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Projected fuel consumption characteristics of hybrid and fuel cell vehicles for 2015-2045

Andrew Burke and Hengbing Zhao

Institute of Transportation Studies, University of California-Davis
One Shields Ave., Davis, California 95616, USA
Email: afburke@ucdavis.edu

Abstract – There are presently a number of technologies being developed that will reduce fuel consumption of passenger cars and SUVs. These technologies are advanced, higher efficiency engines, hybrid-electric vehicles (HEVs and PHEVs), and fuel cell powered vehicles (FCVs). Fuel economies using these technologies have been projected by performing a series of simulations of the advanced vehicles on different driving cycles using the best component models available and control strategies intended to maximize the driveline efficiency. The time period considered in this paper is 2015-2045. The baseline vehicle is that being marketed in 2007. The simulations were run for a mid-size passenger car and a compact SUV. The results of the simulations are presented in terms of the equivalent gasoline fuel economy and reductions in fuel usage are then calculated. As expected, the magnitude of the fuel/energy savings is highest using the fuel cell technology. However, the differences between the technologies are not as large as one might have expected. The fuel savings of the fuel cell vehicles compared to the improved conventional engine/transmission powertrains is about a factor of two and compared to the HEV (charge sustaining) powertrains is only about 15%. In terms of saving petroleum, the PHEV offers the greatest opportunity for fuel savings especially the 40-60 mile design. In general, good agreement was found between the fuel economy and fuel/energy savings projected and those previously published by DOE and MIT. *Copyright Form of EVS25.*

Keywords: fuel economy, fuel savings, vehicle simulations, advanced technologies

1. Introduction

There are presently a number of technologies being developed that will reduce fuel consumption of passenger cars and SUVs. These technologies are advanced, higher efficiency engines, hybrid-electric vehicles (HEVs and PHEVs), and fuel cell powered vehicles (FCVs). One approach to projecting the fuel economies using these technologies is to simulate on the computer the operation of the advanced vehicles on different driving cycles using the best component models available and control strategies intended to maximize the driveline efficiency. A series of vehicle simulations are then performed varying the vehicle and component characteristics to reflect projected improvements in vehicle and component technologies in the future. The time period considered in this paper is 2015-2045. The baseline vehicle is that being marketed in 2010. The simulations have been run for a mid-size passenger car and a compact SUV. The results of the simulations are then presented in terms of the equivalent gasoline consumption of the various vehicle designs and the reductions in fuel usage that are projected for 2015-2045.

The first section of the paper is concerned with presenting the details of the vehicle and powertrain characteristics used in the simulations and how they are assumed to change in the future. The second section presents and compares the simulation results for the different technologies being considered: (1) conventional engine/transmission vehicles, (2) hybrid-electric vehicles including charge sustaining and plug-in hybrid designs, (3) fuel cell powered vehicles. In the final section of the paper, comparisons are made between the projected fuel consumption reductions developed in this paper with those presented in previous studies at MIT and DOE.

2. Projected vehicle and powertrain characteristics

Vehicle weight and road load characteristics

Simulations have been performed for two types of vehicles – a mid-size passenger car and a compact SUV. The characteristics of the vehicles are given in Tables 1 and 2. The vehicle weight (W_V) and road load characteristics (drag coefficient $C_{d,}$ frontal area A_f, and tire rolling resistance f_r) used for the various years in the present simulations are the same as those projected in the DOE study [1]. The weight and drag reductions assumed for the future are reasonably aggressive so the fuel consumption reduction projections should be considered to be reasonably optimistic. The tire rolling resistance was assumed to decrease only slightly due to the need to maintain traction for driving safety. The frontal area of the vehicles was not changed in future years. There is a marked difference in the C_DA of the passenger car and the SUV, which will have significant effects on the projected fuel consumptions of the two classes of vehicles.

