Ch. 1 The Automobile Body

- 1.1 Description of the automotive body types
- 1.2 Body nomenclature
- 1.3 Body mass benchmarking
- 1.4 The body structure as a system
- 1.5 Note on design philosophy

Introduction

- Structure
  - Collection of physical components arranged and supported in such a manner to carry loads
- Load bearing structure in the automotive sense
  - (1) Vehicle body (2) suspension system
- Optimization
  - Mathematical technique for finding the maximum or minimum value of a function of several variables subject to functional constraints, (making the best of anything)
- Vehicle structural design optimization
  - Reduce body weight by making structural design modifications
  - Constraints (performance): strength, durability, crash, handling, comfort

Automobile Body

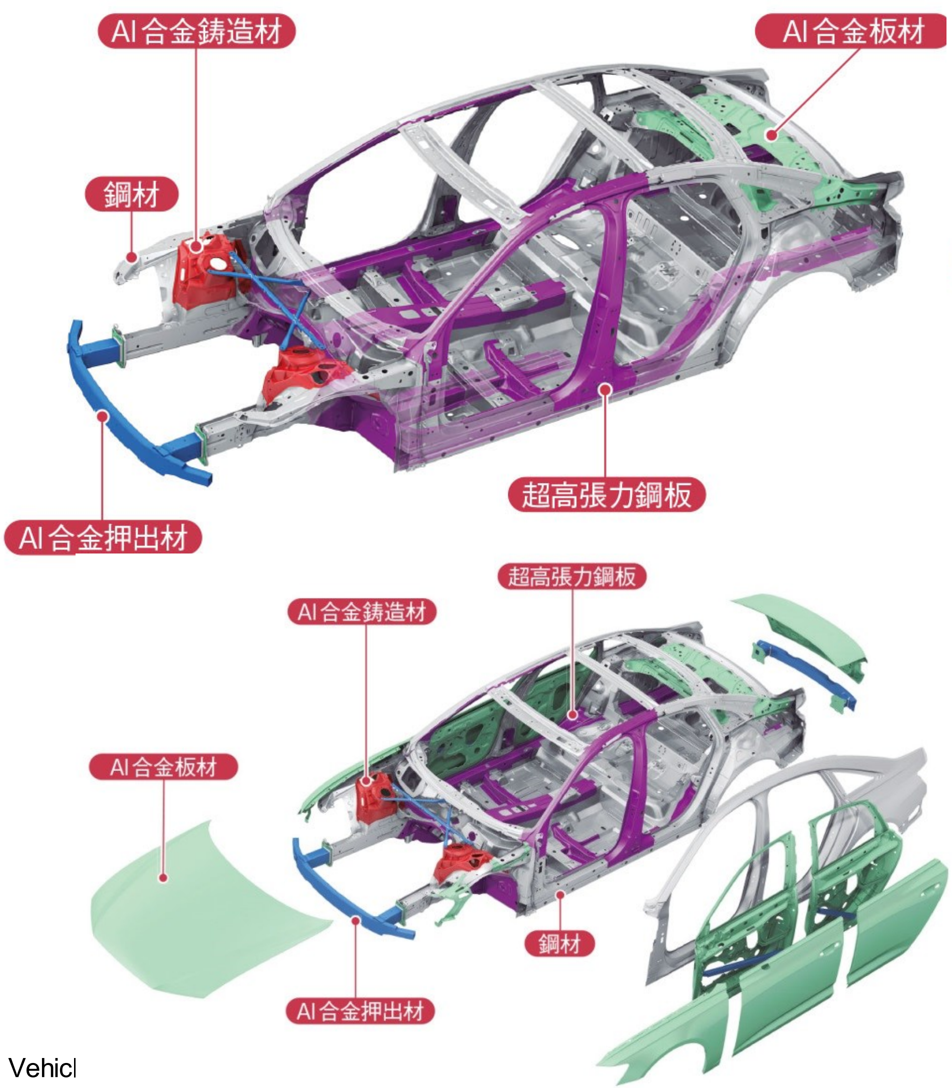
- Vehicle subsystem that performs many functions
  - Basic: armature holding parts of vehicle
  - Refine: noise and vibration (economy ~ luxury)

Audi A6 (2018)

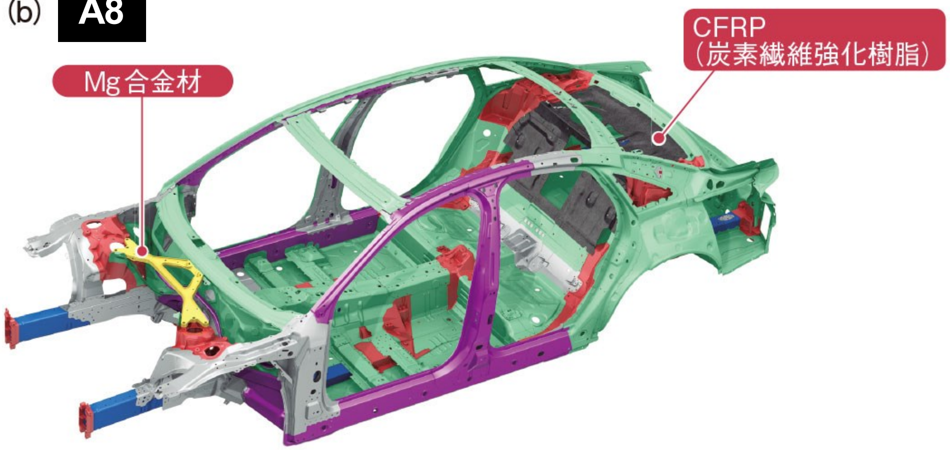
BIW (Body-In-White), 차체

Audi 신세대 PF: MLB evo (2018)

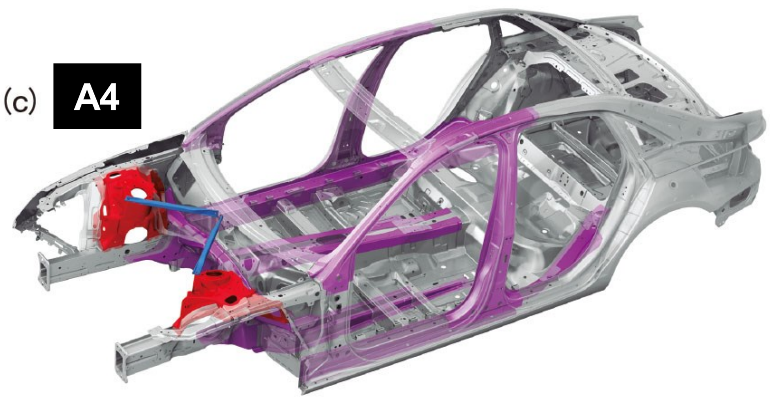
(a) **A6**



(b) **A8**

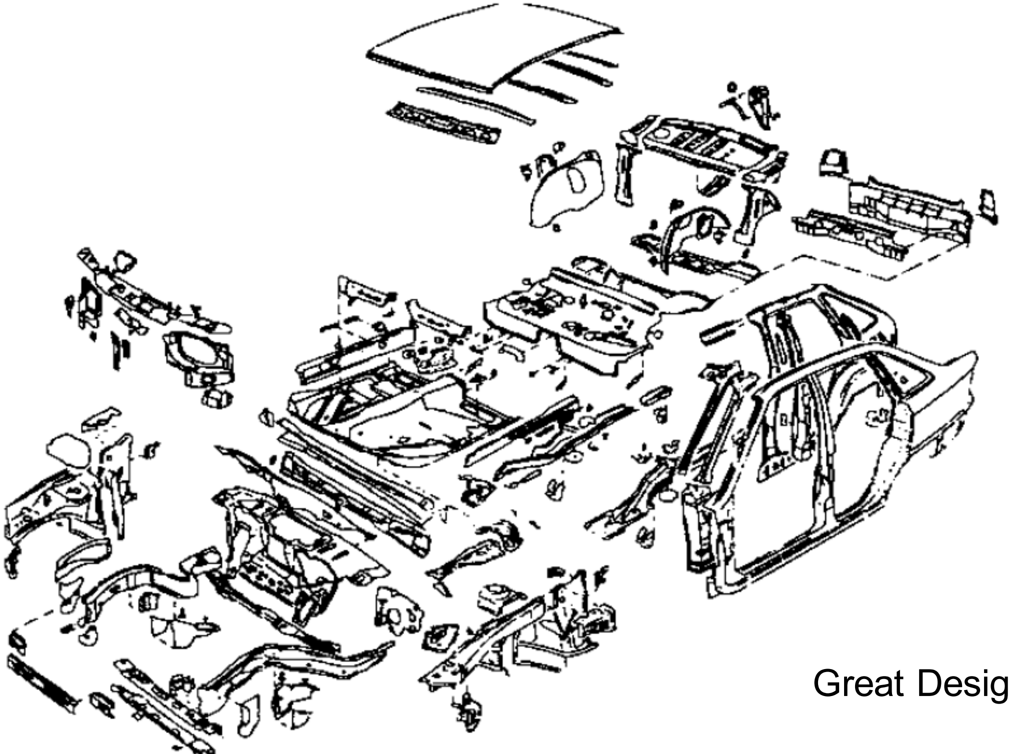


(c) **A4**



Range of Steel Grades

- Assembly of metal stampings
  - Advanced high-strength steel (AHSS, S_{ut} > 440MPa): 10%
  - High-strength steel (HSS, 240< S_{ut} < 440MPa): 35%
  - Mild steel (S_{ut} < 270MPa): 55%



Great Designs in Steel, AISI (2008)

Classification of steel for automotive use

- Metallurgical designation
  - traditional mild steel
  - conventional high strength steel (HSS)
  - advanced high strength steel (AHSS)
- Strength designation
  - HSS, AHSS or extra HSS(780MPa, S_y>550 MPa), ultra HSS or GigaPascal steel (1000MPa)
- Formability designation
  - ability to be formed into simple and complex shapes by different manufacturing processes
  - high work-hardening exponent
  - total elongation

자동차업계 초고장력강판 적용비율 기준		
구분	강성	인장강도
현대기아차	60kg/㎟	590MPa
한국지엠		
쌍용		
르노삼성	100kg/㎟	980MPa
토요타		

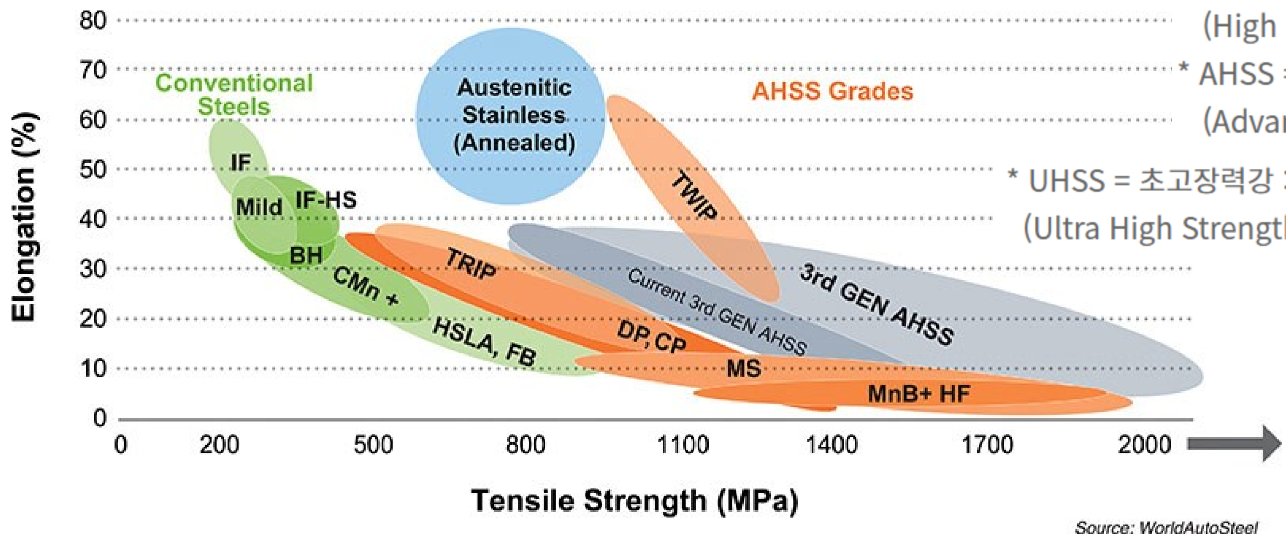
Advanced High-Strength Steels (AHSS)

- First generation
  - dual phase (DP), complex-phase (CP), martensitic (MS) and regular transformation-induced plasticity (TRIP)
- Second generation
  - new generation of transformation-induced plasticity (TRIP), hot-formed (HF), and twinning-induced plasticity (TWIP)

* HSS = 고장력강 : 일반 철 (STEEL)에 비해 강도가 센 철
(High Strength Steel)

* AHSS = 고장력강 : 새롭게 개발된, 성질이 향상된 철강
(Advanced High Strength Steel)

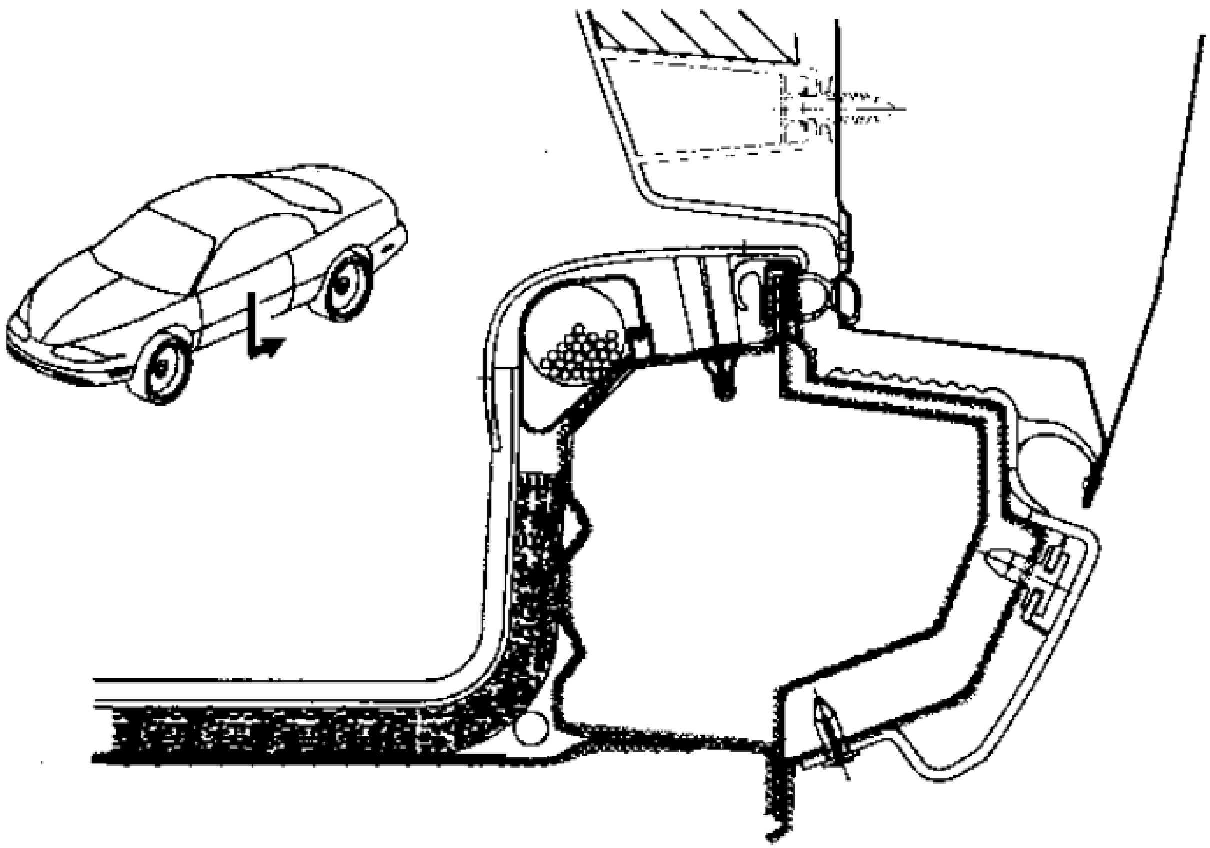
* UHSS = 초고장력강 : AHSS중에서 강도가 기준(700MPa)보다 센 철강
(Ultra High Strength Steel)



https://www.worldautosteel.org/steel-basics/automotive-advanced-high-strength-steel-ahss-definitions/

