	2WD	11.55	27.2	27.1	26.60	MK	877.79	26.25	903.02	715.26	14.54	14.64	-0.05	11.55	11.56	-0.65	-0.69	0.11
61705019	UDDS #1, Ph 1	05/04/17	22	5250	EK2821GP10	2WD	3.61	24.1	24.1	23.22	GA	2180.57	1.47	5545.90	5465.58	8.11	7.97	0.44	7.48	7.45	1.30	1.76	0.63
61705019	UDDS #2, Ph 2	05/04/17	21	5250	EK2821GP10	2WD	3.87	22.4	22.3	22.01	GA	2180.57	1.47	5545.90	5465.58	8.11	7.97	0.44	7.48	7.45	1.30	1.76	0.63
Day 5																							
61705020	UDDS #1, Ph 1	05/05/17	23	5250	EK2821GP10	2WD	3.59	19.6	19.5	18.96	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705020	UDDS #1, Ph 2	05/05/17	21	5250	EK2821GP10	2WD	3.86	21.8	21.8	21.82	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705020	**UDDS #1, Ph 1+2**	05/05/17	**22**	5250	EK2821GP10	2WD	**7.44**	**20.70**	**20.66**	**20.34**	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705020	UDDS #2, Ph 3	05/05/17	23	5250	EK2821GP10	2WD	3.59	23.9	23.8	23.22	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705020	UDDS #2, Ph 4	05/05/17	21	5250	EK2821GP10	2WD	3.85	22.1	21.9	21.88	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705020	**UDDS #2, Ph 3+4**	05/05/17	**22**	5250	EK2821GP10	2WD	**7.44**	**22.93**	**22.74**	**22.51**	MK	1824.76	1.44	11089.05	10931.19	16.14	15.93	-0.10	14.89	14.90	1.40	1.32	0.63
61705021	UDDS #1, Ph 1	05/05/17	24	5250	EK2821GP10	2WD	3.60	24.1	24.1	23.33	GA	2180.86	0.11	5471.71	5465.58	8.04	7.97	0.44	7.48	7.45	0.51	0.95	0.63
61705021	UDDS #1, Ph 2	05/05/17	21	5250	EK2821GP10	2WD	3.88	22.2	22.3	21.99	GA	2180.86	0.11	5471.71	5465.58	8.04	7.97	0.44	7.48	7.45	0.51	0.95	0.63
61705021	**UDDS #1, Ph 1+2**	05/05/17	**22**	5250	EK2821GP10	2WD	**7.48**	**23.09**	**23.11**	**22.61**	GA	2180.86	0.11	5471.71	5465.58	8.04	7.97	0.44	7.48	7.45	0.51	0.95	0.63
61705022	Hwyx2, Ph 1	05/05/17	25	5250	EK2821GP10	2WD	10.25	32.7	32.5	31.59	GA	2355.10	1.73	2658.90	2613.73	22.60	22.60	0.00	20.51	20.51	0.02	0.02	0.25
61705022	Hwyx2, Ph 2	05/05/17	23	5250	EK2821GP10	2WD	10.26	33.0	33.0	32.17	GA	2355.10	1.73	2658.90	2613.73	22.60	22.60	0.00	20.51	20.51	0.02	0.02	0.25
61705023	US06x2, Ph 1	05/05/17	22	5250	EK2821GP10	2WD	1.79	12.6	12.5	12.08	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705023	US06x2, Ph 2	05/05/17	26	5250	EK2821GP10	2WD	6.24	22.3	22.2	21.54	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705023	US06x2, Ph 1+2	05/05/17	**24**	5250	EK2821GP10	2WD	**8.03**	**19.03**	**18.95**	**18.34**	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705023	US06x2, Ph 3	05/05/17	23	5250	EK2821GP10	2WD	1.78	12.6	12.5	12.17	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705023	US06x2, Ph 4	05/05/17	25	5250	EK2821GP10	2WD	6.24	22.3	22.2	21.61	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705023	**US06x2, Ph 3+4**	05/05/17	**24**	5250	EK2821GP10	2WD	**8.02**	**19.07**	**18.97**	**18.45**	GA	10714.18	-2.00	7056.79	7201.06	28.90	28.92	0.21	16.05	16.01	-0.29	-0.08	0.44
61705024	UDDS #1, Ph 1	05/05/17	22	5250	EK2821GP10	2WD	7.47	23.2	23.1	22.80	GA	2180.63	0.50	5492.76	5465.57	8.04	7.97	0.26	7.47	7.45	0.67	0.94	0.63
61705024	UDDS #2, Ph 2	05/05/17	NaN	5250	EK2821GP10	2WD	HANNEL N	0.0	0.0	0.00	GA	2180.63	0.50	5492.76	5465.57	8.04	7.97	0.26	7.47	7.45	0.67	0.94	0.63

