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Electrochemical Capacitors as Energy Storage in Hybrid-Electric Vehicles: Present Status and Future Prospects

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Abstract

The development of electrochemical capacitors (ultracapacitors) has continued since the early 1990s. Activated microporous carbon and hybrid carbon devices from a number of developers world-wide have been tested and evaluated for use in hybrid vehicles of various types. The test data indicate that the useable energy density of the activated carbon devices is about 5 Wh/kg and that of the hybrid carbon devices is 10-12 Wh/kg. The power capability of the carbon/carbon devices can be very high (> 2000 W/kg for a 95% high power pulse); the power capability of the hybrid carbon devices are significantly lower being 500-1000 W/kg for a 95% pulse. This means that the P/E ratio of the hybrid carbon devices is much lower than the carbon/carbon devices and as a consequence, it may be difficult to take full advantage of the higher energy density of the hybrid carbon devices in some applications. Simulation results for various types of hybrid vehicles are presented. The results for micro-hybrids are particularly interesting and surprising, because of the large fuel economy improvements predicted. The improvements were about 40% on the FUDS and ECE-EUD cycles and 20% on the Federal Highway and US06 cycles using the carbon/carbon ultracapacitor units. The improvements were significantly less using the hybrid carbon units because of their lower round-trip efficiencies.

Keywords: electrochemical capacitors, hybrid vehicles, control strategy, fuel economy

1 Introduction

It is well recognized that the future development and successful marketing of hybrid-electric vehicles of various types are highly dependent on the performance and cost of the energy storage technologies available. There seems to be high confidence that the performance and cost of the other mechanical and electrical components in hybrid-electric drivelines are suitable for hybrid vehicle applications, but there remains considerable uncertainty regarding the energy storage technologies. Whether a particular energy storage technology is suitable for use in a particular type of hybrid depends both on its characteristics and the requirements for energy storage in the vehicle design. This paper is concerned with both the requirements for energy storage in various types of hybrid vehicles and the characteristics of the energy storage devices being developed. In the paper, both charge sustaining and plug-in hybrids will be considered and the role of ultracapacitors in providing the energy storage assessed.

2 Hybrid vehicle energy storage requirements

From a vehicle performance point-of-view, energy storage requirements are defined in terms of the peak power (kW) and energy storage capacity (Wh or kWh). The vehicle designer is also interested in the weight and volume of the energy storage unit which follows once the energy and power densities of the technologies are known. It is important to recognize that the energy capacity and the peak power refer to the useable energy capacity and the useable peak power from the energy storage unit for the particular application of interest. By "useable' is meant the "quantity" that can be utilized from the storage unit consistent with other system constraints such as the effect of round-trip efficiency on peak power, depth of discharge on energy capacity and cycle life, and maximum charge voltage on energy capacity, cycle life and safety. These further considerations in most cases result in storage unit performance that is significantly less than one would infer from the name-plate ratings given by the manufacturer of the batteries or ultracapacitors.

A second difficulty in quantifying the peak power and energy requirements are that the useable power and energy requirements can be highly dependent on the control strategy linking operation of the engine and electric drive system. In the case of a charge sustaining hybrid, the useable energy required can vary from 100-300Wh depending on how often and at what power level the engine is used to recharge the energy storage unit (References 1-2). In the case of the plug-in hybrids, the peak power requirement depends on the blending strategy of the electric motor and engine when the vehicle is operating in the "all-electric" or charge depleting mode (References 3-4).

Energy and power requirements for selected hybrid vehicle designs and operating strategies are shown in Table 1 for a mid-size passenger car. Requirements are given for both charge sustaining and plug-in hybrids. These requirements can be utilized to size the battery and ultracapacitors in the vehicles when the characteristics of the energy storage devices are known. In some of the vehicle designs considered in Table 1, ultracapacitors are used to provide the peak power rather than batteries. The objective of this paper is the evaluation of ultracapacitor technology (present and future) to assess whether these vehicle applications of ultracapacitors appear to be feasible and attractive.