Powertrain configurations and component characteristics

As noted previously, this paper is concerned with three types of powertrains - conventional engine/transmission -ICET, hybrid-electric –HEV and PHEV, and hybrid fuel cell with battery (FCVHEV). The powertrain characteristics in terms of component sizing (power, kWh, etc.) for the two vehicles types are given in Tables 1 and 2. The battery types and characteristics used in the simulations are given in Table 3. The engine and electric motor powers were selected to maintain an acceleration time of 9-10 second for 0-60mph (0-96 kmh) for all the vehicles.

For the powertrain in the conventional ICET vehicles, an automatically shifted multi-speed transmission was used with increasing mechanical efficiency. No attempt was made to optimize the transmission gearing or shifting strategy in the present study. All the simulations were performed using gasoline, spark-ignition (Si) engines. The engine characteristics (efficiency maps as a function of torque and RPM) used in the simulations were based on those available in Advisor and PSAT. This included engines currently in passenger cars (ex. Ford Focus and Honda iVTEC) and more advanced engines like those represented by files FC_Priius_JPN_2004, FC_An_iVTEC, and FC_An_GDi. Simulations were run for various vehicles using the different engines for comparison with EPA dynamometer test data. The results are shown in Table 4. In all cases, the comparisons are quite reasonable. For the simulations of vehicles in future years, the maximum engine efficiencies were increased using the values shown in Tables 1 and 2. These values reflect expected significant improvements in engine efficiencies using the technologies discussed in [2-4]. Modifying the engine maps in this way does not include the effects of changes in the basic shape of the contours of constant efficiency which are likely to show less drastic reductions in efficiency at low engine torque/power. The uncertainty in the engine maps is one of largest of uncertainties in the inputs needed to perform the simulations discussed in this paper.

Table 1: Mid-size passenger car inputs used for the UCD vehicle simulations

Vehicle configuration	Parameter	2015	2030	2045
	C_D	.25	.22	.20
	A_F m^2	2.2	2.2	2.2
	F_r	.007	.006	.006
Advanced ICE				
	Engine kW	105	97	97
	Max. engine effic.	39	40	41
	Vehicle test weight kg	1403	1299	1299
	DOE mpg FUDS/HW	29/47	33/54	34/57
HEV				
	Engine kW	73	67	67
	Max.engine effic.%	39	40	41
	Motor kW	26	24	24
	Battery kWh*	1.0	.9	.9
	Vehicle test weight kg	1434	1324	1324
	DOE mpg FUDS/HW	73/61	84/82	89/88
PHEV				
Small battery 25-33 kg *	Engine kW	75	69	68
AER 10-20 mi	Motor kW	61	57	57
	Battery kWh	4.0	3.6	3.6
	Vehicle test weight kg	1475	1361	1354
Large battery 55-80 kg*				
AER 40-60 mi	Engine kW	77	71	67
	Motor kW	63	59	59
	Battery kWh	11.1	9.8	9.4
	Vehicle curb weight kg	1535	1415	1407
FCHEV				
	Fuel cell effic. %	60	62	65
	Fuel cell kW	83	76	72
	Motor kW	103	100	99
	Battery kWh	.93	.85	.85
	Vehicle test weight kg	1516	1383	1366
	DOE mpg FUDS/HW	70/79	102/114	114/130

