Advanced Vehicle Performance Assessment

Michael Duoba and Henning Lohse-Busch

Abstract In order to provide answers about the performance of vehicles driven by electrified drivetrains, appropriate test procedures must be developed that are robust and compatible with the technology. In IEA-HEV-Task 17, these results are presented from vehicles tested at the Argonne National Laboratory Advanced Powertrain Research Facility under direction from the U.S. Department of Energy's Vehicle Technologies research portfolio. Chassis dynamometer testing with controlled conditions was employed and included adoption of sophisticated instrumentation, research techniques and considerable staff expertise in testing advanced automotive vehicle technologies. This process was going on for several years, including BEV and PHEV tests with a Nissan Leaf, a PHEV-converted Prius as well as a Chevy Volt (based on the reporting year 2010). This chapter provides comparisons between the different electrified vehicles in terms of their principal configurations and operating modes, charge-sustaining and electric-only and highlights the major findings.

The focus of this section is to provide a review of current state-of-the-art production vehicles (reporting year 2010) with advanced electrified powertrains. The technologies covered are the HEV, PHEV, and the BEV. Vehicles were production versions instrumented with various degrees of signals (some invasive, others minimally invasive) and tested on a chassis dynamometer according to accepted practice and research-oriented procedures to highlight technology capabilities.

Results are presented from vehicles tested at the Argonne National Laboratory Advanced Powertrain Research Facility (Fig. 1), under direction from the U.S. Department of Energy's Vehicle Technologies research portfolio. Chassis

M. Duoba (✉) · H. Lohse-Busch
Vehicle Systems Research, ANL—Argonne National Laboratory,
9700 South Cass Ave, Lemont, IL 60439, USA
e-mail: mduoba@anl.gov

H. Lohse-Busch
e-mail: hlb@anl.gov

M. Nikowitz (ed.), *Advanced Hybrid and Electric Vehicles*,
Lecture Notes in Mobility, DOI 10.1007/978-3-319-26305-2_4

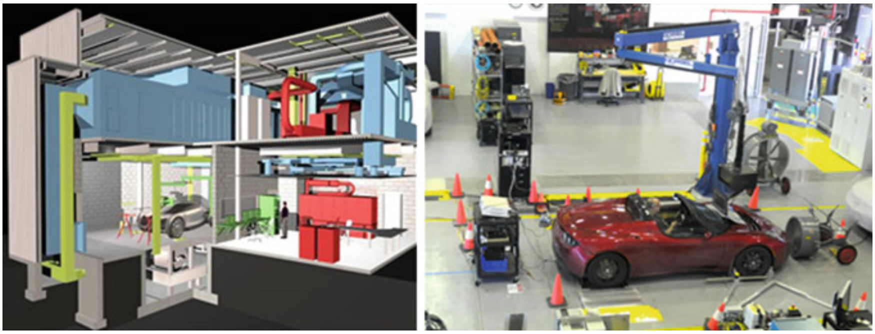

Fig. 1 Advanced powertrain research facility

dynamometer testing with controlled conditions was employed and included adoption of sophisticated instrumentation, research techniques, and considerable staff expertise in testing advanced automotive vehicle technologies.

ANL, a science and engineering research national laboratory, has five main areas of focus. These goals, as stated by the U.S. DoE in 2008, consist of: conducting basic scientific research; operating national scientific facilities; enhancing the nation's energy resources; developing better ways to manage environmental problems and protecting national security.

1 Vehicle Technology Introduction

Five vehicles are highlighted, and the research data and analysis are provided. The highlighted vehicles included Toyota's third-generation (G3) Prius HEV, the Hyundai Sonata HEV, the Ford Fusion HEV, the Chevrolet Volt PHEV, and the Nissan Leaf BEV. More details are shown in Table 1.

Key data of these vehicles are shown in Sect. 2.4 (Current status of low-carbon vehicle technologies (2013–2015)).

1.1 *Toyota G3 Prius HEV*

The Prius is a "power-split" hybrid configuration that couples the engine through a power-split transmission with two motors (sometimes called an "electric continuously variable transmission") that keeps the engine always running at the best load points for all driving conditions. The power-split also allow seamless start-stop and electric traction assist without state changes or weak operation zones that could be detrimental to drive quality (such as torque delays or abrupt torque interruptions from shifting gears or states).

Table 1 Vehicle specifications

					
Model	Toyota Prius	Hyundai Sonata	Ford Fusion	Chevy Volt	Nissan Leaf
HEV/PHEV/BEV	HEV	HEV	HEV	PHEV	BEV
Model year	2010	2011	2010	2012	2012
Curb weight (kg) (lb)	1380	1600	1690	1720	1520
	3040	3460	3720	3780	3350
Passenger/cargo volume (cu. ft.)	94/22	104/11	100/12	(N/a)/11	98/15
Powertrain configuration	Power-split	P2 with BAS	Power-split	Multi-mode w/power-split	Single gear
Rechargeable kWh[a]	N/a	N/a	N/a	10.3	21.2
Max motor/battery kW[a]	26	35–40	25	111	90

[a]Derived from dynamometer testing

As a result of years of continuous refinement of its dedicated hybrid platform, the Prius is the benchmark for HEVs efficiency since its introduction at the turn of this century. The third generation of the Toyota Prius features an impressive achievement of 50 Miles per Gallon (MPG) combined city and highway on its U.S. EPA fuel economy label (92 gCO_2/km in the new European cycle NEFZ). For the third generation (starting in model year 2010), many systems were refined for lower powertrain losses, and some additional features were added to reduce losses encountered in hot and cold temperatures. More details of these are presented in the following chapters of this report.

1.2 Hyundai Sonata HEV

Whereas many of the full HEVs produced in the past 10 years used the power-split powertrain configuration, the Hyundai Sonata hybrid (starting in model year 2011) is a full hybrid with the "P2" architecture, with an added belt-alternator-starter (BAS) motor. There are many opportunities for cost savings with the "P2" hybrid because the drive motor(s) are smaller and the transmission is similar to existing supply lines. The focus of the analysis will be to compare the hybrid Sonata's performance and efficiency with that of a similar sized, power-split full hybrid (Ford Fusion hybrid).

1.3 Ford Fusion HEV

The Ford Fusion hybrid is a good example of a power-split mid-sized HEV that can be compared to the Hyundai Sonata hybrid to highlight the strengths and differences between the two fundamental design approaches. Data were taken from a model year 2010 vehicle. The efficiency in transient stop-and-go driving is exceptional—of the power-split hybrids available at the time of this report, the Fusion hybrid allows the highest electric-only driving speeds.