Consider first charge sustaining hybrid vehicles. In this case, the energy storage unit is sized by both useable power (kW) and energy storage (Wh) requirements. For batteries, the key issues are the power requirement and the minimum useable energy consistent with high cycle life for shallow cycles. The total energy stored in the battery unit is of secondary importance as far as operation of the vehicle is concerned, but it has a strong effect on the weight, volume, and cost of the unit. For ultracapacitors, the key issue is the minimum energy (Wh) required to operate the vehicle in real world driving because the energy density characteristics of ultracapacitors are such that the power and cycle life requirements will be met in most cases if the unit is large enough to met the energy requirement. This is certainly the case for

Table 1: Energy storage requirements for various types of hybrid-electric vehicles

Type of hybrid driveline	System voltage V	Useable energy storage	Maximum pulse power at 90-95% efficiency kW	Cycle life (number of cycles)	Useable depth-of-discharge
Plug-in	300-400	6-12 kWh battery 100-150 Wh ultracapacitors	50-70	2500-3500	deep 60-80%
Charge sustaining	150-200	100-150 Wh ultracapacitors	25-35	300K-500K	Shallow 5-10%
Micro-hybrid	45	30-50 Wh ultracapacitors	5-10	300K-500K	Shallow 5-10%

carbon/carbon devices using microporous carbons, but may not be the case for advanced hybrid ultracapacitors having lower power capability. This question is considered in some detail later in the paper.

For plug-in hybrid vehicles, the energy requirement of the ultracapacitors is essentially the same as for a charge sustaining hybrid and the power requirement is determined by the power rating of the electric drive system in the vehicle. As discussed in Reference 5, the use of ultracapacitors in plug-in hybrids will become more likely with advanced batteries having high energy density. This is the case because it is unlikely that the power density of the advanced batteries will increase sufficiently along with their energy density.

3 Ultracapacitor characteristics and test data

3.1 Cells

3.1.1 Carbon/carbon double-layer devices

There are presently commercially available carbon/carbon ultracapacitor devices (single cells and modules) from several companies – Maxwell, Ness, Batscap, LS Cable, Nippon Chem-Con, and Power Systems (References 6-9). All these companies market large devices with capacitance of 1000-5000 F. These devices are suitable for high power vehicle and stationary applications. The performance of the various devices is given in Table 2. The energy densities (Wh/kg) shown correspond to the useable energy based on constant power discharge tests from V_0 to ½ $V_{0.}$ Peak power densities are given for both matched impedance and 95% efficiency pulses. For most applications with ultracapacitors, the high efficiency power density is the appropriate measure of the power capability of the device. For the large devices, the energy density for most of the available devices is between 3.5-4.5 Wh/kg and the 95% power density is between 800-1200 W/kg. In recent years, the energy density of the devices has been gradually increased for the carbon/carbon (double-layer) technology and the cell voltages have increased to 2.7V/cell using acetonitrile as the electrolyte.

The highest performance carbon/carbon devices tested at UC Davis were from ApowerCap in the Ukraine. These devices are packaged in a laminated pouch (see Figure 1). A summary of the test data for the device is shown in Table 3. The ApowerCap device has an energy density of about 5.5 Wh/kg and a power density for a 95% efficient pulse of 2500 W/kg.

Figure 1: The ApowerCap 450F carbon/carbon device

3.1.2 Hybrid carbon/pseudo-capacitive devices

There has been considerable development of hybrid devices that utilize pseudo-capacitive, non-double-layer mechanisms for electrical charge storage. Most of these devices use carbon in one electrode and psuedo-capacitive or Faradaic materials in the other electrode (Reference 10-12). The most highly developed of these hybrid devices use microporous carbon in the negative and graphitic carbon in the positive electrode. As indicated in Table 2, these devices are being developed by Power Systems and Fuji/JSR Micro. These devices are soft packaged in laminated pouches (see Figure 2). Test data for the Fuji/JSR devices are given in Table 4. Note that the energy density of the devices is 11-12 Wh/kg and the peak power is 900-1000 W/kg for a 95% efficient pulse. The JSR devices are in the early stage of commercialization.