Acceleration performance for all vehicles 0-60 mph 9-10 sec
0-30 mph 3-4 sec

* battery discharged to 30% state-of-charge

Table 2: Compact SUV inputs used for the UCD vehicle simulations

Vehicle configuration	Parameter	2015	2030	2045
	C_D	.37	.35	.33
	A_F m^2	2.9	2.94	2.94
	F_r	.0075	.007	.007
Advanced ICE				
	Engine kW	122	112	112
	Max. engine effic.%	39	40	41
	Vehicle test weight kg	1629	1497	1497
	DOE mpg FUDS/HW	24/34	27/38	28/39
HEV				
	Engine kW	89	81	81
	Max.engine effic.%	39	40	41
	Motor kW	31	28	28
	Battery kWh*	1.2	1.1	1.1
	Vehicle test weight kg	1669	1532	1530
	DOE mpg FUDS/HW	55/46	61/51	63/54
PHEV				
Small battery 25-30 kg *	Engine kW	96	90	89
AER 10-20 mi	Motor kW	66	62	61
	Battery kWh	5.6	5.1	5.0
	Vehicle test weight kg	1719	1576	1570
Large battery 80-100 kg*				
AER 40-60 mi	Engine kW	99	93	91
	Motor kW	69	64	64
	Battery kWh	15.2	14.0	13.5
	Vehicle test weight kg	1802	1654	1644
FCHEV				
	Fuel cell efficiency %	60	62	65
	Fuel cell kW	104	95	92
	Motor kW	129	119	116
	Battery kWh	1.2	1.1	1.1
	Vehicle test weight kg	1875	1705	1683
	DOE mpg FUDS/HW	62/59	73/68	82/77

Acceleration performance for all vehicles 0-60 mph 10-11 sec
0-30 mph 3-4 sec

* battery discharged to 30% state-of-charge
Test weight = curb weight + 136 kg

Table 3: Battery characteristics for use in advanced vehicles - 2015 -2045

	2015				2030-2045			
Powertrain configuration	Battery type	Ah	Wh/kg	Resist. mOhm	Battery type	Ah	Wh/kg	Resist. mOhm
HEV	Li Titanate	4	35	1.1	Li Titanate	4	42	.9
PHEV-20	Ni MnO2	15	120	1.5	Ni MnO2	15	135	1.3
PHEV-40	Ni MnO2	50	140	.8	Ni MnO2	50	170	.65
FCHEV	Li Titanate	4	35	1.1	Li Titanate	4	42	.9

The powertrains for all the hybrid vehicles (HEVs and PHEVs) utilized a single-shaft, parallel arrangement with clutches to permit on/off engine operation at any vehicle speed [5, 6]. The clutch permitted the engine to be decoupled and coupled in an optimum manner. The same engine maps and maximum efficiencies were used for the hybrids as were used for the ICET vehicles. The HEVs operated in the charge sustaining mode and utilized the "sawtooth" control strategy [7, 8] for splitting the power demand between the engine and the electric motor. This strategy results in the vehicle operating in the electric mode most of the time when the power demand is low. When the vehicle power demand is higher, the engine is on providing power to meet the vehicle demand and to recharge the energy storage unit (batteries or ultracapacitors). The "sawtooth" strategy permits the engine to operate most of the time near maximum efficiency. The batteries used in the HEV simulations are given in Table 3. Some improvements in battery characteristics are projected in future years [9, 10].

Table 4 : Comparisons of vehicle fuel economy with different engines

Model/Year	Engine	Driveline type	City mpg	Highway mpg
Focus*/2010	Focus	conventional	28	44
"	An_iVTEC	"	35	50
Focus* / EPA test 2007	Focus	"	30	44
Accord**/ EPA test 2007	VTEC	conventional	26 (2006) 23 (2008)	43 (2006) 38 (2008)
Accord **2008 simulation	Focus An_iVTEC	conventional	20 26	35 43
Camry** EPA test	Focus type	conventional	26 (2006) 23 (2008)	43 (2006) 40 (2008)
Camry HEV** EPA test 2007	Prius 2004	HEV	41	48
Advmid**/2015	Focus	conventional	31	49
"	An_iVTEC	"	41	62
"	Focus	HEV	67	65
"	An_iVTEC	"	73	74

* Compact car
** mid-size car
EPA test results from EPA Fuel Economy Guide 2007 corrected by 1/.9 for the FUDS and 1/.78 for the Highway cycle to obtain the dynamometer test data

For the PHEVs, the batteries were sized (useable kWh) for either a 10-20 mile or 40-60 mile range with all-electric operation on the FUDS and Federal Highway driving cycles in the charge depleting mode. After the batteries were depleted to their minimum state-of-charge, the PHEVs operated in the charge sustaining mode using the same "sawtooth" strategy used for the HEVs. The same single-shaft, parallel hybrid powertrain arrangement used in the HEVs was used in the PHEVs with the larger battery. The sizes of the components for the various PHEV vehicle designs are given in Tables 1 and 2.

