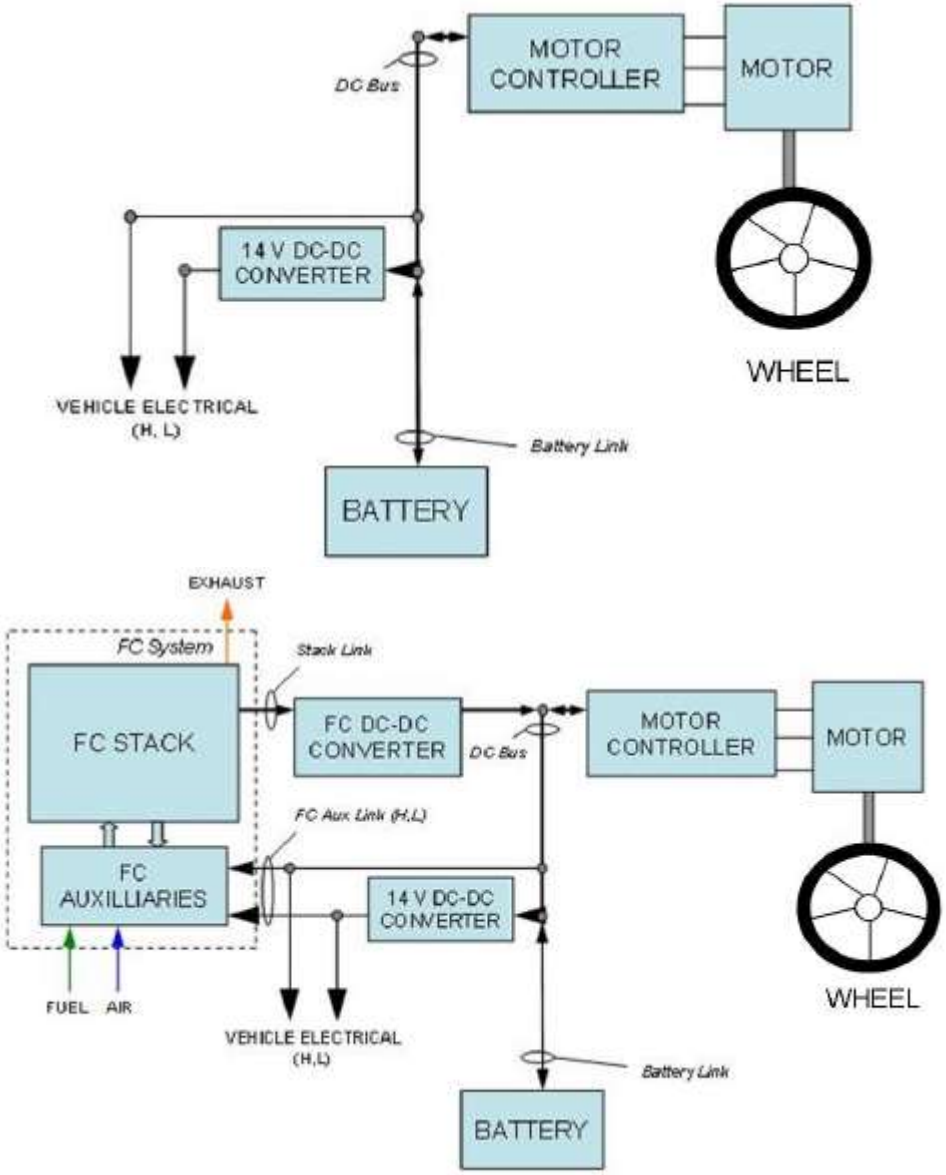
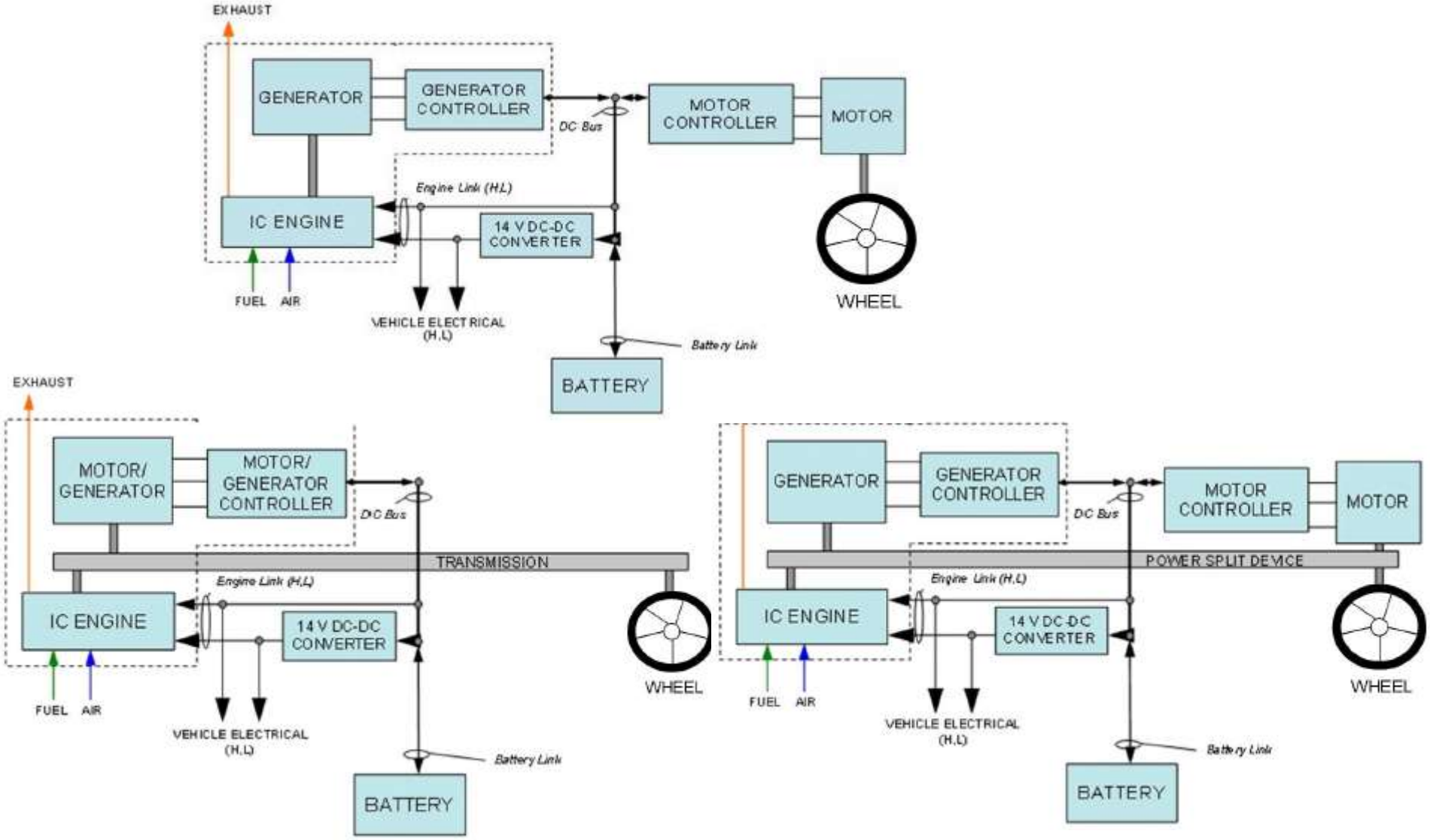
Future Steel Vehicle Propulsion Systems

- evaluation of currently used, as well as emerging powertrain technologies
  - high voltage batteries of varying chemistries, ultra-capacitors, traction and wheel motors, and power electronics, as well as hydrogen storage and infrastructure
- Feasibility study: powertrain architectures, components, performance, cost, and mass
  - Plug-In Hybrid Electric with a 32 km (20 mile) all electric range (PHEV20)
  - Plug-In Hybrid Electric with a 64 km (40 mile) all electric range (PHEV40)
  - Battery Electric Vehicle (BEV)
  - Fuel Cell Electric Vehicle (FCEV)

Advanced Powertrain Block Diagrams: BEV, FCEV



Advanced Powertrain Block Diagrams: PHEV (Series, Parallel, Parallel-Split)



Parallel-Split Series Simulation

- Parallel-split configuration consumes less fuel in charge sustaining mode, and is especially more significant when driven under aggressive driving and travel conditions
- Series configuration consumes slightly less electricity in charge depleting mode, but only enough to extend the range by 1-2 km
- When the powertrain mass difference is considered (mass was assumed to be constant in this study), the efficiency of the parallel-split configuration would increase

FSV Medium Car PHEV Architecture Decision Matrix	Priority	Series	Parallel Split
Fuel Economy / CO2 Emission (70% CD, 30% CS)	5	+	
Driving Range and Performance	2	+	+
Powertrain Weight	4		+
Powertrain System Cost	4		+
Powertrain complexity	3	+	
Platform Sharing with ICE/Transmission Powertrains	1		+
Platform commonality among FSV Variants	4	+	
Score		14	11
		+ Advantageous	

Table 4.3: *PHEV decision matrix*

Future Steel Vehicle: Technology Implementation

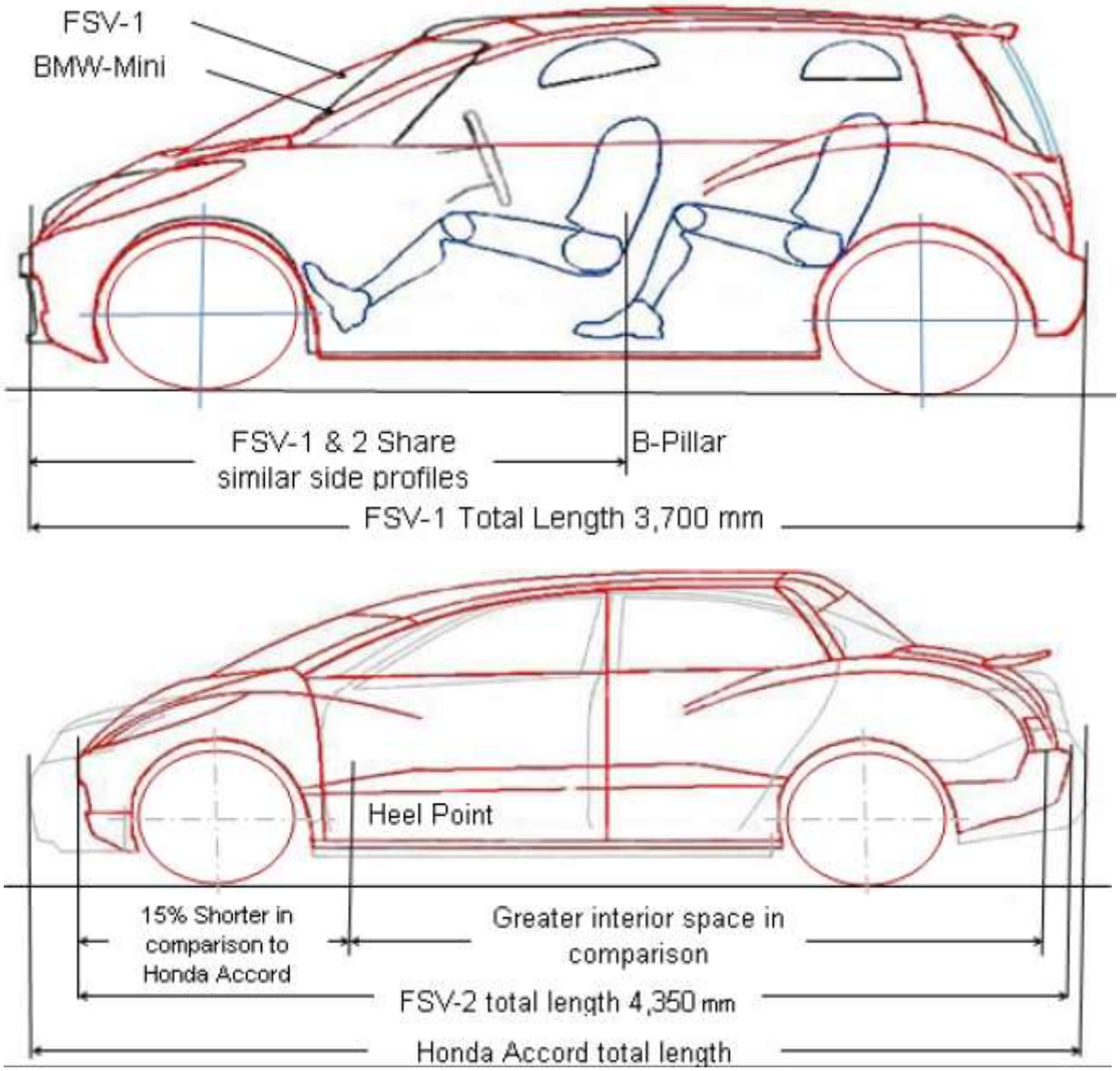
- Vehicle classification
- Size comparison
- Exterior dimensions
- Interior dimensions
- Occupant and luggage carrying capacity
- FSV front-end
- FSV front rails
- FSV powertrain
- Vehicle performance
- Powertrain design evaluation
- Fuel economy and emission
- Cost of ownership