1.4 Chevy Volt PHEV

The Chevy Volt is an important example of PHEV technology. Labeled as an E-REV by the manufacturer (GM), the vehicle still matches the definition of a PHEV and is tested according to the same procedures as any other PHEV. The novel power-split architecture allows for driving in various modes. Having two fundamental modes, this vehicle can be compared to the Prius in sustaining mode and to a BEV (Nissan Leaf) in depleting (electric) mode.

1.5 Nissan Leaf BEV

The Nissan Leaf is a good example of a dedicated EV in a similar compact class as the Volt and Prius. (Although the EPA classifies the Prius and Leaf in the same class as the Sonata and the Fusion, the Leaf, Prius, and Volt are more similarly sized.) The Leaf has all the functionality of a typical sedan but is solely powered by the Li-ion battery pack. As expected, the powertrain is fairly simple and will be an excellent vehicle for evaluating electric driving.

2 HEV Results (Sonata, Fusion, and Prius, CS Mode Volt)

This section highlights the system-level configuration differences among the hybrids (Sonata, Fusion, and Prius) and the charge-sustaining operation of the Volt.

2.1 Introduction to Configurations

There are many ways to couple an engine to one or more e-motors and a set of gears and/or clutches to provide the desired torque and speed at the wheel for driving. The engineering challenge is to use the engine, motor(s), and battery most efficiently. Engine speeds are typically from 600 to 6000 RPM (note that engines to not operate below idle speed). Motor speeds typically spin much faster than engines and can provide positive or negative torque while spinning from −14,000 to 14,000 RPM. A transmission with discrete gear sets can provide a number of ratios to choose from, and one with planetary gears can be used in combination with other planetary gear sets to provide several discrete gear ratios or configured as a power-split device, where the input or output torque is split and the engine speed and speed of the motors are interrelated but with constantly varying ratios. Typically all powertrains have some final drive (FD) gear reduction in order to lower these speeds down to wheel speeds (with high torque).

Figure 2 depicts several simple hybrid powertrain configuration diagrams. The designation “P1” describes the position of the main traction motor. P1 hybrids do not have electric-only propulsion capabilities because of the inability to clutch out the engine. The motor in a P2 configuration can drive the vehicle with the engine

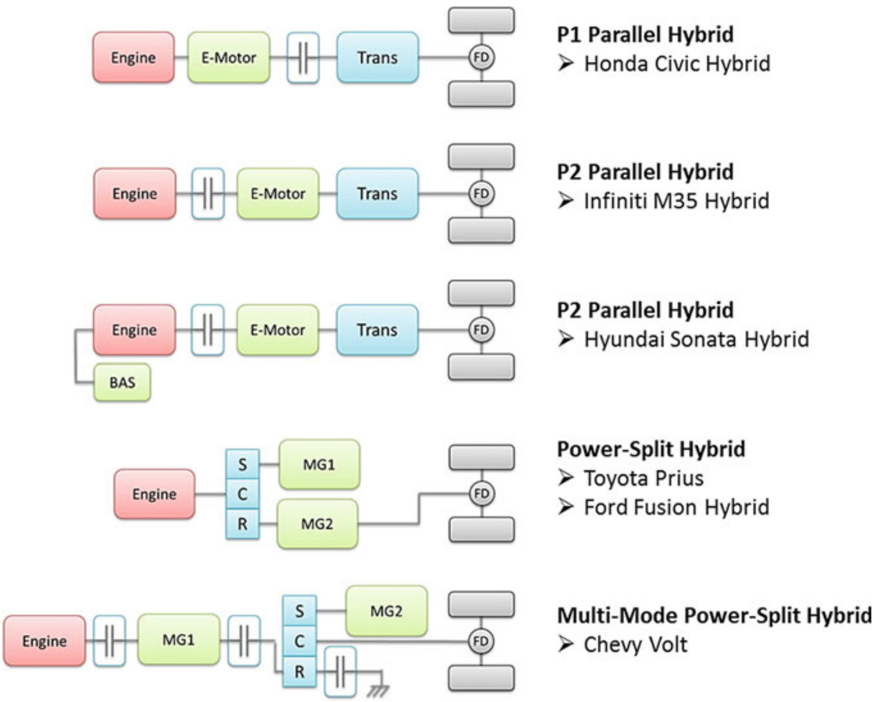

Fig. 2 Overview about Hybrid powertrain configurations

stopped; however, the torque to start the engine must come from the motor and/or by reflecting vehicle inertia back to the engine (and, as a result, cause interruptions in torque to the wheel). By adding a BAS, the engine can be started while disconnected to the transmission. Also, adding a BAS allows the engine to run in a series mode, which provides more efficient low-speed cruising and better management of battery energy levels. The conventional power-split uses a single planetary gear with two motor-generators to allow infinite driving ratios for all driving conditions and engine start-stop capability. However, once again, the engine torque is always in communication with the wheel, and so engine start-stop must be accomplished with torque pulsation countermeasures to ensure acceptable drivability. Another limitation unique to the simple power-split configuration is that electric-only driving can be limited. Components may over-speed when the engine is at zero speed and the vehicle is at high speed. To remedy this limitation, the engine must run above a set vehicle speed and under coast, or, during braking, the engine must remain spinning (but without combustion) until the vehicle speed is below a safe set point.

2.2 Fuel Economy Results

One of the first observations distinguishing the capabilities of the various HEV powertrain configurations is their variations in fuel economy performance, depending upon type of driving. Using the US EPA's adjusted label results to better indicate real-world performance, both the urban and highway MPG results are shown in Fig. 3 for the vehicles highlighted in this report. Typical conventional vehicles achieve higher MPG in the highway rating (in the range of 1.3–1.5 times higher) than the urban rating. The Sonata hybrid with its fixed gear transmission also follows the same trend as conventional vehicles (higher highway MPG) but to a lesser degree (1.14 times). In contrast, the Prius and Fusion power-split hybrids have the opposite relationship. The highway MPG of the Prius is 0.94 times the urban MPG, and the highway MPG of the Fusion is only 0.88 times the urban MPG.