The powertrain arrangement for the fuel cell powered vehicles (FCHEV) consisted of a PEM fuel cell and a lithium-ion battery. The battery is connected to the DC bus by a DC/DC converter that controls the output power of the battery such that the output power of the fuel cell is load leveled [11, 12]. This control strategy greatly reduces the voltage fluctuations of the fuel cell and should significantly increase its durability (lifetime). As indicated in Tables 1 and 2, the peak efficiency of the fuel cell is increased in the future years. The batteries used in the FCHEVs are essentially the same as those used in the HEVs.

3. Vehicle simulation results for 2015-2045

Studies directed toward projecting the fuel economy of vehicles utilizing various advanced powertrain technologies have been performed at the University of California-Davis, Institute of Transportation Studies, for the last 5-10 years [13, 14]. The computer models developed to simulate the advanced vehicles and the results of the simulations are given in [5-8, 11, 12]. The results presented in this paper were obtained using those powertrain models and the vehicle inputs given in Tables 1, 2, and 3. The simulation results are shown in Tables 5-8. Results are given for mid-size passenger cars and compact size SUVs in 2015, 2030, and 2045. Also shown when they are available are simulation results previously published by DOE [1], MIT [4,15], and the National Research Council (NRC) [2].

The results for each type of advanced technology are discussed separately.

Conventional engine/transmission vehicles

For the mid-size passenger cars, the simulation results project fuel savings of 30-40% with reductions in weight and vehicle drag and improvements in engine efficiency. A major fraction of this fuel savings is projected to occur by 2020. For compact SUVs, the projected fuel savings are somewhat less than for the mid-size passenger cars being in the range of 25-35%. Hence even without large changes in vehicle technology, large improvements in fuel economy can be expected in the next 10 years.

Hybrid vehicles (HEVs and PHEVs)

This category of advanced technology includes HEVs (gasoline fueled) and PHEVs (wall plug-in electricity and gasoline). First consider the HEVs. For the mid-size passenger cars, the simulations project fuel savings of 50-60%. For compact SUVs, the projected fuel savings are 40-50%. As would be expected the percentage fuel savings compared to the conventional vehicles become smaller as the engine efficiency increases.

Table 5: Comparisons of fuel economy projections for advanced vehicles by UC Davis, DOE and MIT - <u>Mid-size Passenger car</u>

Year		FUDS mpg*	FHWDS mpg*	% fuel saved**	US06 mpg*	Accel. 0-30 mph/ 0-60 mph
Advanced ICE gasoline						
2015	UCD	41.4	62.3	33.5	37.5	4.3/9.7
	DOE	29	47	9		
	NRC			29		
2030	UCD	47.4	73.3	42.8	44.0	4.7/10.3
	DOE	33	54	20.7		
	MIT	42	68	37.3	44	
2045	UCD	48.9	77.1	45.2	46.1	4.6/10.3
	DOE	34	57			
Advanced	HEV					
2015	UCD	73.3	74.1	53.1	46.5	4.3/9.7
	DOE	73	61	48.5		
	NRC			44		
2030	UCD	85.7	84	59.3	53.7	4.7/10.3
	DOE	84	82	41.6		
	MIT	95	88	62.2	58	
2045	UCD	87.9	89.2	61.0	55.8	4.6/10.3
	DOE	89	88	61.0		
Fuel cell						
2015	UCD	82.6	90.8	60.2	61.3	
	DOE	70	79	53.7		
2030	UCD	102.8	111.5	67.8	76.2	
	DOE	102	114	68.1		
2045	UCD	108.9	119.5	69.8	82.3	
	DOE	114	130	71.7		

