Advanced Vehicle Technology Studies for STEP3

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TRANSITION TO EVs AND PHEVs

Real-World Driving

- City streets and Inter-state highways
- "Real" driving cycles
- Include "grades" (up an down)
- Winter and Summer (cold and hot temperatures)
- Realistic accessory loads (heater, defroster, AC)

Vehicle Simulations to Study Effect of Heating and Cooling Loads on Energy Use and Fuel Economy

- Ambient temperatures varied from 0-25 deg C and accessory loads from 400W to 4000W
- Ambient temperature affects aero-drag, rolling and vehicle driveline friction
- Calculated Wh/mi, range, and mpg in the hybrid mode

Simulation Results for an EV and PHEV on Various Driving Cycles

Leaf-like Vehicle on Various Driving Cycles

Cycle	400W Wh/mi battery	400W Range mi	4000W Wh/mi battery	4000W Range mi
FUDS	219	93	403	51
HW	235	90	312	66
SF-SanRaf	263	81	328	64
SanRaf-SF	296	73	367	56
SF-Fairfield	250	87	348	59
Fairfield-SF	289	72	367	57
SF-urban1	174	117	372	54
SF-urban2	204	101	446	46
Aub-Sac	222	93	295	69
Sac-Aub	330	62	399	52
Davis-Sac	258	81	343	60
Sac-Davis	264	76	347	60
Davis-urban	168	121	337	61
Sac-Truckee	373	56	428	48
Truckee-Sac	210	98	257	80

Chevy Volt-like Vehicle on Various Driving Cycles

Cycle	CD* 400W Wh/mi battery	CD* 400W Range mi	CD 4000W Wh/mi battery	CD 4000W Range mi	CS* 400W mpg	CS 4000W mpg
FUDS	226	46	396	25	36.6	20.0
HW	221	49	286	35	41.2	30.4
SF-SanRaf	261	41	357	30	34.5	23.5
SanRaf-SF	296	36	372	28	31.7	23.8
SF-Fairfield	277	37	360	29	34.5	24.8
Fairfield-SF	316	34	398	27	30.1	23.9
SF-urban1	161	60	410	26	46.6	22.3
SF-urban2	193	50	493	21	38.0	18.1
Aub-Sac	308	33	353	26	43.7	32.3
Sac-Aub	189	54	267	37	27.4	23.8
Davis-Sac	235	46	332	30	37.8	27.0
Sac-Davis	217	49	333	32	36.7	26.8

Percentage changes in the energy consumption and range of the Leaf from changes in ambient temperature and the accessory load

Cycle	Ambient temperature	Accessory load (W)	% increase in Wh/mi	% decrease in range miles
FUDS	25	400 to 4000	92	48
FUDS	25 to 0	400	3	3
FUDS	25 to 0	400 to 4000	102	49
HW	25	400 to 4000	34	25
HW	25 to 0	400	5	5
HW	25 to 0	400 to 4000	40	29
Aub-Sac	25 to 0	400 to 4000	35	26
Sac-Aub	25 to 0	400 to 4000	25	20
Davis -urban	25	400 to 2000	44	30
SF-SanRaf	25 to 0	400 to 4000	40	30
SanRaf-SF	25 to 0	400 to 4000	29	24
SF-urban1	25 to 0	400 to 2000	56	36
SF-urban2	25 to 0	400 to 2000	58	36

Percentage changes in the energy consumption and range of the Volt from changes in accessory load

Cycle	Accessory load (W)	CD mode % increase in Wh/mi	CD mode % decrease in range miles	CS mode % Decrease in mpg
FUDS	400 to 4000	75	45	45
HW	400 to 4000	29	29	26
Aub-Sac	400 to 4000	15	21	26
Sac-Aub	400 to 4000	41	32	13
Davis -urban	400 to 4000	102	51	49
SF-SanRaf	400 to 4000	37	27	32
SanRaf-SF	400 to 4000	26	22	25
SF-urban1	400 to 4000	154	57	52
SF-urban2	400 to 4000	155	58	52