2.3 Engine on-off Capability

Many factors contribute to the ratio of highway-to-urban MPG. For full hybrids, one important feature is the engine can be left off for low-power driving, thereby increasing average engine efficiency when the engine is on. For deceleration and some cruise periods, the engine can remain off until higher demands better suited for high efficiency are needed in the cycle. In Fig. 4, an excerpt of the Urban Dynamometer Driving Schedule (UDDS) cycle is shown for the Prius and Sonata hybrid. Similar engine operation is seen in the stop-and-go driving, mostly under 65 km/h (40 mi/h).

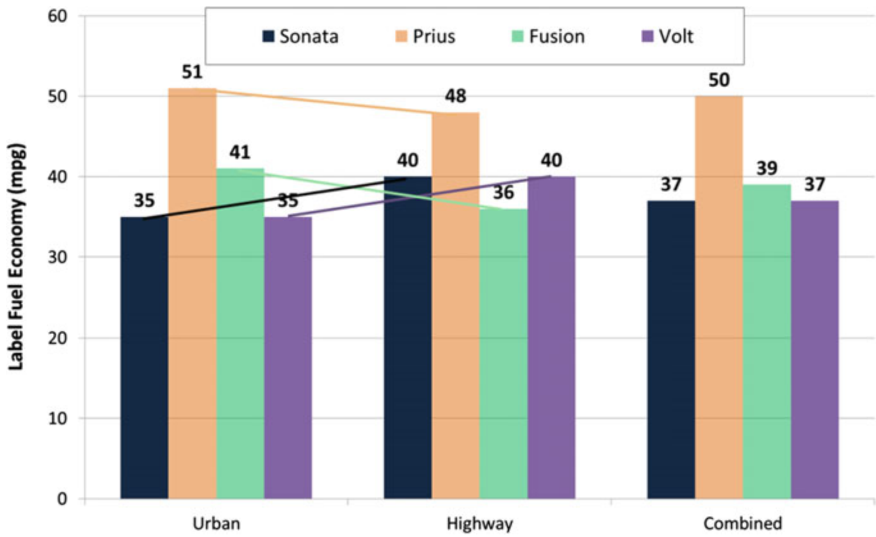

Fig. 3 Comparison of urban and highway MPG ratings

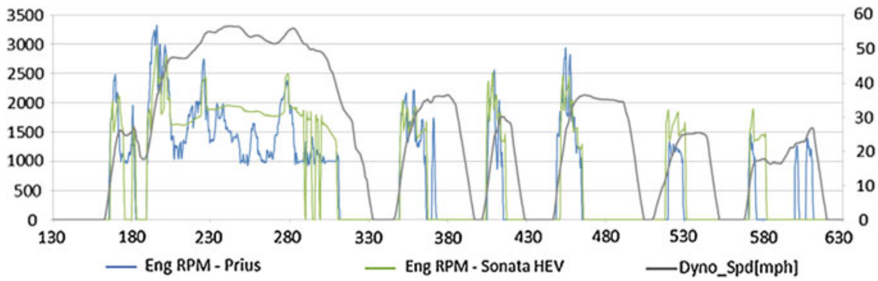

Fig. 4 Prius and Sonata HEV engine operation comparison (RPM by time (s))

In contrast, however, are the particular hybrid's design capabilities to keep the engine off at higher vehicle speeds. The Sonata configuration does have a benefit of shutting down the engine at virtually any vehicle speed. Thus, during low power periods in the highway cycle, the Sonata does have an efficiency advantage. The Fusion and Prius power-split configurations must keep the engine spinning if the vehicle speed is above 55–65 km/h (35–40 mi/h). This is seen in Fig. 5, which compares the Fusion engine speed to the Sonata's. Notice there are several blocks of time in which the Sonata engine is not being used and is not spinning.

A bar graph indicating the relative percentage of time the engine is off during the urban and highway cycles is shown in Fig. 6. The percentages from hybrid to hybrid for the city cycles are not very different (roughly 60–65 %). However, the

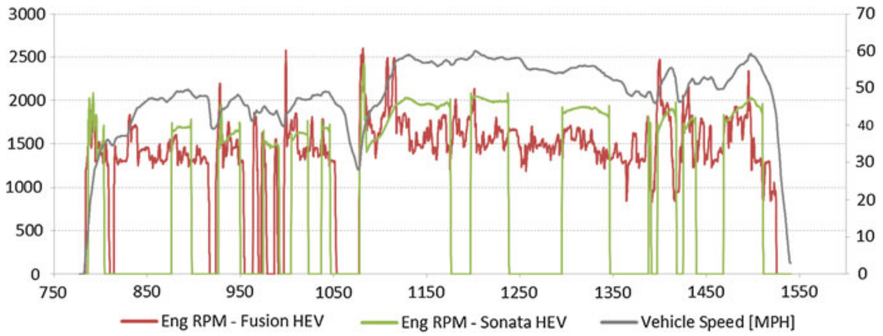

Fig. 5 Fusion HEV engine speed comparison—note engine-off at high vehicle speed

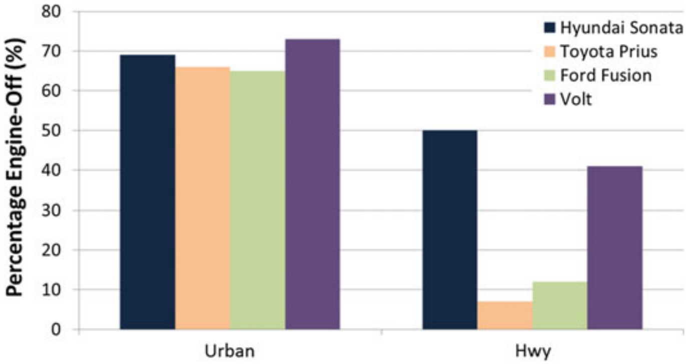

Fig. 6 Engine-off time comparisons

Sonata is able to keep the engine off for 50 % of the highway cycle compared to only 5–12 % for the other remaining hybrids, with the exception of the Volt.

In the urban cycle, the Volt powertrain mostly runs in series-hybrid mode. The engine comes on to charge the battery and meet road demand. However, in contrast to the Prius, which will start the engine for every "hill" in the UDDS, the Volt only starts 9 out of the 18 hills in the cycle. This strategy can be seen in Fig. 7, which shows a plot of the Volt's engine speed—note that the engine comes on less frequently and, in some places, remains on during deceleration. The engine does not, however, stay on below ~30 km/h (20 mi/h) (perhaps GM engineers wanted to reduce driving noise at speeds below ~30 km/h (20 mi/h)) else this is a matter of driving noise acceptance).