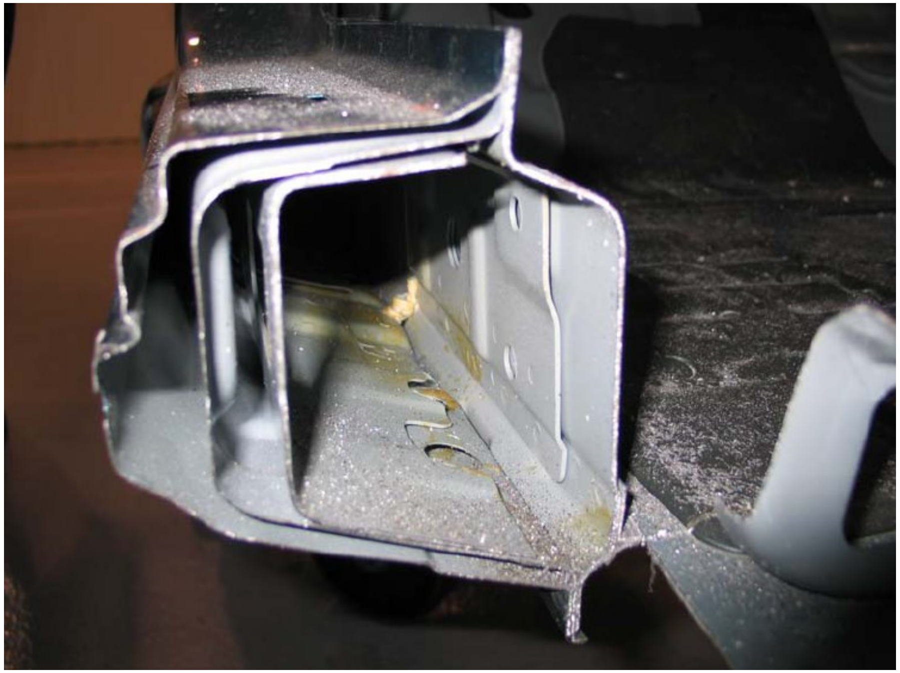
Automobile Body

- Thin-walled structural elements

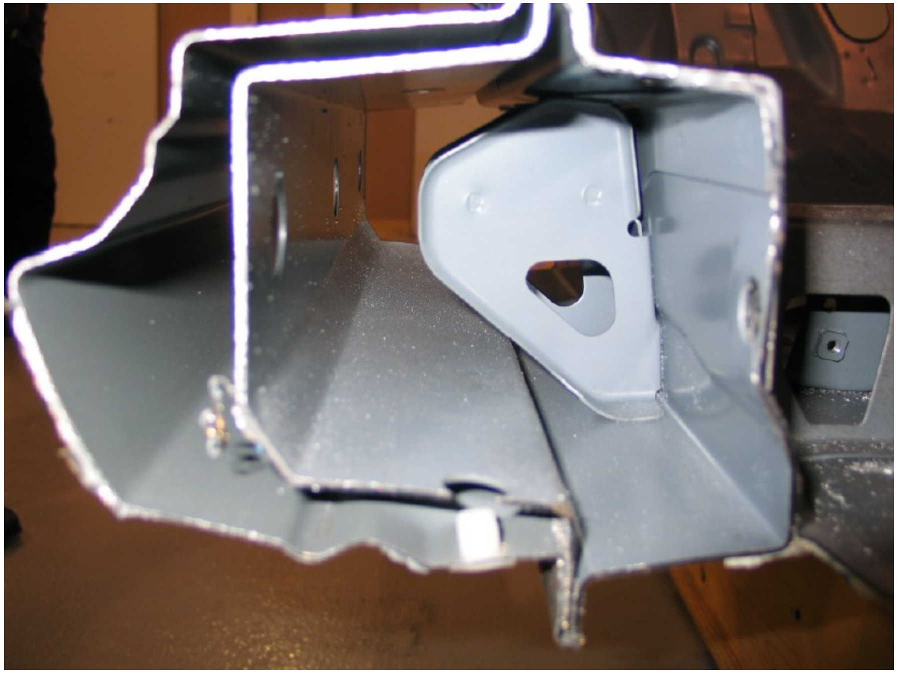


typical section at rocker

Rocker



2004 Hyundai XG350



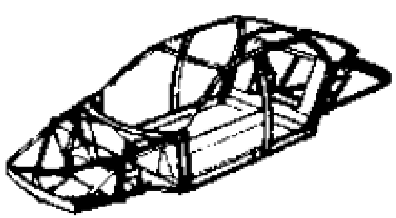
2003 Toyota Camry SE

Body Configurations

Space Frame

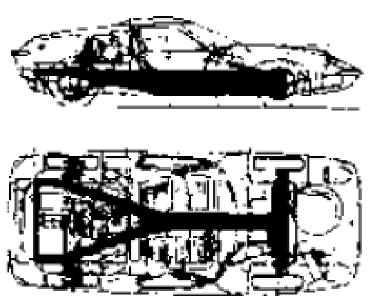
3D network of struts react major loads

unstressed panels



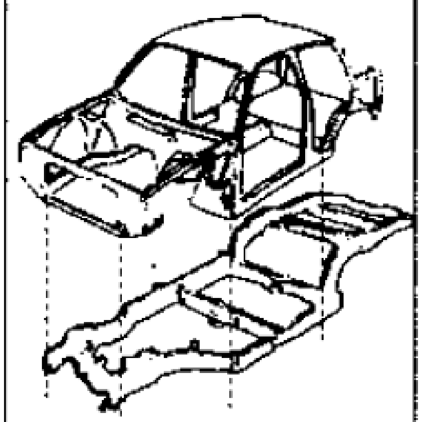
Central Frames

Large tunnel reacts major loads



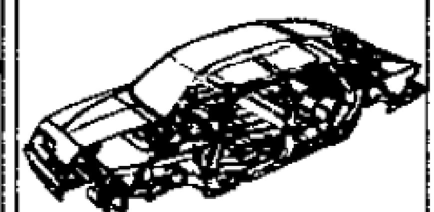
Body-on-Frame

Frame reacts major loads

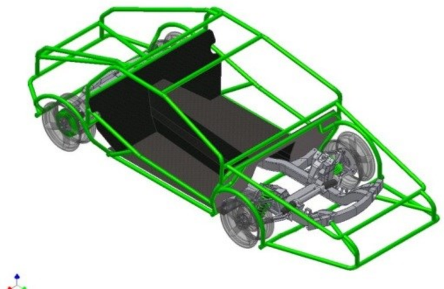


Integral Body-Frame (Monocoque)

Exterior panels and underbody share loads



Automobile Body Types (1)



- Space frame
  - 3D framework of beams connected at nodes
  - Lower cost tooling: roll forming, hydroforming
  - Lower volume vehicles
- Body-on-frame
  - Predominant passenger car type until the 1980's
  - Predominant type for light trucks
  - Ladder frame to which suspensions and powertrain are attached
  - Body shell connected to the frame by flexible body mounts
- Monocoque
  - Integral structure which forms a shell including exterior panels
  - Predominant type currently, most mass efficient configuration

Automobile Body Types (2)

- 모노코크 보디(Monocoque Body, Unit Construction Body)
  - French term for "single shell" or "single hull" (일체형 차체)
  - 자동차의 차체와 프레임을 일체로 제작하여 하중과 충격에 견딜 수 있는 구조로 하여 차의 경량화와 바닥을 낮게 할 수 있음
  - 차체를 상자형으로 제작하여 외력을 차체 전체에 분산시켜 전체로 힘을 받도록 한 것이며 곡면을 이용하여 강도를 증가하도록 결합되어 있음
  - 현가장치나 엔진의 설치부와 같은 외력이 집중되는 부분에는 작은 프레임을 두어 이것을 통하여 차체에 힘을 분산시킴
  - 단점: 프레임 차체에 비해 강성이 약하고 사고 시 차체가 변형될 수 있음

Automobile Body Types (3)

- 프레임 바디, 바디 온 프레임 (Body on Frame)
  - 뼈대인 프레임을 자동차의 하부에 덧댄 차량의 형식
  - 마차 시대부터 사용되어 온 가장 전통적인 차체 구조로 사다리꼴의 프레임에 파워트레인과 차량의 바디를 올리는 형식
  - 높은 강성: 충격의 흡수를 차량의 바디가 아닌 하부 프레임이 담당하기 때문에 노면 충격에 대한 내구성이 우수
  - 사고가 발생했을 때 차량의 프레임과 바디를 분리해서 수리가 가능하기 때문에 정비성이 우수
  - 철로 이루어진 프레임은 무거운 중량 덕분에 연료 효율과 운동성능이 떨어짐
  - 기술의 발전으로 인해 모노코크 바디로도 충분한 강성의 확보가 가능
  - 가격과 시간, 효율을 중시하는 제조사의 입장에서는 모노코크 바디가 유리하고, 오프로드 성능을 강조해야 하는 제조사라면 프레임 바디의 형태가 더 유리

Monocoque vs. Body-on-frame

Unibody vs. body-on-frame architecture

The unibody 2017 Honda Ridgeline is unique in the midsize pickup segment that traditionally has featured sturdy, body-on-frame chassis. Advances in unibody construction have made it more competitive in a segment that has prioritized towing and payload. A look at the pros and cons of the two chassis systems:

Unibody platform

Most common in cars and small-midsize SUVs, the unibody, as the prefix, suggests, is a single chassis of metal pieces united by rivets, welds and glue. Exterior panels like doors, hood and roof are then added.

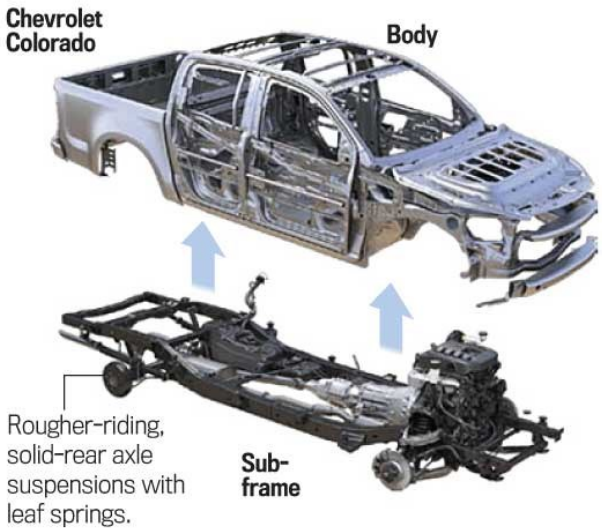
Unibody construction offers better ride quality and handling.

Cabins are more spacious, since the rails don't intrude on interior space.

With improved engineering, unibody construction has become much stiffer.

Body-on-frame platforms

Most common in full-size SUVs and pickup trucks, a metal body is bolted on to a lower sub-frame made up of two long rails reinforced with crossbeams. Exterior panels are added.



Rigidity is particularly prized in heavy-duty trucks that tow more than 20,000 pounds. In the midsize pickup category, a V-6 powered GMC Canyon can tow up to 7,000 pounds, almost 50 percent more than the unibody Ridgeline.

Allows multiple cab and pickup box configurations because different bodies can simply be bolted on the frame.

The Detroit News

(2016.05.22)

[시승기] "이름 빼고 다 바꿨다" 국가대표 프레임바디 SUV 기아차 '모하비 더 마스터'

06

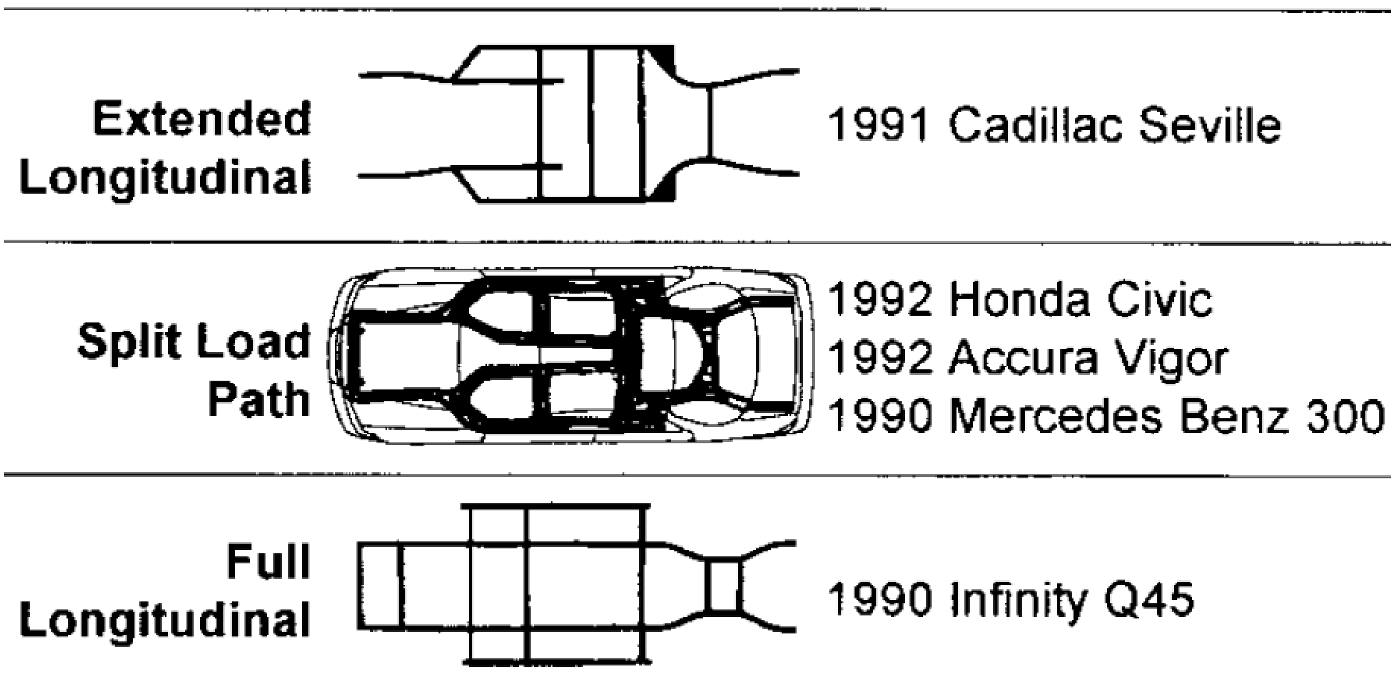
입력 2019.09.14 11:30 | 수정 2019.09.15 21:24

기아자동차 '바디 온 프레임' 방식 대형 SUV '모하비 더 마스터'. 기아자동차 제공

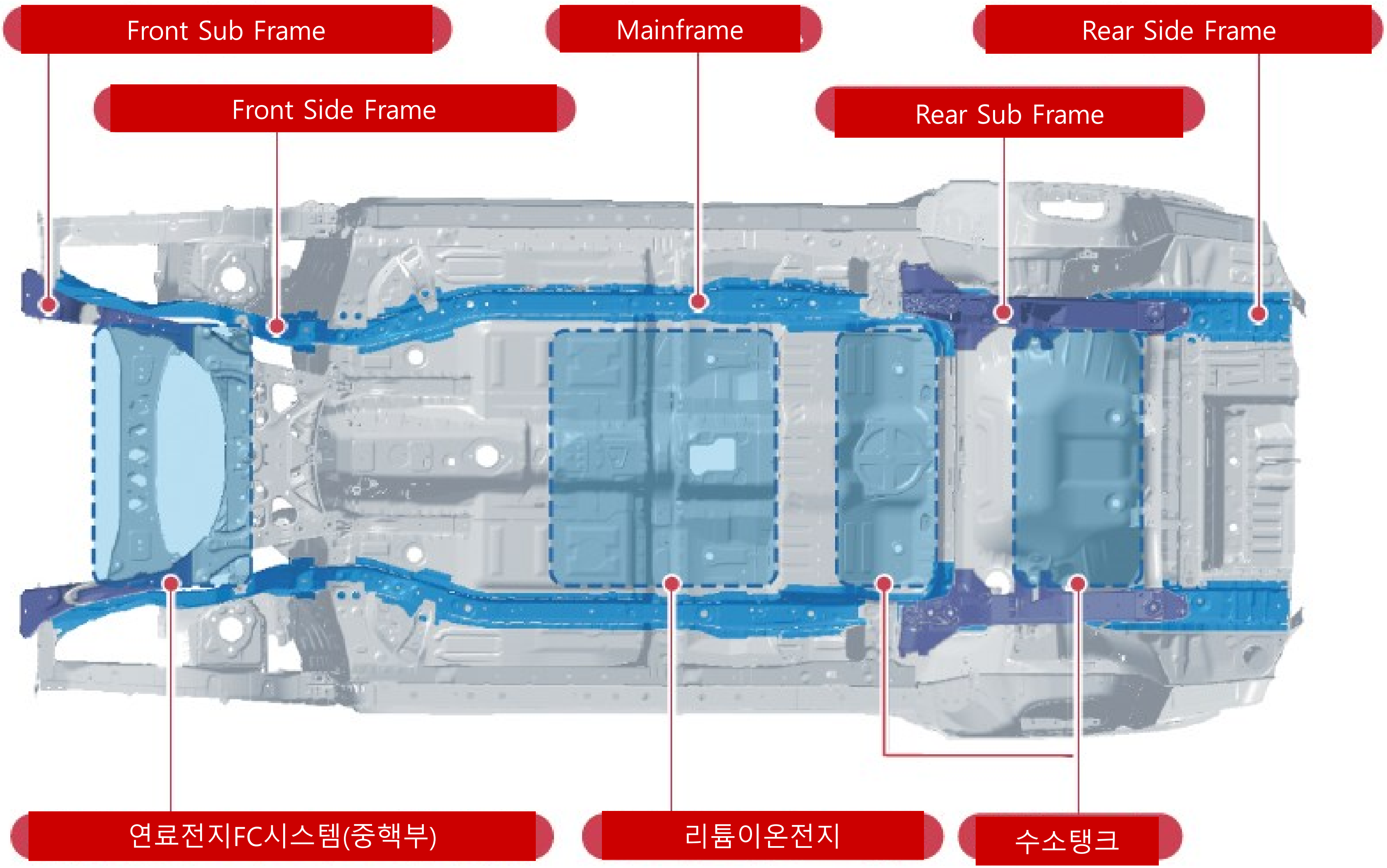
https://www.hankookilbo.com/News/Read/201909141142739026?did=FL&dtype=&dtypecode=&prnewsid=