Future Steel Vehicle Classification

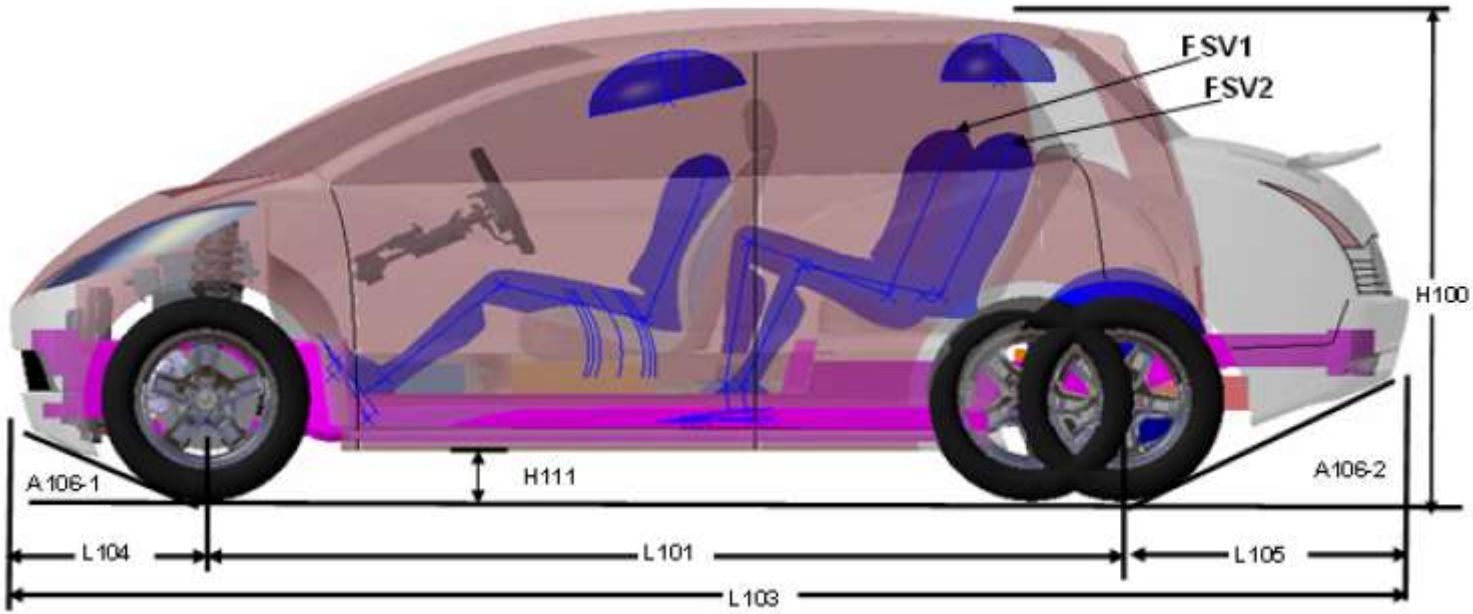
- Over 70% of the cars sold in today's marketplace
  - Small car, (A & B Class) up to 4,000 mm long
  - Mid-class car, (C & D class) up to 4,900 mm long
- Future Steel Vehicle program
  - FSV-1: small vehicle mainly intended for city and shorter daily driving
    - (BEV) Battery Electric Vehicle
    - ($PHEV_{20}$) Plug-In Hybrid Electric with a 32km (20 mile) All Electric Range(AER)
  - FSV-2: at the low-end of the mid-size range of vehicles, intended for long range driving with larger luggage carrying capacity
    - ($PHEV_{40}$) Plug-In Hybrid Electric with a 64km (40 mile) All Electric Range(AER)
    - (FCEV) Fuel Cell hybrid Electric Vehicle

	PHEV (Plug-In Electric Vehicle)	FCEV (Fuel Cell Electric Vehicle)	EV (Electric Vehicle)
FSV1 (Small Vehicle)	X		X
FSV2 (Large Vehicle)	X	X	

Vehicle Size

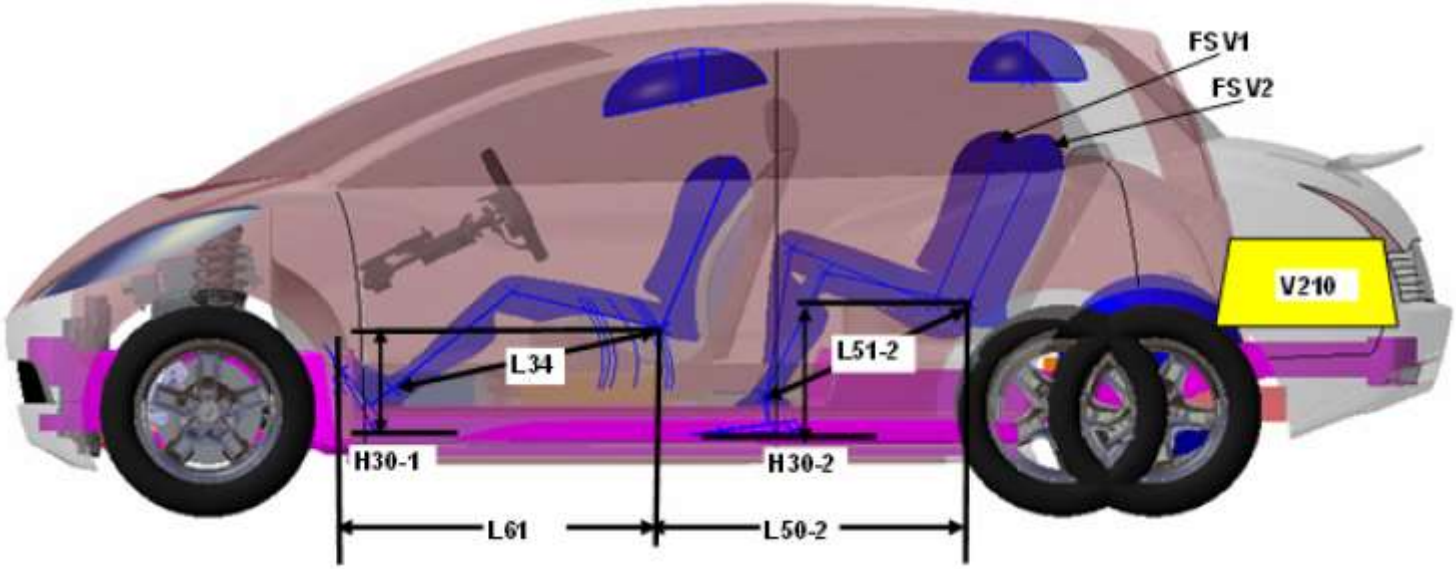


FSV Exterior Dimensions



		FSV1	FSV2
L101	Wheel Base	2524	2800
L103	Total Length	3700	4350
L104	Front Overhang	600	600
L105	Rear Overhang	576	950
H100	Total Height	1540	1540
W103	Total Width	1680	1780
W102	Front Track	1470	1570
W101	Rear Track	1470	1570
H111		150	150
A106-1		23	23
A106-2		25	26

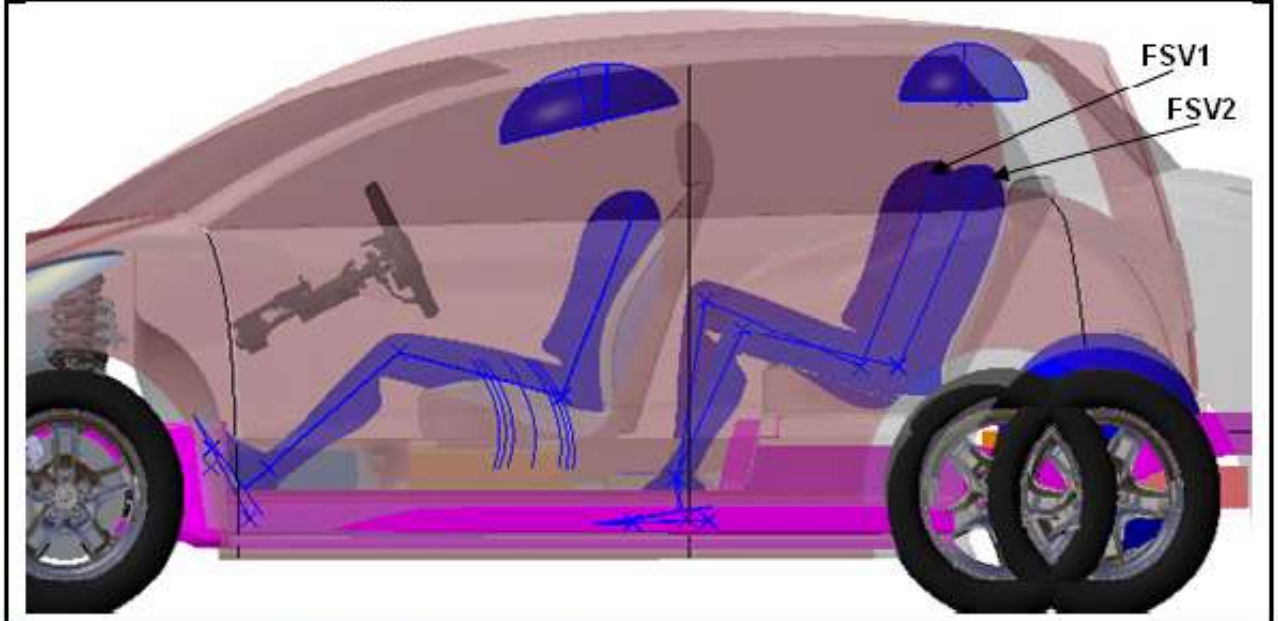
FSV Interior Dimensions



	L34	L61	H30-1	L50-2	L51-2	H30-2	V210
FSV1	1070	945	325	780	825	375	250 L
FSV2	1070	945	325	780	925	375	350 L

Occupant and Luggage Carrying Capacity

FSV1 Occupants:	FSV2 Occupants:
Front Row Seating: 2	Front Row Seating: 2
Rear Row Seating: 2+	Rear Row Seating: 3