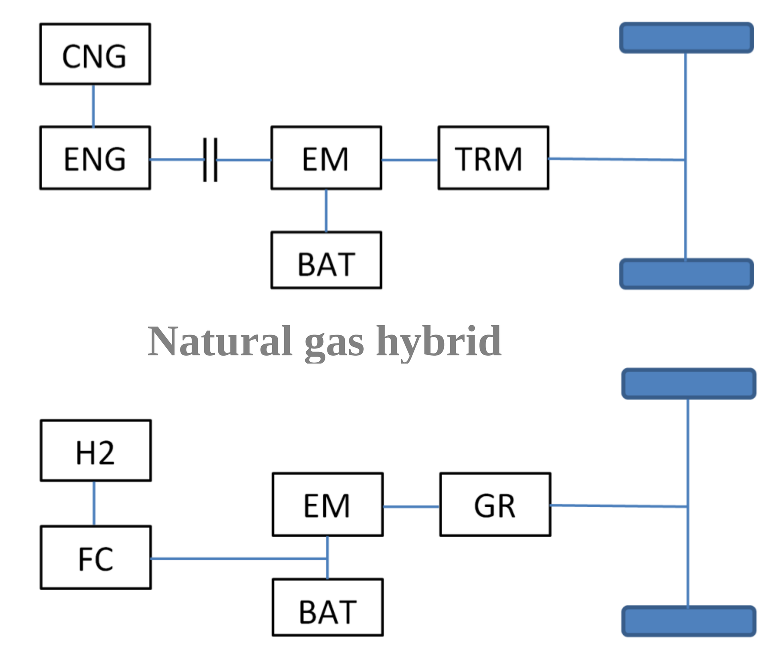
For different driving conditions, accessories such as heating and cooling have a large effect on fuel economy, energy consumption, and electric range of EVs and PHEVs.

TRANSITION TO GASEOUS FUELED VEHICLES

Energy Storage using natural gas and H2

Energy Type	Volume (Gallon)	Weight (Kg)	Gal. Gasoline Equivalent (GGE)	Fuel Density (Kg/L)
Gasoline	8	21	8	0.72
CNG(3600 psi)	29	22	8	0.2
Hydrogen(5000 psi)	88	8	8	0.024
Hydrogen(10000 psi)	54	8	8	0.039

HEV and FCV Driveline Schematics



Natural gas hybrid

Hydrogen fuel cell vehicle

Vehicle price projections 2015-2030

Assumed Component Costs in the Cost Analysis

Component	2015	2020	2025	2030
Fuel cell system $/kW	70	60	50	45
Electric motor/elect. $/kW	45	35	30	27
Lithium battery $/kWh	600	450	400	375
H_2 storage $/kWh	20	15	12	10
CNG storage $/kWh	9	7	6	5
Engine/trans. $/kW	42	42	42	42

Results of the Price Calculations for the CNG HEV and H_2 FCV

Vehicle type	Baseline Vehicle price $	Vehicle price W/o driveline $	2015	2020	2025	2030
Compact	19000	14800				
CNG HEV			26514	25231	24646	24161
H_2 FCV			33275	29510	27540	25690
Mid-size	25000	19000				
CNG HEV			33805	32215	31495	30925
H_2 FCV			40900	36490	34190	31985
Full-size	31000	23500				
CNG HEV			42603	40548	39595	38868
H_2 FCV			48775	43790	41200	39550
Small SUV	25000	19000				
CNG HEV			35605	33813	33010	32377
H_2 FCV			43165	38305	35817	33393
Mid-size SUV	33000	24750				
CNG HEV			42570	40508	39570	38847
H_2 FCV			52418	46860	44043	41265

CO2 Emissions of the Various Vehicle Technologies

The CO2 emissions are related to the mi/kWh

kg CO_2/mi = .076/(mi/kWh)nat.gas [44/16 + .514 + %leakage x30]

This relationship includes upstream and leakage emissions for the natural gas. Leakage assumed is 1.5%.