Monocoque Typical Topologies

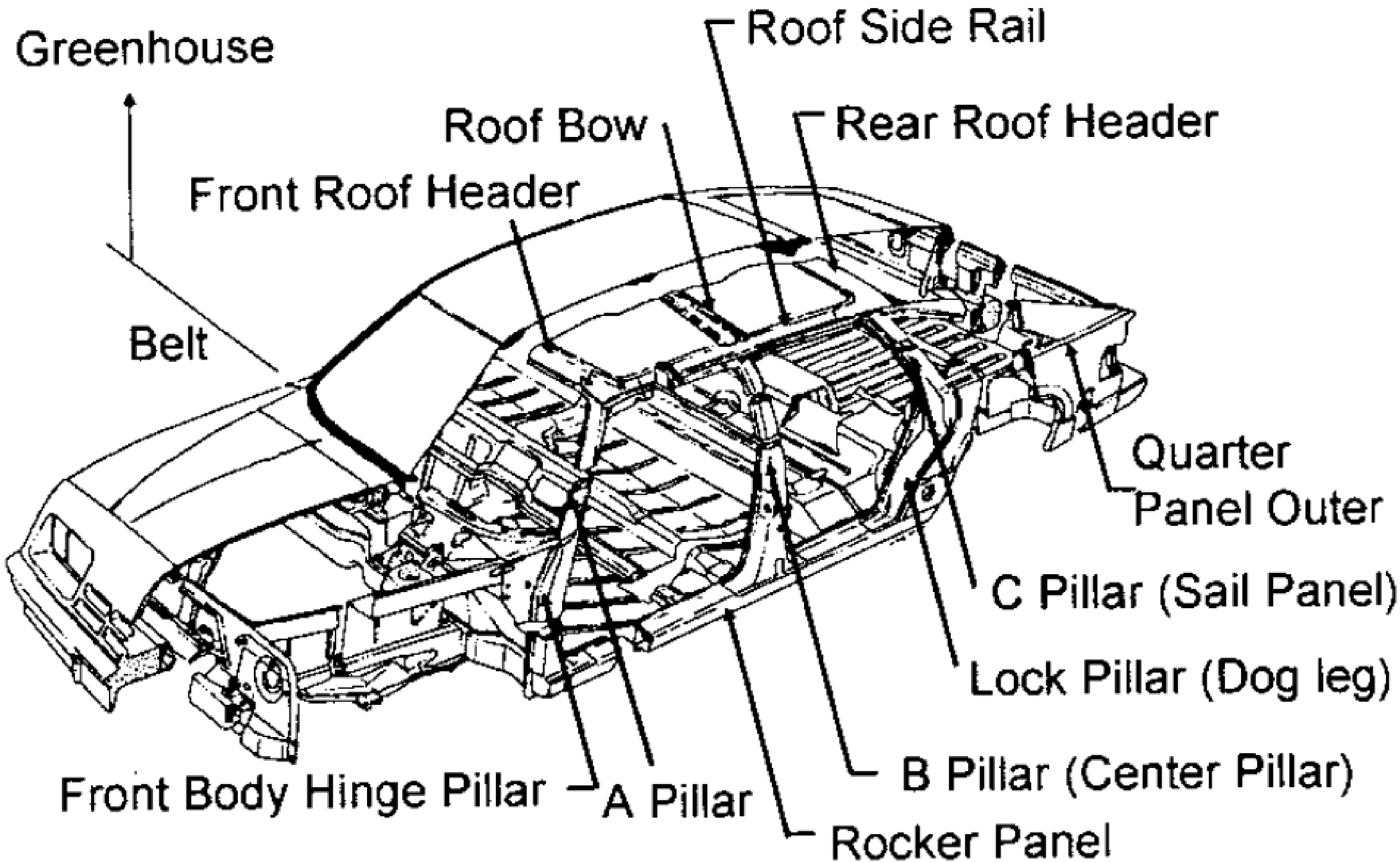
- Topology
  - Arrangement of structural elements (beams/panels) to meet requirements in the most efficient manner
  - Positioning and size of structural elements: package, styling, manufacturing



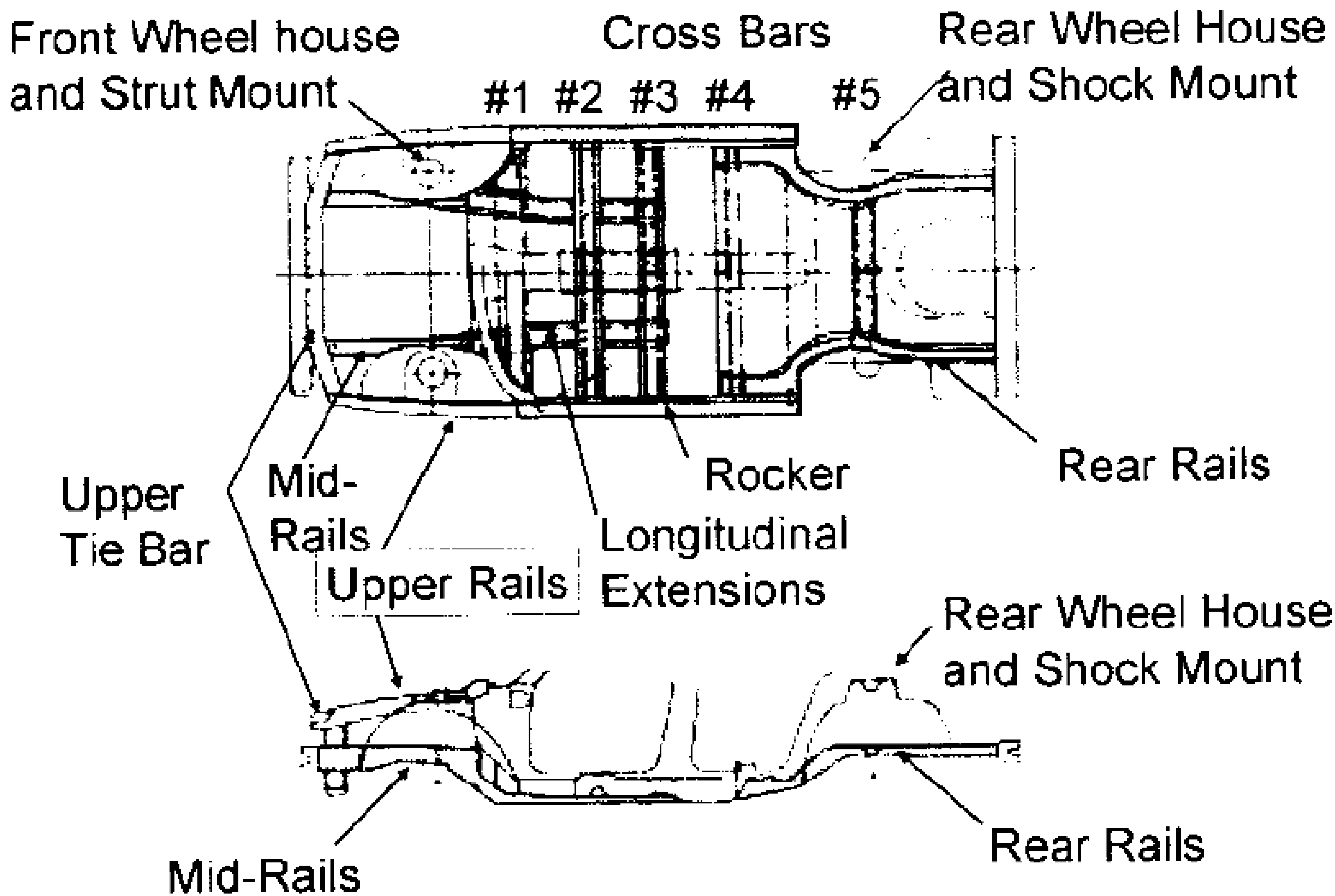
Honda FCV (2016.06)