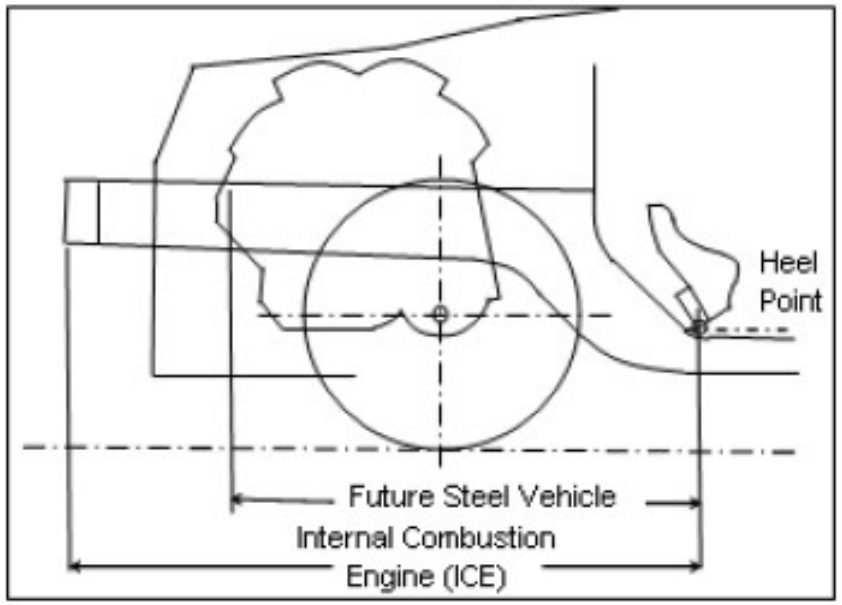


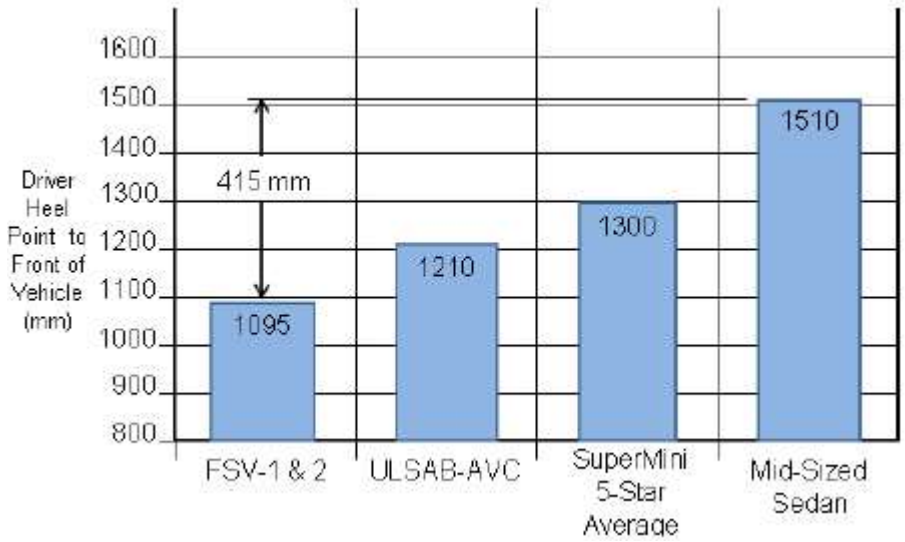
Class	Front Leg Room [mm]	Rear Leg Room [mm]	Luggage [Liters]
FSV-1	**1070**	**825**	**250**
FSV-2	**1070**	**925**	**370**
A	1055	760	170
B	1065	850	340
C	1070	877	370
D	1075	961	450

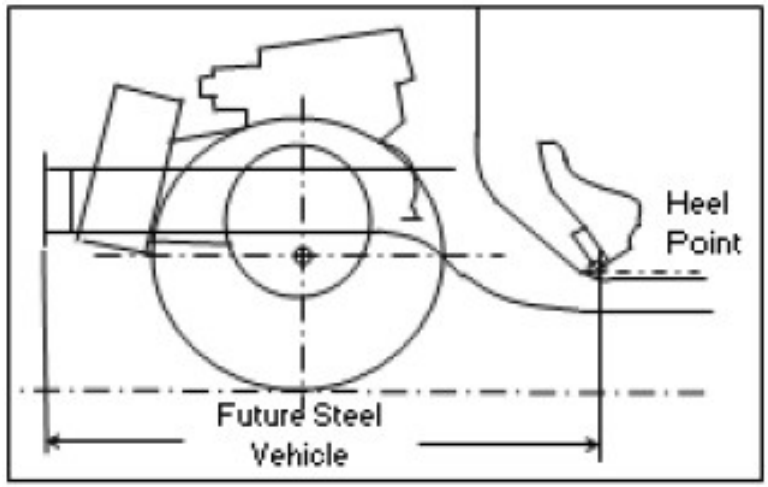
Vehicle Design & Layout

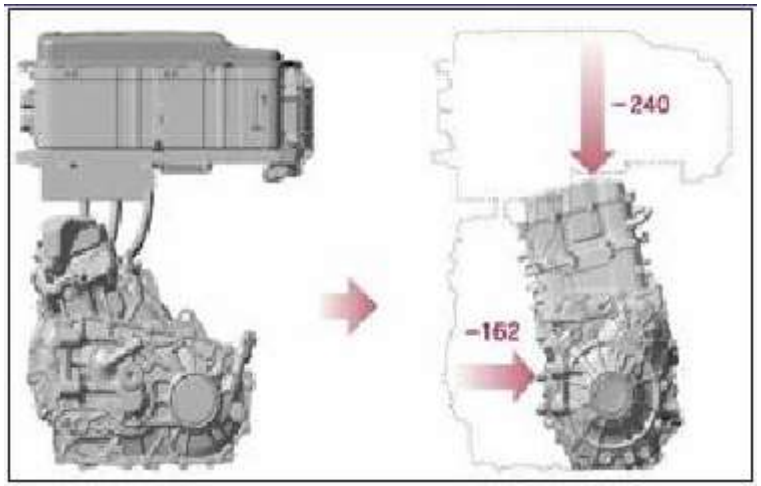
- Common platform theme
  - Utilizing shared technologies in a modular fashion between all four vehicle powertrain variants
- Significant reduction in vehicle front-end length
  - Electrically driven front wheels → simplify the front-end layout
  - 415 mm shorter than a typical mid-size sedan, 205 mm shorter than the 5-star rated Super-Mini Class vehicles
  - FSV-1: 65 mm more legroom, additional 80 liters of cargo space
  - FSV-2: 500 mm shorter than a Honda Accord yet shares the same interior room
  - Space for an optimized front-end structure (front-end rails)
- Compact electric drive
  - Smaller than Honda Clarity FCEV

FSV Front-End



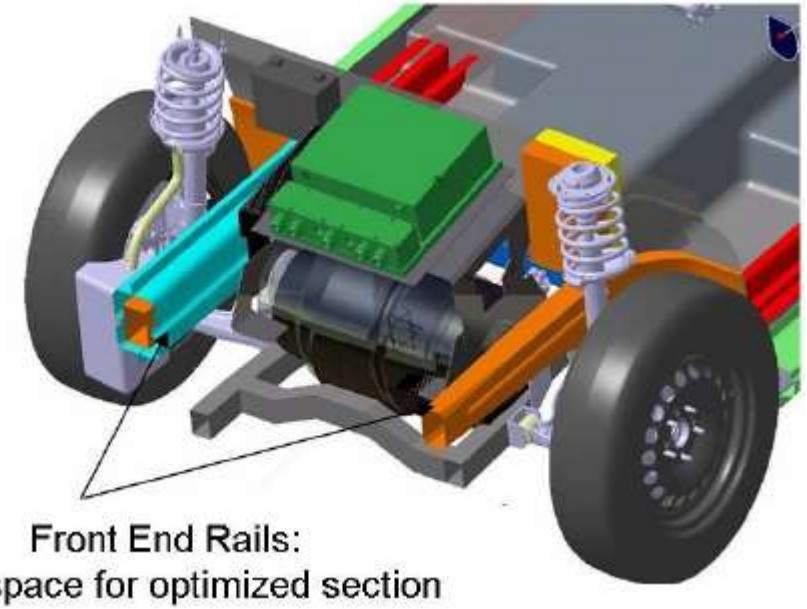






FSV Front Rails

- The size of conventional internal combustion engine and Hybrid Electric Vehicle (HEV) powertrains generally restrict the size and shape of body-structural members in the front-end, leading to inefficient use of materials.
- The FSV's front-end frees up space for an optimized structure. The front-end rails, which play a major roll in controlling and absorbing energy in front crashes, can be optimized for section shape and hence minimizing mass



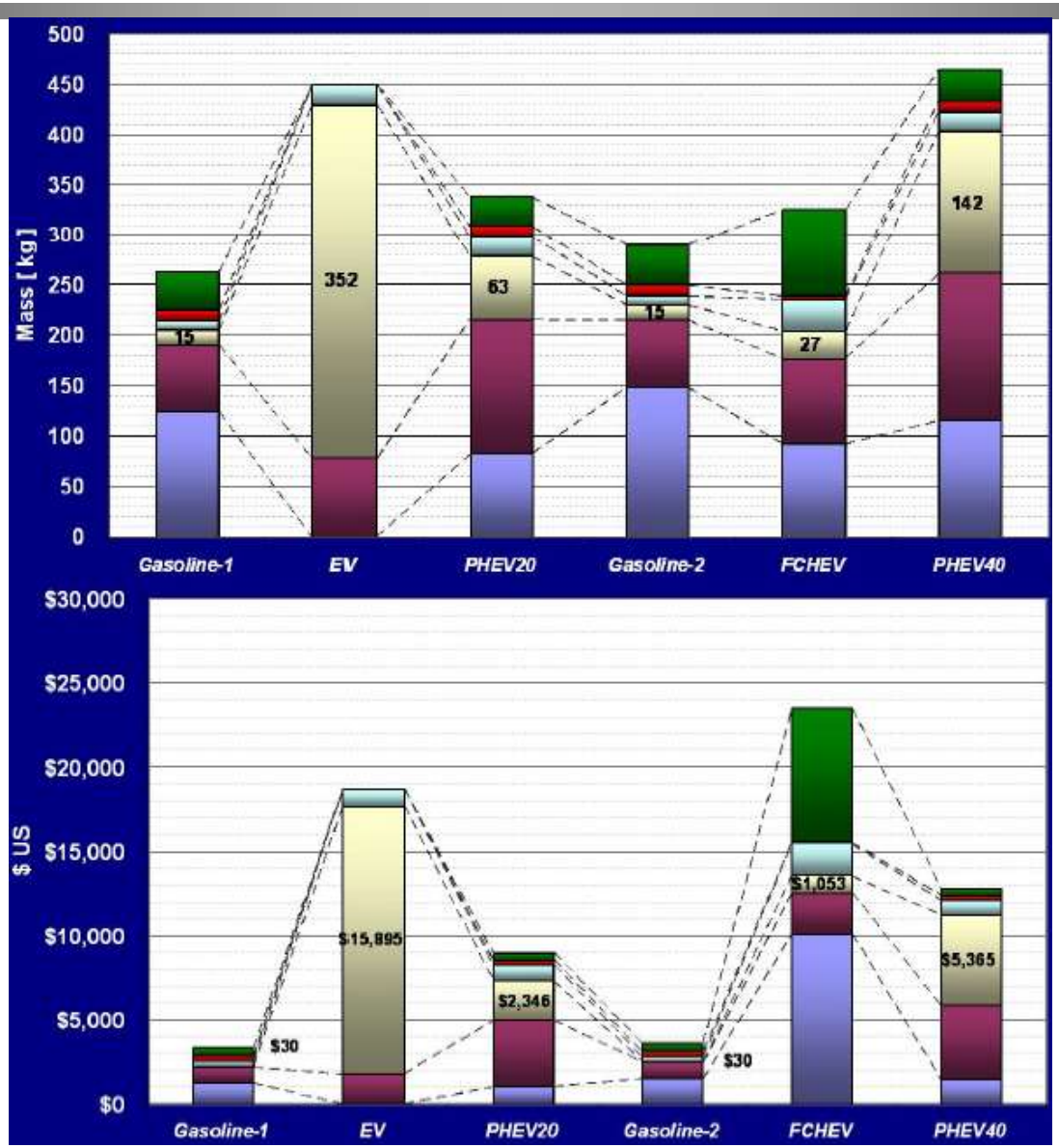
Front End Rails:
More space for optimized section

FSV Powertrain: Options and Performance

- Conventional Internal Combustion Engine (ICE) based smaller more efficient gasoline/diesel vehicles
- Hybrid Electric Vehicles (HEV) predominantly using fossil-based petroleum fuels
- Plug-in Hybrid Electric Vehicles (PHEV) with a limited range of distance driven in electric mode using electricity from the power grid
- Battery Electric Vehicles (BEV) with driving range of approximately 200 km
- Fuel Cell Electric Vehicles (FCEV) using hydrogen gas as a fuel source