* fuel consumption in L/100 km = 238/mpg

** % fuel saved = $(1-(mpg)_0/mpg) * 100$, $(mpg)_0 = 34.5$ (2007–av of the city- hiwy dyno)

Table 6: Projected PHEV fuel economy simulation results - Mid-size Passenger car

Year		Electric range mi	Charge depleting mpg	Charge depleting Wh/mi	Charge sustaining mpg
small battery 25-33 kg					
2015	FUDS	17	All-elec	163	70.0
	FHWDS	17	All-elec	165	69.6
	US06	10	1570	280	45
2030	FUDS	17	3333	143	77
	FHWDS	17	7500	145	84
	US06	11	1500	234	53
2045	FUDS	18	All-elec	140	85.6
	FHWDS	19	All-elec	134	87.8
	US06	11	1400	233	52.8
large battery 55-80 kg					
2015	FUDS	46	All-elec	167	69.1
	FHWDS	45	All-elec	171	71.7
	US06	31	800	251	46.2
2030	FUDS	49	All-elec	141	84.6
	FHWDS	48	All-elec	143	86.0
	US06	32	1495	218	54.5
2045	FUDS	49	All-elec	135	87.8
	FHWDS	49	All-elec	134	92.5
	US06	32	1731	205	59

Table 7: Comparisons of fuel economy projections for advanced vehicles by UC Davis and DOE – Compact SUV

Year		FUDS mpg *	FHWDS mpg *	% fuel saved**	US06 mpg *	Accel. 0-30 mph/ 0-60 mph
Advanced ICE gasoline						
2015	UCD	34	44.4	23	27.3	4.7/11
	DOE	24	34	---		
2030	UCD	38.9	50.3	33	30.8	4.7/11
	DOE	27	38	8		
2045	UCD	40.2	53	36	32.5	4.7/11
	DOE	28	39	10		
Advanced	HEV					
2015	UCD	52.7	44.7	39	29.7	3.6/11
	DOE	54.6	46.4	41		
2030	UCD	58.7	51	45	34	3.6/11
	DOE	61	51	46		
2045	UCD	61	54.1	48	34.9	3.6/11
	DOE	63	54	49		
Fuel cell						
2015	UCD	61	60	50	40.5	
	DOE	62	59	50		
2030	UCD	74.7	73	59	48.8	
	DOE	73	68	57		
2045	UCD	80.8	78.7	62	52.9	
	DOE	82	77	62		

* fuel consumption in L/100 km = 238/mpg

** % fuel saved = $(1-(\text{mpg})_0/\text{mpg}) * 100$, $(\text{mpg})_0 = 30$ (2007–av of the city- hiwy dyno)

Table 8: Projected PHEV fuel economy simulation results – Compact SUV

Year		Electric range mi	Charge depleting mpg	Charge depleting Wh/mi	Charge sustaining mpg
small battery 25-33 kg					
2015	FUDS	19	All-elec.	213	51.9
3/9.1	FHWDS	16	All-elec.	257	45.4
	US06	12	379	384	30.6
2030	FUDS	19	All-elec.	192	57.9
3.2/9.6	FHWDS	14	All-elec.	255	50.6
	US06	10	525	360	34
2045	FUDS	19	All-elec.	188	62.0
3.2/9.6	FHWDS	16	All-elec.	226	53.8
	US06	10	576	348	36.3
large battery 80-100 kg					
2015	FUDS	49	All-elec.	218	54.6
	FHWDS	40	All-elec.	266	46.1
	US06	28	547	385	30.7
2030	FUDS	51	All-elec.	192	60.4
	FHWDS	41	All-elec.	239	51.4
	US06	28	781	351	33.9
2045	FUDS	50	All-elec.	188	62.6
	FHWDS	41	All-elec.	230	55.2
	US06	28	879	338	36.5