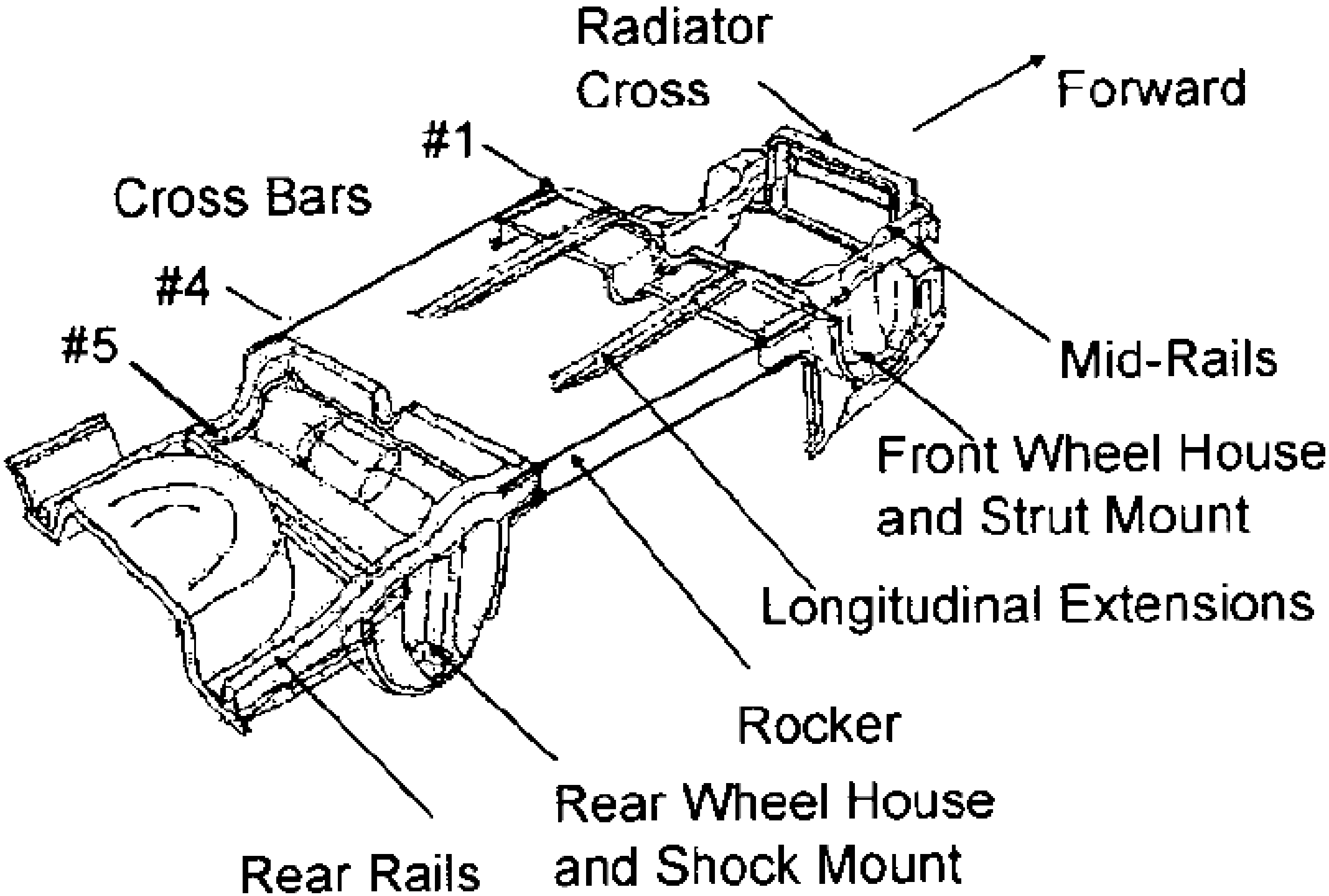
Body Nomenclature



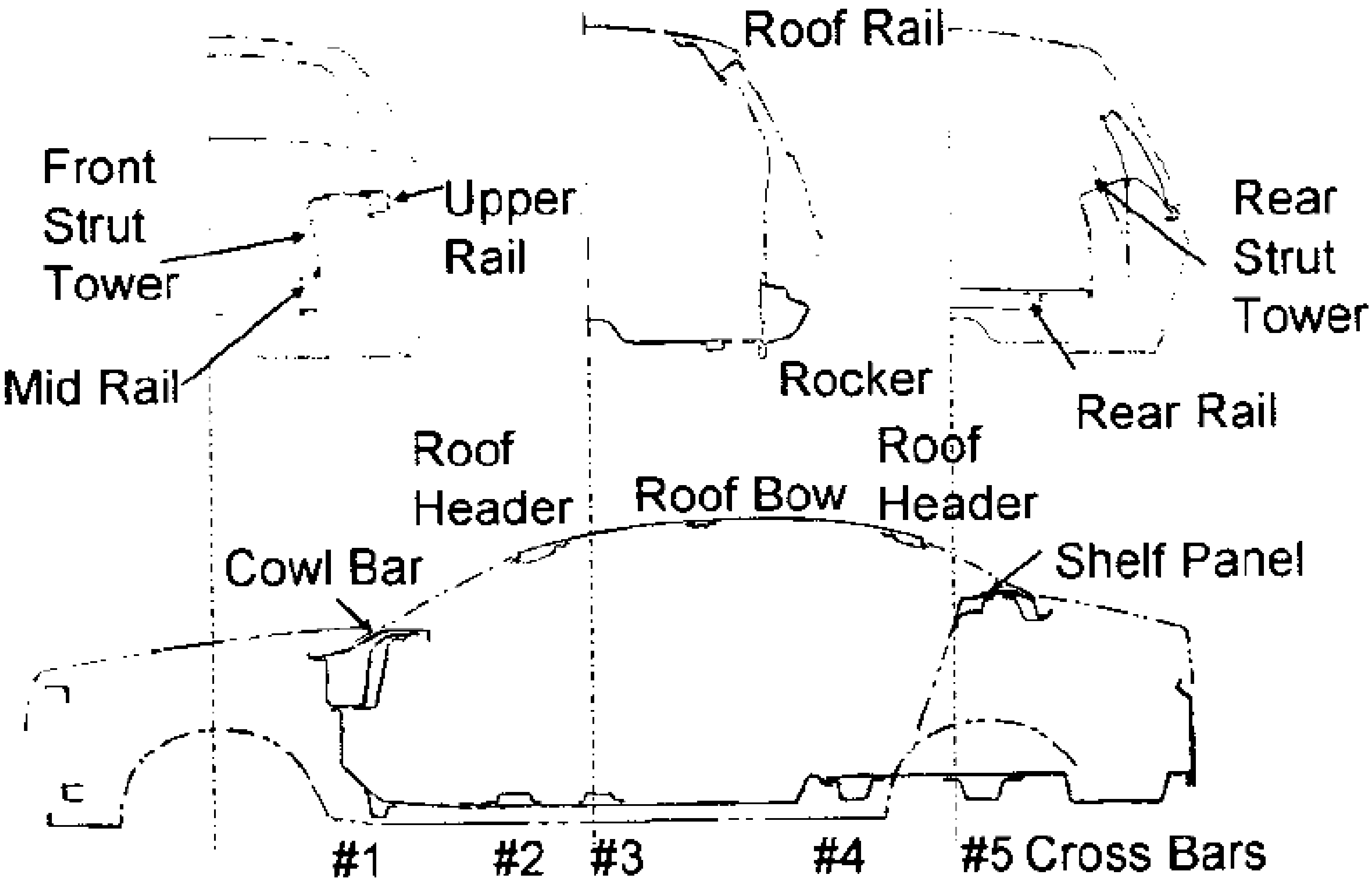
Underbody Members



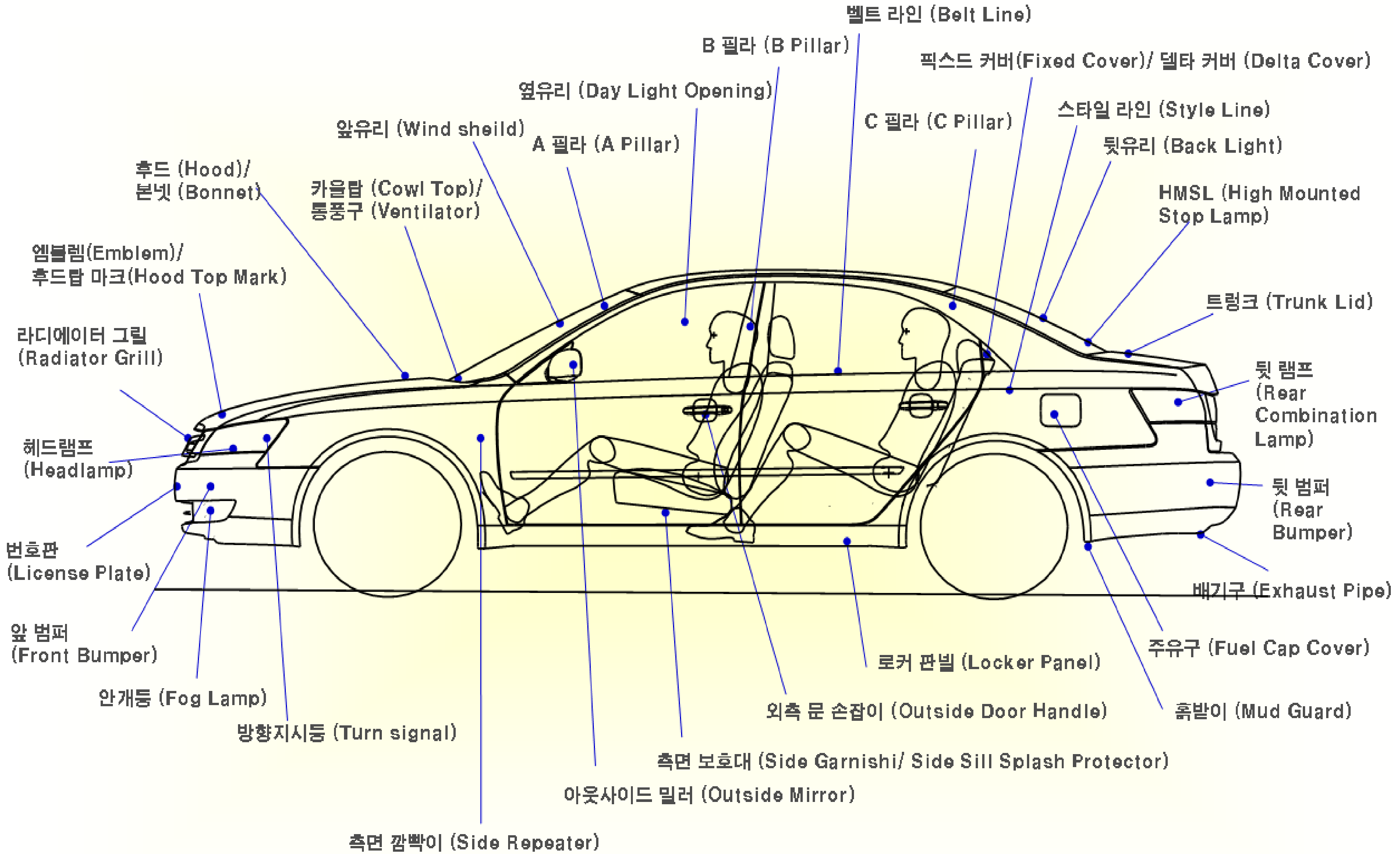
Underbody Members: Bottom View



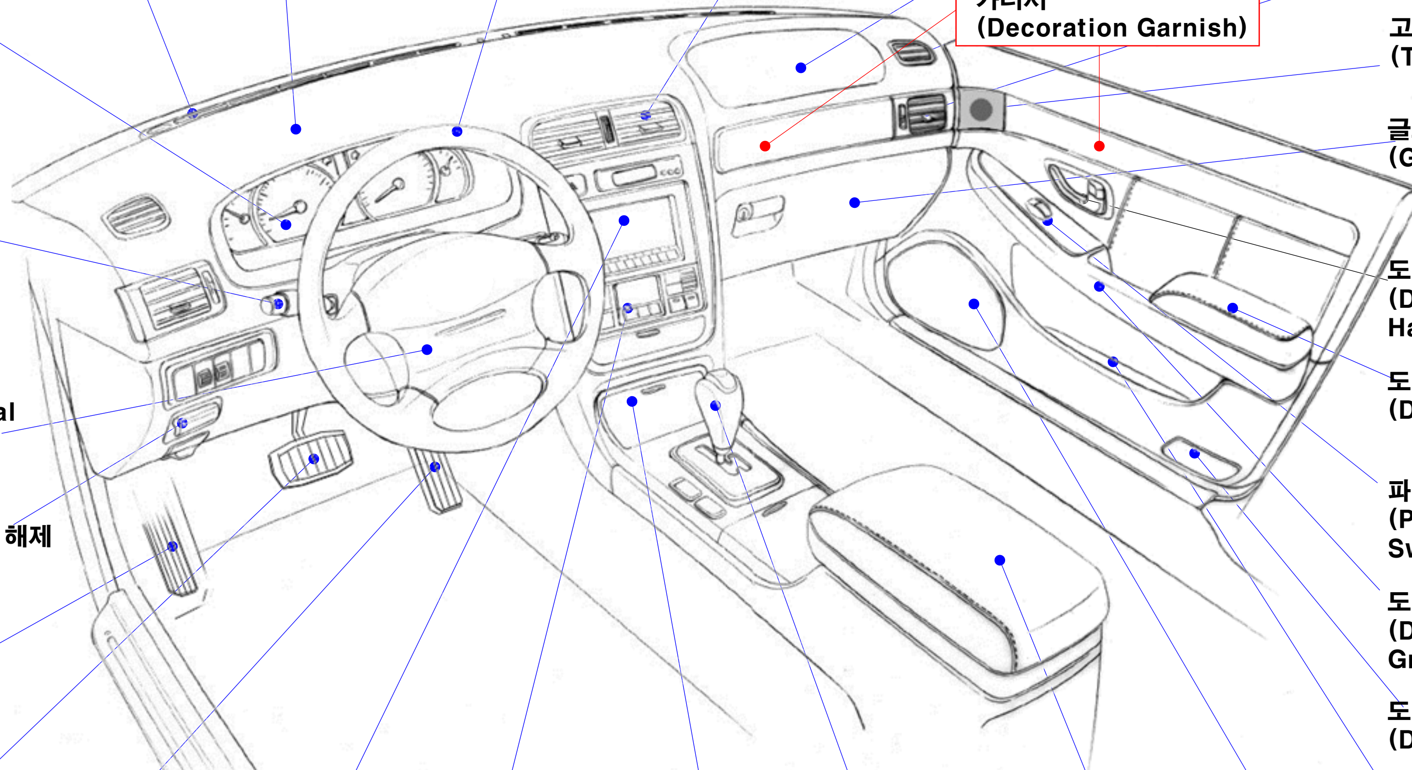
Cross Sections



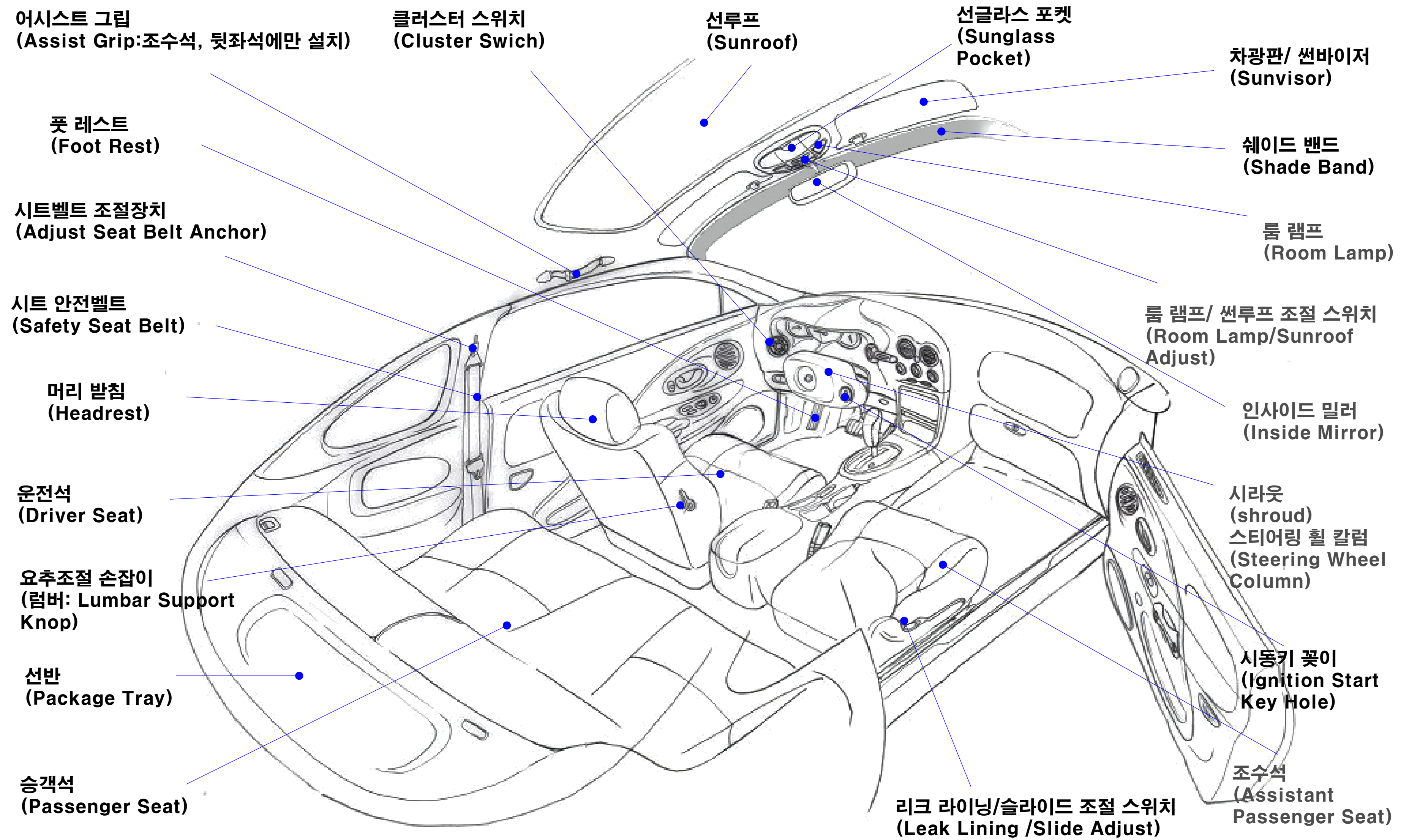
Exterior Nomenclature



Interior Nomenclature:
Crash Pad, Console, Door Trim

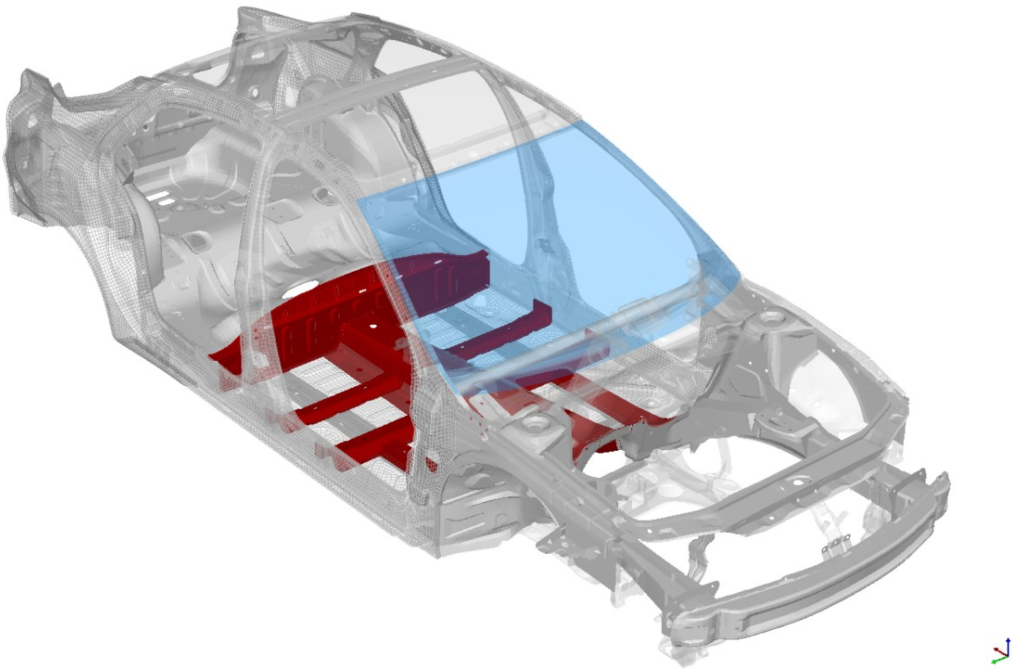


Interior Nomenclature:
Seat, Head Lining, Pillar Trim

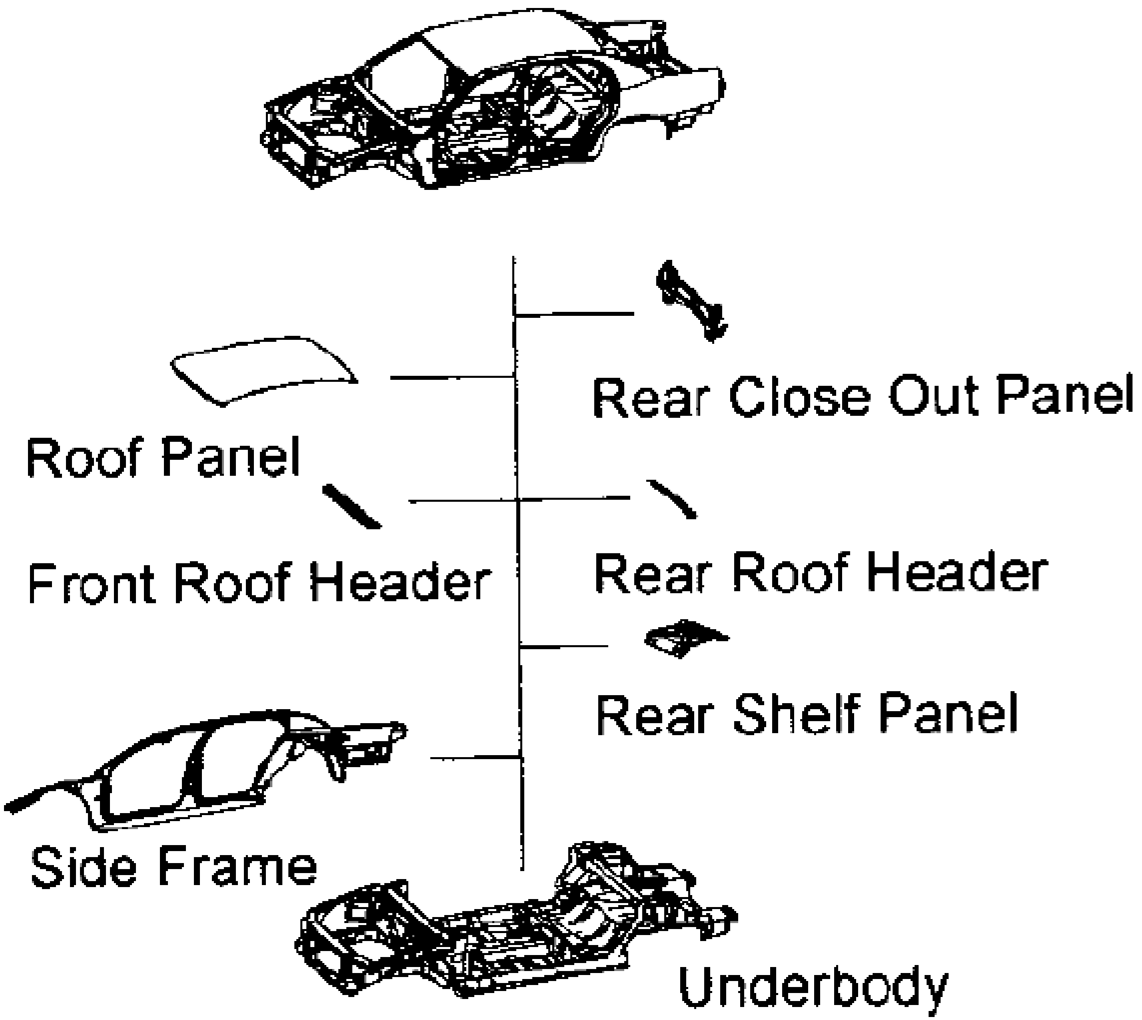


BIW (1)