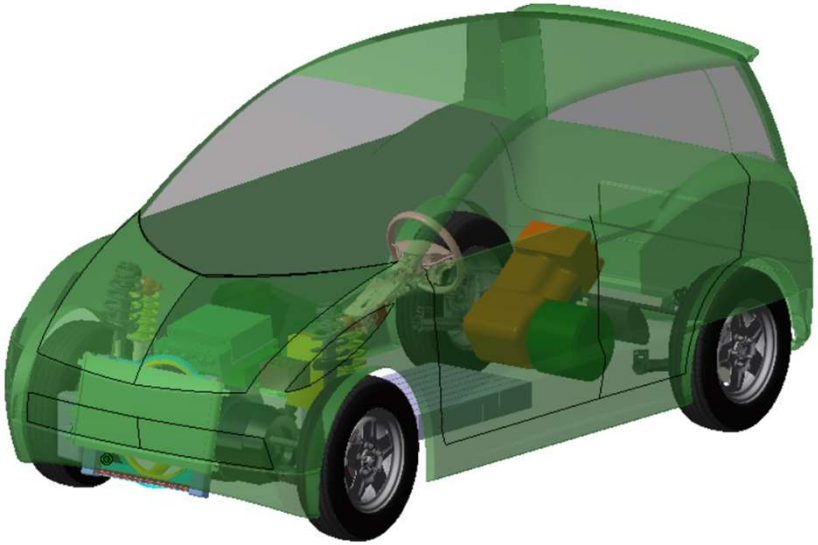
	Plug-in Hybrid (PHEV)	**Fuel Cell** (FCEV)	**Battery Electric** (BEV)
FSV 1 A-B class	**PHEV 20** Electric Range - 32km (20mi) Total Range - 500km Max Speed -150km/h 0-100km/h 11-13s		**BEV** Total Range - 250km Max Speed -150km/h 0-100km/h 11-13s
FSV 2 C-D class	**PHEV 40** Electric Range - 64km (40mi) Total Range - 500km Max Speed - 161km/h 0-100km/h 10-12s	**FCEV** Total Range - 500km Max Speed - 161km/h 0-100km/h 10-12s	

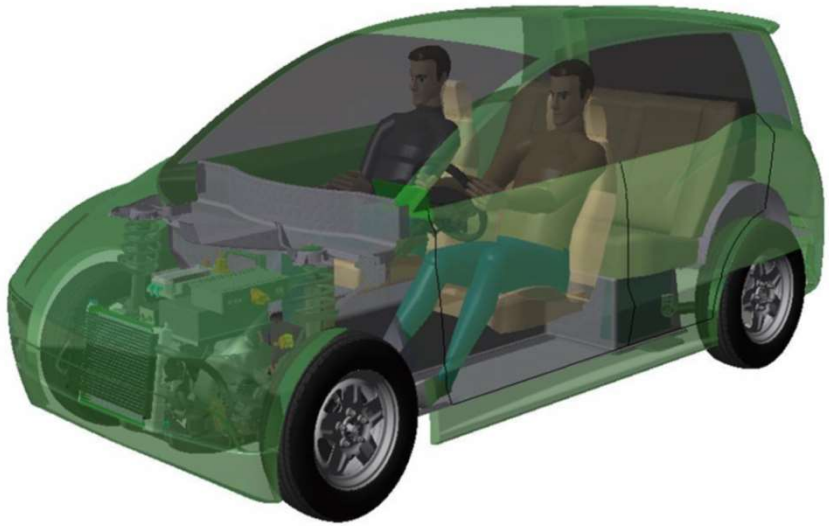
FSV Powertrain: Mass and Cost



FSV-1

- 4-door hatchback, 3,700 mm long
- 175/65 R15 tires with a rolling resistance of 0.007
- $PHEV_{20}$/BEV
  - Common front-end and front wheel drive traction motor
  - Rated at a peak power of 67 kW (49 kW continuous power)





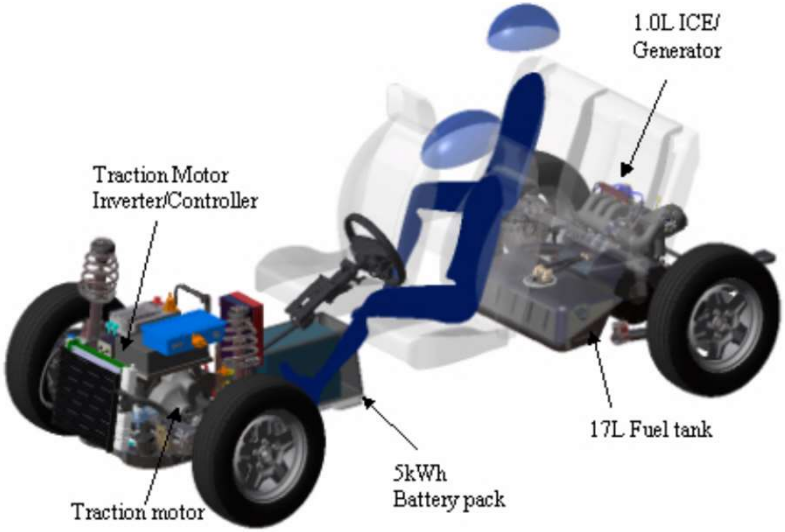
FSV-1: $PHEV_{20}$

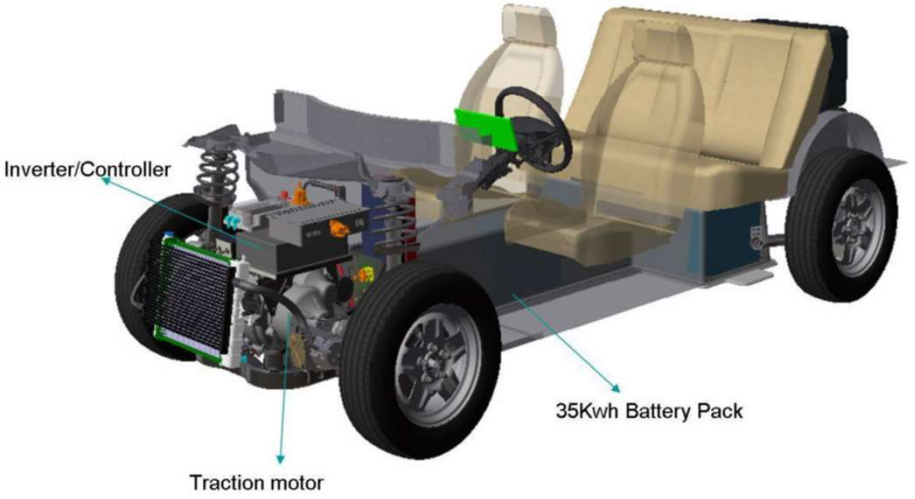
- All electric range of 32 km (20 miles) on a fully charged battery pack
  - 5 kWh capacity (45 kg mass, 36-liter volume): lithium-ion manganese based cell
  - Charging time: 2.5 hours (120 V, 15 amp)
- Extended range of 500 km by a rear mounted 1.0L-3 cyl gasoline engine/generator set
- 50/50 vehicle mass split between front and rear wheels
  - Similar to Daimler's Smart-For-Two and Mitsubishi's i-Minicar
- Hydroformed rear subframe assembly that can support the engine/generator mounts
- Under floor structure: 5 kWh battery pack in the tunnel
- Rear multi-link suspension that will form the basis of the rear structure
  - Sufficient structure to handle all the dynamic and rear impact crash loading

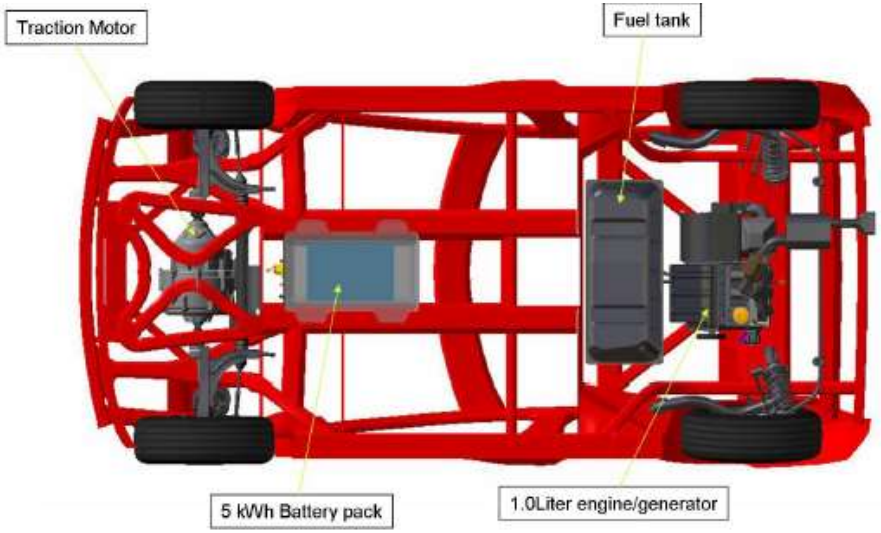
FSV-1: BEV

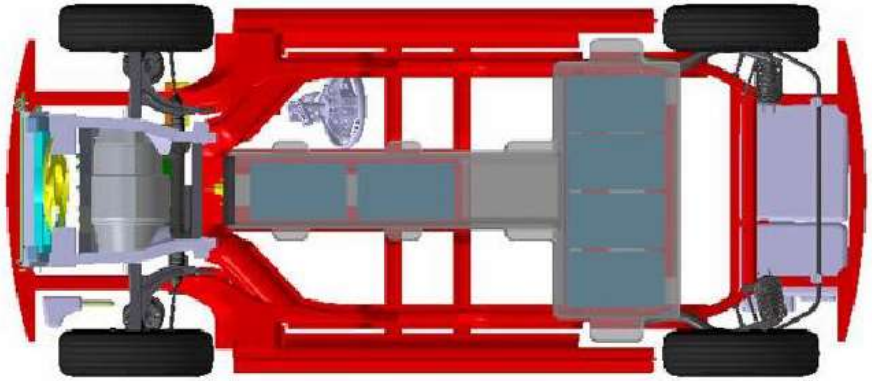
- Designed to have a range of 250 km
- Battery pack: 35 kWh (347 kg mass, 280 liter volume)
  - Packaging into a small vehicle is a major challenge
  - From underneath the rear seat occupants floor into the tunnel and below the front floor
- Under floor structures
  - Support the significant weight of the battery during road loading
  - Protect it when subjected to frontal, and side and rear crash impact loads
  - Full-size under floor longitudinal member, coupled with several cross members and additional tunnel reinforcements

FSV-1: Layout & Design









Estimated Mass(kg): FSV-1

	ICE 1 2010	ICE 1 2020	HEV 1 2010	HEV 1 2020	FSV 1 $PHEV_{20}$	FSV 1 BEV
Body Non-Structure	245	190	215	190	190	190
Body Structure	272	241	272	237	173	190
Front Suspension	59	40	62	45	40	45
Rear Suspension	53	39	61	37	26	35
Steering	17	17	17	17	16	16
Brakes	38	31	40	33	29	32
Drivetrain	222	197	297	252	215	78
Fuel, Battery, Exhaust	48	55	104	105	98	347
Wheels and Tires	78	59	68	55	38	44
Air Conditioning	32	42	27	33	36	36
Electrical	55	63	55	66	63	58
Bumpers	26	21	23	24	20	23
Closures	54	48	49	44	46	46
TOTAL	1199	1044	1290	1138	990	1,137

Powertrain components	Mass [kg]	Cost [US $]
Li-ion Battery and controller	346.5	15,895
Traction Motor System (67kW)	78	1,742

Powertrain components	Mass [kg]	Cost [US $]
Li-ion Battery and controller	58.2	2,346
Genarator/Traction Drive (75kW)	132.8	3,975
IC Engine(1.0L)	82.5	1,050
Fuel system	29.3	415
Exhaust System	10.8	300