Day 6																							
61705025	Cold Start Idle Test		22	5250	EK2821GP10	2WD	0.00			0.00	KS	0.00	NaN	0.00	0.00	0.00	0.00	NaN	0.00	0.00	NaN	NaN	NaN
61705026	SSS warmup with robot		25	5250	EK2821GP10	2WD	9.19			32.95	Robot	231.71	14.02	560.70	491.74	11.71	11.68	0.13	10.00	9.98	0.16	0.29	0.06
61705027	Transmission mapping		-31	5250	EK2821GP10	4WD	38.98			22.99	Robot	0.00	Inf	11699.24	0.00	57.46	0.00	Inf	38.98	0.00	NaN	Inf	NaN
Day 7																							
61705028	Transmission mapping		-37	5250	EK2821GP10	2WD	28.75			14.14	Robot	0.00	Inf	1769.63	0.00	29.45	0.00	Inf	28.75	0.00	NaN	Inf	NaN
Day 8																							
61705029	LA92x2, Ph 1		23	5250	EK2821GP10	2WD	9.83			18.32	Robot	4535.27	-1.87	14291.42	14564.20	28.19	28.10	0.12	19.66	19.63	0.20	0.32	0.61
61705029	LA92x2, Ph 2		22	5250	EK2821GP10	2WD	9.83			19.99	Robot	4535.27	-1.87	14291.42	14564.20	28.19	28.10	0.12	19.66	19.63	0.20	0.32	0.61
61705030	UDDS, 10000#, norm mode		23	10000	EK2821GP10	2WD	7.47			15.95	Robot	3786.55	0.46	5490.90	5465.55	12.35	12.28	0.26	7.47	7.45	0.32	0.58	0.78
Refuel with new batch of tier 3 certification fuel																							
61705031	UDDS, 10000#, tow mode		23	10000	FD2421GP10	2WD	7.47			14.40	Robot	3786.81	0.17	5474.61	5465.57	12.34	12.28	0.27	7.47	7.45	0.23	0.50	0.78
61705032	US06x4, Ph 1, prep		26	5250	FD2421GP10	2WD	8.02			12.77	Robot	10589.21	-2.31	14067.62	14400.59	57.53	57.83	0.13	32.07	32.03	-0.66	-0.53	0.44
61705032	US06x4, Ph2, 10000#		26	5250	FD2421GP10	2WD	8.02			16.03	Robot	10589.21	-2.31	14067.62	14400.59	57.53	57.83	0.13	32.07	32.03	-0.66	-0.53	0.44
61705032	US06x4, Ph 3, 5250#, tow mode		27	5250	FD2421GP10	2WD	8.02			18.33	Robot	10589.21	-2.31	14067.62	14400.59	57.53	57.83	0.13	32.07	32.03	-0.66	-0.53	0.44
61705032	US06x4, Ph 4, 5250#, sport mode		27	5250	FD2421GP10	2WD	8.02			18.13	Robot	10589.21	-2.31	14067.62	14400.59	57.53	57.83	0.13	32.07	32.03	-0.66	-0.53	0.44
61705033	SSSx3, 0% grade, normal mode		25	5250	FD2421GP10	2WD	6.23			24.12	Robot	1644.44	33.01	2854.07	2145.79	25.27	24.99	0.12	18.69	18.67	0.99	1.12	0.19
61705033	SSSx3, 0% grade, tow mode		25	5250	FD2421GP10	2WD	6.23			23.33	Robot	1644.44	33.01	2854.07	2145.79	25.27	24.99	0.12	18.69	18.67	0.99	1.12	0.19
61705033	SSSx3, 0% grade, sport mode		25	5250	FD2421GP10	2WD	6.23			23.24	Robot	1644.44	33.01	2854.07	2145.79	25.27	24.99	0.12	18.69	18.67	0.99	1.12	0.19
61705034	Transmission & enigine mapping , 4WD		22	5250	FD2421GP10	2WD	2.14			6.39	KS	0.00	Inf	383.18	0.00	0.79	0.00	Inf	2.14	0.00	NaN	Inf	NaN
Day 9, 10, 11: Facility maintenance																							
61706001	UDDSx1, 1 bag	6/1/2017	21	5250	FD2421GP10	2WD	7.48	20.8	20.7	20.57	GA	2180.91	0.58	5497.57	5465.62	8.02	7.97	0.35	7.48	7.45	0.34	0.69	0.63
Day 12																							
61706002	UDDSx2, 4 bag, ph1	06/02/17	24	5250	FD2421GP10	2WD	3.59	19.5	19.5	18.98	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706002	UDDSx2, 4 bag, ph2	06/02/17	22	5250	FD2421GP10	2WD	3.85	22.0	21.7	21.91	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706002	UDDSx2, 4 bag, ph1+2	06/02/17	**23**	5250	FD2421GP10	2WD	**7.45**	**20.75**	**20.58**	**20.39**	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706002	UDDSx2, 4 bag, ph3	06/02/17	23	5250	FD2421GP10	2WD	3.61	23.8	23.8	23.34	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706002	UDDSx2, 4 bag, ph4	06/02/17	22	5250	FD2421GP10	2WD	3.89	22.1	21.9	22.05	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706002	UDDSx2, 4 bag, ph3+4	06/02/17	**23**	5250	FD2421GP10	2WD	**7.50**	**22.88**	**22.79**	**22.65**	MK/GA	1824.56	0.97	11037.46	10931.15	16.13	15.93	0.33	14.95	14.90	0.90	1.24	0.63
61706003	UDDSx1, 2 bag, ph1	06/02/17	24	5250	FD2421GP10	2WD	3.61	24.0	24.1	22.96	GA	2180.67	0.47	5491.52	5465.58	8.05	7.97	0.73	7.50	7.45	0.27	1.00	0.63
61706003	UDDSx1, 2 bag, ph2	06/02/17	22	5250	FD2421GP10	2WD	3.89	22.7	22.5	22.21	GA	2180.67	0.47	5491.52	5465.58	8.05	7.97	0.73	7.50	7.45	0.27	1.00	0.63
61706004	HWYx2, 2 bag, ph1	06/02/17	25	5250	FD2421GP10	2WD	10.24	32.6	32.7	31.48	MK	2355.01	0.82	2635.28	2613.72	22.51	22.60	-0.19	20.48	20.51	-0.18	-0.37	0.25
61706004	HWYx2, 2 bag, ph2	06/02/17	25	5250	FD2421GP10	2WD	10.24	32.9	33.1	32.07	MK	2355.01	0.82	2635.28	2613.72	22.51	22.60	-0.19	20.48	20.51	-0.18	-0.37	0.25
61706005	US06x2, 4 bag, ph1	06/02/17	23	5250	FD2421GP10	2WD	1.79	12.6	12.5	11.92	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706005	US06x2, 4 bag, ph2	06/02/17	26	5250	FD2421GP10	2WD	6.25	22.0	22.0	21.28	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706005	US06x2, 4 bag, ph1+2	06/02/17	**25**	5250	FD2421GP10	2WD	**8.04**	**18.87**	**18.81**	**18.12**	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706005	US06x2, 4 bag, ph3	06/02/17	23	5250	FD2421GP10	2WD	1.79	12.8	12.6	12.29	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706005	US06x2, 4 bag, ph4	06/02/17	26	5250	FD2421GP10	2WD	6.25	22.1	22.2	21.47	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706005	US06x2, 4 bag, ph3+4	06/02/17	**25**	5250	FD2421GP10	2WD	**8.04**	**19.03**	**18.97**	**18.42**	GA	10689.71	-1.54	7088.44	7199.34	28.94	28.92	0.41	16.08	16.01	-0.32	0.09	0.43
61706006	SSS 0-80-0, 0% 3% and 6% grade, ph1	06/02/17	25	5250	FD2421GP10	2WD	6.21	24.6	24.5	24.18	MK	1644.47	18.65	2545.95	2145.79	24.92	24.99	-0.13	18.64	18.67	-0.16	-0.29	0.19
61706006	SSS 0-80-0, 0% 3% and 6% grade, ph2	06/02/17	25	5250	FD2421GP10	2WD	6.21	15.4	15.3	14.95	MK	1644.47	18.65	2545.95	2145.79	24.92	24.99	-0.13	18.64	18.67	-0.16	-0.29	0.19
61706006	SSS 0-80-0, 0% 3% and 6% grade, ph3	06/02/17	24	5250	FD2421GP10	2WD	6.21	10.8	10.9	10.55	MK	1644.47	18.65	2545.95	2145.79	24.92	24.99	-0.13	18.64	18.67	-0.16	-0.29	0.19
61706007	UDDSx1, 2 bag, ph1	06/02/17	23	5250	FD2421GP10	2WD	3.61	23.9	24.0	23.23	GA	2180.61	0.69	5503.20	5465.59	8.09	7.97	0.54	7.49	7.45	0.96	1.51	0.63
61706007	UDDSx1, 2 bag, ph2	06/02/17	23	5250	FD2421GP10	2WD	3.89	22.2	22.3	22.08	GA	2180.61	0.69	5503.20	5465.59	8.09	7.97	0.54	7.49	7.45	0.96	1.51	0.63
61706007	UDDSx1, 2 bag, ph1+2	06/02/17	**23**	5250	FD2421GP10	2WD	**7.49**	**22.98**	**23.10**	**22.62**	GA	2180.61	0.69	5503.20	5465.59	8.09	7.97	0.54	7.49	7.45	0.96	1.51	0.63