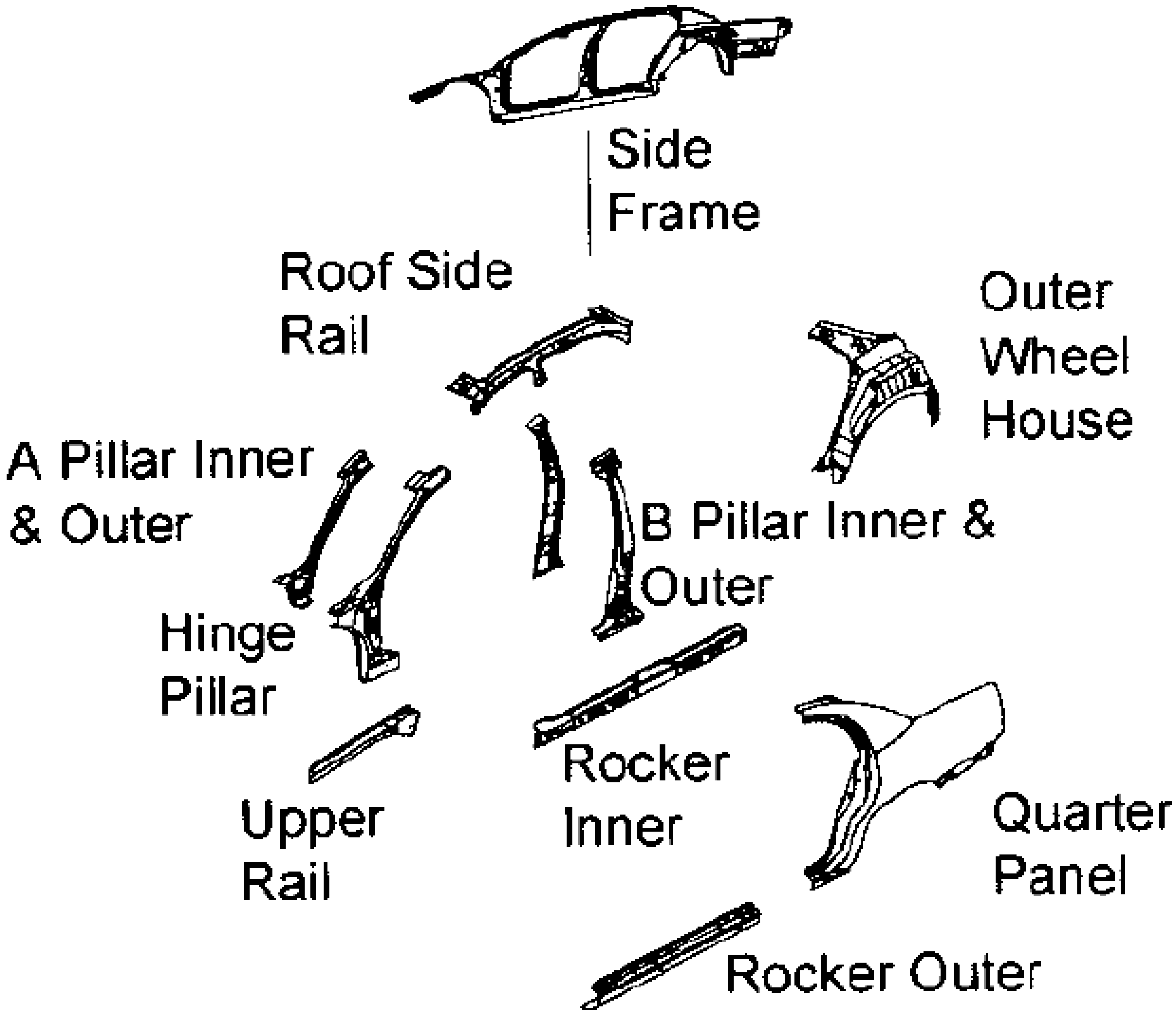
- Stage in vehicle assembly comprising the assembled but unpainted panel-work, extruding trim and chassis items
  - Side frame
  - Underbody
  - Roof panel
  - Front/Rear roof header
  - Rear close out panel
  - Rear shelf panel



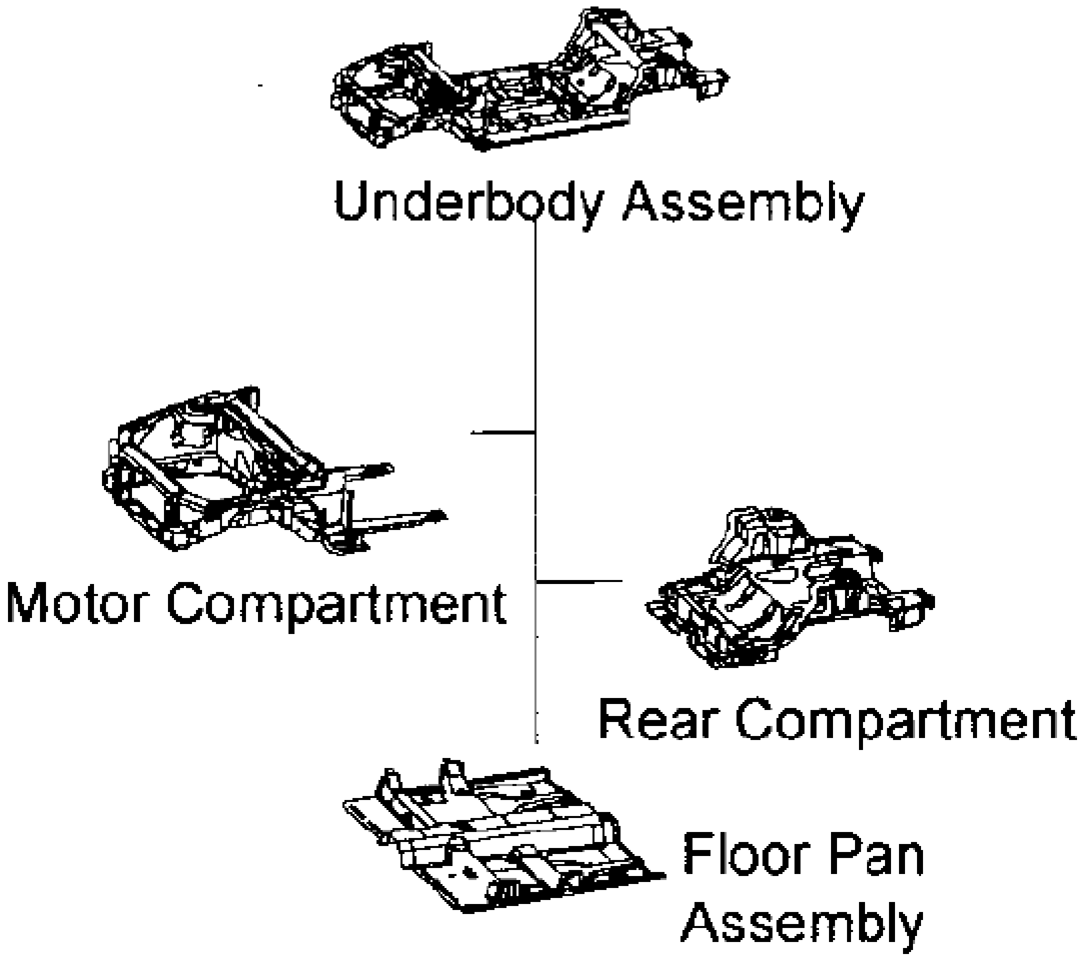
BIW (2)


Roof Panel
Front Roof Header
Side Frame
Rear Close Out Panel
Rear Roof Header
Rear Shelf Panel
Underbody

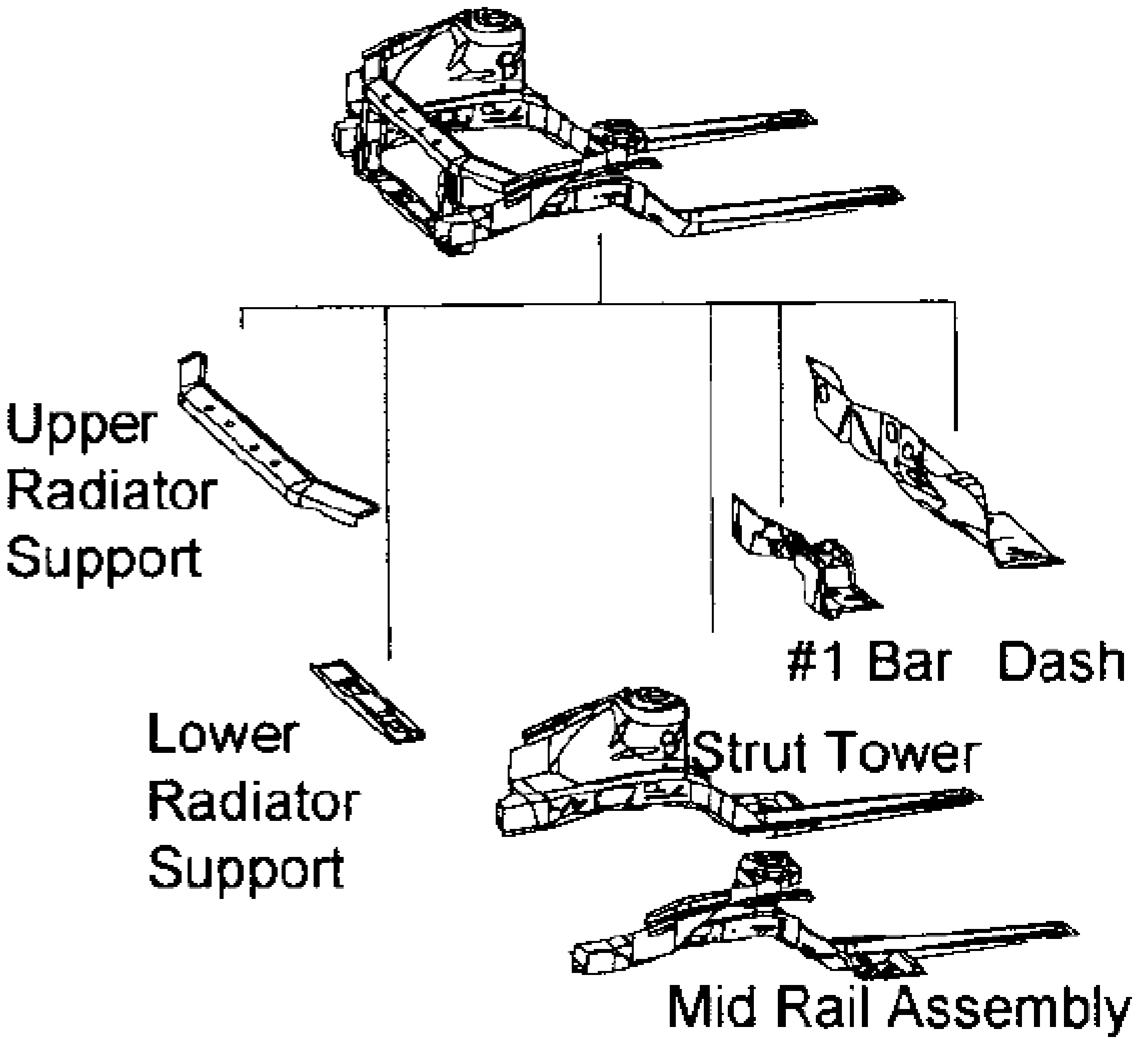
Side Frame


Side Frame
Roof Side Rail
Outer Wheel House
A Pillar Inner & Outer
B Pillar Inner & Outer
Hinge Pillar
Upper Rail
Rocker Inner
Quarter Panel
Rocker Outer

