UCDAVIS

SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS

An Institute of Transportation Studies Program

The fuel economy of MD/HD trucks 2015-2050

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Scope

Vehicle types

- Medium-duty trucks
- Heavy-duty trucks and buses

Vehicle technologies

- Engine/transmission
- Hybrid-electric
- Battery-electric
- Fuel cell

Fuel energy

- Diesel/NG
- Electricity
- Hydrogen

Trucks and buses to consider in the simulations

Truck Type	Technologies	Description / Example	Miles/day Operating days/yr	EMFAC 2015 MY mpg	DOE/EPA baseline 2010 mpg
Long Haul	Diesel, hybrid, CNG SI(500), LNG CI(500), FC(500)	Class 8 sleeper cab	287 miles/day 312 days/yr	6.6	6.6
Short haul	Diesel, hybrid, CNG(250), FC(250), BEV (100-250)	Class 8 non sleeper cab	140 miles/day 312 days/yr	6.5	7.0
MD urban	Diesel, Gas, diesel hybrid, CNG(250), FC(150-250), BEV(100-250)	Delivery truck (UPS)	80 312	8.6	8.8
Transit Bus	Diesel, hybrid, CNG(300), FC(300), BEV(150-300)	Transit Bus	150 327	4.6	6.7
Other Bus	Diesel, hybrid, CNG(300), FC(300), BEV(150-300)	Coach Greyhound	90 292	8.6	
HD pickup	Diesel, Gas, CNG, Hybrid, FC, BEV, PHEV	Ford F250	70 327	18	13.5
MD vocational	Diesel, PHEV, BEV(150-250), FC(250)	No simulation (mpg Data from EMFAC)	20 312	8.4	
HD vocational	Diesel, CNG, BEV(150-250), FC(250)	No simulation (mpg Data from EMFAC)	145 312	6.7	

Key aspects of the vehicle simulations

- UC Davis version of ADVISOR
- Road load parameters varied
- Drive component characteristics varied
- Hybrid-electric control strategy optimized engine efficiency
- Lithium titanate oxide (LTO) batteries used for hybrid and fuel cell powertrains
- Lithium Cobalt Manganese (LCOMn) batteries used for EVs
- Fuel cell efficiency varied with power ratio (60% max.)

Sources for the inputs for the simulations

- Supertruck papers and reports
- National Academy 21st century truck book, second review
- DOE/EPA truck standards documents (Phase I and II) especially GEM simulation chapter
- Selected reports on vehicle aerodynamic drag of trucks and buses
- Battery test data from UC Davis
- Previous UC Davis truck simulation studies

Vehicle road and powertrain input parameters

MD city Deliv.	Test Weight kg	C_D /A_F	f_r	Tire dia. (m)	Final drive ratio	Access. Load (kW)	Engine kW/ max. effic.	Transm no. spds/ effic.
2017	7500	.75/7.8	.008	.85	2.85	1.3	150/.42	6/.95
2020								
2025								
2030	6900	.6/7.8	.007	.85	2.85	1.3	150/.46	6/.96
2035								
2040								
2050	6750	.55/7.2	.006	.85	2.85	1.3	150/.48	6/.96
City transit bus								
2017	14600	.79/7.9	.009	1.5	3.8	6	280/.43	10/.92
2020								
2025								
2030	13750	.65/7.1	.0075	1.5	3.8	6	280/.48	10/.95
2035								
2040								
2050	13225	.55/7.1	.006	1.5	3.8	6	280/.50	10/.96