Day 13																							
61706008	UDDSx2, 4 bag, ph1	06/05/17	21	5250	FD2421GP10	2WD	3.60	19.4	19.4	19.36	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706008	UDDSx2, 4 bag, ph2	06/05/17	22	5250	FD2421GP10	2WD	3.85	21.5	21.7	22.15	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706008	UDDSx2, 4 bag, ph1+2	06/05/17	**21**	5250	FD2421GP10	2WD	**7.45**	**20.45**	**20.54**	**20.71**	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706008	UDDSx2, 4 bag, ph3	06/05/17	23	5250	FD2421GP10	2WD	3.61	23.3	23.6	23.30	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706008	UDDSx2, 4 bag, ph4	06/05/17	22	5250	FD2421GP10	2WD	3.88	22.2	22.2	22.36	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706008	UDDSx2, 4 bag, ph3+4	06/05/17	**22**	5250	FD2421GP10	2WD	**7.49**	**22.70**	**22.83**	**22.81**	MK/GA	1824.75	0.96	11035.71	10931.19	16.13	15.93	0.23	14.94	14.90	0.98	1.22	0.63
61706009	UDDSx1, 2 bag, ph1	06/05/17	21	5250	FD2421GP10	2WD	3.61	23.8	23.7	23.16	GA	2181.00	1.33	5538.31	5465.60	8.07	7.97	0.63	7.50	7.45	0.63	1.26	0.63
61706009	UDDSx1, 2 bag, ph2	06/05/17	23	5250	FD2421GP10	2WD	3.89	22.2	22.2	22.47	GA	2181.00	1.33	5538.31	5465.60	8.07	7.97	0.63	7.50	7.45	0.63	1.26	0.63
61706009	UDDSx1, 2 bag, ph1+2	06/05/17	**22**	5250	FD2421GP10	2WD	**7.50**	**22.94**	**22.88**	**22.80**	GA	2181.00	1.33	5538.31	5465.60	8.07	7.97	0.63	7.50	7.45	0.63	1.26	0.63
61706010	HWYx2, 2 bag, ph1	06/05/17	20	5250	FD2421GP10	2WD	10.28	31.3	31.4	31.30	GA	2355.39	0.26	2620.63	2613.74	22.66	22.60	0.21	20.56	20.51	0.05	0.26	0.25
61706010	HWYx2, 2 bag, ph2	06/05/17	23	5250	FD2421GP10	2WD	10.28	32.6	32.4	32.51	GA	2355.39	0.26	2620.63	2613.74	22.66	22.60	0.21	20.56	20.51	0.05	0.26	0.25
61706011	US06x2, 4 bag, ph1	06/05/17	22	5250	FD2421GP10	2WD	1.78	12.7	12.6	12.37	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
61706011	US06x2, 4 bag, ph2	06/05/17	22	5250	FD2421GP10	2WD	6.24	22.3	22.2	21.88	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
61706011	US06x2, 4 bag, ph1+2	06/05/17	**22**	5250	FD2421GP10	2WD	**8.02**	**19.10**	**19.01**	**18.69**	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
61706011	US06x2, 4 bag, ph3	06/05/17	23	5250	FD2421GP10	2WD	1.79	12.9	12.8	12.63	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
61706011	US06x2, 4 bag, ph4	06/05/17	24	5250	FD2421GP10	2WD	6.25	22.3	22.2	21.87	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
61706011	US06x2, 4 bag, ph3+4	06/05/17	**23**	5250	FD2421GP10	2WD	**8.03**	**19.18**	**19.09**	**18.81**	GA	10693.95	-2.35	7030.21	7199.71	28.92	28.92	0.28	16.06	16.01	-0.27	0.01	0.43
Day 14 - Cell at 95 F																							
Switch test cell to 95F with 850 W/m2																							
61706012	UDDSx2, 4 bag, ph1	06/06/17	37	5250	FD2421GP10	2WD	3.59	17.3	17.1	16.72	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706012	UDDSx2, 4 bag, ph2	06/06/17	35	5250	FD2421GP10	2WD	3.86	17.1	17.2	17.26	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706012	UDDSx2, 4 bag, ph1+2	06/06/17	**36**	5250	FD2421GP10	2WD	**7.45**	**17.16**	**17.13**	**16.99**	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706012	UDDSx2, 4 bag, ph3	06/06/17	36	5250	FD2421GP10	2WD	3.60	19.8	19.7	19.21	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706012	UDDSx2, 4 bag, ph4	06/06/17	35	5250	FD2421GP10	2WD	3.89	17.4	17.4	17.24	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706012	UDDSx2, 4 bag, ph3+4	06/06/17	**36**	5250	FD2421GP10	2WD	**7.49**	**18.47**	**18.44**	**18.14**	MK/GA	1824.71	1.13	11054.88	10931.17	16.08	15.93	0.26	14.94	14.90	0.65	0.92	0.63
61706013	SC03x2, 2 bag, ph1	06/06/17	37	5250	FD2421GP10	2WD	3.59	17.4	17.5	17.09	GA	1903.20	0.56	5092.28	5063.93	8.53	8.40	0.40	7.19	7.16	1.07	1.49	0.67
61706013	SC03x2, 2 bag, ph2	06/06/17	36	5250	FD2421GP10	2WD	3.59	17.6	17.8	17.31	GA	1903.20	0.56	5092.28	5063.93	8.53	8.40	0.40	7.19	7.16	1.07	1.49	0.67
61706014	SC03x1, 1 bag, ph1	06/06/17	36	5250	FD2421GP10	2WD	3.59	17.8	17.7	17.33	GA	2677.75	1.78	2577.04	2531.94	4.27	4.20	0.39	3.59	3.58	1.32	1.74	0.67
61706015	US06x3, 3 bag, ph1	06/06/17	39	5250	FD2421GP10	2WD	8.03	16.8	16.7	15.97	GA	10616.12	-3.15	10458.91	10799.32	43.22	43.37	0.27	24.09	24.02	-0.62	-0.35	0.43
61706015	US06x3, 3 bag, ph2	06/06/17	38	5250	FD2421GP10	2WD	8.03	17.2	17.1	16.49	GA	10616.12	-3.15	10458.91	10799.32	43.22	43.37	0.27	24.09	24.02	-0.62	-0.35	0.43
61706015	US06x3, 3 bag, ph3	06/06/17	38	5250	FD2421GP10	2WD	8.03	17.4	17.3	16.58	GA	10616.12	-3.15	10458.91	10799.32	43.22	43.37	0.27	24.09	24.02	-0.62	-0.35	0.43
Swtich test cell back to 72F																							
61706016	US06x2, 4 bag, ph1	06/06/17	20	5250	FD2421GP10	2WD	1.78	12.5	12.6	12.19	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
61706016	US06x2, 4 bag, ph2	06/06/17	20	5250	FD2421GP10	2WD	6.24	21.8	21.8	21.01	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
61706016	US06x2, 4 bag, ph1+2	06/06/17	**20**	5250	FD2421GP10	2WD	**8.02**	**18.73**	**18.76**	**18.11**	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
61706016	US06x2, 4 bag, ph3	06/06/17	20	5250	FD2421GP10	2WD	1.77	12.8	12.8	12.37	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
61706016	US06x2, 4 bag, ph4	06/06/17	20	5250	FD2421GP10	2WD	6.23	21.8	21.9	21.22	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
61706016	US06x2, 4 bag, ph3+4	06/06/17	**20**	5250	FD2421GP10	2WD	**8.00**	**18.85**	**18.91**	**18.33**	MK	10692.53	0.02	7201.14	7199.56	29.05	28.92	0.00	16.01	16.01	0.45	0.45	0.43
Day 15 - Cell at 95 F, then switch to 20F																							
Switch test cell to 95F with 850 W/m2																							
61706017	UDDSx2, 4 bag, ph1	06/07/17	37	5250	FD2421GP10	2WD	3.59	17.3	17.1	16.64	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706017	UDDSx2, 4 bag, ph2	06/07/17	35	5250	FD2421GP10	2WD	3.85	17.0	17.2	17.21	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706017	UDDSx2, 4 bag, ph1+2	06/07/17	**36**	5250	FD2421GP10	2WD	**7.45**	**17.14**	**17.14**	**16.93**	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706017	UDDSx2, 4 bag, ph3	06/07/17	36	5250	FD2421GP10	2WD	3.61	20.1	19.9	19.29	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706017	UDDSx2, 4 bag, ph4	06/07/17	35	5250	FD2421GP10	2WD	3.87	17.4	17.4	17.32	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706017	UDDSx2, 4 bag, ph3+4	06/07/17	**36**	5250	FD2421GP10	2WD	**7.48**	**18.59**	**18.54**	**18.22**	MK/GA	1824.73	1.05	11046.35	10931.19	16.09	15.93	0.17	14.93	14.90	0.81	0.99	0.63
61706018	SC03x2, 2 bag, ph1	06/07/17	37	5250	FD2421GP10	2WD	3.59	17.5	17.6	17.11	GA	1903.08	0.18	5072.86	5063.90	8.52	8.40	0.35	7.18	7.16	0.99	1.35	0.67
61706018	SC03x2, 2 bag, ph2	06/07/17	35	5250	FD2421GP10	2WD	3.59	18.0	18.0	17.49	GA	1903.08	0.18	5072.86	5063.90	8.52	8.40	0.35	7.18	7.16	0.99	1.35	0.67
61706019	US06x2, 4 bag, ph1	06/07/17	37	5250	FD2421GP10	2WD	1.78	11.2	11.1	10.60	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
61706019	US06x2, 4 bag, ph2	06/07/17	40	5250	FD2421GP10	2WD	6.24	20.4	20.2	19.37	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
61706019	US06x2, 4 bag, ph1+2	06/07/17	**39**	5250	FD2421GP10	2WD	**8.02**	**17.24**	**17.10**	**16.37**	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
61706019	US06x2, 4 bag, ph3	06/07/17	37	5250	FD2421GP10	2WD	1.78	11.1	11.1	10.51	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
61706019	US06x2, 4 bag, ph4	06/07/17	39	5250	FD2421GP10	2WD	6.24	21.0	20.8	19.96	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
61706019	US06x2, 4 bag, ph3+4	06/07/17	**38**	5250	FD2421GP10	2WD	**8.02**	**17.53**	**17.42**	**16.64**	GA	10692.75	-2.54	7016.63	7199.56	28.86	28.92	0.19	16.04	16.01	-0.38	-0.19	0.43
Swtich test cell to 20F																							
61706020	UDDSx1, 1 bag	6/7/2017	-15	5250	EH1021LT10-HW	2WD	7.49	19.4	19.4	19.43	GA	2180.40	0.71	5504.21	5465.55	8.07	7.97	0.58	7.49	7.45	0.76	1.36	0.63