Table 2: Summary of the performance characteristics of ultracapacitor devices

Device	V rated	C (F)	R (mOhm)	RC (sec)	Wh/kg (1)	W/kg (95%) (2)	W/kg Match. Imped.	Wgt. (kg)	Vol. lit.
Maxwell*	2.7	2885	.375	1.08	4.2	994	8836	.55	.414
Maxwell	2.7	605	.90	.55	2.35	1139	9597	.20	.211
ApowerCap**	2.7	55	4	.22	5.5	5695	50625	.009	---
Apowercap**	2.7	450	1.4	.58	5.89	2574	24595	.057	.045
Ness	2.7	1800	.55	1.00	3.6	975	8674	.38	.277
Ness	2.7	3640	.30	1.10	4.2	928	8010	.65	.514
Ness (cyl.)	2.7	3160	.4	1.26	4.4	982	8728	.522	.38
Asahi Glass (propylene carbonate)	2.7	1375	2.5	3.4	4.9	390	3471	.210 (estimated)	.151
Panasonic (propylene carbonate)	2.5	1200	1.0	1.2	2.3	514	4596	.34	.245
EPCOS	2.7	3400	.45	1.5	4.3	760	6750	.60	.48
LS Cable	2.8	3200	.25	.80	3.7	1400	12400	.63	.47
BatScap	2.7	2680	.20	.54	4.2	2050	18225	.50	.572
Power Sys. (activated carbon, propylene carbonate) **	2.7	1350	1.5	2.0	4.9	650	5785	.21	.151
Power Sys. (graphitic carbon, propylene carbonate) **	3.3 3.3	1800 1500	3.0 1.7	5.4 2.5	8.0 6.0	486 776	4320 6903	.21 .23	.15 .15
Fuji Heavy Industry-hybrid (AC/graphitic Carbon) **	3.8	1800	1.5	2.6	9.2	1025	10375	.232	.143
JSR Micro (AC/graphitic carbon)**	3.8	1000 2000	4 1.9	4 3.8	11.2 12.1	900 1038	7987 9223	.113 .206	.073 .132

(1) Energy density at 400 W/kg constant power, Vrated - 1/2 Vrated
(2) Power based on P=9/16*(1-EF)*V2/R, EF=efficiency of discharge
* Except where noted, all the devices use acetonitrile as the electrolyte
** all device except those with ** are packaged in metal containers, these devices are in laminated pouches

Table 3: Test data for the Pouch packaged APowerCap device
Constant current discharge data 2.7V - 0

Current A	Time sec	Capacitance F	Resistance mOhm
10	120.5	450	-----
20	60.3	453	-----
40	30	453	-----
80	14.7	452	1.4
120	9.6	455	1.4
160	7.1	456	1.3

Constant power discharges data   2.7 – 1.35V

Power W	W/kg *	Time sec	Wh	Wh/kg
12.5	219	95.5	.332	5.82
22	385	54.9	.336	5.89
41.5	728	28.8	.332	5.82
80.5	1412	14.6	.326	5.72
120	2105	9.1	.303	5.31

* weight of device - 57 gm as tested

Table 4: Test data for the JSR 2000F cell
Constant Current discharge   3.8V – 0V

Current (A)	Time (sec)	C(F)	Resistance (mOhm) **
30	102.2	2004	---
50	58.1	1950	---
80	34.1	1908	---
130	19.1	1835	2.0
200	11.1	1850	1.9
250	8.2	1694	1.84

** resistance is steady-state value from linear V vs. time discharge curve

Constant Power discharges   3.8V – 2.2V

Power (W)	W/kg	Time(sec)	Wh	Wh/kg *	Wh/L *
102	495	88.3	2.5	12.1	18.9
151	733	56	2.35	11.4	17.8
200	971	40	2.22	10.8	16.9
300	1456	24.6	2.05	10.0	15.7
400	1942	17	1.89	9.2	14.4
500	2427	12.5	1.74	8.5	13.3