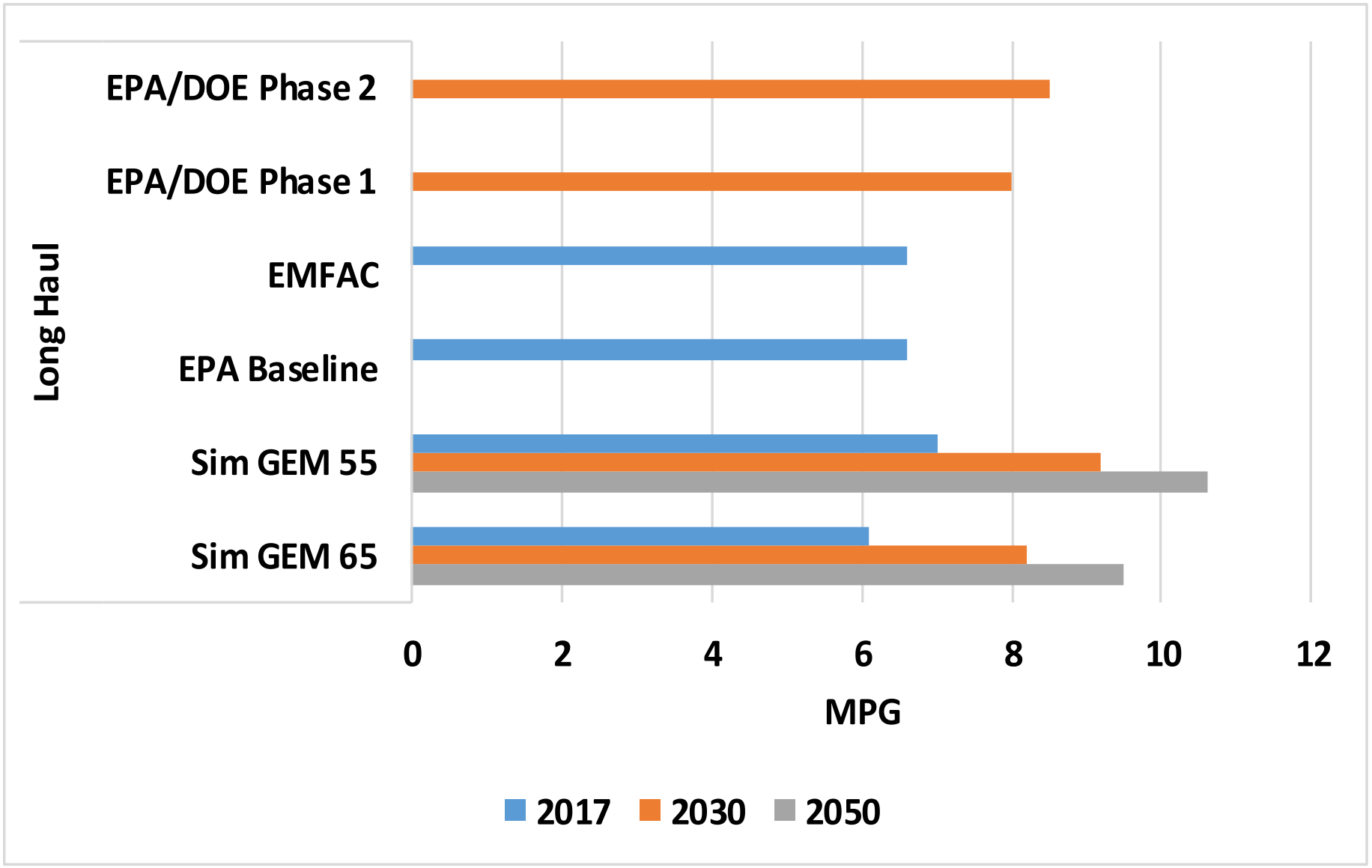
Summary of powertrain/vehicle inputs

Truck type	Vehicle weight kg	Engine kW, effic.	Transm., effic,	Electric motor kW	Battery kwh	Electric range miles	Fuel cell kW	Type of driving cycles
Long haul								
Conv-diesel	30000-29000	320, .43-.52	10 speed, .95-.96					highway
Fuel cell	30000-29000			300	5	300-500	300-	highway
MD city Deliv.								
Conv-diesel	7500-6750	150, .42-.50	6 speed, .95-.96					Urban, highway
Hybrid-diesel	7500-6750	150, .42-.50	6 speed, .95-.96	75	2			Urban, highway
EV	7500-6750		2 speed, .95-.96	125	50-100	50-100		Urban, highway
Fuel cell	7500-6750		2 speed, .95-.96	125	2	100	150	Urban, highway
City transit bus								
Conv-diesel	14600-13225	280, .53-.50	10 speed, .95-.96					urban
Hybrid-diesel	14600-13225	280, .53-.50	10 speed, .95-.96	120	5			urban
EV			2 speed, .95-.96	250	150-300	100-200		urban
Fuel cell	14600-13225		2 speed, .95-.96	250		200-300	300	urban