The CO2 emissions for the various technologies are

EV	1.44 mi/kWh nat. gas	196 gmCO2/mi
HEV	1.38	205
FCV	1.14	248
ICE	25 mpg (gasoline)	368

Using natural gas for an HEV is nearly as clean for CO2 as generating electricity for an EV. Fuel cell using hydrogen from steam reforming natural gas is not as low in CO2 emissions as combustion in an HEV

Simulated Fuel Economy of Mild EVS

Vehicle type	Eng. Pow kW	Electric motor kW	Supercap. mpg (1)	Li Batteries mpg (2)
Compact	97	15	47.4/49.8	45/47.7
Mid-size	125	25	41.1/44.2	40.3/43.1
Full-size	160	50	38.1/43.5	38.5/42.0
Small SUV	140	25	39.1/43.0	37.8/42.1
Mid-size SUV	150	40	36.2/39.5	34.3/38.4
Delivery Truck	200	50	12.2/10.7	11.8/10.7

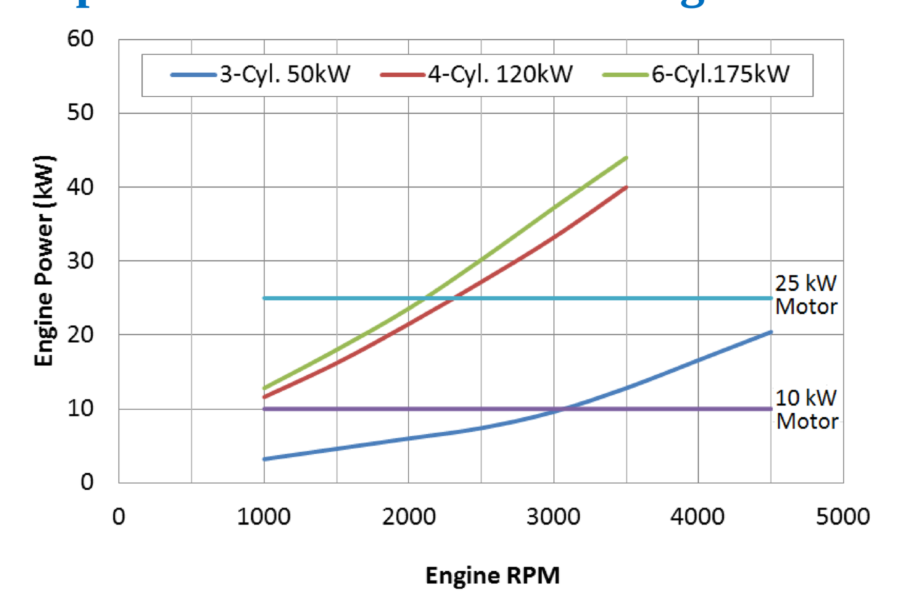
(1) Carbon/carbon supercapacitor, 1200 F from Yunasko, 1/10 bat. Wh
(2) LiTiO battery from Altairnano 3.8 Ah
(3) mpg FUDS cycle/ mpg Highway cycle

ADVANCED HYBRID VEHICLES

Energy Storage Unit Requirements for Various Types of Electric Drive Mid- size Passenger Cars

Type of electric driveline	System voltage V	Useable energy storage	Maximum pulse power at 90-95% efficiency kW	Cycle life (number of cycles)	Useable depth-of-discharge
Electric	300-400	15-30 kWh	70-150	2000-3000	deep 70-80%
Plug-in hybrid	300-400	6-12 kWh battery 100-150 Wh ultracapacitors	50-70	2500-3500	deep 60-80%
Charge sustaining hybrid	150-200	100-150 Wh ultracapacitors	25-30	300K-500K	Shallow 5-10%
Micro-hybrid	45	30-50 Wh ultracapacitors	5-10	300K-500K	Shallow 5-10%

Minimum Engine Power for Efficiency Operation for Various Size Engines



SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

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