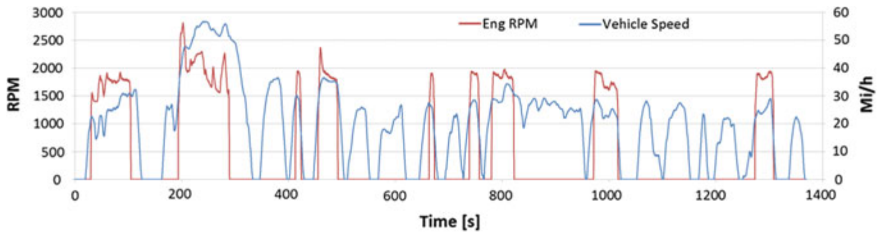

Fig. 7 Volt engine operation—UDDS

2.4 Engine Utilization

Another factor affecting efficient operation is the engine operating points. The plots in Fig. 8 are histograms of engine speed for the Prius, Fusion, Sonata, and Volt in hybrid mode. The Prius engine is optimized for low-RPM efficiency, and so it has the most RPM counts in the 1000–1250 RPM range. The Fusion has the most RMP counts in the 1250–1500 RPM range, which is a much higher range than all the other bins. The Sonata is less capable of running at fixed RPM, and so there is some spread in RPM range. The highest bins are 1500–1750 RPM in the urban cycle and 1750–2000 RPM in the highway cycle. The Volt has a high peak at 1750–2000 RPM and lower peaks on the highway cycle.

2.5 Regen

During stop-and-go driving, a vehicle has a good opportunity to recapture kinetic energy through the electric drive system (termed “regenerative braking” or “regen”). Revisiting the earlier point of hybrid urban/highway fuel economy ratio, the effect of recapturing kinetic energy during the cycle is significant. More specifically, as the vehicle captures more energy during braking, it can achieve increasingly higher overall efficiency. One interesting observation about the vehicles discussed in this section is the Volt has a much higher motor and battery capability. Thus, there is a higher potential to capture more regen in the Volt.

Looking at the regen in the aggressive US06 drive cycle for both the Fusion and the Volt, the differences are evident. The total road load power is plotted with the battery power in both Figs. 9 and 10). In the Fusion, road power peaks near 40 kW, but regen levels peak at ~22 kW. With a similar road power (same 1800 kg (4000 lb) test weight), the Volt leaves less regen power untapped by peaking its regen power at ~30 kW.

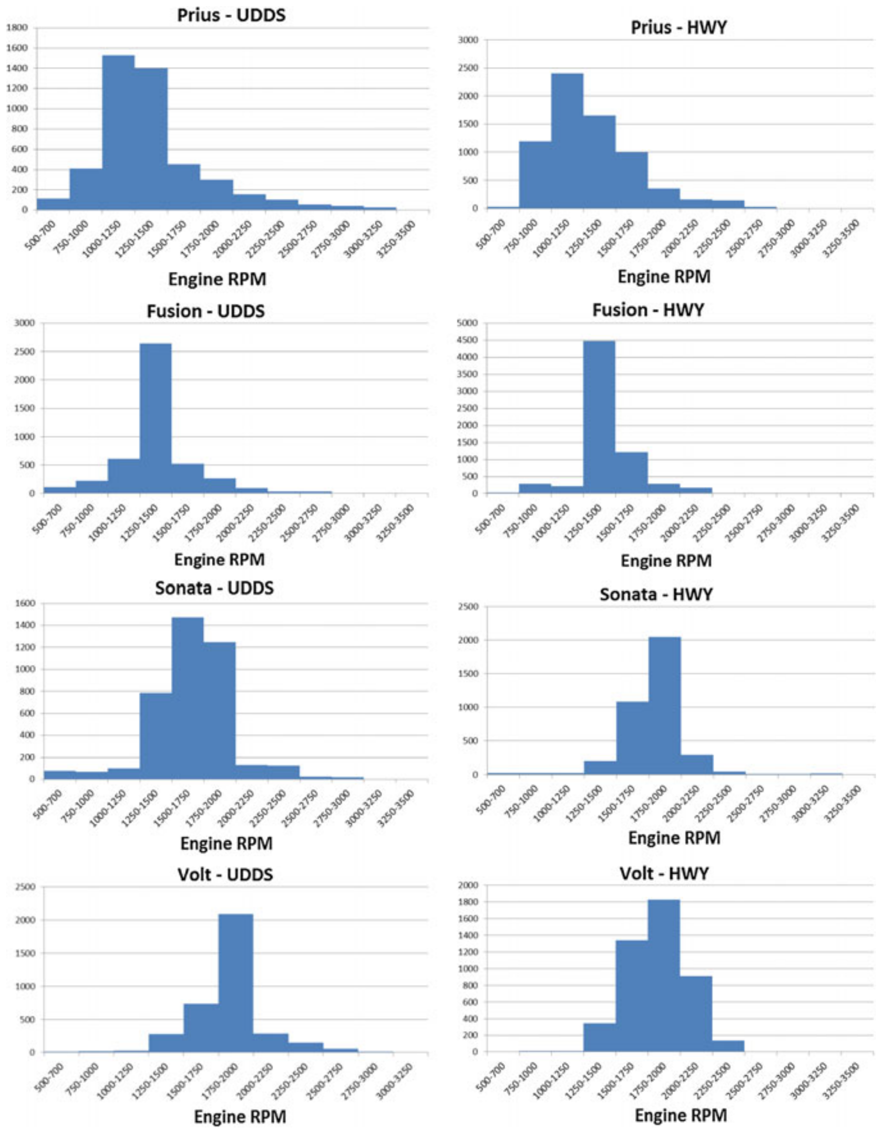

Fig. 8 Engine RPM histograms for Prius, Fusion, Sonata, Volt Hybrids

2.6 Improving Efficiency with Improved Thermal Management

As U.S. fuel economy ratings have switched to include hot and cold test temperatures, the opportunity for more fuel savings in efficient A/C designs and quicker