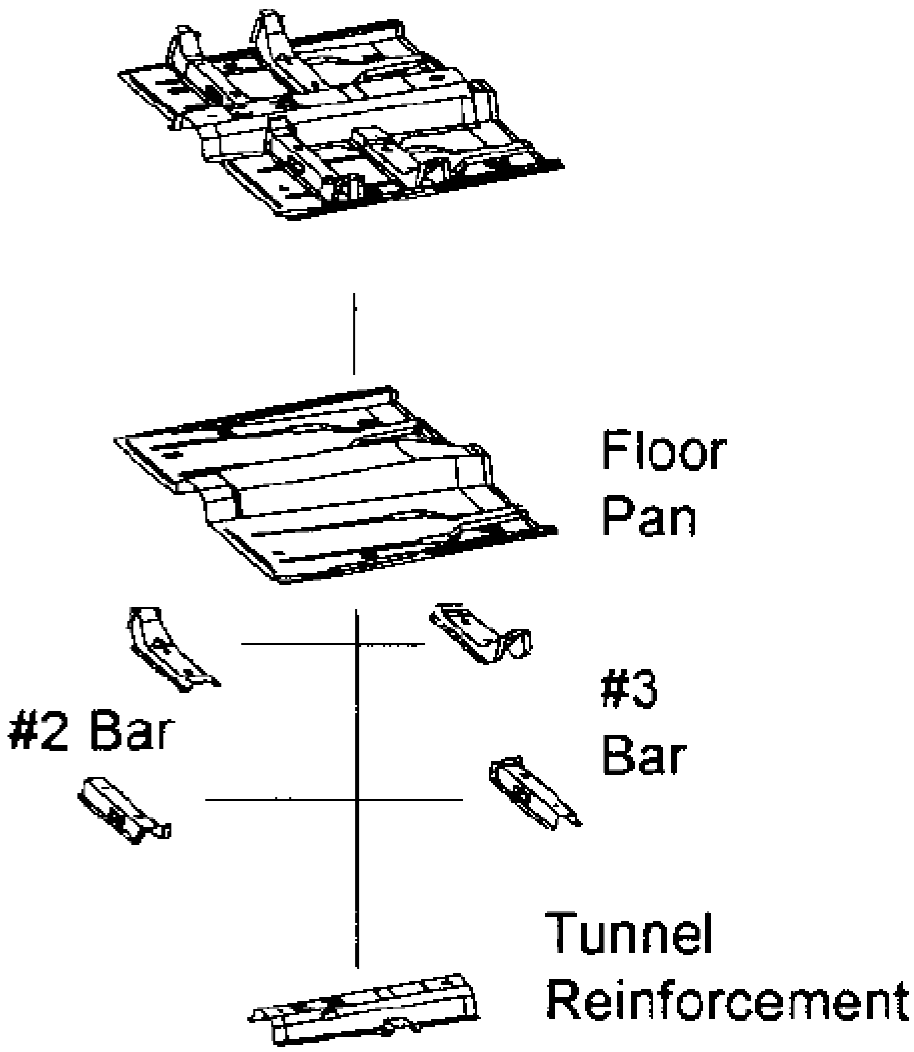
Underbody


Underbody Assembly
Motor Compartment
Rear Compartment
Floor Pan
Assembly

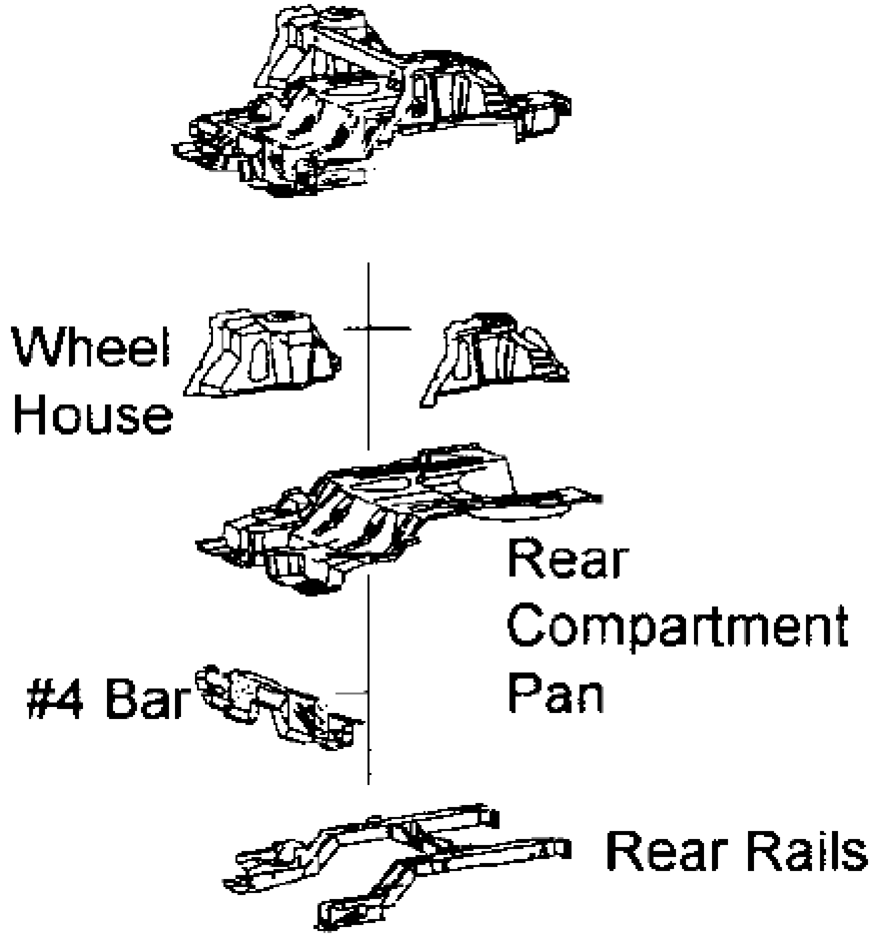
Motor Compartment



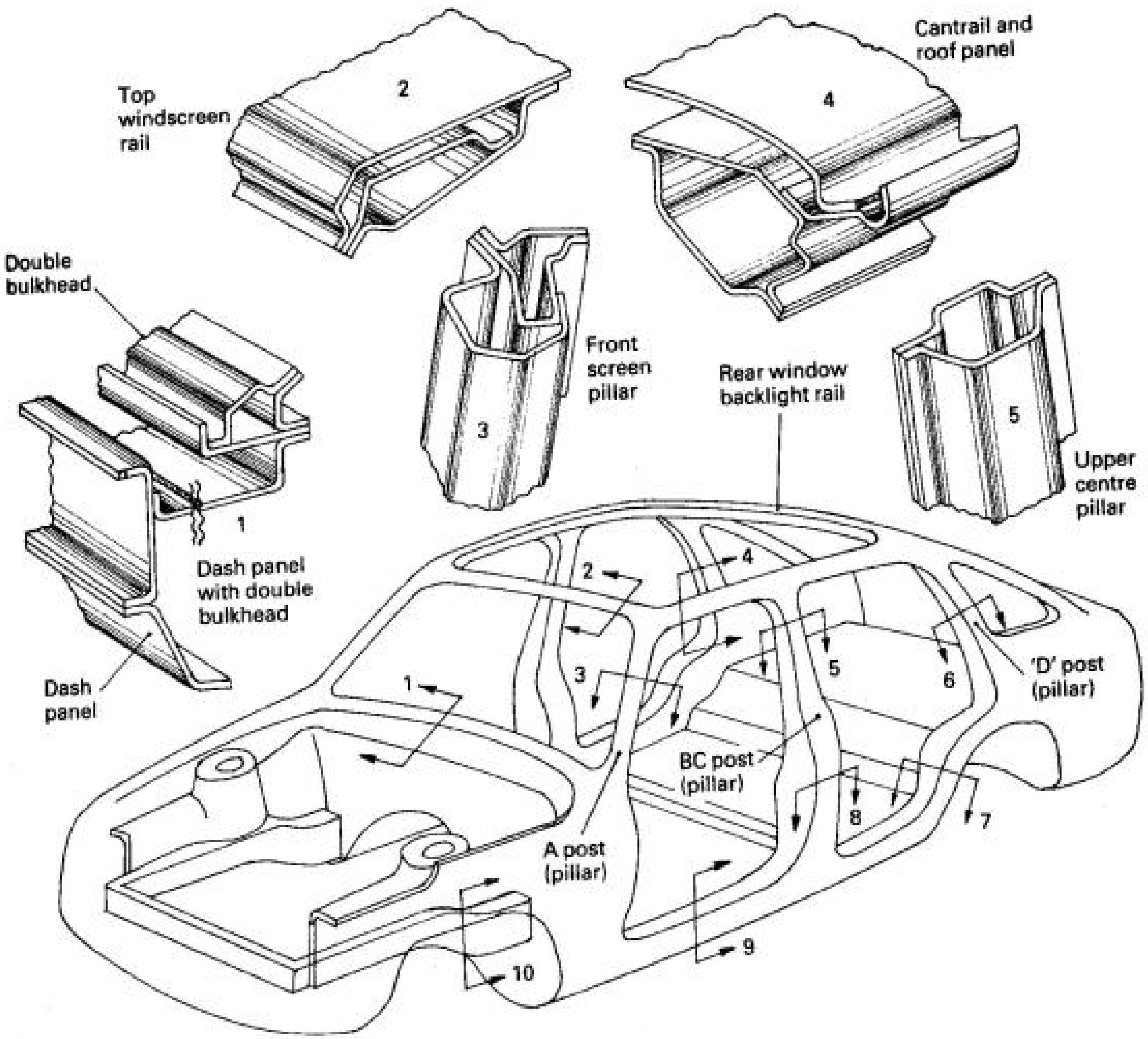
Floor Pan



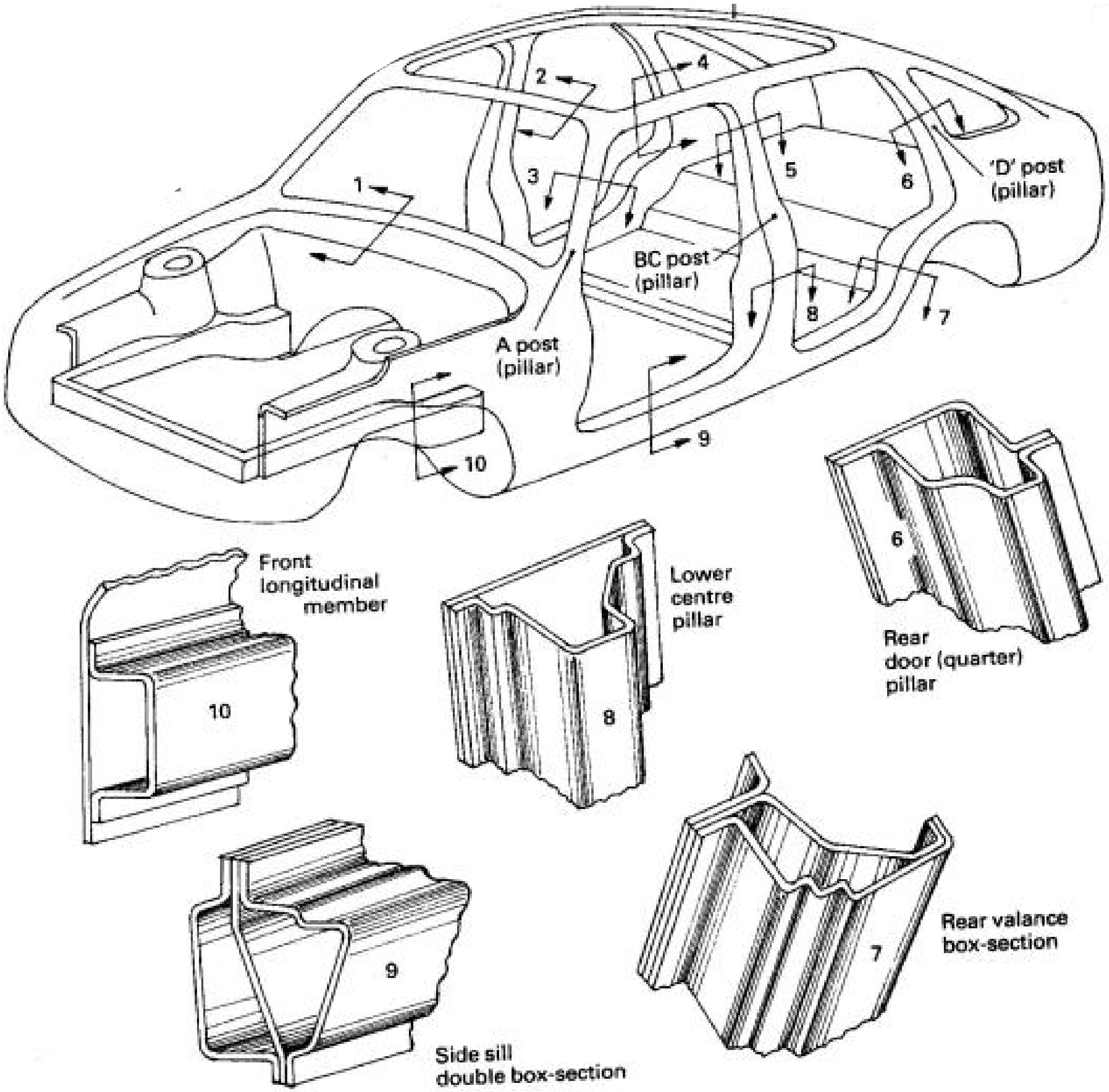
Rear Compartment



Load Bearing Body Box-Section Members

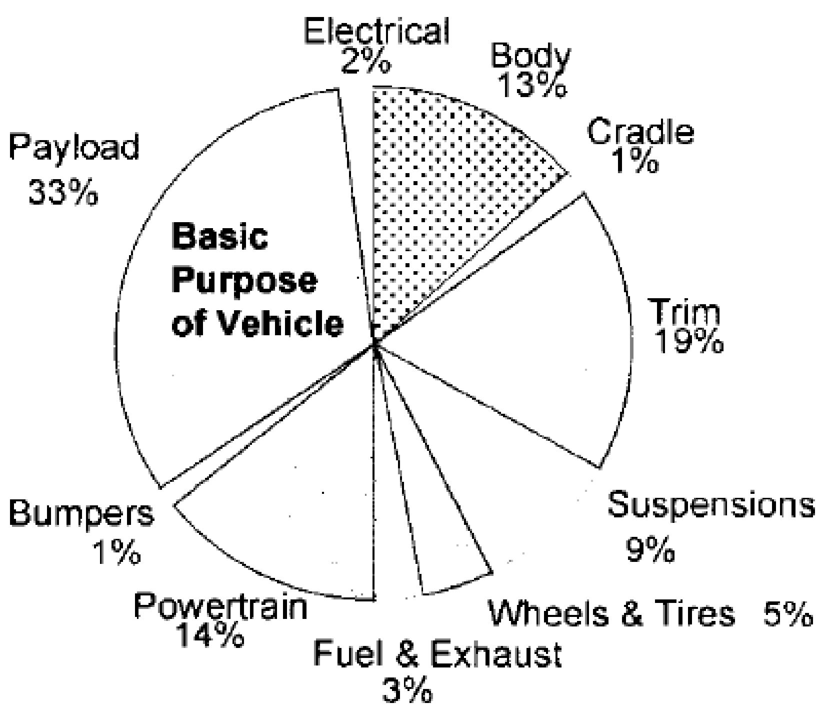


Load Bearing Body Box-Section Members

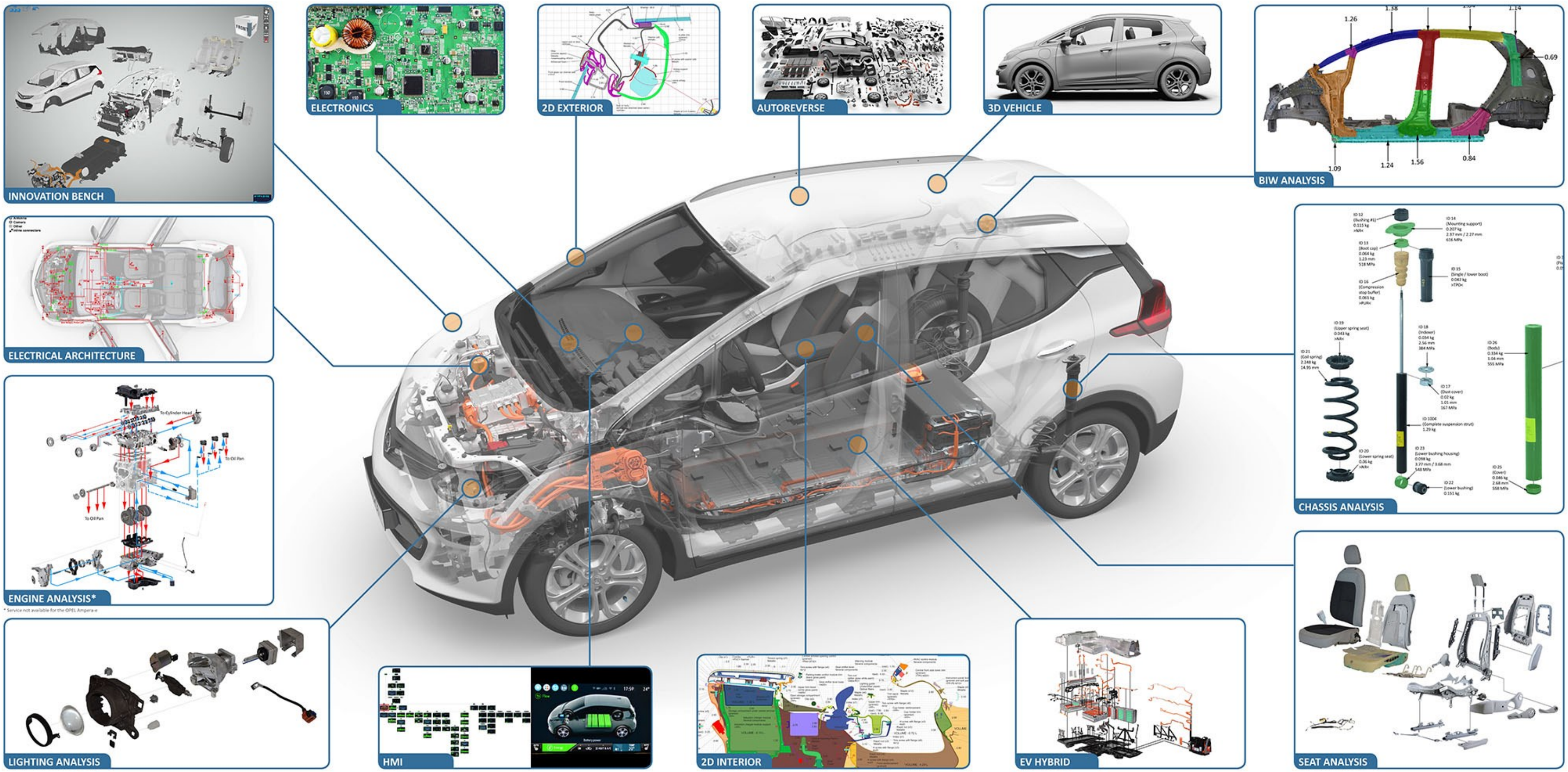


Body Mass Benchmarking: A2Mac1.com

- Mass ≈ 325 kg (100 sedans: 2002-2008 Model Year)
  - Body shell: no trim(내장), glass, closure(도어, 트렁크, 본닛)
  - Functions: fuel economy, acceleration performance, handling
- Structural efficiency < 0.2
  - (body structure mass)/(gross vehicle mass)



typical mid-size vehicle
- Integral body
- Front wheel drive



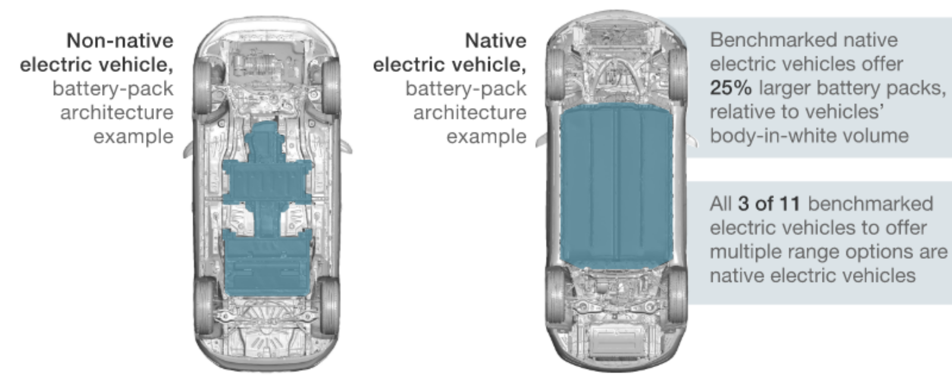
INNOVATION BENCH
ELECTRONICS
2D EXTERIOR
AUTOREVERSE
3D VEHICLE
BIW ANALYSIS
ELECTRICAL ARCHITECTURE
CHASSIS ANALYSIS
ENGINE ANALYSIS*
* Service not available for the OPEL Ampera-e
LIGHTING ANALYSIS
HMI
2D INTERIOR
EV HYBRID
SEAT ANALYSIS

A2Mac1, McKinsey Center for Future Mobility

Electric-vehicle price and range by year of launch

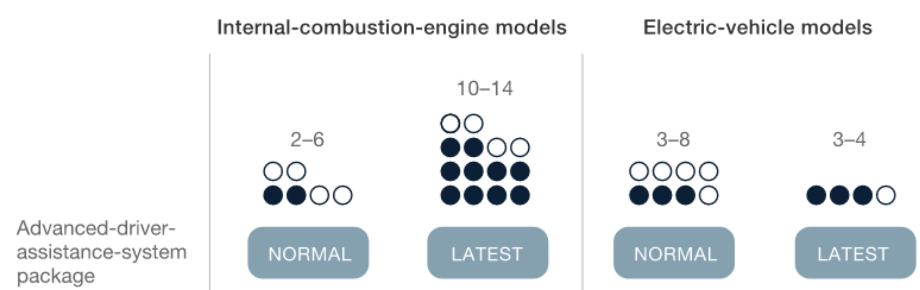
[1]Range according to Environmental Protection Agency. Where EPA data not available, New European Driving Cycle or OEM data was used; sales price based on German market OEM data.

Batteries of native electric vehicles require less compromise and allow for greater flexibility.



Benchmarking shows a potential trend toward consolidating electronic control units in (some) electric vehicles.