Technical Specification & Performance

- Powertrain System Analysis Toolkit (PSAT)
  - developed by Argonne National Labs
  - simulation tool based on Matlab/Simulink software
  - specifically designed for transient performance evaluation of vehicle powertrains
- Recursive process
  - Inputs such as vehicle total mass, auxiliary power, etc. would be assumed
  - Characteristics of powertrain components (mass, volume, efficiency, etc.) are incorporated into the vehicle design
  - Vehicle design is iterated to accommodate the necessary powertrain and a new mass is determined
  - Updated vehicle total mass, auxiliary power, etc. are returned back to the powertrain designers for verification of vehicle performance

FSV-1: Vehicle Design

Vehicle Design Parameters (comparable to OEM standards)		**BEV**			**PHEV$_{20}$**	
			Curb +Driver	GVW	Curb +Driver	GVW
Front wheel drive		yes	yes		yes	
Wheel base	[mm]	2461	2461		2461	
Weight distribution	[%/%]	50/50				
Center of gravity height	[mm]	530				
Coefficient of drag (Cd)		0.25	0.25		0.25	
Vehicle frontal area	[m^2]	2.1	2.1		2.1	
Tire size and specifications			P175/65R15		P205/60R16	
Tire rolling resistance		0.007	0.007		0.007	
Auxiliary power demand, Max. continuous	[W]	2200				
Auxiliary power demand, Test	[W]		700		700	
Mechanical accessory losses	[W]		0		715	
Road condition, Brake + Acceleration		Dry Asphalt	Dry Asphalt		Dry Asphalt	
Passenger capacity		4+				
Cargo volume	[Liters]	250				
Curb weight	[kg]	1100	1100		1000	
Payload	[kg]	360		360		360
Driver weight	[kg]	75	75		75	
Vehicle test weight	[kg]	-	1175	1460	1075	1360

FSV-1: Powertrain Design

Powertrain Design Parameters (comparable to OEM standards)		**BEV**			**PHEV$_{20}$**	
			Curb +Driver	GVW	Curb +Driver	GVW
Regenerative braking		yes	yes		yes	
Peak engine power (mechanical)	[kW]		n/a		53	
Fuel cell power (electrical)	[kW]		n/a		n/a	
Battery capacity	[kWh]		35.1		5.1	
Traction motor mechanical capacity (Continuous/ Peak/ Max RPM)	[kW]		49 / 49 / 8700 rpm		49 / 49 / 8700 rpm	
Peak motor power (mechanical)	[kW]		49		49	
Peak generator power (electrical)	[kW]		n/a		48	
Final drive/differential	[ratio]		6.44		6.44	
Powertrain weight	[kg]		441		335	
Battery weight	[kg]		347		58	
Fuel tank capacity	[kg]		n/a		13	
Type of PHBEV		Series	n/a		Series	

FSV-1: Vehicle Performance

IC Engine, Peak (mechanical)	N/A
Generator, Peak (electrical)	N/A
Traction Motor, Peak (mechanical)	49 kW

	Units	Specs	Traction Power Peak 49 kW Curb + Driver	Peak 49 kW GVW	Continuous 49 kW Curb + Driver	Continuous 49 kW GVW	Capability
Performance							
Acceleration							
0 - 100 km/h, Curb + Driver	sec.	11-13	12.4 @ 49 kW	—	—	—	
Peak Grade							
30 km/h - 30 sec., GVW	%	22	—	22 @ 28 kW	—	—	
Continuous Grade							
73 km/h - Continuous, GVW	%	10	—	—	—	10 @ 36 kW	
90 km/h - Continuous, GVW	%	10	—	— —	—	10 @ 46 kW	
100 km/h - Continuous, GVW	%	10		—	—	9 @ 49 kW	
Top Speed							
Continuous, GVW	km/h	150	—	—	—	150 @ 31 kW	
Range							
Curb + Driver, UDDS	km	250	—	—	296	—	

Limited Perfomance =
Unable to Perfom =

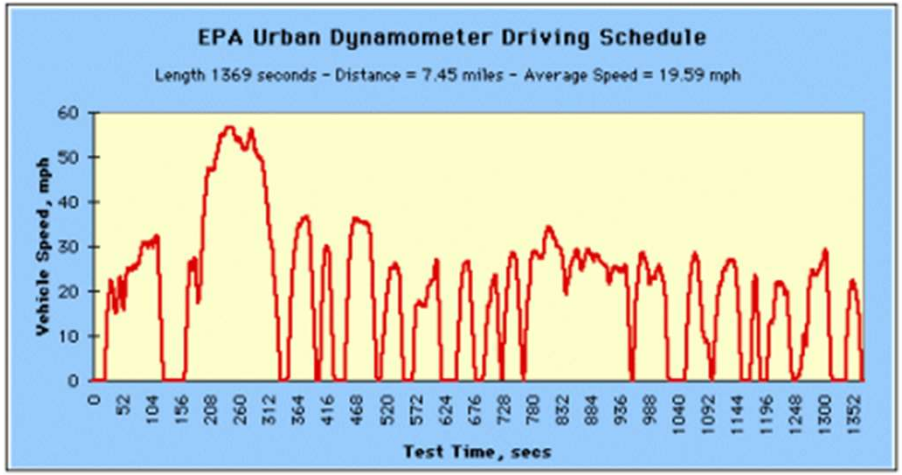
IC Engine, Peak (mechanical)	50 kW
Generator, Peak (electrical)	48 kW
Traction Motor, Peak (mechanical)	49 kW

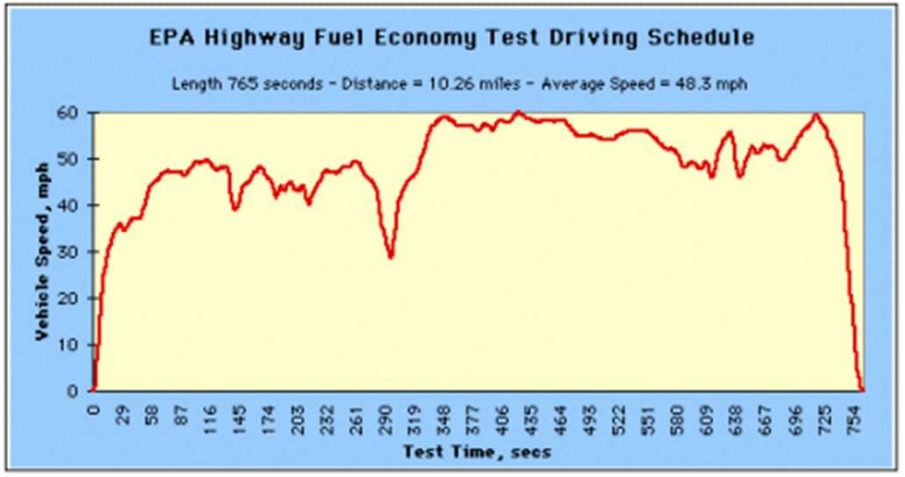
	Units	Specs	Traction Power Peak 49 kW Curb + Driver	Peak 49 kW GVW	Continuous 49 kW Curb + Driver	Continuous 49 kW GVW	Capability
Performance							
Acceleration							
0 - 100 km/h, Curb + Driver	sec.	11-13	11.3 @ 49 kW	—	—	—	
Peak Grade							
30 km/h - 30 sec., GVW	%	22	—	22 @ 26 kW	—	—	
Continuous Grade							
73 km/h - Continuous, GVW	%	10	—	—	—	10 @ 33 kW	
90 km/h - Continuous, GVW	%	10	—	— —	—	10 @ 43 kW	
112 km/h - Continuous, GVW	%	10		—	—	10 @ 49 kW	
Top Speed							
Continuous, GVW	km/h	150	—	—	—	150 @ 28 kW	
Range							
Curb + Driver, UDDS	km	500	—	—	556	—	

Limited Perfomance =
Unable to Perfom =

EPA Vehicle Chassis Dynamometer Driving Schedules (DDS)

- Urban Dynamometer Driving Schedule (UDDS)
  - LA4 or the city test
- Federal Test Procedure (FTP)
  - EPA75
- Highway Fuel Economy Driving Schedule (HWFET)





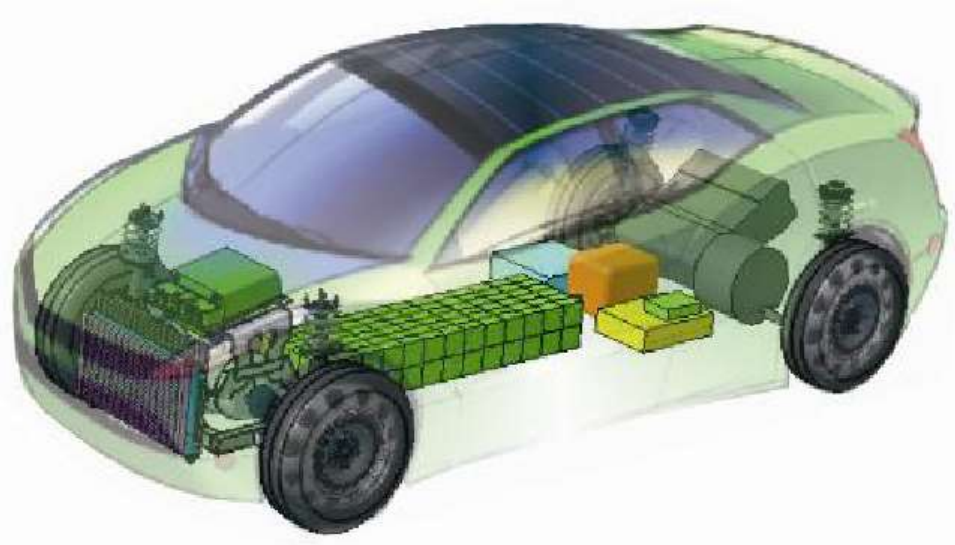
https://www.epa.gov/vehicle-and-fuel-emissions-testing/dynamometer-drive-schedules

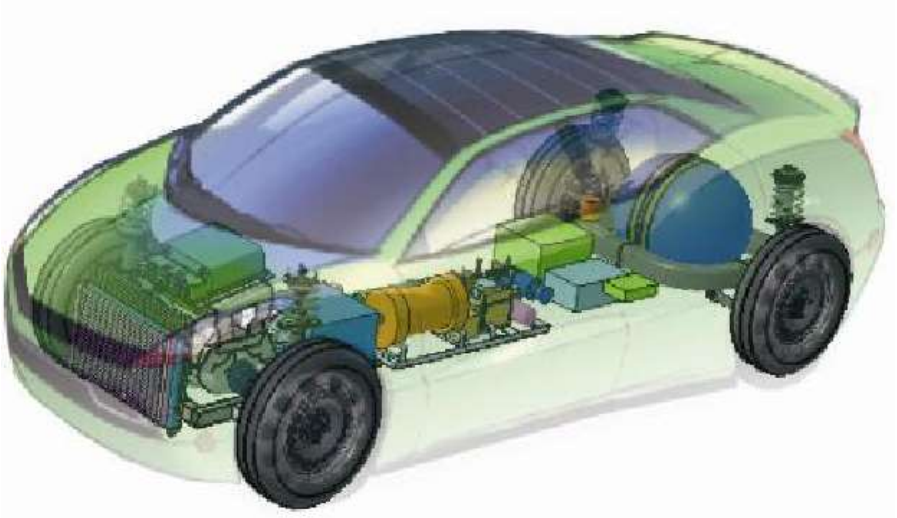
Benchmark: 2009 Mitsubishi i-MiEV

		MIEV	FSV1	FSV1	
				MIEV	MIEV2
Length	[mm]	3395	3700	3700	3395
Width	[mm]	1475	1680	1680	1475
Height	[mm]	1600	1540	1540	1600
Curb Weight	[kg]	1080	1232	928	750
Seat Capacity		4	4+	4+	4
Drive System		rear wheel drive	front wheel drive	front wheel drive	rear wheel drive
Assumptions					
Battery					
Type		Li-ion	Li-ion	Li-ion	Li-ion
Voltage	[V]	330	334	334	334
Total Energy	[kWh]	16.4	35	16.4	16.4
Motor					
Type		permanent magnet	permanent magnet	permanent magnet	permanent magnet
Cont. Power	[kW]	31	49	31	31
Max. Power	[kW]	47	67	47	47
Max. Torque	[Nm]	180	220	180	180
Drag Coefficient		0.25	0.25	0.25	0.25
Rolling Resistance		0.007	0.007	0.007	0.007
Torque Coupling Ratio		1.2	1.2	1.2	1.2
Differential Ratio		3.1	3.1	3.1	3.1
Frontal Area	[m^2]	1.9	2.1	2.1	1.9
Tire Size		195/65R14	175/65R15	175/65R15	195/65R14
Results					
Rage for 70% SOC (Japan 10-15)	[km]	125	247	133	150
Rage for 85% SOC (Japan 10-15)	[km]	157	308	166.7	182
Electr. Consumption	[Wh/km]	88.7	96.6	83.6	74
Acceleration (0- 60km/h)	[s]	10.6	8.7	9.5	7.7
Acceleration (0-100km/h)	[s]	18	14.6	16.1	13
Top Speed	[$\frac{km}{h}$]	180	198	180	180