* based on the weight and volume of the active cell materials
Cell weight 206 gm, 132 cm3

Pulse resistance test

Current (A)	Pulse (5sec) mOhm
100	2
200	1.9

3.2 Modules

For vehicle applications, the cells are connected in series to form higher voltage modules. The module voltage utilized depends on the application and varies from 16V to about 60V. The characteristics of modules (Reference 6, 13) from several companies are summarized in Table 5. The electrical characteristics (capacitance and resistance) of the module follow directly from the cell characteristics. Note, however, that the weight and volume of the modules are significantly greater than the cells alone with packaging factors of .6-.7.

All the modules being marketed utilize balancing circuits for each cell to prevent over-voltage of the cell and to minimize cell-to-cell variability during cycling. For this reason, it is best to base the energy storage and power capacity of the modules on the cell weight and volume, but to include the packaging factors in determining the weight and volume of the ultracapacitor unit to be installed in a vehicle. When the energy storage (Wh) and power requirements (kW) are given for a particular application, the data given in Tables 2 and 5 can be used to determine the characteristics of the ultracapacitor unit for use in a vehicle.

4 Applications for hybrid vehicles

It is of interest to evaluate ultracapacitor unit designs for the hybrid vehicle applications shown in Table 1. The ultracapacitor devices/technologies used in this design exercise are those consistent with the data shown in Tables 3 and 4, which have been designated as carbon/carbon (Table 3) and hybrid carbon (Table 4). The carbon/carbon device has an useable an energy density of 5 Wh/kg and a high power density of 2500 W/kg for a 95% efficient pulse. The hybrid carbon device has a high energy density of 11-12 Wh/kg and a modest power of 1038 W/kg for a 95% efficient pulse. The characteristics of the ultracapacitor units using the two technologies for each of the applications are given in Table 6.

4.1 Micro-hybrids

The ultracapacitor units for the micro-hybrid vehicle are quite small and light and provide the power required for this application. It would appear that the carbon/carbon devices are the best choice for this application as they are well developed at the present time, have proven cycle life, and will be lower cost. The higher energy density of the hybrid carbon devices is not needed for this application.

4.2 Charge sustaining hybrids

The data given in Table 6 indicate that this is a difficult application for ultracapacitors because it requires both relatively high energy storage (Wh) and high power (kW). This application seems to need the higher energy density of the hybrid carbon devices, but their power capability for high efficiency pulse power is less than would be optimum. The power requirement of 35 kW selected for this application is relatively high and some charge sustaining hybrids have been designed with significantly lower electric motor power (ex. the single shaft Honda hybrids with 10-15 kW). The carbon/carbon units would function satisfactorily in the high power, charge sustaining hybrids, but their volume and weight would not be much different than batteries.

4.3 Plug-in hybrids

In the plug-in hybrid, the ultracapacitor would be used to assist the energy storage battery (12 kWh) in providing the power when the vehicle was operating in the charge depleting mode. As discussed in Reference 5, it makes most sense to use ultracapacitors with high energy density batteries which do not have sufficiently high power capability to provide the total power alone. For the designs given in Table 6, it is assumed the battery energy density is 200 Wh/kg and that the battery will provide one-third of the total power of 70 kW

Table 5: Ultracapacitor module characteristics

Module *	Weight/ Volume kg/lt.	Cell capacitance F	Voltage	Wh (Wh/kg)	Power (kW) (90% effic.)	Weight packaging factor	Volume packaging factor
Ness (194 F)	18.5/ 20.9		48	43/ 2.1	19.1	.655	.36
Ness (100F)	9.1/7.22		48	22.5/ 2.47	10.8	.769	.692
Maxwell (145 F)	13.5/ 13.4		48	36/ 2.7	14.5	.627	.484
Maxwell (430F)	5.0/ 4.85		16	11.8/ 2.36	4.8	.564	.445
Asahi Glass 280F	3.75/ 2.95		16	7.65/ 2.04	2.1	.528	.422
Power Systems	4.4/ 4.8		32	11/ 2.5	2.5	.573	.375
Power Systems	7.2/ 8		59	20/ 2.78	4.7	.642	.413
EPCOS	29/24		56	49/ 1.7	16	.5	.48