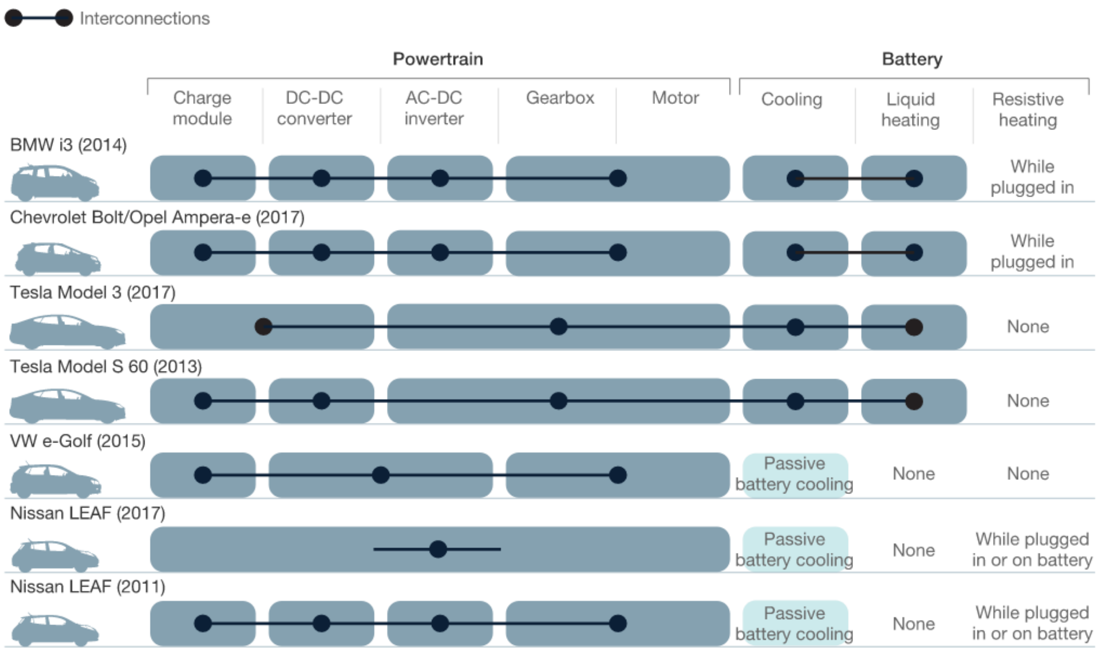
Electronic control units per vehicle by engine type and driver assistance package, range



What a teardown of the latest electric vehicles reveals about the future of mass-market Evs (2018)

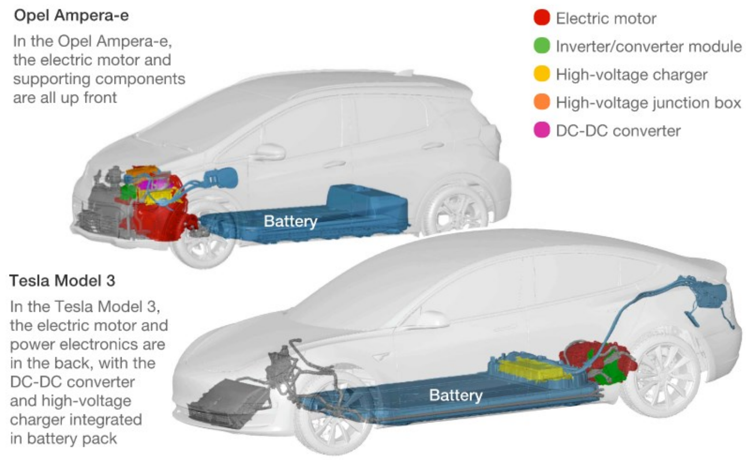
Design approaches to managing electric-vehicle powertrain and battery thermal management still vary widely among original equipment manufacturers.

Integration and interconnection of electric-vehicle powertrain thermal-management system

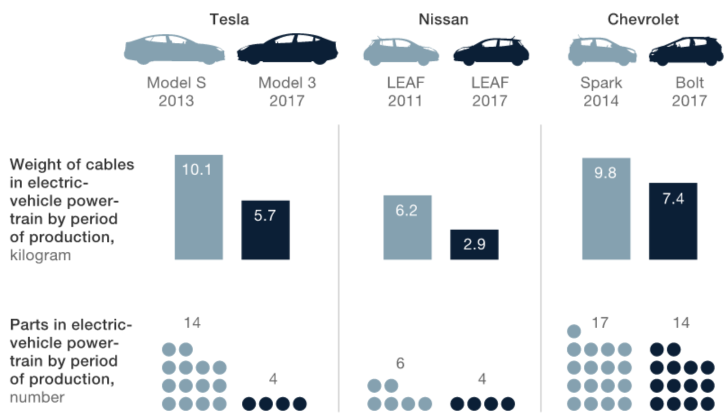


Note: Exhibit is a simplification of more detailed schematics.

Electric-vehicle powertrain architectures vary, even among the newest models.



The design of wiring elements in electric-vehicle powertrains suggests greater integration with newer models.



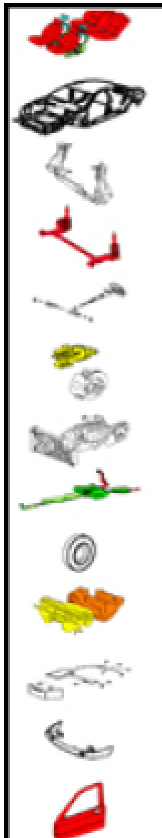
Original equipment manufacturers follow varying powertrain and battery supply-chain strategies for electric vehicles.

Electric-vehicle manufacturers' battery supply-chain strategies — Make | Buy

	Battery cell	Battery pack	Battery management system	Power electronics[1]	Motor	Transmission[2]
BYD E6 (2015)						Not available
Tesla S 60 (2013)	Panasonic					Borg-Warner[4]
BMW i3 (2014)	Samsung		Preh			
VW e-Golf (2015)	Panasonic		Panasonic[3]	Bosch		
Chevrolet Spark (2014)	A123		A123			Not available
VW e-up! (2013)	Panasonic		Panasonic[3]	Bosch		
Nissan LEAF (2011)	AESC	AESC	Calsonic Kansei	Calsonic Kansei/Denso		Aichi
Nissan LEAF (2017)	AESC	AESC	Calsonic Kansei	Calsonic Kansei/Denso		Aichi
Chevrolet Bolt/Opel Ampera-e (2017)	LG	LG	LG	LG	LG	LG

[1] DC-DC converter and AC-DC inverter.
[2] Only single-speed transmission.
[3] Formerly Ficosa, now owned by Panasonic.
[4] Formerly Eaton, now owned by BorgWarner.

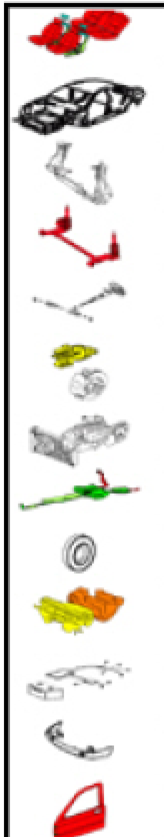
Mass Estimates (kg): small car



	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

Source: Future Steel Vehicle: Phase I – Executive Summary (2009)

Mass Estimates (kg): mid-class car



	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

Source: Future Steel Vehicle: Phase I – Executive Summary (2009)

자동차의 구조부

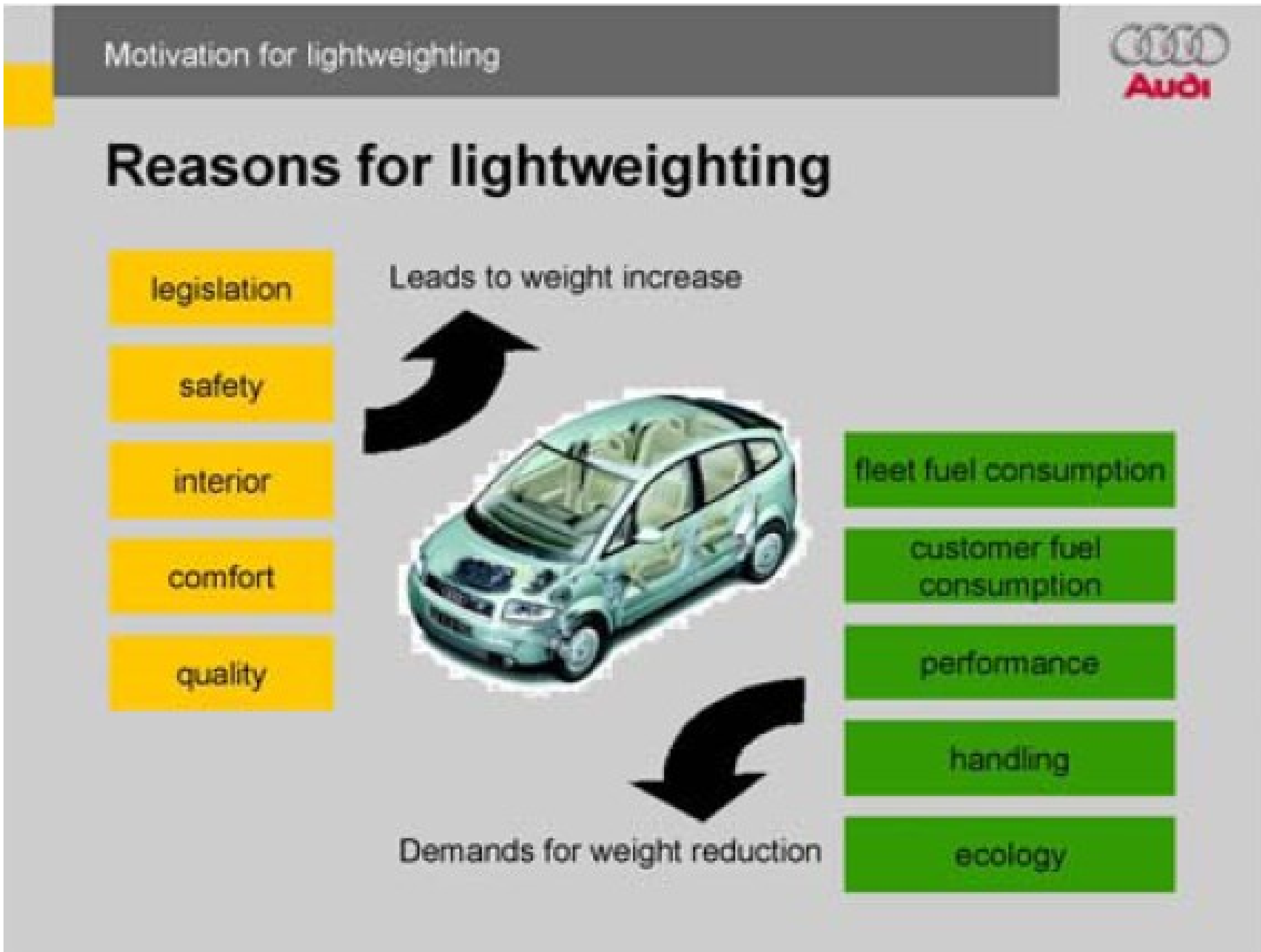
부위			중량비율(%)
차체 부품 관련	프레임 계	비 충격흡수	20
		충격흡수	
	외판 계	후드/트렁크	6
		사이드	
		루프	
	외장 계		7
	내장 계		11
휠 주변 관련	서스펜션 계	전/후 암	12
		스프링	
		댐퍼	
		서브프레임	
	휠 계		7
	조향 계	기어박스	3
		스티어링	
파워트레인 관련	흡배기/연료 계		7
	연료장치 계		
	트랜스미션 계		18
	엔진 계		
전장품/기타			9

구조부(프레임/외판) 현황

<table>
<tr><th></th><th></th><th></th><th></th><th></th><th>재료
(MPa)</th><th>판두께
(mm)</th><th>중량
(kg)</th><th>요구사항</th></tr>
<tr><td rowspan="3">프레임 계</td><td rowspan="2">찌그러지지 않는 부위</td><td>단순 구조</td><td>보강 부위</td><td>범퍼 빔
도어 빔</td><td>980</td><td>1.60</td><td>50</td><td>충격강도
피로강도
용접성</td></tr>
<tr><td>복잡 구조</td><td>구조 부위</td><td>프론트필러
B필러</td><td>590</td><td>1.30</td><td>130</td><td>충격강도
피로강도
강성
성형성</td></tr>
<tr><td colspan="2">찌그러지는 부위</td><td>충격 흡수 부위</td><td>프론트사이드 멤버
프론트크로스 멤버</td><td>440</td><td>1.40</td><td>80</td><td>에너지흡수성
강성</td></tr>
<tr><td colspan="3">외판 계</td><td>외판 부위</td><td></td><td>340</td><td>0.65</td><td>80</td><td>외관표면품질
덴트저항성
인장강성</td></tr>
</table>

* 차량 전체 중량을 1300kg으로 가정하고 산출

Lightweight Development (1)



Lightweight Development (2)

Audi 80

Year of construction 1972

ca. 850kg

Audi A4

Year of construction 2007

ca. 1440kg

Example for drivers-assistant systems		
Comfort	**Safety**	**Infotainment**
Electric adjustment of: front seats steering column exterior mirrors	Speed and distance control system Adaptive Cruise Control (ACC) Electronic Stabilization Program (ESP) Anti-lock Brake System (ABS)	Radio Data System (RDS) Traffic Massage Channel (TMC)
Seat heating / ventilation / memory	Electro mechanical parking brake	Dynamic navigation
Power steering	Airbag	Emergency call
Air-conditioning	Seatbelt	Voice control
Auxiliary heating	Light and Rain sensor	
Coming home leaving home	Dynamic headlight range control	
Keyless entry	Lane change assistant	
Central locking system	Tire pressure monitoring system	

Source: Vieweg Handbuch Kraftfahrzeugtechnik, 3. Auflage

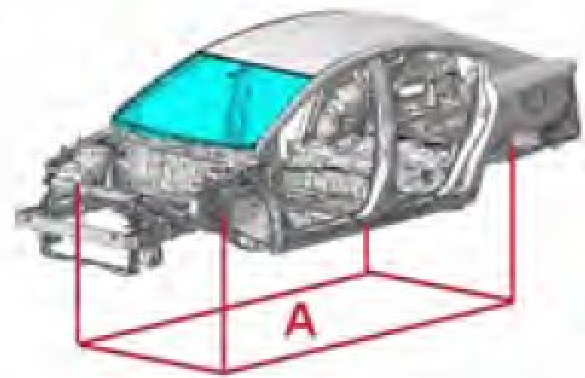
Body Structure - Lightweight Index

$$\frac{M_{BIW}}{C_T \cdot A}\left[\frac{kg}{N \cdot m/\deg \cdot m^2} \cdot 10^3\right] = 4.01$$

M_{BIW} [kg]: BIW mass including bolted elements and glued windscreen

C_t[kNm/deg] : Torsion stiffness of BIW including bolted elements and glued windscreen

A [m^2]: Projected area (wheel base · tread)



Vehicle	Lightweight Index (L)	Torsional Stiffness (kN-m/deg)	Body Mass (kg)	Contact Area (m^2)
FSV-BEV	2.56	20	190	3.71
SLC	1.8	25.5	180	3.9
VW Polo V (2010)	3.5	18	227	3.6
VW Golf V	2.88	25	281	3.9
Toyota Avensis (2008)	4.01	n/a	n/a	3.99

Lightweight Quantification

Lightweight quality

$$L = \frac{m_{Ger}}{c_T * A}\left[\frac{kg}{\frac{Nm}{\circ} * m^2} * 10^{-3}\right]$$

m_{ger} = Body structure weight (without doors and closures)

c_T = Torsion stiffness (with screens)

A = contact patch (wheel track x wheel base)

Example: BMW 3rd series

316 (E30) – 1982

m_{leer} = 1030kg

m_{Ger} = 260kg

c_T = 6500Nm/°

L = 8,60

316i (E36) – 1990

m_{leer} = 1266kg

m_{Ger} = 310kg

c_T = 10300Nm/°

L = 5,67

316i (E46) – 1998

m_{leer} = 1385kg

m_{Ger} = 284kg

c_T = 20000Nm/°

L = 3,02

316i (E96) – 2005

m_{leer} = 1320kg

m_{Ger} = 267kg

c_T = 25000Nm/°

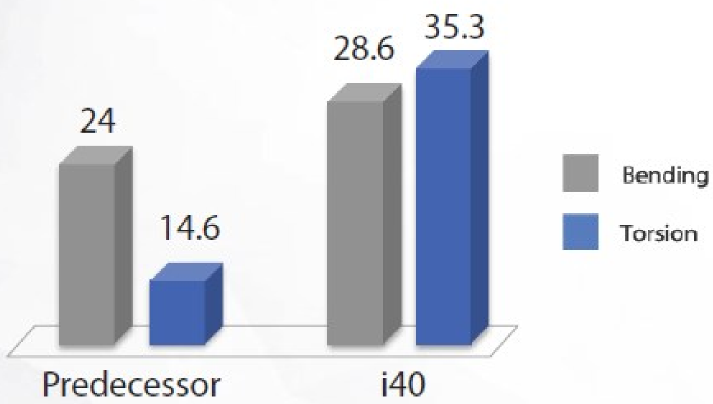
L = 2,58

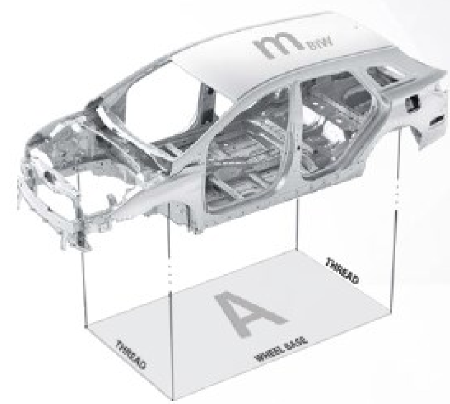
Source: B. Lüdtke, 1999

Body stiffness & lightweight index

- Increased the torsional stiffness by **141%** and the bending stiffness by **19%**.
- Achieved **11%** more torsional and **23%** more bending stiffness compared to competition

	i40	Predecessor
LIGHTWEIGHT INDEX	2.09	4.41
BIW WEIGHT	325.6	302.3
TORSIONAL STIFFNESS	35.3	14.6
AREA	4.415	4.69





$$L = \frac{m_{BIW}}{C_T A} \times 10^3$$

L	Body stucture efficiency index
m_{BIW}	BIW weight
CT	Body torsional static stiffness
A	Body projection area considering vehicle spec.