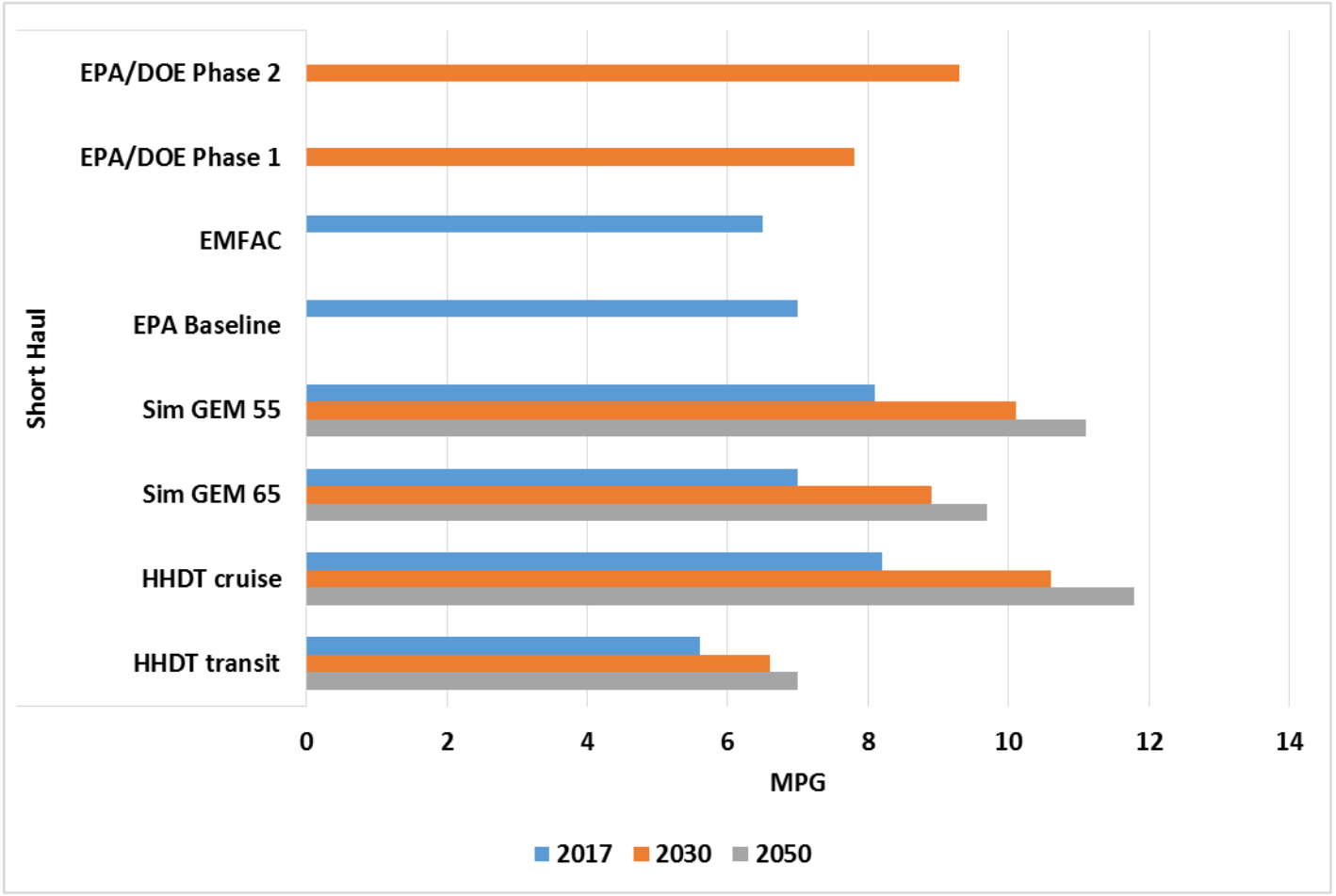
HD trucks- Conventional diesel fuel economy