Two types of PHEVs were simulated – one type with a small battery and all-electric range of 10-20 miles and one type with a larger battery and a range of 40-50 miles. There does not seem to be a large reduction in electrical energy useage (only about 15%) in the all-electric mode projected from 2015-2045 and the fuel economy of the of the various vehicle designs in the charge sustaining mode is very similar to the corresponding HEV. As a result one would expect the energy useage (electricity plus gasoline) of the 10-20 mile PHEV would decrease by a greater fraction in the future than the 40-50 mile PHEV which would travel a greater fraction of miles on electricity. The split between electricity and gasoline for either vehicle would depend on its use pattern (average miles driven per day and long trips taken). For a known use pattern, the simulation results given in Tables 6 and 8 can be used to calculate the annual electricity and gasoline usage.

The fuel cell powered vehicles use hydrogen as the fuel. As with the HEV, gasoline fueled hybrids, the batteries are recharged from the fuel cell using fuel and not from the wall-plug. The fuel economy in Tables 5 and 7 are gasoline equivalent values, but are easily interpreted as mi/kg H_2 since the energy in a kg H_2 is close to that in a gallon of gasoline. Hence the fuel savings shown for the fuel cell vehicles can be interpreted as fraction of energy saved relative to that in the gasoline used in the baseline 2007 conventional vehicle. Hence the use of the fuel cell technology would reduce energy use by 60-70% for the mid-size passenger car and by 50-60% for the compact SUV.

Comparisons of fuel savings using the various technologies

The fuel savings results are summarized in Table 9 for the mid-size passenger car and the compact SUV. As expected, the magnitude of the fuel/energy savings is highest using the fuel cell technology. However, the differences between the technologies are not as large as one might have expected. The fuel savings of the fuel cell vehicles compared to the improved conventional engine/transmission powertrains is about a factor of two and compared to the HEV (charge sustaining) powertrains is only about 15%. This does not include the differences in the efficiencies in producing gasoline from petroleum and hydrogen from natural gas or coal. In terms of saving petroleum, the PHEV offers the greatest opportunity for fuel savings especially the 40-50 mile design. It is difficult to quantize the savings as it depends on the use-pattern of the vehicle and the energy source used to generate the electricity, but it will be significantly greater than the HEV.

Table 9: Summary of fuel savings for various technologies

% fuel savings*

Technology	Mid-size passenger car	Compact SUV
Engine/transmission	30-40	25-35
HEV	50-60	40-50
FCHEV	60-70	50-60

* period 2015-2045

4. Comparisons of the simulation results from the various studies

Simulation results are available from previous studies by DOE [1] and MIT [4, 15] as well as a recent report by the NRC (National Research Council) [2]. These results are noted in Tables 5 and 7 for comparison with the results obtained in the present study. The UC Davis results are close to the DOE results except for the conventional advanced gasoline ICE vehicles. These differences are large over the complete period (2015-2045) of the study. However, the UC Davis and MIT fuel economy projections for the mid-size passenger car for 2030 are in good agreement for both the advanced ICE and HEV technologies. In addition, the percent fuel savings projected by the NRC for the advanced ICE vehicle in 5-10 year time period is close to that projected in the UC Davis study (29% compared to 33% in 2015). In the case of the HEV technology, the NRC projects a fuel saving of 44% and UC Davis projects 53% in 2015. For the HEV and fuel cell vehicle technologies, the DOE and UC Davis studies are in good agreement over the complete time period of the study with the agreement being closest in the 2030-2045 time periods. It should be noted that the vehicle characteristics used in the UC Davis were selected to match those of the DOE study. Hence the agreement between the two studies indicates consistency in the modeling approaches in the two studies for the HEV and fuel cell vehicle technologies.