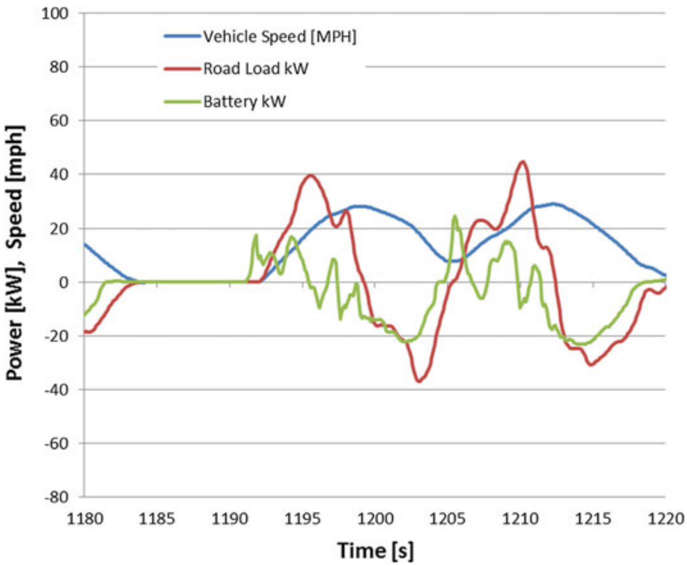

Fig. 9 Fusion battery power

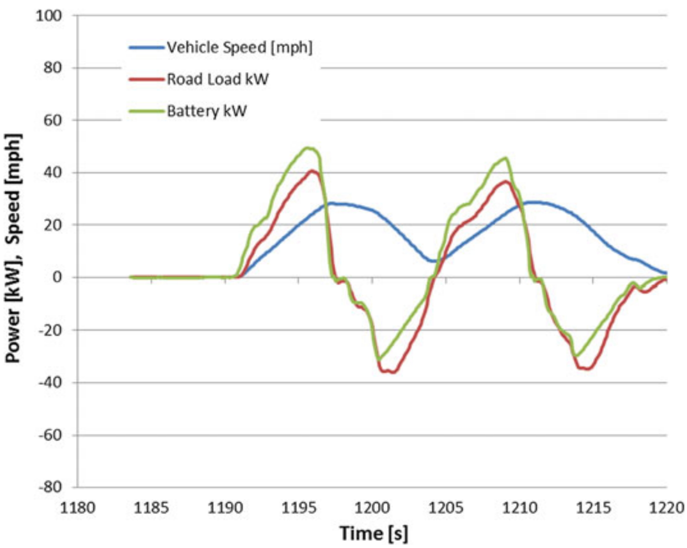

Fig. 10 Volt battery power

warm-up have prompted manufacturers to add new hardware and controls. The Prius has a special coolant circuit that warms engine coolant with exhaust heat during warm-up. The Prius also has an advanced A/C design that Toyota claims will reduce compressor power consumption by 11–24 % [1].

The Sonata has a transmission oil heat exchanger to take heat from the coolant and warm up the transmission oil. Testing the effects of these particular features is challenging because differences between cold and warm operation are obfuscated by many differences in operation and battery utilization during initial start-up. Testing is ongoing and is expected to help overcome some of the current challenges.

3 Electric Vehicle Operation Comparison (Chevy Volt in EV Mode and Nissan Leaf BEV)

3.1 Configuration Comparison

Electric drive powertrains may be the simplest with regard to propulsion component configuration. An e-motor typically has a wide speed range and does not require a launching mechanism (an engine cannot launch a vehicle from stop with fixed gearing without a component or feature that can provide torque at the wheel at zero speed). The Nissan Leaf has a single motor with a single fixed gear. By contrast, the Volt has two e-motors and two electric-only drive modes that can be controlled to provide the best torque or power capabilities at the highest efficiency.

3.2 Operational Differences

The first Volt mode is a one-motor mode. The second mode shares the load between two motors. The Volt uses primarily the first mode, but for part of the time, it uses the second, two-motor mode at speeds above 70 km/h (45 mi/h). However, there are times when the second mode is used at lower speeds. Figure 11 is a plot of vehicle tractive load versus vehicle speed; operation of the second mode is shown in red. Cruise loads at and around highway speeds show use of the two-motor mode and during some accelerations through 15–45 km/h (10–30 mi/h).

3.3 Battery Utilization and Recharge Efficiencies

Taking a well-defined look at various points on the entire energy pathway of a plug-in vehicle helps bring focus with respect to defining efficiencies. “Charger Efficiency” may actually mean several things to various researchers. Figures 12 and 13 show the measured electrical energy flows schematically. The test measurement arrangement for both the Volt and the Leaf did not include a measurement point between the Electric Vehicle Supply Equipment (EVSE) and charger—therefore,