Day 16 - Cell at 20F																							
61706021	HWYx3, 3 bag, ph1	06/08/17	-3	5250	EH1021LT10-HW	2WD	10.22	22.9	22.8	23.15	MK	2392.05	1.16	3966.02	3920.61	33.79	33.90	-0.21	30.72	30.78	-0.12	-0.33	0.25
61706021	HWYx3, 3 bag, ph2	06/08/17	-5	5250	EH1021LT10-HW	2WD	10.24	29.3	29.6	30.36	MK	2392.05	1.16	3966.02	3920.61	33.79	33.90	-0.21	30.72	30.78	-0.12	-0.33	0.25
61706021	HWYx3, 3 bag, ph3	06/08/17	-6	5250	EH1021LT10-HW	2WD	10.25	30.5	30.4	31.05	MK	2392.05	1.16	3966.02	3920.61	33.79	33.90	-0.21	30.72	30.78	-0.12	-0.33	0.25
61706022	US06x2, 4 bag, ph1	06/08/17	-5	5250	EH1021LT10-HW	2WD	1.78	12.5	12.3	12.32	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706022	US06x2, 4 bag, ph2	06/08/17	-2	5250	EH1021LT10-HW	2WD	6.24	21.5	21.5	21.77	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706022	US06x2, 4 bag, ph1+2	06/08/17	**-4**	5250	EH1021LT10-HW	2WD	**8.02**	**18.50**	**18.48**	**18.61**	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706022	US06x2, 4 bag, ph3	06/08/17	-6	5250	EH1021LT10-HW	2WD	1.78	12.6	12.6	12.89	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706022	US06x2, 4 bag, ph4	06/08/17	-3	5250	EH1021LT10-HW	2WD	6.24	21.9	21.8	22.19	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706022	US06x2, 4 bag, ph3+4	06/08/17	**-5**	5250	EH1021LT10-HW	2WD	**8.02**	**18.86**	**18.81**	**19.13**	GA	10692.31	-2.27	7036.06	7199.53	28.87	28.92	0.15	16.04	16.01	-0.29	-0.15	0.43
61706023	UDDSx1, 2 bag, ph1	06/08/17	-6	5250	EH1021LT10-HW	2WD	3.60	22.0	22.1	22.13	GA	2161.32	0.73	5505.40	5465.60	8.02	7.97	-0.01	7.45	7.45	0.71	0.70	0.63
61706023	UDDSx1, 2 bag, ph2	06/08/17	-7	5250	EH1021LT10-HW	2WD	3.85	20.2	20.5	21.03	GA	2161.32	0.73	5505.40	5465.60	8.02	7.97	-0.01	7.45	7.45	0.71	0.70	0.63
61706023	UDDSx1, 2 bag, ph1+2	06/08/17	**-7**	5250	EH1021LT10-HW	2WD	**7.45**	**21.05**	**21.27**	**21.55**	GA	2161.32	0.73	5505.40	5465.60	8.02	7.97	-0.01	7.45	7.45	0.71	0.70	0.63
Day 17 - Cell at 20F																							
61706024	UDDSx2, 4 bag, ph1	06/09/17	-6	5250	EH1021LT10-HW	2WD	3.59	14.3	14.2	13.91	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706024	UDDSx2, 4 bag, ph2	06/09/17	-7	5250	EH1021LT10-HW	2WD	3.84	18.6	18.4	19.06	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706024	UDDSx2, 4 bag, ph1+2	06/09/17	**-7**	5250	EH1021LT10-HW	2WD	**7.44**	**16.21**	**16.09**	**16.17**	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706024	UDDSx2, 4 bag, ph3	06/09/17	-5	5250	EH1021LT10-HW	2WD	3.60	21.7	21.7	21.74	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706024	UDDSx2, 4 bag, ph4	06/09/17	-7	5250	EH1021LT10-HW	2WD	3.86	20.5	20.3	20.81	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706024	UDDSx2, 4 bag, ph3+4	06/09/17	**-6**	5250	EH1021LT10-HW	2WD	**7.46**	**21.07**	**20.94**	**21.25**	MK/GA	1824.77	1.22	11064.75	10931.18	16.10	15.93	-0.01	14.90	14.90	1.04	1.04	0.63
61706025	UDDSx1, 2 bag, ph1	06/09/17	-6	5250	EH1021LT10-HW	2WD	3.60	23.0	23.1	22.67	GA	2180.90	0.52	5493.94	5465.60	8.00	7.97	0.13	7.46	7.45	0.32	0.46	0.63
61706025	UDDSx1, 2 bag, ph2	06/09/17	-7	5250	EH1021LT10-HW	2WD	3.86	21.2	21.5	21.83	GA	2180.90	0.52	5493.94	5465.60	8.00	7.97	0.13	7.46	7.45	0.32	0.46	0.63
61706025	UDDSx1, 2 bag, ph1+2	06/09/17	**-6**	5250	EH1021LT10-HW	2WD	**7.46**	**22.01**	**22.24**	**22.22**	GA	2180.90	0.52	5493.94	5465.60	8.00	7.97	0.13	7.46	7.45	0.32	0.46	0.63
Switch to tier II 88 AKI certification fuel																							
Day 18 - Cell at 72F																							
61706026	Octane Adjuster Cycle w/ UDDS prep, ph1	06/12/17	26	5250	EH1021LT10-HW	2WD	8.03	18.5	18.5	18.15	GA	5199.25	-0.23	16844.46	16884.07	50.14	50.02	0.21	30.72	30.66	0.03	0.24	0.47
61706026	Octane Adjuster Cycle w/ UDDS prep, ph2	06/12/17	25	5250	EH1021LT10-HW	2WD	8.01	18.1	18.1	17.51	GA	5199.25	-0.23	16844.46	16884.07	50.14	50.02	0.21	30.72	30.66	0.03	0.24	0.47
61706026	Octane Adjuster Cycle w/ UDDS prep, ph3	06/12/17	20	5250	EH1021LT10-HW	2WD	7.46	23.2	22.6	22.34	GA	5199.25	-0.23	16844.46	16884.07	50.14	50.02	0.21	30.72	30.66	0.03	0.24	0.47
Day 19 - Cell at 72F																							
61706027	UDDSx2, 4 bag, ph1	06/13/17	23	5250	EH1021LT10-HW	2WD	3.58	19.2	19.3	18.27	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706027	UDDSx2, 4 bag, ph2	06/13/17	22	5250	EH1021LT10-HW	2WD	3.85	21.1	21.1	20.89	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706027	UDDSx2, 4 bag, ph1+2	06/13/17	**23**	5250	EH1021LT10-HW	2WD	**7.44**	**20.18**	**20.17**	**19.54**	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706027	UDDSx2, 4 bag, ph3	06/13/17	23	5250	EH1021LT10-HW	2WD	3.60	23.9	23.9	22.69	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706027	UDDSx2, 4 bag, ph4	06/13/17	22	5250	EH1021LT10-HW	2WD	3.87	22.2	22.0	21.47	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706027	UDDSx2, 4 bag, ph3+4	06/13/17	**22**	5250	EH1021LT10-HW	2WD	**7.47**	**22.98**	**22.88**	**22.05**	MK/GA	1824.45	0.72	11010.08	10931.10	15.98	15.93	0.04	14.91	14.90	0.28	0.33	0.63
61706028	UDDSx1, 2 bag, ph1	06/13/17	24	5250	EH1021LT10-HW	2WD	3.60	24.0	24.1	22.61	GA	2184.51	1.05	5523.38	5465.88	8.06	7.97	0.52	7.49	7.45	0.58	1.11	0.63
61706028	UDDSx1, 2 bag, ph2	06/13/17	22	5250	EH1021LT10-HW	2WD	3.89	21.8	21.9	21.18	GA	2184.51	1.05	5523.38	5465.88	8.06	7.97	0.52	7.49	7.45	0.58	1.11	0.63
61706028	UDDSx1, 2 bag, ph1+2	06/13/17	**23**	5250	EH1021LT10-HW	2WD	**7.49**	**22.84**	**22.89**	**21.84**	GA	2184.51	1.05	5523.38	5465.88	8.06	7.97	0.52	7.49	7.45	0.58	1.11	0.63
61706029	HWYx2, 2 bag, ph1	06/13/17	25	5250	EH1021LT10-HW	2WD	10.26	32.1	32.1	30.56	GA	2355.04	0.35	2622.91	2613.72	22.54	22.60	0.03	20.52	20.51	-0.26	-0.23	0.25
61706029	HWYx2, 2 bag, ph2	06/13/17	25	5250	EH1021LT10-HW	2WD	10.26	32.7	32.6	31.18	GA	2355.04	0.35	2622.91	2613.72	22.54	22.60	0.03	20.52	20.51	-0.26	-0.23	0.25
61706030	US06x2, 4 bag, ph1	06/13/17	22	5250	EH1021LT10-HW	2WD	1.78	12.1	12.1	11.39	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706030	US06x2, 4 bag, ph2	06/13/17	26	5250	EH1021LT10-HW	2WD	6.24	21.2	21.2	20.01	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706030	US06x2, 4 bag, ph1+2	06/13/17	**24**	5250	EH1021LT10-HW	2WD	**8.02**	**18.17**	**18.15**	**17.13**	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706030	US06x2, 4 bag, ph3	06/13/17	23	5250	EH1021LT10-HW	2WD	1.77	12.1	12.0	11.41	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706030	US06x2, 4 bag, ph4	06/13/17	26	5250	EH1021LT10-HW	2WD	6.24	21.1	21.1	19.94	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706030	US06x2, 4 bag, ph3+4	06/13/17	**25**	5250	EH1021LT10-HW	2WD	**8.01**	**18.13**	**18.07**	**17.11**	GA	10690.15	-0.98	7129.11	7199.38	28.94	28.92	0.13	16.03	16.01	-0.04	0.09	0.43
61706031	55 mph SSS, 1 bag, ph1	06/13/17	26	5250	EH1021LT10-HW	2WD	9.20	33.0	33.0	31.90	MK	231.72	8.35	532.81	491.74	11.75	11.68	0.25	10.01	9.98	0.35	0.60	0.06
61706032	SSS 0-80-0, 0% 3% and 6% grade, ph1	06/13/17	23	5250	EH1021LT10-HW	2WD	6.22	0.0	24.0	23.39	GA	1644.40	18.27	2537.88	2145.79	24.74	24.99	-0.09	18.65	18.67	-0.91	-0.99	0.19
61706032	SSS 0-80-0, 0% 3% and 6% grade, ph2	06/13/17	24	5250	EH1021LT10-HW	2WD	6.21	0.0	14.7	14.24	GA	1644.40	18.27	2537.88	2145.79	24.74	24.99	-0.09	18.65	18.67	-0.91	-0.99	0.19
61706032	SSS 0-80-0, 0% 3% and 6% grade, ph3	06/13/17	24	5250	EH1021LT10-HW	2WD	6.22	0.0	10.0	9.64	GA	1644.40	18.27	2537.88	2145.79	24.74	24.99	-0.09	18.65	18.67	-0.91	-0.99	0.19
61706033	WOTs 0-80x3, 1 bag, ph1	06/13/17	23	5250	EH1021LT10-HW	2WD	3.06	0.0	13.1	17.16	GA	35878.62	-1.03	2256.37	2279.90	5.99	11.58	-30.24	3.06	4.39	-34.86	-48.27	0.45
61706034	Passing Manuevers, 0% 3% and 6% grade, ph1	06/13/17	26	5250	EH1021LT10-HW	2WD	10.02	0.0	11.3	12.13	GA	17809.56	16.85	3917.66	3352.80	19.39	19.64	-2.27	10.02	10.26	1.00	-1.28	0.42
61706035	UDDSx1, 1 bag, ph1	06/13/17	21	5250	EH1021LT10-HW	2WD	7.45	10.7	10.7	10.27	GA	2181.00	1.38	5540.91	5465.60	8.03	7.97	-0.01	7.45	7.45	0.80	0.80	0.63
61706036	UDDSx1, 1 bag, ph1	06/13/17	21	5250	EH1021LT10-HW	2WD	7.50	155.9	206.1	21.96	GA	2180.57	1.64	5554.95	5465.58	8.13	7.97	0.70	7.50	7.45	1.32	2.05	0.63