5. Summary and conclusions

There are presently a number of technologies being developed that will reduce fuel consumption of passenger cars and SUVs. These technologies are advanced, higher efficiency engines, hybrid-electric vehicles (HEVs and PHEVs), and fuel cell powered vehicles (FCVs). Fuel economies using these technologies have been projected by performing a series of simulations of the advanced vehicles on different driving cycles using the best component models available and control strategies intended to maximize the driveline efficiency. The time period considered in this paper is 2015-2045. The baseline vehicle is that being marketed in 2007. The simulations have been run for a mid-size passenger car and a compact SUV. The results of the simulations are presented in terms of the equivalent gasoline fuel economy of the various vehicle designs and the reductions in fuel usage are calculated for 2015-2045. The fuel saving results are summarized below.

As expected, the magnitude of the fuel/energy savings is highest using the fuel cell technology. However, the

% fuel savings*

Technology	Mid-size passenger car	Compact SUV
Engine/transmission	30-40	25-35
HEV	50-60	40-50
FCHEV	60-70	50-60

* period 2015-2045

differences between the technologies are not as large as one might have expected. The fuel savings of the fuel cell vehicles compared to the improved conventional engine/transmission powertrains is about a factor of two and compared to the HEV (charge sustaining) powertrains is only about 15%. In terms of saving petroleum, the PHEV offers the greatest opportunity for fuel savings especially the 40-60 mile design.

Simulation results are available from previous studies by DOE and MIT as well as a recent report by the NRC (National Research Council). The UC Davis and MIT fuel economy projections for the mid-size passenger car for 2030 are in good agreement for both the advanced ICE and HEV technologies. In addition, the percent fuel savings projected by the NRC for the advanced ICE vehicle in 5-10 year time period is close to that projected in the UC Davis study (29% compared to 33% in 2015). In the case of the HEV technology, the NRC projects a fuel saving of 44% and UC Davis projects 53% in 2015. For the HEV and fuel cell vehicle technologies, the DOE and UC Davis studies are in good agreement over the complete time periods of the study with the agreement being closest in the 2030-2045 time periods.

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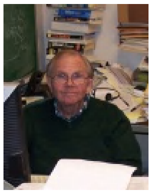
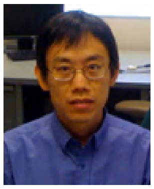


Andrew Burke, Research faculty
ITS-Davis, University of California - Davis,
One Shields Ave., Davis, CA 95616, USA.
Tel.: +1 (530) 752-9812
Email: afburke@ucdavis.edu

Ph.D., 1967, Princeton University. Since 1974, Dr. Burke's research has involved many aspects of electric and hybrid vehicle design, analysis, and testing. He was a key contributor on the US Department of Energy Hybrid Test Vehicles (HTV) project while working at the General Electric Research and Development Center. He continued his work on electric vehicle technology, while Professor of Mechanical Engineering at Union College and later as a research manager with the Idaho National Engineering Laboratory (INEL). Dr. Burke joined the research faculty of the ITS-Davis in 1994. He directs the EV Power Systems Laboratory and performs research and teaches graduate courses on advanced electric driveline technologies, specializing in batteries, ultracapacitors, fuel cells and hybrid vehicle design. Dr. Burke has authored over 80 publications on electric and hybrid vehicle technology and applications of batteries and ultracapacitors for electric vehicles.



Hengbing Zhao, Research Engineer
ITS-Davis, University of California - Davis,
One Shields Ave., Davis, CA 95616, USA
Tel.: +1 (530) 754-9000
Email: hbzhao@ucdavis.edu

He received his Ph.D. at Zhejiang University in 1999. His research has involved many aspects of battery-powered electric vehicles, uninterruptible power sources, distributed power generation systems, fuel cell systems, and fuel cell vehicles. His particular interests are fuel cell system, fuel cell vehicle, hybrid drivetrain design and evaluation, and distributed power generation systems.