Long	haul		HD trucks				
2017	mpg		2030	mpg		2050	Mpg
Sim. GEM65	6.1		Sim. GEM65	8.2		Sim. GEM65	9.5
Sim. GEM55	7.0		Sim. GEM55	9.2		Sim. GEM55	10.6
EPA baseline	6.6		EPA/DOE Phase I	8.0			
EMFAC	6.6		EPA/DOE Phase II	8.5			
Short	haul		HD trucks				
2017	mpg		2030	mpg		2050	mpg
HHDT-transit	5.6		HHDT-transit	6.6		HHDT-transit	7.0
HHDT-cruise	8.2		HHDT-cruise	10.6		HHDT-cruise	11.8
GEM65	7		GEM65	8.9		GEM65	9.8
GEM55	8.1		GEM55	10.1		GEM55	11.1
EPA baseline	7.0		EPA/DOE Phase I	7.8			
EMFAC	6.5		EPA/DOE Phase II	9.3			

HD trucks- Conventional diesel fuel economy



Simulation results for the diesel short haul truck



Simulation results for battery-powered transit buses

2030

Transit bus EV*	kWh/mi	**kWh for 100 miles	**kWh for 200 miles
Manhattan	2.2	275	550
NYcomp	1.8	240	480
ARB-TR	1.43	180	360
HHDT-CR	1.2	150	300
65mph const.	1.33	166	332

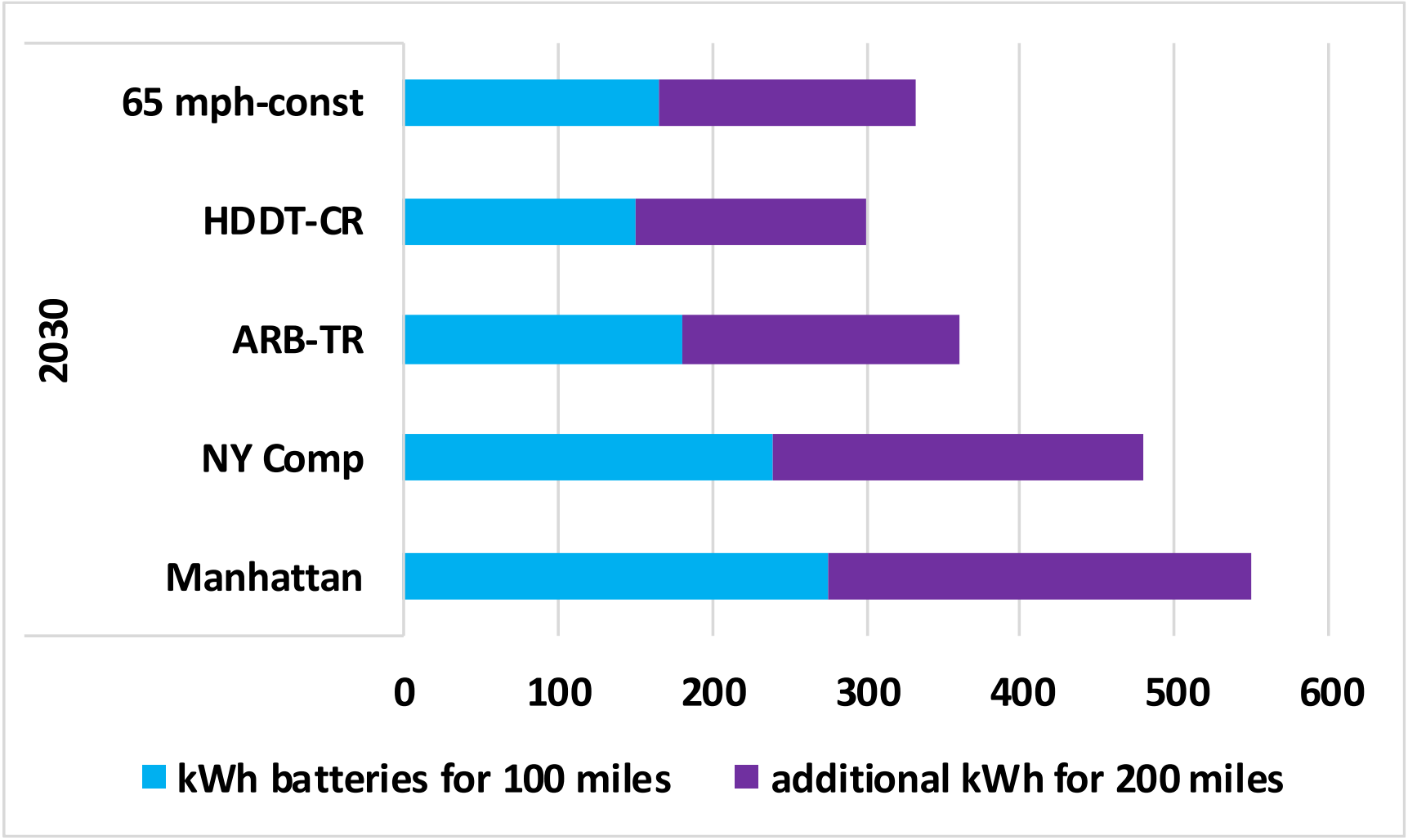
* C_D =.35, A_F =7.5, wt. =15,000 kg, f_r =.0075, 6 kW access. load