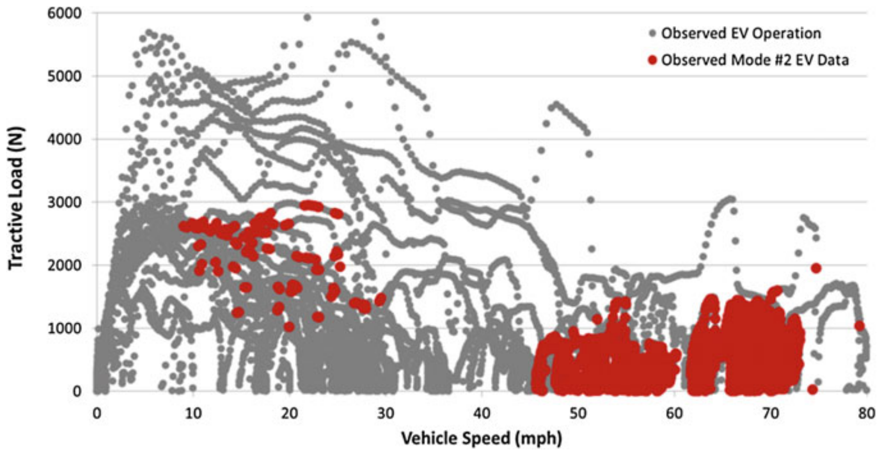

Fig. 11 Volt operation in "Mode 2" electric-only mode

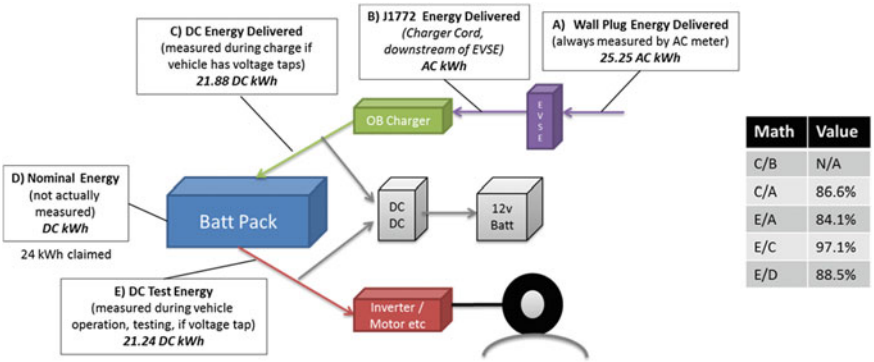

Fig. 12 Quantifying discharge energy, recharge energy, and efficiency—Leaf

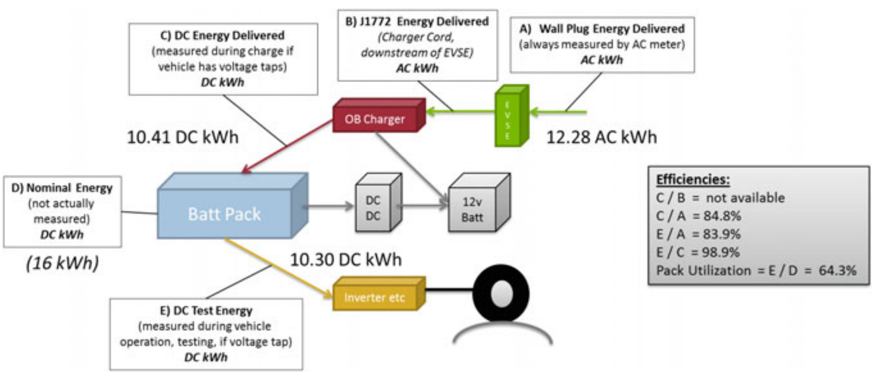

Fig. 13 Quantifying discharge energy, recharge energy, and efficiency—Volt

Table 2 Dynamometer settings, energy consumption and cycle energy for Volt and Leaf

Specification	Volt	Leaf
Test weight	4000	3750
A (lbf)	28.66	33.78
B (lbf/MPH)	−0.0132	0.0618
C (lbs/MPH^2)	0.0202	0.0228
	Volt (Wh/mi)	Leaf (WH/mi)
UDDS	211.65	199.40
HWY	223.72	231.90

only data on AC energy into and DC energy into the pack were available. Note that the efficiency calculation from point A to C includes losses in the EVSE and standby losses of the vehicle during recharge. Sometimes, researchers need to relate the DC watt-hours consumed during driving to the AC watt-hours supplied by the electric grid. This analysis requires the use of the ratio of E to A (not to be mistaken with C to A).

The Leaf and Volt have similar efficiencies at their respective measurement locations. Note to maximize range, the Leaf uses over 88 % of its nominal capacity. However, because a PHEV retains some battery energy for charge-sustaining operation, in terms of pack utilization (the calculation of E/D), the total used energy in the Volt's battery pack is lower than the Leaf's.

3.4 Electric Powertrain Efficiency Comparisons

Table 2 lists the test weight and "target" road load settings for the Leaf and Volt with the UDDS and HWY DC Wh/mi. The data show that the Leaf consumes less DC battery energy per mile on the UDDS than the Volt, but the opposite is the case for the HWY cycle.

There are two competing forces that determine EV watt-hour consumption rate. One is the differences in forces (and energy) required to drive the cycle, and the other is the efficiency at which the drive system can provide propulsion (and recuperate energy during regenerative braking). The Leaf has the advantage of being lighter (and thus less energy is needed to drive stop-and-go), but the Volt has the advantage of having lower driving losses at all speeds (all three terms are lower in the Volt). Closer examination of the consumption rates will require an examination of efficiency.

In Table 3, the tractive energy to drive the vehicles on both cycles is shown. These energies are measured at the chassis dynamometer surface, which is downstream of losses incurred in the driven tire. They are broken out by direction—"Pos Wh" is the integrated positive force at the dynamometer (mostly during acceleration), and "Neg Wh" is the integrated negative force (mostly during braking). All the battery energy going into and out of the battery is tracked during the time steps

Table 3 Energy consumption and cycle energy for Volt and Leaf

	Dynamometer		Battery		Efficiency	
	Pos Wh	Neg Wh	Wh-Traction	Wh-Braking	Traction (%)	Braking (%)
Leaf UDDS	190.7	−102.2	259.6	−65.8	73.5	64.4
Volt UDDS	180.2	−113.5	280.5	−67.0	64.2	59.0
Leaf HWY	173.1	−22.8	247.0	−14.1	70.1	61.8
Volt HWY	143.3	−28.4	244.1	−14.9	58.7	52.5

of positive and negative forces. They are also listed in Table 3. Although the total tractive energy required to drive the Leaf on the UDDS is higher, the amount of energy consumed is lower. The Leaf is more efficient at using DC energy to propel the vehicle through the UDDS cycle. However, the Volt's advantage in lower propulsion energy to drive the HWY cycle is more pronounced. This is consistent with the fact that the Volt dynamometer road coefficients are lower, and these forces dominate in the HWY cycle. The positive and negative conversion efficiencies (DC energy to drive energy) of the Leaf and Volt are also shown in Table 3.

4 Auxiliary Loads HEV, PHEV, and BEV

4.1 Standby Auxiliary Losses

All of the vehicles discussed in this report take all power for operating low-voltage electronic hardware from the high voltage bus. The amount of standby power can have a significant impact on overall efficiency, especially for cycles with a low average speed. This load includes fans, pumps, actuators, lights, and computers. By looking at the output power flowing out of the main DC bus during a stop near the end of the UDDS cycle, the standby loads can be quantified. The standby losses for several test vehicles are shown in Fig. 14.

Earlier generations of the Prius had multiple management computers in different locations running the powertrains many subsystems. They have since mostly been consolidated, and this could be one of the reasons for the much lower standby power. Compared to the HEVs or Volt PHEV, BEVs do not have as many subsystems to monitor and be powered during standby and therefore could be the reasons for the low losses seen in the Leaf.