Day 20 - Cell at 72F																							
61706037	UDDSx2, 4 bag, ph1	06/14/17	23	5250	EH1021LT10-HW	2WD	3.59	19.2	19.4	18.26	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706037	UDDSx2, 4 bag, ph2	06/14/17	20	5250	EH1021LT10-HW	2WD	3.87	22.1	21.8	21.24	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706037	UDDSx2, 4 bag, ph1+2	06/14/17	22	5250	EH1021LT10-HW	2WD	7.46	20.64	20.57	19.69	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706037	UDDSx2, 4 bag, ph3	06/14/17	24	5250	EH1021LT10-HW	2WD	3.60	23.8	23.6	22.51	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706037	UDDSx2, 4 bag, ph4	06/14/17	22	5250	EH1021LT10-HW	2WD	3.87	22.6	22.2	21.67	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706037	UDDSx2, 4 bag, ph3+4	06/14/17	23	5250	EH1021LT10-HW	2WD	7.46	23.13	22.88	22.07	MK	1824.49	1.23	11066.02	10931.12	16.12	15.93	0.16	14.93	14.90	1.02	1.19	0.63
61706038	UDDSx1, 2 bag, ph1	06/14/17	24	5250	EH1021LT10-HW	2WD	3.61	24.1	24.2	22.73	GA	2181.59	1.10	5525.84	5465.67	8.04	7.97	0.37	7.48	7.45	0.55	0.92	0.63
61706038	UDDSx1, 2 bag, ph2	06/14/17	22	5250	EH1021LT10-HW	2WD	3.87	22.6	22.3	21.70	GA	2181.59	1.10	5525.84	5465.67	8.04	7.97	0.37	7.48	7.45	0.55	0.92	0.63
61706038	UDDSx1, 2 bag, ph1+2	06/14/17	23	5250	EH1021LT10-HW	2WD	7.48	23.34	23.18	22.18	GA	2181.59	1.10	5525.84	5465.67	8.04	7.97	0.37	7.48	7.45	0.55	0.92	0.63
61706039	HWYx2, 2 bag, ph1	06/14/17	25	5250	EH1021LT10-HW	2WD	10.27	32.4	32.4	30.62	GA	2355.16	2.16	2670.25	2613.73	22.60	22.60	0.09	20.53	20.51	-0.06	0.02	0.25
61706039	HWYx2, 2 bag, ph2	06/14/17	25	5250	EH1021LT10-HW	2WD	10.27	32.5	32.7	31.14	GA	2355.16	2.16	2670.25	2613.73	22.60	22.60	0.09	20.53	20.51	-0.06	0.02	0.25
61706040	US06x2, 4 bag, ph1	06/14/17	22	5250	EH1021LT10-HW	2WD	1.78	12.3	12.3	11.55	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706040	US06x2, 4 bag, ph2	06/14/17	26	5250	EH1021LT10-HW	2WD	6.25	21.2	21.2	20.01	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706040	US06x2, 4 bag, ph1+2	06/14/17	24	5250	EH1021LT10-HW	2WD	8.03	18.28	18.25	17.21	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706040	US06x2, 4 bag, ph3	06/14/17	23	5250	EH1021LT10-HW	2WD	1.78	12.3	12.1	11.43	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706040	US06x2, 4 bag, ph4	06/14/17	26	5250	EH1021LT10-HW	2WD	6.24	21.1	21.1	19.89	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706040	US06x2, 4 bag, ph3+4	06/14/17	25	5250	EH1021LT10-HW	2WD	8.02	18.21	18.08	17.09	GA	10693.09	-0.63	7154.31	7199.59	28.92	28.92	0.24	16.05	16.01	-0.22	0.01	0.43
61706041	UDDSx1, 2 bag, ph1	06/14/17	23	5250	EH1021LT10-HW	2WD	3.60	22.5	22.6	21.47	MK	2180.88	0.96	5518.11	5465.61	8.03	7.97	0.00	7.45	7.45	0.77	0.78	0.63
61706041	UDDSx1, 2 bag, ph2	06/14/17	22	5250	EH1021LT10-HW	2WD	3.86	21.5	21.5	21.30	MK	2180.88	0.96	5518.11	5465.61	8.03	7.97	0.00	7.45	7.45	0.77	0.78	0.63
61706041	UDDSx1, 2 bag, ph1+2	06/14/17	23	5250	EH1021LT10-HW	2WD	7.45	21.96	22.03	21.38	MK	2180.88	0.96	5518.11	5465.61	8.03	7.97	0.00	7.45	7.45	0.77	0.78	0.63
Day 21 - Cell at 72F																							
61706042	UDDSx2, 4 bag, ph1	06/15/17	24	5250	EH1021LT10-HW	2WD	3.60	20.1	19.7	18.65	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706042	UDDSx2, 4 bag, ph2	06/15/17	22	5250	EH1021LT10-HW	2WD	3.87	22.1	22.1	21.46	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706042	UDDSx2, 4 bag, ph1+2	06/15/17	23	5250	EH1021LT10-HW	2WD	7.47	21.12	20.86	20.01	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706042	UDDSx2, 4 bag, ph3	06/15/17	23	5250	EH1021LT10-HW	2WD	3.60	24.6	23.8	22.75	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706042	UDDSx2, 4 bag, ph4	06/15/17	23	5250	EH1021LT10-HW	2WD	3.87	22.2	22.3	21.70	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706042	UDDSx2, 4 bag, ph3+4	06/15/17	23	5250	EH1021LT10-HW	2WD	7.47	23.33	23.03	22.19	GA	1836.21	0.23	10956.92	10931.26	16.00	15.93	0.25	14.94	14.90	0.19	0.45	0.63
61706043	UDDSx1, 2 bag, ph1	06/15/17	23	5250	EH1021LT10-HW	2WD	3.60	24.0	23.7	22.72	GA	2184.46	1.15	5528.93	5465.90	8.06	7.97	0.37	7.48	7.45	0.83	1.22	0.63
61706043	UDDSx1, 2 bag, ph2	06/15/17	22	5250	EH1021LT10-HW	2WD	3.88	22.3	22.4	21.81	GA	2184.46	1.15	5528.93	5465.90	8.06	7.97	0.37	7.48	7.45	0.83	1.22	0.63
61706043	UDDSx1, 2 bag, ph1+2	06/15/17	23	5250	EH1021LT10-HW	2WD	7.48	23.06	23.00	22.24	GA	2184.46	1.15	5528.93	5465.90	8.06	7.97	0.37	7.48	7.45	0.83	1.22	0.63
61706044	HWYx2, 2 bag, ph1	06/15/17	25	5250	EH1021LT10-HW	2WD	10.26	32.2	32.2	30.56	GA	2356.54	2.29	2673.68	2613.78	22.58	22.60	0.02	20.52	20.51	-0.10	-0.08	0.25
61706044	HWYx2, 2 bag, ph2	06/15/17	25	5250	EH1021LT10-HW	2WD	10.26	32.5	32.5	31.02	GA	2356.54	2.29	2673.68	2613.78	22.58	22.60	0.02	20.52	20.51	-0.10	-0.08	0.25
61706045	US06x2, 4 bag, ph1	06/15/17	25	5250	EH1021LT10-HW	2WD	8.02	17.9	17.8	16.86	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706045	US06x2, 4 bag, ph2	06/15/17	25	5250	EH1021LT10-HW	2WD	8.03	18.2	18.1	17.31	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706045	US06x2, 4 bag, ph1+2	06/15/17	25	5250	EH1021LT10-HW	2WD	16.05	18.04	17.96	17.08	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706045	US06x2, 4 bag, ph3	06/15/17	NaN	5250	EH1021LT10-HW	2WD	T FOUND (	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706045	US06x2, 4 bag, ph4	06/15/17	NaN	5250	EH1021LT10-HW	2WD	T FOUND (	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706045	US06x2, 4 bag, ph3+4	06/15/17	#DIV/0!	5250	EH1021LT10-HW	2WD	#VALUE!	#VALUE!	#VALUE!	#VALUE!	0.00	0.00	0.00	0.00	0.00	29.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61706046	UDDSx1, 2 bag, ph1	06/15/17	22	5250	EH1021LT10-HW	2WD	3.60	23.2	23.2	21.57	GA	2180.63	0.86	5512.69	5465.57	8.02	7.97	0.14	7.46	7.45	0.56	0.70	0.63
61706046	UDDSx1, 2 bag, ph2	06/15/17	20	5250	EH1021LT10-HW	2WD	3.86	21.9	21.6	21.34	GA	2180.63	0.86	5512.69	5465.57	8.02	7.97	0.14	7.46	7.45	0.56	0.70	0.63
61706046	UDDSx1, 2 bag, ph1+2	06/15/17	21	5250	EH1021LT10-HW	2WD	7.46	22.53	22.35	21.45	GA	2180.63	0.86	5512.69	5465.57	8.02	7.97	0.14	7.46	7.45	0.56	0.70	0.63