Table 6: Ultracapacitor units for hybrid vehicle applications

Vehicle design	ultracap energy stored Wh	ultracap peak power kW	system voltage V	No. of cells	Capac-itance F	Max. power 90% eff. kW	Weight (kg) / volume (L) cells unit*
Micro-hybrid	30	6	48				
Carbon/carbon				18	2550	>10	6 / 4.6 9/ 9.2
Hybrid carbon				14	2000	5.7	2.8/ 1.8 4.3/ 3.6
Charge sustaining hybrid	150	35	200				
Carbon/carbon				80	2865	>50	30/ 23 46/ 46
Hybrid carbon				65	2000	26	13/ 9 20/ 18
Plug-in Hybrid 12 kWh bat. **	200	45	300				
Carbon/carbon				120	2200	> 100	40/ 30 61/ 60
Hybrid carbon				84	2000	36	18/ 12 28/ 24

* Packaging factors: weight .65 volume .5
** Energy density of the battery in the Plug-in hybrid - 200 Wh/kg,
Vehicle electric use 156 Wh/km

requiring a battery power density of about 400 W/kg. Combining ultracapacitors with the battery will also make thermal management of the battery less demanding and extend the battery cycle life as it will not be subjected to the high current pulses which are taken by the ultracapacitor unit. The results shown in Table 6 indicate that this application also needs the high energy density of the hybrid carbon device and that the power density of that device is marginally high enough. Note that even using the hybrid carbon devices, the weight of the ultracapacitor unit will be about one-third that of the battery unit. The combined weight of the two energy storage units is likely to be about 100 kg for a plug-in hybrid with an all-electric range of about 50 miles

5 Computer simulations of hybrid vehicles using ultracapacitors

Simulations of mid-size passenger cars using the ultracapacitors in micro-hybrid, charge sustaining, and plug-in hybrid powertrain designs were performed using the **Advisor** vehicle simulation program. All the powertrains were in the same vehicle having the following characteristics: test weight 1660 kg, C_d =.3, A_F =2.25 m^2 , RRCF =.009. The engine map used in the simulations was for a Ford Focus 2L, 4-cylinder engine. The rated engine power was 120 kW for the conventional ICE vehicle and the micro-hybrid and 110 kW for the charge sustaining and plug-in hybrids. The electric component sizes/power are given in Table 6. All the hybrids use the single-shaft approach similar to the Honda Civic hybrid.

The simulation results are summarized in Table 7 for a conventional ICE vehicle and each of the hybrid designs. Results are given for fuel usage in terms of both L/100 km and mpg for various driving cycles. It is clear from Table 7 that large improvements in fuel usage are predicted for all the hybrid powertrains using ultracapacitors for energy storage. The simulation results will be discussed separately for each hybrid design.

Table 7 Summary of the vehicle fuel economy simulation results using ultracapacitors for various driving cycles L/100 km / mpg