FSV-2

- 4-door sedan, 4,350 mm long
- same wheels as that of FSV-1
- $PHEV_{40}$/FCEV
  - Common front-end and front wheel drive traction motor
  - Rated at a peak power of 75 kW (55 kW continuous power)





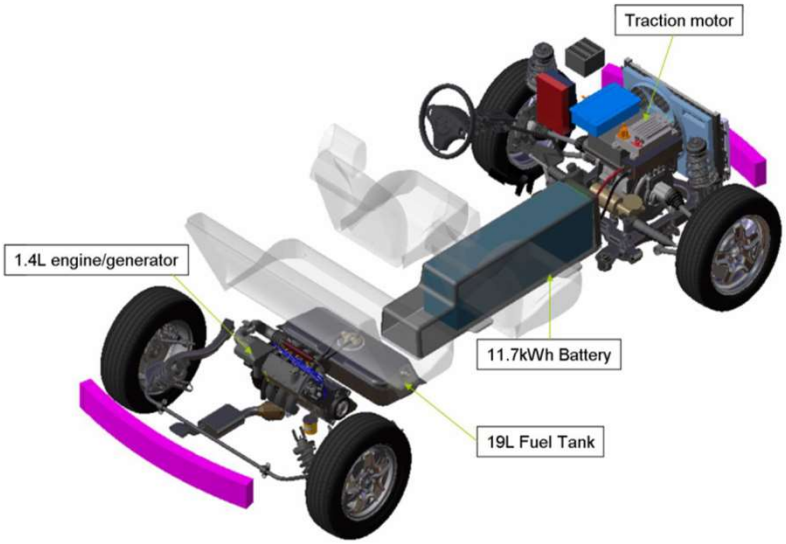
FSV-2: $PHEV_{40}$

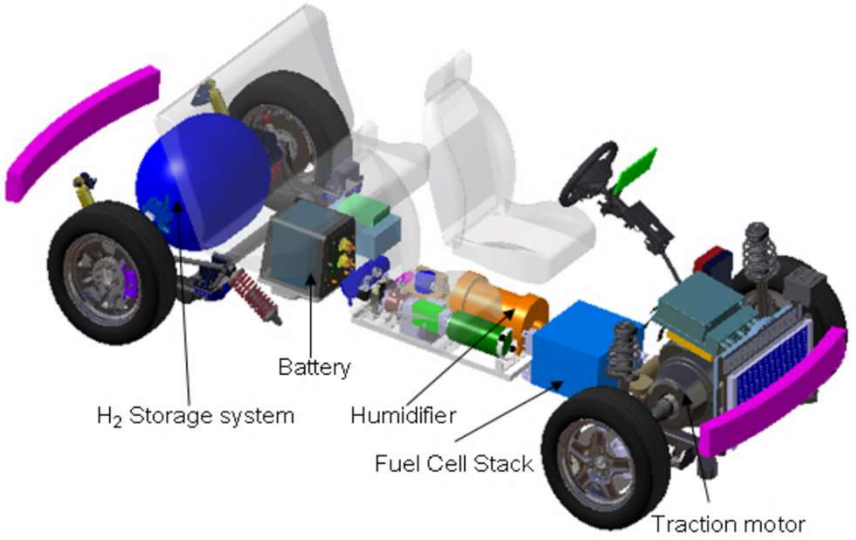
- All-electric range of 64 km (40 miles) on a fully charged battery
  - 11.7 kWh capacity (105 kg mass, 86-liter volume): lithium-ion manganese based cell
  - Charging time: 5.5 hours (120 V, 15 amp)
- Extended range of 500 km by a rear mounted 1.4L-4 cyl gasoline engine/generator set
- Component packaging and structural challenges for this vehicle are similar to the $PHEV_{20}$

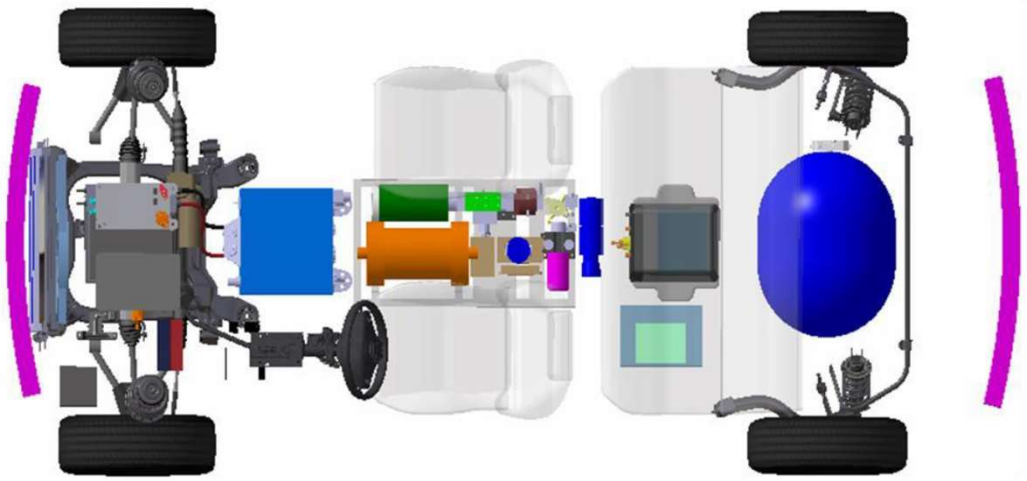
FSV-2: FCEV

- All-electric driving range of 500 km
- Fuel cell
  - Device that uses hydrogen (or hydrogen-rich fuel) and oxygen to create electricity by an electro-chemical process
  - Use the chemical energy of hydrogen to cleanly and efficiently produce electricity, with water and heat as by-products
- Hydrogen storage capacity: 3.4 kg, 95 liters, 65 MPa at 15°C
- Fuel-cell stack system: 240 cells (92 kg, 65 kW of power)
- Battery pack: 2.3 kWh capacity (27 kg mass, 25-liter volume), lithium-ion manganese based cell
- Underbody structure: sufficient support and protection to the fuel stack assembly packaged in the front floor tunnel, and the high-pressure hydrogen tank under the rear floor

FSV-2: Layout & Design







Estimated Mass(kg): FSV-2

	ICE 2 2010	ICE 2 2020	HEV 2 2010	HEV 2 2020	FSV 2 $PHEV_{40}$	FSV 2 FCEV
Body Non-Structure	302	210	257	210	210	210
Body Structure	337	298	337	303	198	175
Front Suspension	73	49	76	55	51	44
Rear Suspension	65	45	73	44	52	34
Steering	21	21	21	21	19	19
Brakes	47	37	49	40	37	34
Drivetrain	274	244	359	304	261	177
Fuel, Battery, Exhaust	59	68	125	127	178	114
Wheels and Tires	96	72	80	73	70	61
Air Conditioning	40	52	35	46	47	47
Electrical	68	78	68	82	83	93
Bumpers	33	25	31	28	26	22
Closures	67	59	62	55	48	48
TOTAL	1,483	1,260	1574	1388	1279	1079

Powertrain components	Mass [kg]	Cost [US $]
Li-ion Battery and controller	136.5	5,365
Genarator/Traction Drive (75kW)	145.9	4,385
IC Engine(1.4L)	115.5	1,470
Fuel system	30.3	415
Exhaust system	10.8	300

Powertrain components	Mass [kg]	Cost [US $]
Li-ion Battery and controller	27.3	1,503
Traction Motor (75kW)	84.6	2,463
Fuel Cell system (65kW)	92	10,081
Hydrogen Storage(3.4L)	87	7,919

FSV-2: Vehicle Design

Vehicle Design Parameters (comparable to OEM standards)			**PHEV$_{40}$**		**FCEV**	
			Curb +Driver	GVW	Curb +Driver	GVW
Front wheel drive		yes	yes		yes	
Wheel base	[mm]	2578	2578		2578	
Weight distribution	[%/%]	50/50				
Center of gravity height	[M]	0.53				
Coefficient of drag (Cd)		0.25	0.25		0.25	
Vehicle frontal area	[m^2]	2.25	2.25		2.25	
Tire size and specifications			P175/65R15		P175/55R15	
Tire rolling resistance		0.007	0.007		0.007	
Auxiliary power demand, Max. continuous	[W]	2500				
Auxiliary power demand, Test	[W]		700		700	
Mechanical accessory losses	[W]		1000		0	
Road condition, Brake + Acceleration		Dry Asphalt	Dry Asphalt		Dry Asphalt	
Passenger capacity		4+				
Cargo volume	[Liters]	370				
Curb weight	[kg]	1300	1300		1300	
Payload	[kg]	437.5		437.5		437.5
Driver weight	[kg]	75	75		75	
Vehicle test weight	[kg]	-	1375	1737.5	1375	1737.5

FSV-2: Powertrain Design

Powertrain Design Parameters (comparable to OEM standards)			**PHEV$_{40}$**		**FCEV**	
			Curb +Driver	GVW	Curb +Driver	GVW
Regenerative braking		yes	yes		yes	
Peak engine power (mechanical)	[kW]		67		n/a	
Fuel cell power (electrical)	[kW]	n/a	n/a		65	
Battery capacity	[kWh]		11.7		2.3	
Traction motor mechanical capacity (Continuous/ Peak/ Max RPM)	[kW]		54 / 75 / 7600 rpm		54 / 75 / 7600 rpm	
Peak motor power (mechanical)	[kW]		75		75	
Peak generator power (electrical)	[kW]		60		n/a	
Final drive/differential	[ratio]		5.38		5.38	
Powertrain weight	[kg]		461		318	
Battery weight	[kg]		137		27	
Fuel tank capacity	[kg]		14		3.4	
Type of PHEV		Series / Parallel	Series		n/a	

FSV-2: Vehicle Performance

IC Engine, Peak (mechanical)	70 kW
Generator, Peak (electrical)	60 kW
Traction Motor, Peak (mechanical)	75 kW

	Units	Specs	Traction Power				Capability
			Peak 75 kW		Continuous 55 kW		
			Curb + Driver	GVW	Curb + Driver	GVW	
Performance							
Acceleration							
0 - 100 km/h, Curb + Driver	sec.	10-12	11.4 @ 75 kW	—	—	—	
Peak Grade							
40 km/h - 30 sec., GVW	%	22	—	22 @ 44 kW	—	—	
Continuous Grade							
73 km/h - Continuous, GVW	%	10	—	—	—	10 @ 42 kW	
90 km/h - Continuous, GVW	%	10	—	—	—	10 @ 54 kW	
112 km/h - Continuous, GVW	%	10	—	10 @ 71 kW	—	7 @ 54 kW	
Top Speed							
Continuous, GVW	km/h	161	—	—	—	161 @ 75 kW	
Range							
Curb + Driver, UDDS	km	500	—	—	577	—	

Limited Perfomance =
Unable to Perfom =

FC Stack, Peak (gross electrical)	74 kW
FC Engine, Peak (net electrical)	62 kW
Traction Motor, Peak (mechanical)	75 kW