Day 22 - Cell at 72F																							
61706047	UDDSx2, 4 bag, ph1	06/16/17	24	5250	EH1021LT10-HW	2WD	3.60	0.0	0.0	18.38	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706047	UDDSx2, 4 bag, ph2	06/16/17	22	5250	EH1021LT10-HW	2WD	3.87	0.0	0.0	21.55	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706047	UDDSx2, 4 bag, ph1+2	06/16/17	**23**	5250	EH1021LT10-HW	2WD	**7.46**	**#DIV/0!**	**#DIV/0!**	**19.90**	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706047	UDDSx2, 4 bag, ph3	06/16/17	23	5250	EH1021LT10-HW	2WD	3.60	0.0	0.0	22.69	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706047	UDDSx2, 4 bag, ph4	06/16/17	22	5250	EH1021LT10-HW	2WD	3.86	0.0	0.0	21.74	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706047	UDDSx2, 4 bag, ph3+4	06/16/17	**23**	5250	EH1021LT10-HW	2WD	**7.46**	**#DIV/0!**	**#DIV/0!**	**22.19**	GA	1836.07	0.24	10957.13	10931.23	16.01	15.93	0.15	14.92	14.90	0.34	0.49	0.63
61706048	US06x2, 4 bag, ph1	06/16/17	24	5250	EH1021LT10-HW	2WD	1.78	12.2	12.3	11.49	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
61706048	US06x2, 4 bag, ph2	06/16/17	28	5250	EH1021LT10-HW	2WD	6.24	20.8	21.0	19.77	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
61706048	US06x2, 4 bag, ph1+2	06/16/17	**26**	5250	EH1021LT10-HW	2WD	**8.03**	**18.01**	**18.12**	**17.04**	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
61706048	US06x2, 4 bag, ph3	06/16/17	24	5250	EH1021LT10-HW	2WD	1.78	12.5	12.2	11.75	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
61706048	US06x2, 4 bag, ph4	06/16/17	26	5250	EH1021LT10-HW	2WD	6.24	20.7	20.9	19.71	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
61706048	US06x2, 4 bag, ph3+4	06/16/17	**25**	5250	EH1021LT10-HW	2WD	**8.02**	**18.07**	**18.05**	**17.14**	GA	10693.11	-0.60	7156.46	7199.59	29.02	28.92	0.21	16.05	16.01	0.16	0.37	0.43
Day 23 - Cell at 72F																							
61706049	UDDSx2, 4 bag, ph1	06/21/17	24	5250	EH1021LT10-HW	2WD	3.60	19.3	19.4	18.61	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706049	UDDSx2, 4 bag, ph2	06/21/17	22	5250	EH1021LT10-HW	2WD	3.86	21.9	21.8	21.80	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706049	UDDSx2, 4 bag, ph1+2	06/21/17	**23**	5250	EH1021LT10-HW	2WD	**7.46**	**20.57**	**20.56**	**20.13**	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706049	UDDSx2, 4 bag, ph3	06/21/17	23	5250	EH1021LT10-HW	2WD	3.59	23.9	23.5	22.67	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706049	UDDSx2, 4 bag, ph4	06/21/17	22	5250	EH1021LT10-HW	2WD	3.86	22.0	21.8	21.67	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706049	UDDSx2, 4 bag, ph3+4	06/21/17	**22**	5250	EH1021LT10-HW	2WD	**7.45**	**22.87**	**22.55**	**22.14**	MK	1824.61	1.32	11074.96	10931.15	16.06	15.93	0.06	14.91	14.90	0.72	0.78	0.63
61706050	ssing Manuevers- 15950, 10600, and 7000 lbs load, p	06/21/17	27	5250	EH1021LT10-HW	2WD	9.82	0.0	10.3	11.50	GA	53190.75	22.40	4103.77	3352.80	39.13	36.24	-3.98	9.85	10.26	11.07	7.98	0.68
61706051	55 mph SSS, ph1	06/21/17	25	5250	EH1021LT10-HW	2WD	9.19	33.0	32.9	31.88	Robot	231.89	14.53	563.19	491.74	11.71	11.68	0.13	10.00	9.98	0.15	0.28	0.06
61706052	Pedal tip ins, ph1	06/21/17	23	5250	EH1021LT10-HW	2WD	12.54	0.0	18.6	20.22	Robot	0.00	Inf	5301.48	0.00	18.85	0.00	Inf	12.54	0.00	NaN	Inf	NaN
Day 23 - Cell at 72F																							
61706053	55mph SSS and Pedal tip ins, ph1	06/22/17	27	5250	EH1021LT10-HW	2WD	9.19	0.0	32.4	30.89	Robot	87.56	1328.02	7022.20	491.74	57.86	12.42	270.46	36.96	9.98	20.47	365.81	0.12
61706053	55mph SSS and Pedal tip ins, ph2	06/22/17	24	5250	EH1021LT10-HW	2WD	26.96	0.0	17.9	17.87	Robot	87.56	1328.02	7022.20	491.74	57.86	12.42	270.46	36.96	9.98	20.47	365.81	0.12
Day 24 - Cell at 72F																							
61706054	55mph SSS and Pedal tip ins at 15950 lbs, ph1	06/23/17	26	5250	EH1021LT10-HW	2WD	9.19	0.0	32.9	31.72	Robot	110.24	1345.77	7109.46	491.74	74.54	13.16	343.05	44.20	9.98	21.75	466.20	0.17
61706054	55mph SSS and Pedal tip ins at 15950 lbs, ph2	06/23/17	-27	5250	EH1021LT10-HW	2WD	34.20	0.0	17.4	17.39	Robot	110.24	1345.77	7109.46	491.74	74.54	13.16	343.05	44.20	9.98	21.75	466.20	0.17
61706055	5mph SSS and Pedal tip ins from 35 and 55 mph, ph	06/23/17	26	5250	EH1021LT10-HW	2WD	9.19	0.0	33.5	31.96	Robot	38.64	1925.76	9961.56	491.74	94.03	11.92	666.39	76.46	9.98	2.84	688.76	0.08
61706055	5mph SSS and Pedal tip ins from 35 and 55 mph, ph	06/23/17	-84	5250	EH1021LT10-HW	2WD	66.47	0.0	22.5	24.07	Robot	38.64	1925.76	9961.56	491.74	94.03	11.92	666.39	76.46	9.98	2.84	688.76	0.08