4.2 Hot and Cold Temperatures

There are standard temperature conditions for most dynamometer testing. However of great interest in advanced technology vehicle are the effects of hot and cold

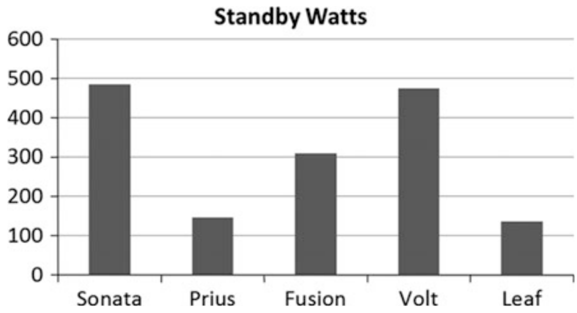

Fig. 14 Standby electrical loads

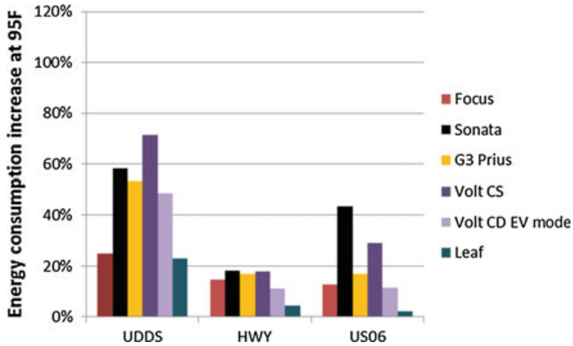

Fig. 15 Hot temperature consumption penalties for various vehicles

temperatures on the efficiency of various types of vehicle technologies. A number of vehicles were testing hot at 35 °C (95 °F) with a solar load of 850 W/m^2 and the vehicle air conditioner in operation and again cold at −7 °C (19 °F) with the vehicle heater in operation. The various consumption penalties are compared in Figs. 15 and 16. Added to the vehicles in this study as a baseline was a conventional model-year 2004 Focus.

The hot temperature penalty does not include the initial temperature cabin temperature pull-down. Most drivers are aware of the penalty in fuel consumption associated with operating air conditioning in a conventional vehicle—especially for stop-and-go driving. But the penalties are much more profound for most of the vehicles studied in the report. The Prius and Volt have consumption penalties of over 50 %.

During cold testing, two UDDS cycles are run, the first initiated after an overnight rest at cold conditions and the second initiated 10 min after the first; results from both are presented in Fig. 16. Of profound significance is the fact that, in the Ford Focus, the additional losses from running at cold temperatures (with the heater) have a relatively low impact on fuel consumption; however, the other vehicles suffer very high penalties under the same operating conditions. HEVs are not able to fully utilize the hybrid function until the cabin and, to some extent, the battery are at operating temperature. Notice the consumption penalties are lower in the second UDDS cycle (after warm-up). The penalties are higher for the Leaf and

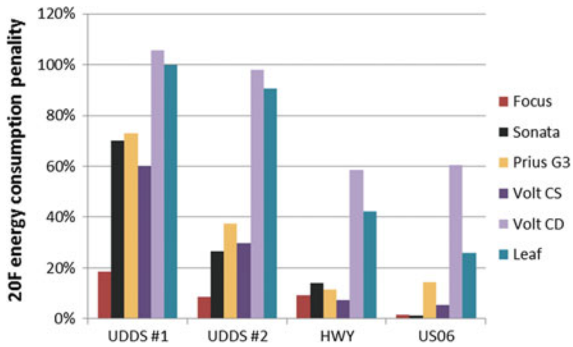

Fig. 16 Cold temperature consumption penalties for various vehicles

the Volt running electric-only because the heat comes from the battery, not from engine waste heat. As cycle speeds increase, cabin heat power becomes less significant to total energy use and so the penalties are lower. However, the Volt in electric only (Charge Depleting (CD)) and the Leaf have high consumption penalties for all the cycles run. These data suggest that BEV manufacturers should consider equipping vehicles destined for climates with cold winters with alternative technology (e.g., a fuel-fired heater) to avoid an infrequent but likely situation in which a vehicle is stranded without power or heat in a snowstorm. The range of a BEV range could drop by one-half that expected for typical driving if there is an extreme traffic jam during inclement winter weather.

5 Conclusions

This report shows various examples of state-of-the art HEVs, PHEVs, and BEVs. Comparisons are drawn between vehicles in terms of their principal operating modes: charge-sustaining (HEVs Sonata, Fusion, and Prius) and electric-only (PHEV Volt and BEV Leaf). The Sonata and Fusion are of similar size, which enables direct comparisons of fuel efficiency. The Leaf, Prius, and Volt are also of similar size for cross comparisons. The Fusion and Prius have essentially the same basic configuration but control approaches that are perhaps unique to each car company. The Volt has a multi-mode configuration transmission with two electric-only modes: a series mode and a power-split mode.

Comparing the design approach used for the Sonata with that used for established hybrids is useful. It is a “full hybrid,” and thus from a basic level, the Sonata has all the features of the other hybrids discussed in this report, but it has a “P2” based architecture that reduces the motor size and uses more off-the-shelf automotive components. These features have the potential to reduce vehicle costs and cut initial investment for production. Test data reveal that there are advantages in highway driving with a more direct torque path of the engine and the opportunity to shut down the engine regardless of vehicle speed to save fuel. However, the Sonata step transmission does not have the flexibility of the power-split to optimize engine operation at all times in city driving.

The Volt has a more complex configuration for electric driving than the Leaf fixed gear transmission; however, the efficiency data do not show efficiency advantages over the Leaf. The Leaf has higher efficiencies in terms of DC energy to the propulsion system and loads measured at the dynamometer. Compared to the Leaf, the Volt is heavier and consumes more DC energy driving on the UDDS cycle but because of its lower driving losses, the Volt uses less DC energy driving the HWY cycle. The Volt and leaf have similar conversion efficiencies from the AC wall plug to the battery and out of the battery.

Standby losses were highly varied among the vehicles discussed in this report. The Volt and Sonata losses were similarly three times higher than those of the Prius, with the Volt falling in between.

Highly efficient vehicles can offer very high fuel efficiency, but these benefits rapidly deteriorate in hot and cold conditions. Running the heater off battery energy in electric-only mode of either a PHEV or BEV can double the consumption rate (reducing the range to one-half).

6 Future Trends

The degrees of freedom in powertrain design expand exponentially with modern hybrid technology. Integrating motors into transmission systems offers additional design and control levers for automotive designers in the now competitive market for advanced efficient mobility. On the basis of understanding the current vehicles and taking notice of announcements of soon-to-be released vehicles, some trends in the state of the technology can be speculated.

During a Task 17 workshop in Chicago (2013), Valeo presented their forecast for the progress of different drive train solutions (as it can be seen in Fig. 17). Figure 17 shows the expected dominance of mild and full hybrid vehicles in the year 2022. It can be seen, that the ICE will still dominate in the future but the amount of alternative propulsion systems (xEVs) is supposed to strongly increasing, starting from 2020.