	Units	Specs	Traction Power				Capability
			Peak 75 kW		Continuous 55 kW		
			Curb + Driver	GVW	Curb + Driver	GVW	
Performance							
Acceleration							
0 - 100 km/h, Curb + Driver	sec.	10-12	11.4 @ 75 kW	—	—	—	
Peak Grade							
40 km/h - 30 sec., GVW	%	22	—	22 @ 44 kW	—	—	
Continuous Grade							
73 km/h - Continuous, GVW	%	10	—	—	—	10 @ 42 kW	
90 km/h - Continuous, GVW	%	10	—	—	—	10 @ 54 kW	
112 km/h - Continuous, GVW	%	10	—	10 @ 71 kW	—	7 @ 55 kW	
Top Speed							
Continuous, GVW	km/h	161	—	—	—	161 @ 75 kW	
Range							
Curb + Driver, UDDS	km	500	—	—	577	—	

Limited Perfomance =
Unable to Perfom =

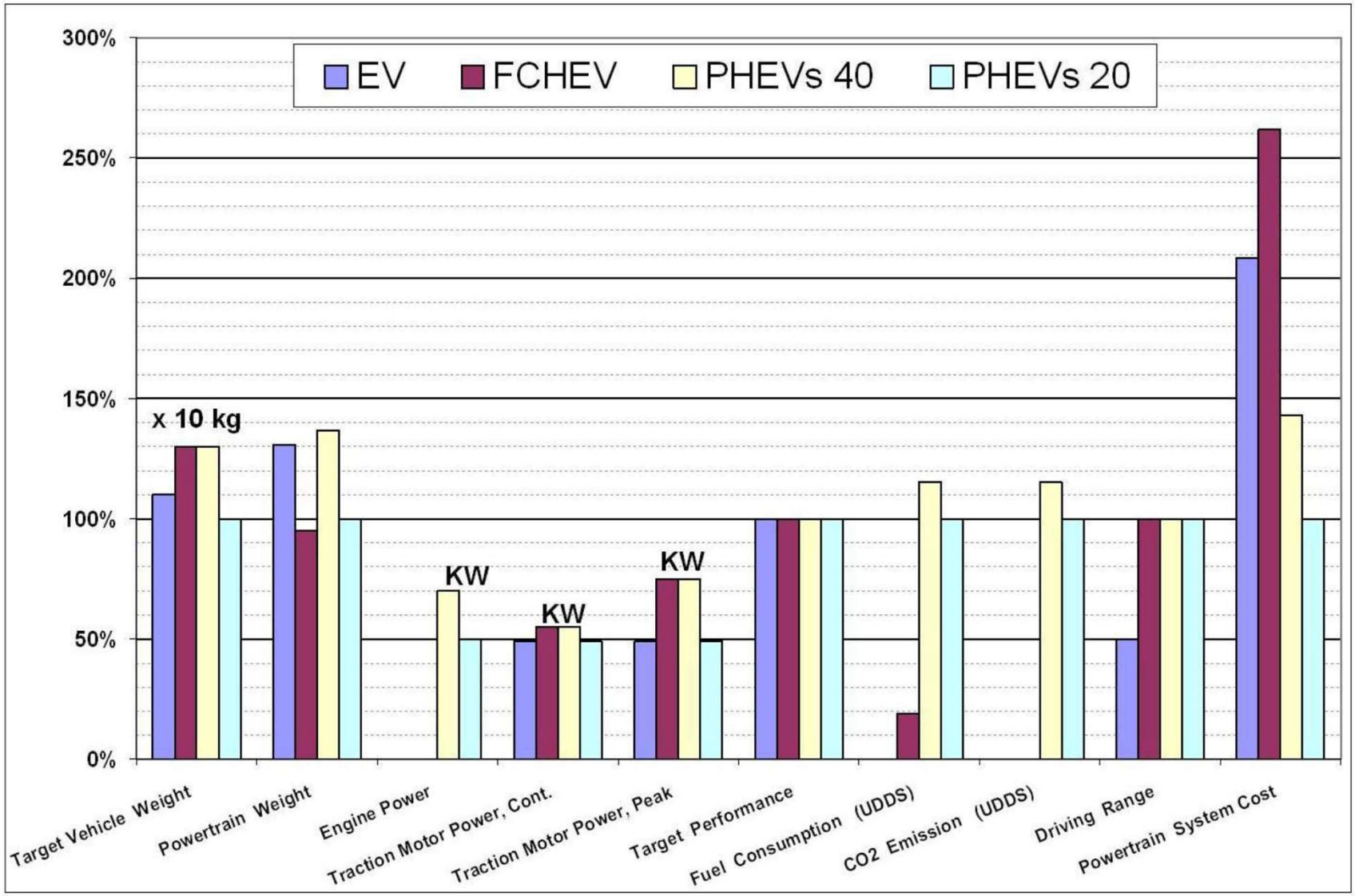
Vehicle Performance: Results Summary

	Capability			
	FCEV	$PHEV_{40}$	EV	$PHEV_{20}$
Performance				
Acceleration				
0 - 100 $\frac{km}{h}$, Curb + Driver				
Peak Grade				
30/40 $\frac{km}{h}$ - 30 sec., GVW				
Continuous Grade				
73 $\frac{km}{h}$ - Continuous, GVW				
90 $\frac{km}{h}$ - Continuous, GVW				
100/112 $\frac{km}{h}$ - Continuous, GVW				
Top Speed				
Continuous, GVW				
Range				
Curb + Driver, UDDS				

Limited Perfomance =

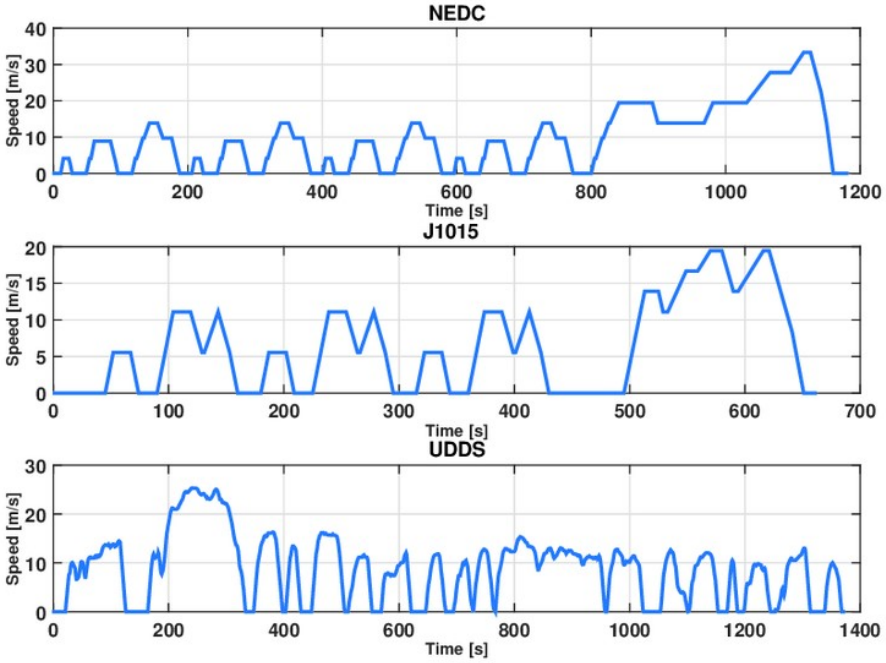
Unable to Perfom =

Powertrain Design Evaluation Results



Fuel Economy and Emissions

		UDDS	Japan 10-15	NEDC
$PHEV_{40}$ Series Mid-size: 1300kg Vehicle + 75kg driver				
Charge Depleting	[Wh / km]	107	110	111
	[L / 100km]	0	0	0
	[g CO_2 / km]	0	0	0
Charge Sustaining	[Wh / km]	0	0	0
	[L / 100km]	3.8	3.79	3.79
	[g CO_2 / km]	88.4	88	88
$PHEV_{20}$ Series Small-size: 1000kg Vehicle + 75kg driver				
Charge Depleting	[Wh / km]	92.5	94.9	96.9
	[L / 100km]	0	0	0
	[g CO_2 / km]	0	0	0
Charge Sustaining	[Wh / km]	0	0	0
	[L / 100km]	3.3	3.27	3.43
	[g CO_2 / km]	76.7	76	79.8
EV Series Small-size: 1100kg Vehicle + 75kg driver				
	[Wh / km]	88.9	92.8	96.4
	[g CO_2 / km]	0	0	0
FCEV Series Mid-size: 1300kg Vehicle + 75kg driver				
	[kg / 100km]	0.632	0.669	0.653
	[g CO_2 / km]	0	0	0



(Refer to “FSV Environmental Assessment” slide)

Cost of Ownership

- Vehicle total life: 200,000 km (125,000 miles)
- PHEV vehicles: 70% of distance traveled in electric mode, and 30% of the distance traveled in HEV mode
- Cost of electricity: $0.12/kWh
- Cost of gasoline: $1.18/liter ($4.5/gallon)
- Cost of hydrogen gas: $5.00 /kg, as currently charged by some stations in California on the Hydrogen Highway

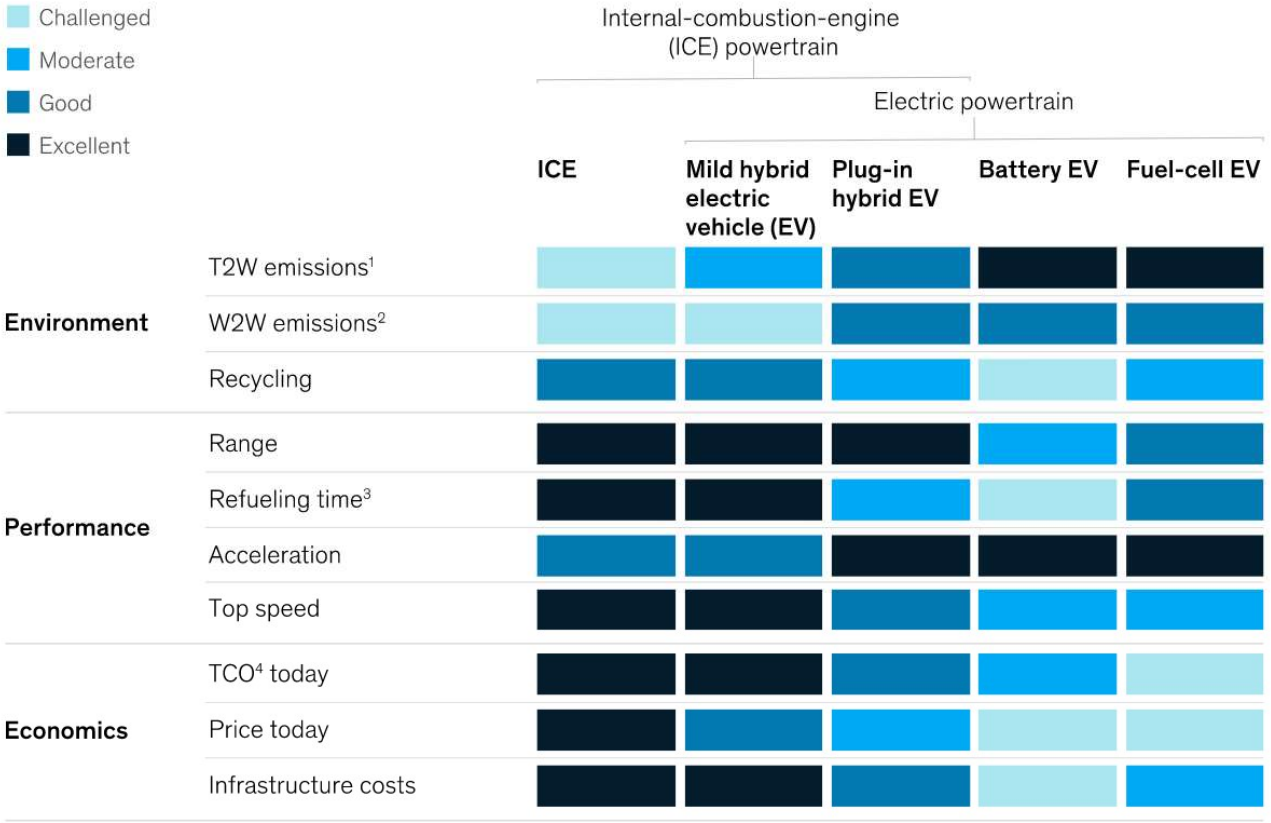
Cost of Ownership: FSV-1

	Petroleum Based				FSV-1 Dual Fuel Based Electricty form Grid and Petroleum			
	ICE 2020 18 $\frac{km}{l}$ (42.7 MPG)		HEV 2020 27.2 $\frac{km}{l}$ (64 MPG)		BEV - EV 114 $\frac{Wh}{km}$		$PHEV_{20}$ 106 $\frac{Wh}{km}$ & 26.7 $\frac{km}{l}$ (62.7 MPG)	
	[total $]	[per km]	[total $]	[per km]	[total $]	[per km]	[total $]	[per km]
Vehicle Cost	16,250	0.081	18,090	0.090	32,535	0.163	22,810	0.114
Overhead	6,094	0.030	6,094	0.030	6,094	0.030	6,094	0.030
Vehicle Cost without Powertrain	7,746	0.039	7,746	0.039	7,746	0.039	7,746	0.039
Powertrain Cost	2,350	0.012	3,350	0.017	2,945	0.015	6720	0.034
Battery Cost	C 60		900	0.005	15,750	0.079	2250	0.011
Vehicle Use Cost	14,097	0.070	9,738	0.050	2,731	0.014	6,232	0.030
Gasoline $1.18 per l ($4.50 per gal US)	13,097	0.065	8,738	0.044			4,460	0.022
Oil Change $40 $40 per 8,000 km	1,000	0.005	1,000	0.005			500	0.003
Electricity $0.12per kwh					2,731	0.014	1,272	0.006
Total Cost of Ownership	30,346	0.152	27,828	0.139	35,266	0.176	29,041	0.145