Appendix D: Built sheet for Ford F-150 test vehicle

KAN-000485 TX 9-NORMAL,NB,200485,GM092 10959 220161217 BLEND 8475 ULC CERT | CERT | CERT | U TRD | R RAMP | TX BUMP | C CAMP | BOOK | EXFL

1FTEW1EGX HKC32685 NB GU13

Ford
Go Further
ford.com

VEHICLE DESCRIPTION
F-150
2017 F-150 4X4 SUPERCREW
145" WHEELBASE
3.5L V6 ECOBOOST W/AUTO S/S
ELEC 10-SPEED AUTO W/TOW MO

EXTERIOR
INGOT SILVER
INTERIOR
MEDIUM GRAY CLOTH 40/20/40

HK **C32685**

STANDARD EQUIPMENT INCLUDED AT NO EXTRA CHARGE

EXTERIOR
- BOXLINK
- DAYTIME RUNNING LIGHTS
- EASY FUEL CAPLESS FILLER
- FOG LAMPS
- FULLY BOXED STEEL FRAME
- HALOGEN HEADLAMPS
- HEADLAMPS - AUTOLAMP (ON/OFF)
- LOCKING REMOVABLE TAILGATE
- MANUAL FOLD POWER MIRRORS
- PICKUP BOX TIE DOWN HOOKS
- REAR PRIVACY GLASS
- SPARE TIRE & WHEEL LOCK
- TOW HOOKS
- TRAILER SWAY CONTROL

INTERIOR
- 1TOUCH UP/DOWN DR/PASS WIN
- 60/40 FOLD-UP REAR BENCH SEAT
- A/C W/MANUAL CLIMATE CONTROL, SINGLE ZONE
- CRUISE CONTROL
- DUAL SUNVISORS
- MAP POCKETS- DRIVER & PASS
- OUTSIDE TEMP DISPLAY
- POWER LOCKS AND WINDOWS
- POWERPOINTS
- TILT/TELESCOPE STR COLUMN

FUNCTIONAL
- 4-WHEEL DISC BRAKES W/ABS
- CURVE CONTROL
- ELECT 4X4 SHIFT-ON-FLY
- FADE-TO-OFF INTERIOR LIGHT
- FAIL-SAFE COOLING SYSTEM
- HILL START ASSIST
- MYKEY
- OUTBOARD MNTD REAR SHOCKS
- PWR RACK AND PINION STEER

SAFETY/SECURITY
- ADVANCETRAC WITH RSC
- AIRBAGS - FRONT SEAT MOUNTED SIDE IMPACT
- AIRBAGS - SAFETY CANOPY SIDE CURTAIN
- CTR HIGH MOUNT STOP LAMP
- PERIMETER ALARM
- SECURICODE KEYLESS KEYPAD
- SOS POST CRASH ALERT SYS
- TIRE PRESSURE MONITOR SYS

WARRANTY
- 3YR/36,000 BUMPER / BUMPER
- 5YR/60,000 POWERTRAIN
- 5YR/60,000 ROADSIDE ASSIST

INCLUDED ON THIS VEHICLE	(MSRP)
EQUIPMENT GROUP 301A	2,150.00
•XLT SERIES	
•REAR-WINDOW DEFROSTER	
•8-WAY POWER DRIVERS SEAT	
•BOXLINK	
•REAR VIEW CAMERA	
•SIRIUS XM SATELLITE RADIO	
OPTIONAL EQUIPMENT/OTHER	
3.5L V6 ECOBOOST W/AUTO S/S	2,095.00
ELEC 10-SPEED AUTO W/TOW MODE	500.00
3.31 ELECTRONIC LOCK RR AXLE	420.00
7000# GVWR PACKAGE	
FRONT LICENSE PLATE BRACKET	NO CHARGE
SELECTSHIFT TRANSMISSION	
PRO TRAILER BACKUP ASSIST	
TRAILER TOW PACKAGE	895.00
MIRROR MAN FOLD W/POWER GLASS	
AUTO START/STOP	
23 GALLON FUEL TANK	
XLT CHROME APPEARANCE PACKAGE	1,695.00
.275/65R 18 OWL (A/S A/T)	
.CHROME STEP BARS	
.18" CHROME-LIKE PVD WHEELS	
TX BADGE	

PRICE INFORMATION	(MSRP)
BASE PRICE	$40,635.00
TOTAL OPTIONS/OTHER	7,755.00
TOTAL VEHICLE & OPTIONS/OTHER	48,390.00
DESTINATION & DELIVERY	1,195.00
TOTAL BEFORE DISCOUNTS	**49,585.00**
XLT MID DISCOUNT	**- 1,000.00**
XLT DISCT CHRM OR SPRT	**- 750.00**
TOTAL SAVINGS	**- 1,750.00**

RAMP ONE: CA5B
RAMP TWO:
FINAL ASSEMBLY PLANT: KANSAS CITY
METHOD OF TRANSP.: CONVOY
ITEM #: 52-T487 O/T 2
GM092 N RB 2X 745 000485 12 09 16

TOTAL MSRP $47,835.00

This label is affixed pursuant to the Federal Automobile Information Disclosure Act. Gasoline, License, and Title Fees, State and Local taxes are not included. Dealer installed options or accessories are not included unless listed above.

EPA DOT **Fuel Economy and Environment** Gasoline Vehicle

Fuel Economy
20 MPG combined city/hwy
17 city 23 highway
5.0 gallons per 100 miles

Standard Pickup Trucks range from 15 to 22 MPG. The best vehicle rates 119 MPGe.

These estimates reflect new EPA methods beginning with 2017 models.

You spend **$2,250** more in fuel costs over 5 years compared to the average new vehicle.

Annual fuel cost **$1,850**

Fuel Economy & Greenhouse Gas Rating (tailpipe only): 4 (1–10 Best)

Smog Rating (tailpipe only): 5 (1–10 Best)

This vehicle emits 453 grams CO_2 per mile. The best emits 0 grams per mile (tailpipe only). Producing and distributing fuel also create emissions; learn more at fueleconomy.gov.

Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle. The average new vehicle gets 26 MPG and costs $7,000 to fuel over 5 years. Cost estimates are based on 15,000 miles per year at $2.45 per gallon. MPGe is miles per gasoline gallon equivalent. Vehicle emissions are a significant cause of climate change and smog.

fueleconomy.gov
Calculate personalized estimates and compare vehicles

Smartphone QR Code™

GOVERNMENT 5-STAR SAFETY RATINGS

Overall Vehicle Score		★★★★★
Frontal Crash	Driver	★★★★★
	Passenger	★★★★★
Side Crash	Front seat	★★★★★
	Rear seat	★★★★★
Rollover		★★★★

Overall: Based on the combined ratings of frontal, side and rollover. Should ONLY be compared to other vehicles of similar size and weight.

Frontal: Based on the risk of injury in a frontal impact. Should ONLY be compared to other vehicles of similar size and weight.

Side: Based on the risk of injury in a side impact.

Rollover: Based on the risk of rollover in a single-vehicle crash.

Star ratings range from 1 to 5 stars (★★★★★), with 5 being the highest.
Source: National Highway Traffic Safety Administration (NHTSA).
www.safercar.gov or 1-888-327-4236

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01/20/2017

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Appendix E: Peer Review Feedback

"Laboratory Testing of a 2017 Ford F-150 3.5L V6 EcoBoost® with a 10 speed Transmission"

ANL APRF NHTSA Benchmark Report, March 2018

Peer Review by

Douglas J. Nelson, Ph.D., PE, Fellow SAE International
Professor of Mechanical Engineering
Virginia Tech
Blacksburg, Virginia 24061

The subject report is a comprehensive document of the extensive chassis dynamometer testing performed by the Advanced Powertrain Research Facility (APRF) at Argonne National Laboratory (ANL, or Argonne). The purpose of the benchmark testing is to evaluate the efficiency and energy consumption of the advanced technologies in this vehicle, and provide quality data to support the Corporate Average Fuel Economy (CAFE) modeling and validation activities within NHTSA. The testing is not focused on fuel economy certification testing, however certification results are appropriately used to validate the benchmark testing.