****80% of battery capacity is used initially, 150 Wh/kg 2030, 225 Wh/kg 2050**

2050

Transit bus EV*	kWh/mi	kWh for 100 miles	kWh for 200 miles
Manhattan	1.83	230	460
NYcomp	1.46	182	364
ARB-TR	1.1	138	276
HHDT-CR	.86	108	216
65mph const.	1.04	130	260

Simulation results for battery-powered transit buses 2030



Simulation results for hydrogen fuel cell transit buses

2030

Transit bus* **Driving cycles**	mi/gal gasoline equiv.	mi/kgH_2**	kgH_2 for 150 miles	kgH_2 for 300 miles
Manhattan cycle	8.8	8.4	19.8	39.6
NY comp	11.4	10.9	15.3	30.6
ARB-TR	14.6	13.9	12.0	24
HHDT-CR	18.1	17.3	9.6	19.2
65mph const.	15.1	14.4	11.6	23.2

* C_D =.35, A_F =7, wt. =15000 kg, f_r =.006, 6 kW access. load

****90% of H_2 capacity is used, mi/kgH_2 = mi/gal gasol. equiv./1.0475**

2050

Transit bus*	mi/gal gasoline equiv.	mi/kgH_2**	kgH_2 for 150 miles	kgH_2 for 300 miles
Manhattan cycle	9.5	9.1	18.3	36.3
NY comp	12.0	11.5	14.5	29
ARB-TR	15.6	14.9	11.2	22.4
HHDT-CR	21.1	20.1	8.3	16.6
65mph const.	17.8	17.0	9.8	19.6

* C_D =.30, A_F =7, wt. =14500 kg, f_r =.005, 6 kW access. load

2030 Long haul hydrogen fuel cell vehicles

Long haul* **Driving cycles**	mi/gal gasoline equiv.	mi/kgH_2**	kgH_2 for 100 miles	kgH_2 for 300 miles	kgH_2 for 500 miles
GEM65	8.9	8.5	13.07	39	65
GEM55	9.4	9.0	12.35	37	62
HHDT-CR	9.9	9.45	11.76	35	59
65mph const	8.8	8.4	13.23	40	66