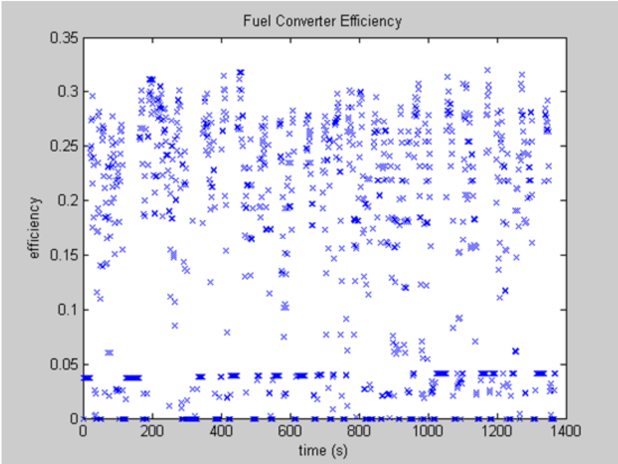
Driveline type	Energy storage type	Voltage and weight cells (kg)	EM Peak kW	FUDS	HWFET	US06	ECE-EUDC
ICE baseline				10/ 23.8	6.9/ 34.4	9.6 24.7	9.7/ 24.6
Micro-HEV	Lead-acid/ ultracaps	48					
	Carbon/carbon	6 kg	6	5.7/ 41.7	5.3/ 44.7	7.8/ 30.6	5.9/ 40.2
	Hybrid carbon	3 kg	6	7.3/ 32.8	6.3/ 38.0	8.9/ 26.7	7.1 33.4
Charge sustaining hybrid	Ultracaps	200					
	Carbon/carbon	30 kg	35	5.4/ 43.8	5.0/ 47.9	7.1/ 33.6	5.5/ 43.2
	Hybrid carbon	13 kg	35	5.8/ 40.9	5.2/ 45.8	8.0/ 29.9	5.8/ 41.3
Plug-in hybrid	12 kWh Li battery and ultracaps	300	70 kW with 45 kW from ultracaps				
	Carbon/carbon	40 kg	45	5.5/ 43.2	5.0/ 47.7	7.0/ 33.9	5.5/ 42.9
	Hybrid carbon	18 kg	45	5.8 41.2	5.2/ 46.2	7.9/ 30.2	5.8/ 41.2

5.1 Micro-hybrids

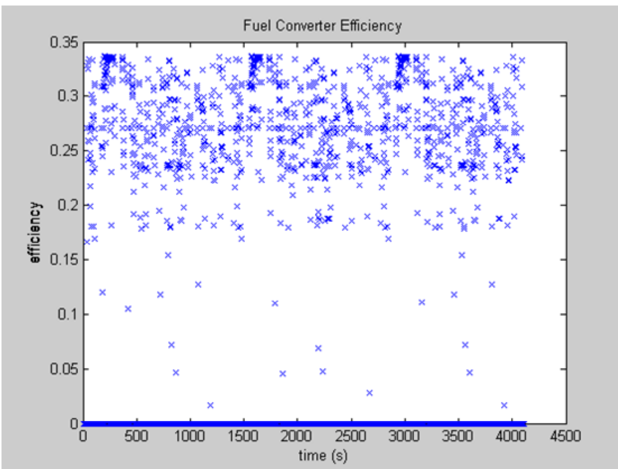
The results for the micro-hybrids are particularly interesting and surprising, because of the large fuel economy improvements predicted. These improvements were about 40% on the FUDS and ECE-EUD cycles and 20% on the Federal Highway and US06 cycles using the carbon/carbon ultracapacitor units. The improvements were significantly less using the hybrid carbon units because of their lower round-trip efficiencies.

In the micro-hybrid designs, the rated engine power used was the same as that in the conventional ICE vehicle in order that the performance of the hybrid vehicle when the energy storage in the ultracapacitors is depleted would be the same as the conventional vehicle. The ultracapacitors were used to improve fuel economy with only a minimal change in vehicle acceleration performance. The control strategy used was to operate on the electric drive when possible and to recharge the ultracapacitors when the engine was operating. As shown in Figure 1, this resulted in a large improvement in average engine efficiency from 19% in the ICE vehicle to 30% in the micro-hybrid even though the electric motor had a peak power of only 6 kW.