The report reviews and documents laboratory facilities, methods and instrumentation used to generate the test results. ANL has world-class vehicle testing facilities and personnel in the APRF. The equipment, test methods and quality control are designed to produce accurate and reliable data for energy consumption.

The goals of the study are to produce a robust data set that can be used for model generation and validation of fuel consumption for the specific technologies present in this F-150 vehicle. The test plan is appropriately set up to first produce standard drive cycle certification data for validation of the test results, and then test specific sub-systems and off-cycle conditions. Specific attention is paid to thermal conditions, including ambient conditions, cabin temperature control, and transient powertrain warm-up. Powertrain thermal conditions and cabin heating/cooling are particularly important for accurately predicting fuel consumption from models, and also to develop new technologies to address this facet of energy consumption.

The Ford F-150 test vehicle used in this study is one of the highest volume production vehicles in one of the largest market segments (full size pickup trucks) in the US. The specific vehicle configuration tested has a down-sized and turbocharged engine using both direct injection (DI) and port fuel injection (PFI), engine idle stop (or start/stop) capability, active grille shutters, and a 10 speed transmission using skip shift. These advanced powertrain technologies are combined with an aluminum intensive body for weight savings to provide improved fuel economy. Many of these new powertrain features are expected to supplant previous technologies, in part to meet future CAFE standards.

The test results presented in the report are documented to be of high quality and repeatability. The very broad range of tests serve to characterize each of the features of the powertrain mentioned above, along with transmission shift mode (normal, sport and tow/haul), effect of fuel anti-knock index (AKI or octane), and vehicle weight loading (such as cargo or towing).

The individual tests and results are well documented using figures and tables in the body of the report, but the real value from testing is for component modeling using the detailed data logs that will be available. The parameters that are recorded from this non-invasive instrumentation are sufficient to characterize the component control, shift strategies and torque converter clutch lock-up behavior, decel fuel cutoff, and grille shutter position under many different conditions. Detailed, often invasive (and expensive) instrumentation of intermediate torque values (such as across a torque converter) are not required for model development of existing components like transmissions or torque converters. The details of each component operation as documented by the data is much more useful for model fidelity and control strategy emulation.

The bulk of the testing results are carefully reduced down to energy consumption as a function of each of the parameters investigated from the test plan. These parameters include; drive cycle, ambient temperature with cabin temperature control, powertrain initial conditions (cold start vs hot start), fuel AKI, transmission shift mode, engine idle stop enabled, performance maneuvers, and others. The report shows how component operation, such as engine load and speed, DI vs PFI split, and transmission gear, contribute to the fuel used for vehicle operation. This detailed analysis allows the test data to be properly applied to model development and validation.

The report also provides powertrain efficiency results based on SAE J2951 positive cycle energy output relative to fuel energy input. Fuel economy alone does not determine why a particular test used more or less fuel. For example, a US06 cycle generally has low fuel economy. The powertrain efficiency analysis reveals that the engine operates at relatively high thermal efficiency, and the fuel consumption is due to the high vehicle energy output at the wheels for the US06 cycle. Powertrain efficiency necessarily evaluates full vehicle level results, but the changes in powertrain efficiency as a function of each test condition is very useful in identifying component level technology behavior for model validation.

Overall, this report clearly documents the energy consumption behavior of the technologies employed on this Ford F-150 vehicle. The report is well organized, and accurately documents the results from the test program. The detailed quality data generated as a result of this controlled laboratory testing should form the basis of robust models for technology evaluation in the CAFE program.

ANL APRF NHTSA Benchmark Testing of MY 2017 Ford F150

Summary Report

Prepared by Giorgio Rizzoni (see bio in Appendix)

1. Test Vehicle and Lab setup

1.a *Please comment description of laboratory, instrumentation approach, and APRF certification testing. More specifically, your views of the laboratory facilities and equipment utilized, relative to other facilities. Is there any need to improve on the facilities or methods employed? If so, why?*

Argonne National Lab (ANL) has operated an Advanced Powertrain Research Facility (APRF) for some 20 years. This reviewer is quite familiar with the operation and characteristics of the APRF, having served as an Associate Technical Team Member of the Vehicle Systems Analysis Technical Team of the U.S. DRIVE Partnership between 2013 and 2016. During this time, I had the opportunity to participate in numerous program reviews of the work done by ANL-APRF in characterizing and evaluating the fuel economy, energy efficiency and emissions of a number of vehicles, mostly with focus on alternative fuels and powertrains. During the course of these reviews, it became apparent that the test capabilities and instrumentation of the APRF are of the highest quality, and far exceed the minimum requirements for certification testing. The four-wheel-drive chassis dynamometer is operated in an environmental chamber capable of low- and high-temperature testing, and the available instrumentation permits both non-intrusive and intrusive testing to evaluate not only the fuel economy and emissions of the vehicle, but also to perform distinct and specific tests to evaluate the energy efficiency and power consumption of specific subsystems and components in the vehicle. In addition, the APRF team has developed considerable software analysis capabilities that allow the team to present results in comprehensive and carefully thought-out graphical and tabular forms. In my 30+ year career as an automotive researcher, I have not come across a public-domain test facility of this kind that matches the capabilities of the APRF. The work presented in this report is of the highest quality.

1.b *Please comment on the test plan and its appropriateness to the goals of the study. Are there areas needing improvement, or not? If so, why?*

The test plan is quite comprehensive and far exceeds the minimum requirements of certification testing. I have no suggestions for further improvement.

1.c *Please comment on the specification of the test vehicle(s). How representative are they of current and future technology trends? Why?*

The vehicle tested in this report represents a clear trend in today's light-duty truck offerings, coupling a downsized, boosted, port- plus direct-injection engine coupled to a 10-speed automatic transmission. Ford has been a leader with their "EcoBoost" technology for boosted engines, and the current F150 offering represents best-in-class technology, as clearly demonstrated by the considerable fuel economy improvements of the V6 EcoBoost technology with 10-speed transmission when compared to the more traditional naturally aspirated V8 with 10-speed transmission. The results presented in the report clearly support these statements and suggest that the technologies embodied in the current generation Ford F150 are representative of future trends for conventional (i.e.: non-hybrid) powertrains.

2. Test Results and analysis

2.a Please comment on the quality of the tests conducted. Are they representative of how vehicle should be evaluated? What other tests within Level 1 instrumentation do you recommend?

The tests conducted in the study were comprehensive, and representative of a meaningful number of test conditions including certification tests, and of additional tests representing different fuels and environmental conditions.

2.b Please comment on the presentation of the individual test results and analysis. How else would you like to see the results? Do you recommend other parameters to be logged and presented from Level 1 instrumentation?

The graphical and tabular summary of the test results give a clear and concise representation of the results. I made some recommendations on minor improvements that I believe have been incorporated in the final report.

2.c Please comment on the energy analysis conducted?

The energy analysis, including both fuel economy and powertrain efficiency, is comprehensive and includes consideration of hot- and cold-start conditions, and of different vehicle modes of operation (accel/decel, cruise, stop), while also presenting the distribution of operating points in the engine speed-load plane, and an analysis of transmission operation and its effect in fuel economy.

2.d Please comment on the powertrain efficiency (J2951) analysis? Do you think this represents technology effectiveness appropriately in terms of full vehicle testing?

The J2951 analysis is clearly presented, and reflects the comments already made in *2.c* above.

3. General Comments

3.a Please comment on the organization, readability, accuracy, and clarity of the report

As part of the peer review process, I took the time to carefully review the report, and made a number of editorial suggestions that, in my opinion, further enhanced the already excellent quality of the report. I believe that the final product is a well-organized, readable, clear and accurate report.

3.b Please provide any other comments you may have on the Level 1 testing

The additional analysis presented in the report on: transmission and torque converter operating strategy (including three different transmission operating modes); vehicle performance (acceleration and passing maneuvers); start-stop operation; vehicle fuel injection strategies (PFI-DI); fuel cut-off strategies; cycle thermal test conditions; comparison of fuels with different AKI ratings; and active grill shutter operation further enhances the quality and completeness of the report.

DOT HS 812 520
July 2018

U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

13614-070218-v2a