6.1 Future HEVs

Toyota engineers have been optimizing their "synergy drive" hybrid powertrain for nearly two decades. From a broad view, little has changed since 1997; however, each motor, gear, subsystem, and electronic system has been refined for maximum efficiency in the last generations. Any shortcomings were identified and addressed with either redesigned or substituted hardware. Inefficiencies found specifically in high-speed driving and from low temperatures were addressed in the 3rd generation

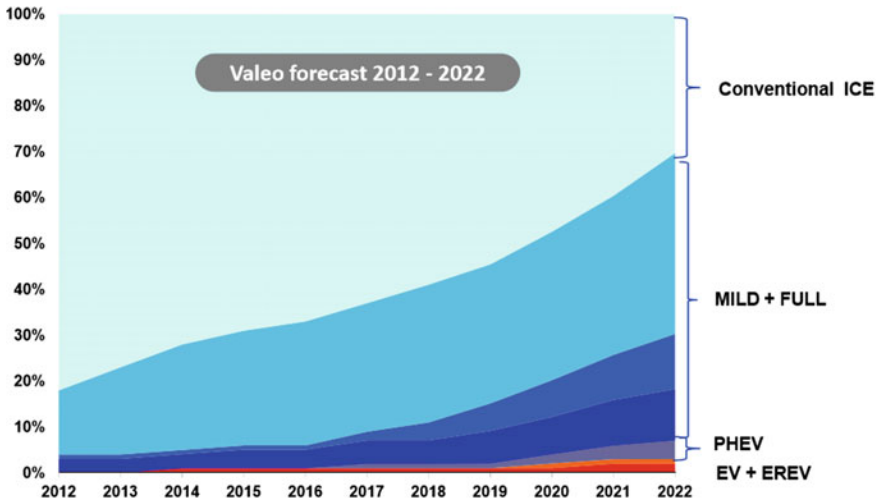

Fig. 17 Forecast for the progress of different drive train concepts [2]

Prius. Ford has also improved on early hybrid offerings, and its vehicles demonstrate high urban-cycle efficiencies. Ford announcements of next-generation Fusion and C-Max hybrids are on par or perhaps slightly better than the Toyota's in terms of powertrain efficiencies.

More P2 hybrids are becoming available, mostly from European manufacturers, like Audi, BMW, Porsche, VW and Citroen. European OEMs are invested in sequential manual and dual clutch transmissions, and it makes sense that they take this direction for their hybrid designs. Drivability and urban driving fuel economy will be challenges that will be addressed in future revisions. In the United States, planetary gear automatics are still the primary transmission choice, and this type of transmission shares many of the parts and designs of the transmissions used in the power-split type of hybrid. It will be interesting to see if GM will use the "2-mode" hybrid transmission for any future non-plug-in hybrids. It was recently that GM's 2-mode hybrid for trucks applications was cancelled [3].

Because label fuel economy is now according to the "5-cycle" method [4], which includes higher speeds and cold and hot temperatures, manufacturers are starting to include new efficiency features that specifically address these conditions. Expect more thermal recovery devices for quicker warm-up, higher regenerative braking, and improved gearing for economy at high speeds.

6.2 Future PHEVs

In model year 2013, Toyota and Ford started to release PHEV versions of their HEVs. Both companies are leveraging the existing power-split architectures but are bound to limitations of engine off at higher vehicle speeds and/or road demands. The challenge is to design the system to use electric-only drive capability as much as possible in order to displace the most fuel in everyday driving for a given investment in battery capacity. The more the engine turns on, the more difficult it is to increase the fuel-only MPG. Consider the very mild in-use MPG benefit recorded in fleet testing after-market converted Prius hybrids [5]. The Prius engine turns on under medium to heavy accelerations and at speeds above 100 km/h (60 mi/h).

In 2013 Ford announced the C-Max Energi PHEV to higher power and speed electric-only capabilities than any other blended PHEV offered yet (32 km (21 mi.) range and 140 km/h (85 mi/h) electric-only capability) [6]. Indeed, the C-Max Energi surpassed both the Chevrolet Volt and the Prius Plug-in Hybrid. The overall combined gasoline-electricity fuel economy rating for the 2013 model year C-Max Energi is 4.1 L/100 km (58 mpg) equivalent, the same rating as the Prius PHV and the Ford Fusion Energi, making all three PHEVs the most fuel efficient cars in EPA's midsize class.

A new technology with system-level impacts is wireless charging.

If inexpensive, wireless charge parking spots can be rolled out, battery costs could be cut. For example, if the 2013 Prius with 15–20 km (9–11 mi.) of electric range were to recharge every time it is parked, the total daily miles driven electrically without inconveniencing the driver could be increased significantly. Lower-cost PHEVs could increase their potential market penetration.

For further information please have a look at IEA-IA-HEV **Task 26: Wireless power transfer for EVs** (http://www.ieahev.org/tasks/wireless-power-transfer-task-26/).

6.3 Future BEVs

The first generation of BEVs didn't include systems like thermal management systems or well improved battery management systems, like the first-generation Leaf. The lack of such a system may lower initial costs, but time will tell if the batteries will last as long as customer expectations. Current studies shows that thermal management systems can help to improve the systems performance and therefore increase the driving range, by reducing the energy consumption. The 2013 Ford Focus BEV does include a thermal management system. The impacts of this system and the overall performance will be reported in future work.

References

1. Automotive Engineering Online. "2010 Prius First with Ejector-Cycle Air Conditioning," August 10, 2009, Available online at: http://www.sae.org/mags/aei/6741 (accessed June 6th, 2015)
2. Valeo (Wojdyla, C.), IEA-IA-HEV-Task 17 workshop, Chicago, USA. 2011

3. Autoblog.com. "GM Cancels next-gen hybrid truck/SUV program," 2012, Available online at: www.autoblog.com (accessed May 28th, 2015)
4. United States Federal Register. "Revisions and Additions to Motor Vehicle Fuel Economy Label," 75 FR 58078, Sept. 23rd. 2010
5. Shirk, M. "Hymotion Prius Conversion PHEV Demonstration Summary Report," INL/EXT-11-23746. Dec. 2011
6. Autoblog.com, "2013 Ford C-Max Energi," Available online at: www.autoblog.com. (accessed May 23rd, 2015)