Additional computer simulations were made for higher motor power (up to 12 kW) and larger ultracapacitor energy storage (up to 50 Wh). It was found that the improvements in fuel economy were only marginally greater. Using a motor power of 3 kW reduced the fuel economy improvement on the FUDS by more than 50%. Note from Table 7 that the fuel economy improvements using the carbon/carbon ultracapacitors were for all the cycles greater than those using the hybrid carbon devices. This was the case because the round-trip efficiencies for the carbon/carbon units were 95-98% and those of the hybrid carbon units were 75-90% for the various driving cycles. As noted previously, the hybrid carbon devices had higher energy density, but even though their power density for 95% efficiency was relatively high (1050 W/kg), it was not proportionally higher – that is twice as high- as the carbon/carbon devices with lower energy density. These results show clearly that it is essentially to develop high energy



Engine operating efficiency for the ICE vehicle-average engine efficiency .19



Engine operating efficiency for the micro-hybrid - average engine efficiency .30

Figure 1 A comparison of engine efficiencies for a conventional ICE vehicle and a micro-hybrid on the FUDS cycle using carbon/carbon ultracapacitor

density ultracapacitors with proportionally higher power density; otherwise their use in vehicle applications will be compromised.

5.2 Charge sustaining hybrids

The fuel economy simulation results for charge sustaining hybrids are also shown in Table 7 for a mid-size passenger car using both carbon/carbon and hybrid carbon ultracapacitors. Using the carbon/carbon ultracapacitor unit, the fuel savings are about 45% for the FUDS and ECE-EUD cycles and about 27% for the Federal Highway and US06 cycles. These improvement values are higher than for the micro-hybrid, but not by as large a factor as might be expected. The prime advantage of the high power electric driveline in the charge sustaining hybrid is that it yields large fuel economy improvements even for high power requirement driving cycles like the US06. The fuel economy improvements using the hybrid carbon ultracapacitor unit are not much less (5-10%) than those with the carbon/carbon unit even though the round-trip efficiency of the hybrid carbon unit is only 85-90% compared to 98% for the carbon/carbon unit. Since the volume of the hybrid carbon unit is relatively small - 43% of that of the carbon/carbon unit, it appears that the charge sustaining hybrid application is a better application for the present hybrid carbon technology than the micro-hybrid application.

5.3 Plug-in hybrids

The plug-in hybrid vehicle studied is one that utilizes a high energy density battery (200 Wh/kg) and ultracapacitors that would provide two-thirds of the power to a 70kW electric motor. The electric energy use of the vehicles in the charge depleting mode (engine off) is assumed to be 156 Wh/km resulting in a charge depleting range of 60 km (38 mi.) for 80% DOD of the battery. The fuel economy results shown in Table 7 are for vehicle operation in the charge sustaining mode after the energy battery (12 kWh) has been depleted. As expected in this mode, the operation of the plug-in hybrid vehicle is essentially the same as previously discussed for the charge sustaining hybrid. Hence the hybrid carbon ultracapacitor unit would also be suitable for the plug-in hybrid. The combined weight of the cells in the battery and hybrid carbon ultracapacitors would be 78 kg for a plug-in hybrid with an all-electric range of about 40 miles. The combined weight using the carbon/carbon ultracapacitors would be 100 kg. Using a high power lithium-ion battery with an energy density of 100 Wh/kg without ultracapacitors, the weight of the battery cells alone would be 120 kg. Hence for plug-in hybrids combining a battery with ultracapacitors may be an attractive design option.

6 Summary and conclusions

The development of electrochemical capacitors (ultracapacitors) has continued since the early 1990s. Activated microporous carbon and hybrid carbon devices from a number of developers world-wide have been tested and evaluated for use in hybrid vehicles of various types. The test data indicate that the useable energy density of the activated carbon devices is about 5 Wh/kg and that of the hybrid carbon devices is 10-12 Wh/kg. The power capability of the carbon/carbon devices can be very high (> 2000 W/kg for a 95% high power pulse); the power capability of the hybrid carbon devices are significantly lower being 500-1000 W/kg for a 95% pulse. This means that the P/E ratio of the hybrid carbon devices is much lower than the carbon/carbon devices and as a consequence, it may be difficult to take full advantage of the higher energy density of the hybrid carbon devices in some applications.

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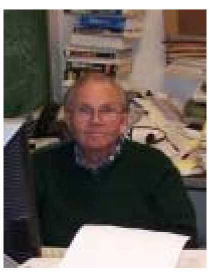

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