* C_D =.55, A_F =9.5, wt. =29500 kg, f_r =.0055, 1.5 kW access. load

2050

Long haul * **Driving cycles**	mi/gal gasoline equiv.	mi/kgH_2**	kgH_2 for 100 miles	kgH_2 for 300 miles	kgH_2 for 500 miles
GEM65	9.2	8.78	12.66	38	63
GEM55	10.1	9.64	10.37	31	52
HHDT-CR	10.9	10.41	10.67	32	53
65mph const	9.3	8.8	11.36	34	57

* C_D =.45, A_F =9.5, wt. =29000 kg, f_r =.005, 1.5 kW access. load

Hybrid-electric simulation results for several HDV types

Short haul trucks

	HEV 2017, 2030, 2050	CONV Diesel 2017, 2030, 2050	HEV/CONV Diesel 2017, 2030, 2050
Driving cycles			
HHDT-TR	6.7, 8.0, 8.6	5.6, 6.6, 7.0	1.2, 1.21, 1.23
HHDT-CR	8.2, 10.6, 12.0	8.2, 10.6, 11.8	1.0, 1.0, 1.02
GEM65	7.0, 8.6, 9.8	7.0, 8.9, 9.8	1.0, 1.04, 1.0
GEM55	8.1, 10.4, 11.7	8.1,10.1, 11.1	1.0, 1.03, 1.05

MD delivery trucks

	HEV 2017, 2030, 2050	CONV Diesel 2017, 2030, 2050	HEV/CONV Diesel 2017, 2030, 2050
Driving cycles			
Delivery cycle	13.6, 17.6, 20.0	9.6, 11, 12.1	1.42, 1.6, 1.65
Non-FW 15mpg av.	12.3. 15.5, 17.0	8.9, 10.7, 11.5	1.38, 1.45, 1.48
ARB-Trans.	14.6, 18.2, 20.5	9.8, 12.1, 13.1	1.49, 1.5, 1.56

City transit buses

	HEV 2017, 2030, 2050	CONV Diesel 2017, 2030, 2050	HEV/CONV Diesel 2017, 2030, 2050
Driving cycles			
NYcomp	4.5, 5.4,5.9	7.3, 9.5, 11.0	1.6,1.76, 1.86
ARB-TR	6.1, 7.6, 8.5	9, 12, 14	1.48, 1.58, 1.65
HHDT-CR	8.0, 11.5, 14.2	7.8,11.3, 13.8	1.03, 1.03, 1.03

Energy economy ratios based on the mi/galD equiv.

2030 simulation results

City driving conditions

MD delivery truck

powertrain	mi/galD	Ratio
Diesel	11.0	1.0
Hybrid diesel	17.6	1.6
H2FC	23.3	2.1
EV*	41.7	3.8

*battery charging efficiency 90%

Transit bus

powertrain	mi/galD	Ratio
Diesel	7.6	1.0
Hybrid diesel	12.0	1.6
H2FC	16.4	2.2
EV	24.3	3.2

HD pickup truck

powertrain	mi/galD	Ratio
Diesel	13.3	1.0
Hybrid diesel	32.9	2.5
H2FC	37.4	2.8
EV	85.8	6.5

Highway driving at 65 mph

Long haul truck

powertrain	mi/galD	Ratio
Diesel	8.2	1.0
H2FC	9.9	1.21

Intercity bus

powertrain	mi/galD	Ratio
Diesel	10.1	1.0
H2FC	16.9	1.7
EV	26.1	2.6

HD pickup truck

powertrain	mi/galD	Ratio
Diesel	23.5	1.0
Hybrid diesel	31	1.3
H2FC	38.7	1.7
EV	82.7	3.5

Summary and conclusions

- Relatively large reductions in energy use can be gained with advanced driveline in urban driving, but the reductions are smaller for highway (65mph) driving.
- Decreasing the road load is key to reducing significantly the energy use for all the technologies and truck types.
- Fuel cells seem to be a reasonable replacement for engines for long haul trucks and inter-city buses
- Battery-electric, HEV and PHEV powertrains seem reasonable for most truck types and buses that are used primarily in urban areas.
- The fuel economy of all the trucks and buses depends significantly on the driving cycle and to a lessor extent on the accessory loads.