Cost of Ownership: FSV-2

	Petroleum Based				Hydrogen Gas Comp. 70 Mpa		Electricity & Petroleum	
	ICE 2020 $16\frac{km}{l}$ (38MPG)		HEV2020 $19\frac{km}{l}$ (45MPG)		FCEV $0.632\frac{kgH_2}{km}$		PHEV$_{40}$ $119\frac{Wh}{km}$ & $20\frac{km}{l}$ (47 MPG)	
	[total $]	[per km]	[total $]	[per km]	[total $]	[per km]	[total $]	[per km]
Vehicle Cost	21,760	0.110	23,910	0.120	42,153	0.210	31,479	0.160
Overhead	8,160	0.041	8,160	0.041	8,160	0.041	8,160	0.041
Vehicle Cost without Powertrain	10,500	0.053	10,500	0.053	10,500	0.053	10,500	0.053
Powertrain Cost	3,100	0.016	4,350	0.022	22,458	0.112	7554	0.038
Battery Cost			900	0.005	1,035	0.005	5265	0.026
Vehicle Use Cost	15,717	0.080	13,427	0.070	6,320	0.030	6,873	0.030
Gasoline $1.18 per l ($4.50 per Gal US)	14,717	0.074	12,427	0.062			4,759	0.024
Oil Change $40 Per 8050 km	1,000	0.005	1,000	0.005			400	0.002
Electricity $0.12 per kwh							1,714	0.009
Hydrogen $5.00 per kg					6,320	0.032		
Total Cost of Ownership	37,477	0.190	37,337	0.190	48,473	0.240	38,352	0.190

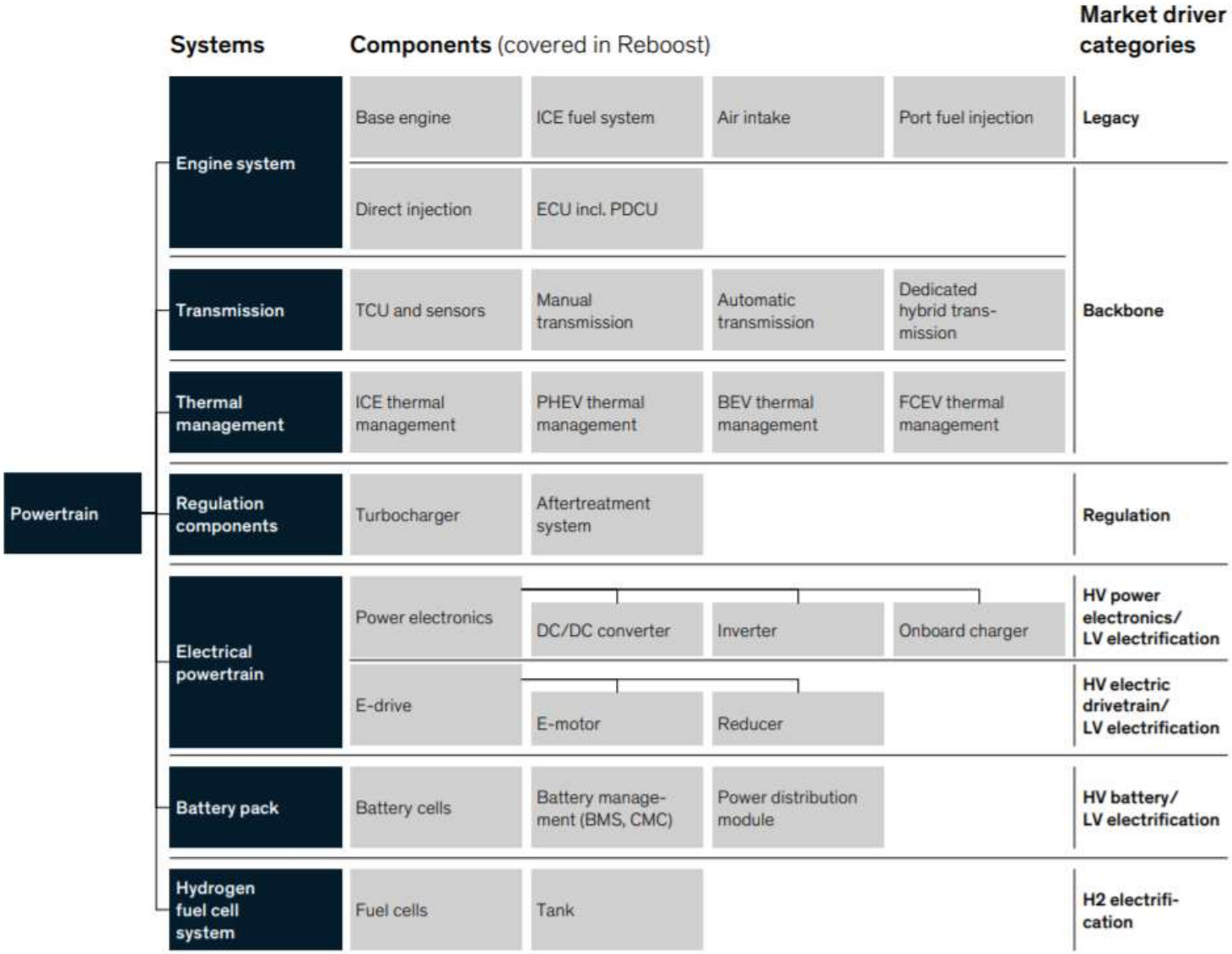
Today's powertrain technologies have both strengths and limitations.



[1]Tank-to-wheel emissions, ie, tailpipe emissions that a vehicle produces locally via the combustion of fossil fuels; these emissions are subject to current regulations globally.
[2]Well-to-wheel emissions, ie, emissions related to the fuel cycle or generation of electricity, the production of the vehicle and battery, and the use of the vehicle; largely dependent on a country's energy mix.
[3]Considering only the time needed to refuel or charge the vehicle, not infrastructure availability.
[4]Total cost of ownership, strongly depending on region and vehicle segment.
[5]Estimated CO2 savings considered for certification tests.
Source: McKinsey Center for Future Mobility

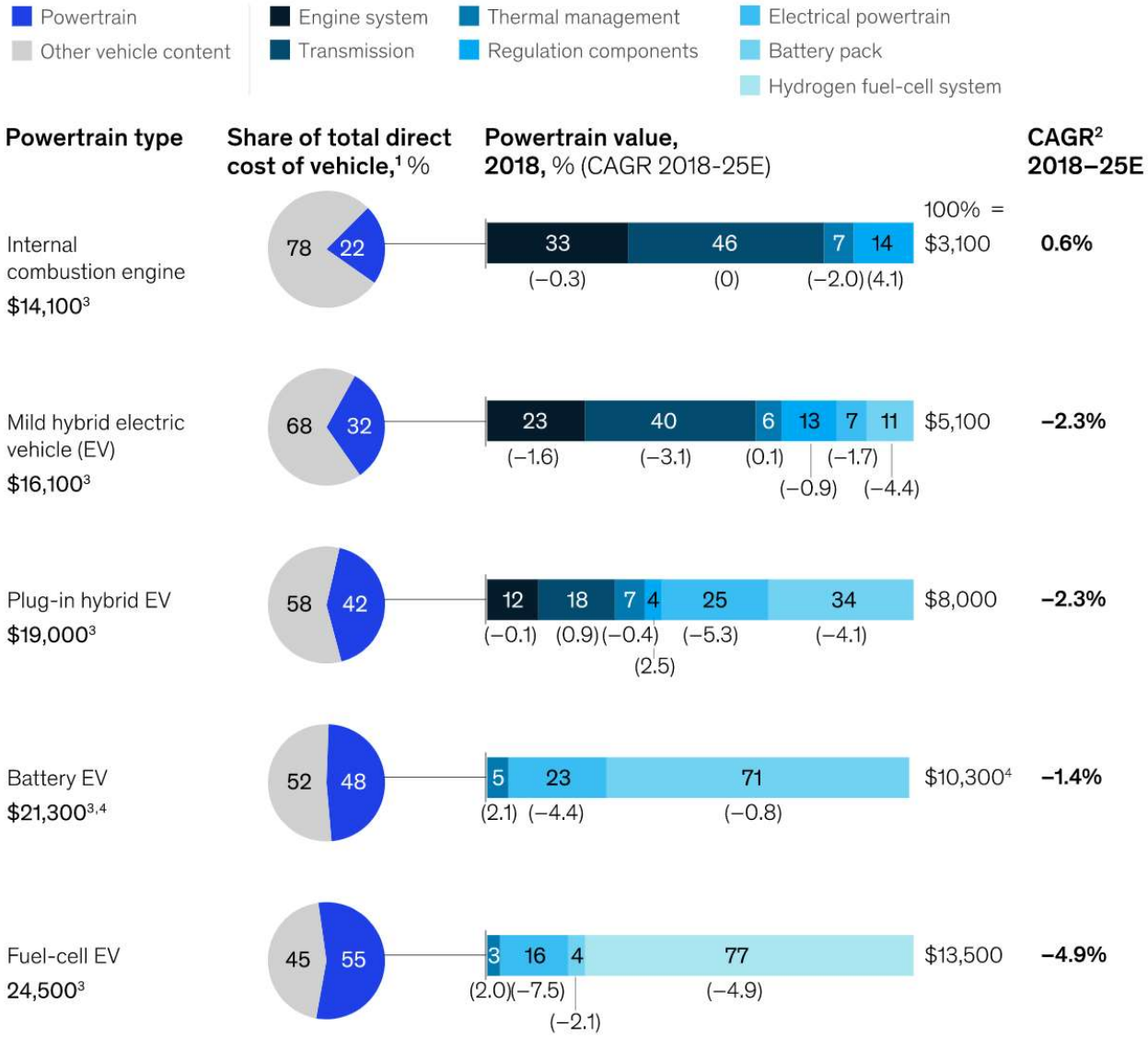
Reboost: A comprehensive view on the changing powertrain component market and how suppliers can succeed (2019.11)

Applied powertrain market split



Source: McKinsey Center for Future Mobility

The automotive-powertrain-component market has started to become a different industry—changing from a stable technology to a complex portfolio game.



[1]For OEM before margin, overhead, taxes, and subventions, but includes supplier margin and overhead.
[2]Compound annual growth rate.
[3]Assuming an average C-segment vehicle, for simplification, with constant value for non-powertrain part of vehicle.
[4]Average 40 kilowatt-hour battery power for a C-segment vehicle.
Source: McKinsey Center for Future Mobility