Category	Acronym	Description	Ultimate Tensile Strength (MPa) Range
Low Strength (LSS)	Mild	Mild Steel	Less than 270
High Strength Steels (HSS)	IF	Intersitial Free	410-420
	BH	Bake Hardenable	340-400
	HSLA	High-Strength Low Alloy	450-780
Advanced High Strength Steels (AHSS)	DP	Dual Phase	440-1270
	FB	Ferritic-bainitic (SF - stretch flangeable)	450-600
	CP	Complex Phase	800-1470
	MS	Martensitic	1200-1500
Ultra High Strength Steels (UHSS)	TRIP	Transformation-induced plasticity	600-980
	HF	Hot-formed (boron)	480-1900
	TWIP	Twinning-induced plasticity	900-1200

Vehicle Mass Reduction Roadmap Study 2025-2035

CENTER FOR AUTOMOTIVE RESEARCH

Carla Bailo
Shashank Modi
Michael Schultz
Terni Fiorelli
Brett Smith
Nicklaus Snell

Table 1: Vehicles studied for baseline material analysis

Small Car	Mid-Size Car	Small SUV	Mid-Size SUV	Pickup
Honda Civic	Ford Fusion	Jeep Wrangler	Traverse	Silverado
Honda Accord	Tesla Model 3	Chevy Equinox	Pacifica	Ram Pickup
Hyundai Elantra		Ford Escape	Explorer	F Series
Nissan Altima		Edge	Pilot	Sierra
Nissan Sentra		CR-V	Grand Cherokee	Tacoma
Toyota Camry		Tucson	Highlander	
Toyota Corolla		Cherokee		
		Compass		
		CX-5		
		Rogue		
		Outback		
		Forester		
		Rav4		

Components	MY2020 baseline fleet	2016 study: 5% M.R. level
Fender	BH Steel and Aluminum (50:50)	HSS/BH Steel
A-pillar	UHSS 1500 Hot Formed	UHSS HF Steel
Floor	HSS 440-590 with UHSS Reinforce.	Mild with AHSS
Front Bumper Structure	Mostly Aluminum with some Steel	Aluminum
Roof Panel	Mild/B.H. Steel	Mild Steel
Door Outer	LSS And Aluminum	B.H. Steel and Aluminum
Hood	95% Aluminum	Aluminum
Decklid	LSS, Al, Mag, Comp.	B.H. Steel and Aluminum
Engine Cradle/Front frame	LSS 400-600	HSLA
Steering Knuckle	HSS 400-500 And Aluminum	Aluminum
IP Beam	HSS And Two Magnesium	AHSS

Table 5: Mass Reduction Potential of Materials

Lightweight Material	Mass Reduction Opportunity
Magnesium	30-70%
Carbon fiber composites	50-70%
Aluminum and Al matrix composites	30-60%
Titanium	40-55%
Glass fiber composites	25-35%
Advanced high strength steel	15-25%
High strength steel	10-28%

Source: U.S. Department of Energy

Table 6: Mass Reduction percentages of each material used for this project

Material	**MR%** (relative to mild steel)
AHSS	10%
UHSS	25%
Aluminum	45%
Magnesium	50%
Polymer Composite	60%

Source: CAR Research

Vehicle System
Closures
BIW
Unsprung Mass
Interiors
Powertrain

Decreasing priority

Table 10: LOW Total Cost $/kg range (material + processing)

Material	2020	2025	2030	2035
Mild	1.45	1.45	1.45	1.45
HSS	1.51	1.51	1.51	1.51
AHSS	1.97	1.94	1.92	1.90
UHSS	2.05	2.03	2.00	1.98
Al	3.76	3.66	3.57	3.48
Mag	5.97	5.40	4.84	4.29
Comp	57.14	49.13	42.51	31.90

Table 11: HIGH Total Cost $/kg range (material + processing)

Material	2020	2025	2030	2035
Mild	1.75	1.75	1.75	1.75
HSS	1.81	1.81	1.81	1.81
AHSS	2.27	2.24	2.22	2.20
UHSS	2.35	2.33	2.30	2.28
Al	4.37	4.27	4.18	4.09
Mag	6.27	5.70	5.34	4.79
Comp	57.14	53.41	45.81	39.57

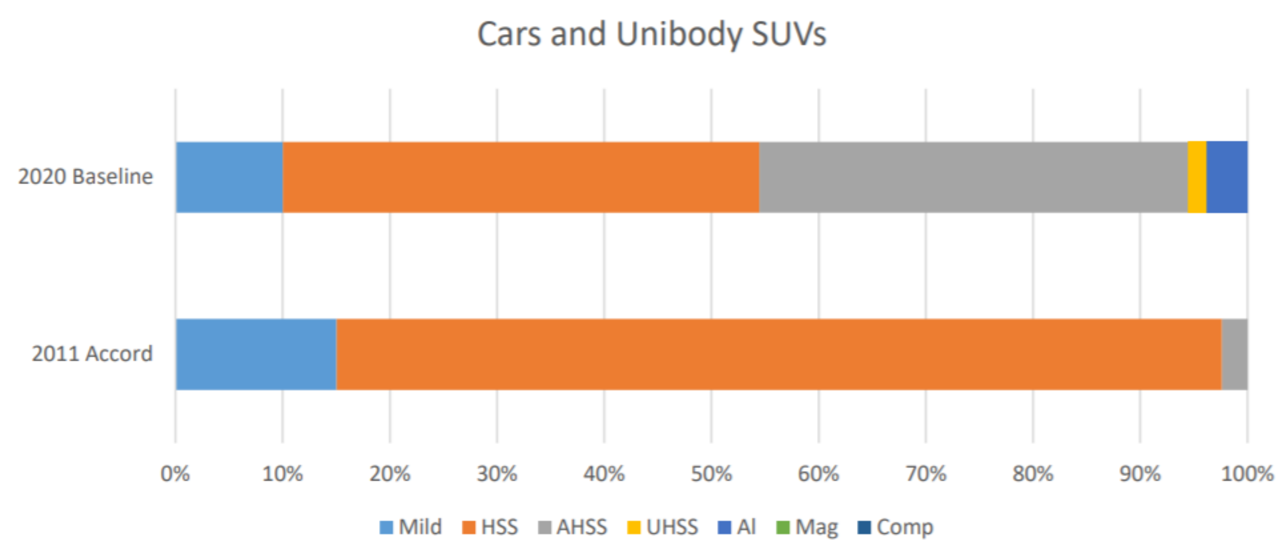
Factors Affecting Automaker Lightweighting Targets

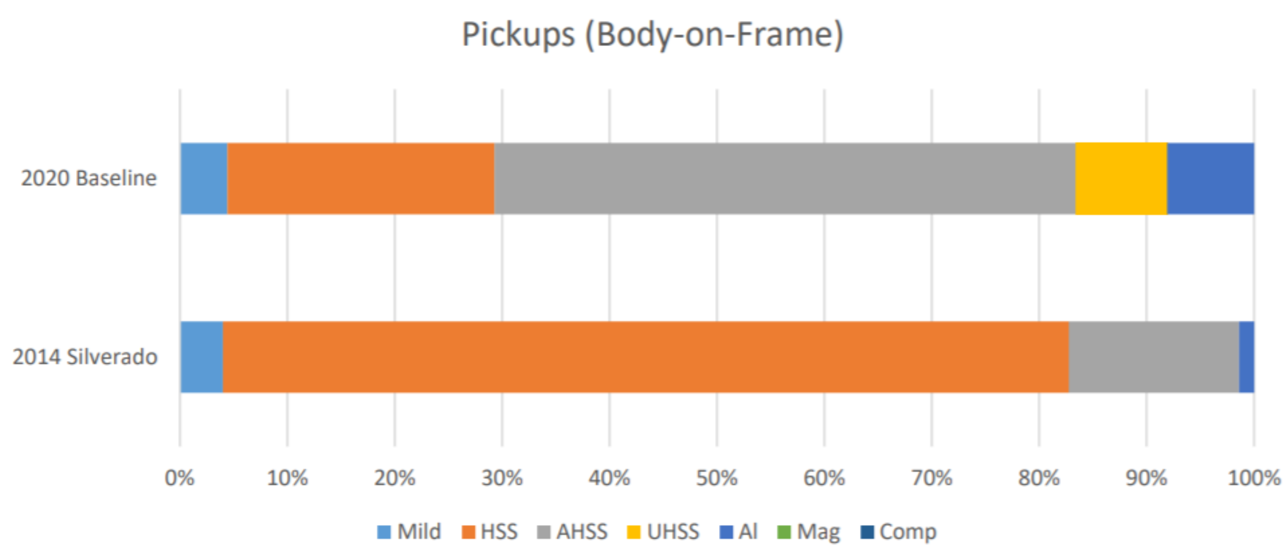
- Fuel Economy and GHG regulations
- Electrification volume
- Battery cell energy density (weight of the battery pack)
- Battery pack cost

	High	Low
Electrification Volume (CAFE/GHG proxy)	>25% BEV, 30-50% Hybrids	<15% BEV, 20-25% Hybrids
Battery Pack cost	$145-$160 per kWh	<$100 per kWh (2030+ projected)
Battery Cell Energy Density	900 Wh/Liter	700 Wh/Liter

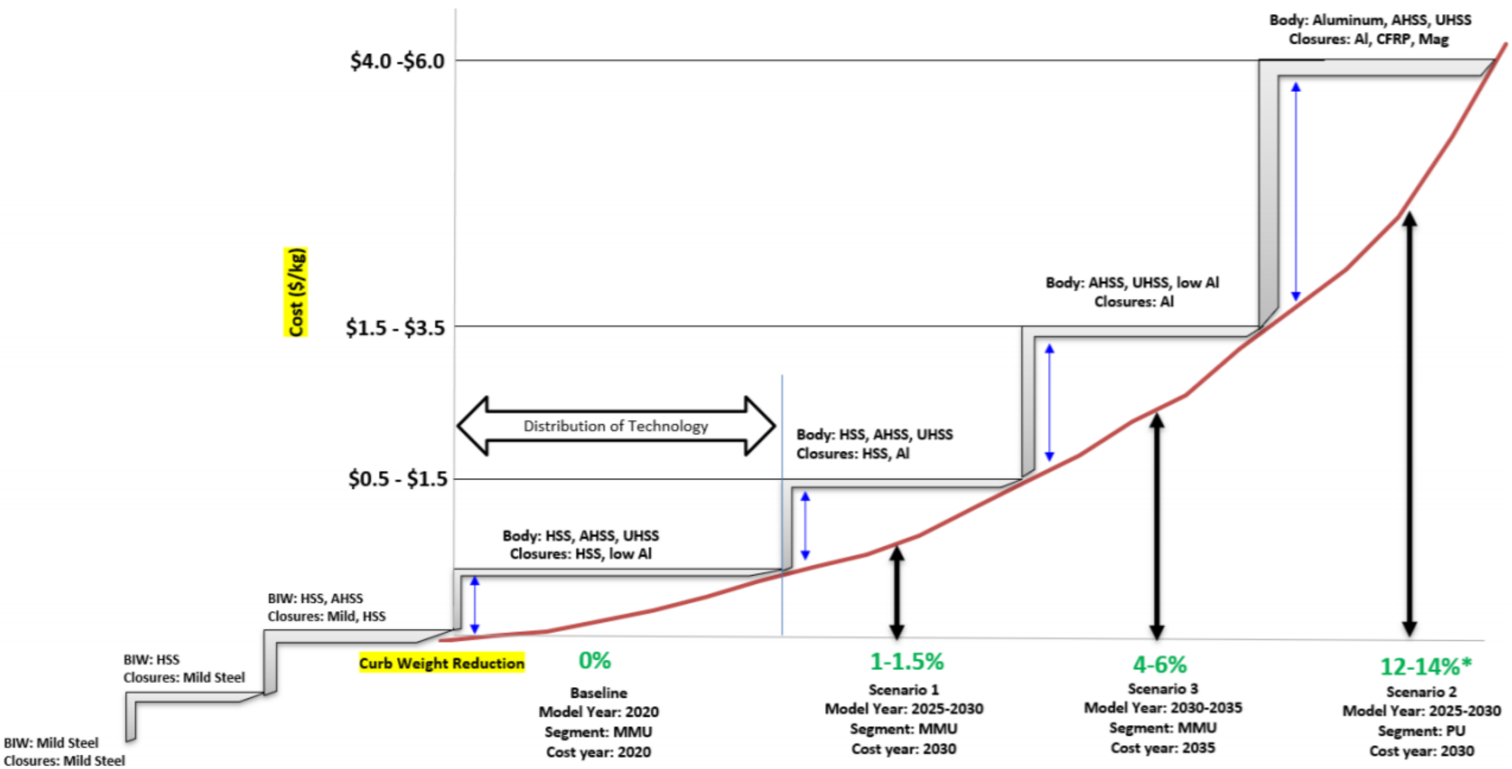
Year/Variable	Electrification Volume	Battery Pack Cost	Battery Cell Energy Density
2020-2025	Low	High	Low
2025-2030	Mass Market: Low Premium - High	High	Low
2030-2035	High	Low	Low

Material Distribution

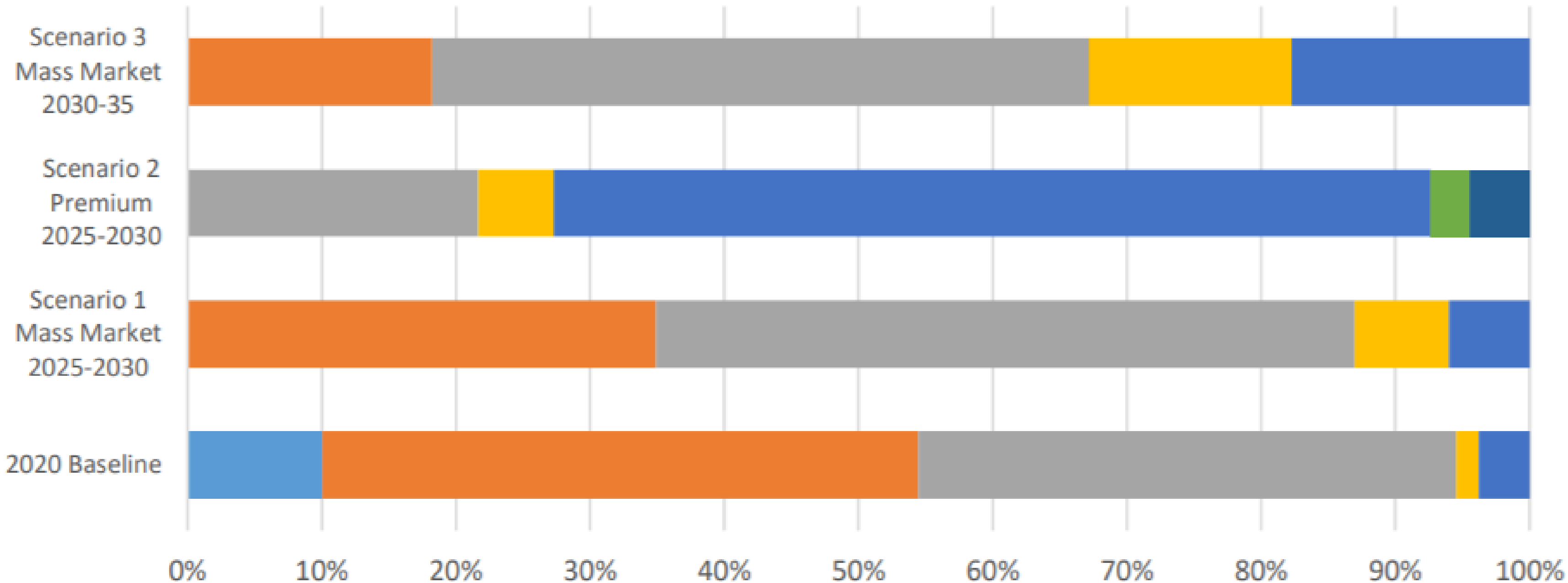




Scenario	Electrification Volume (CAFE/GHG proxy)	Battery Pack cost	Battery Density	Cost penalty per kg of weight saved	Expected Material Trend	BIW+Closures Weight Reduction (2020 baseline)	Curb Weight Reduction (2020 baseline)	Expected Year
Baseline	Low	High	Low	NA	Body: HSS, AHSS, UHSS Closures: HSS, low Al	NA	NA	NA
Scenario One	Low	High	Low	$0.5- $1.5 CY: 2030	Body: HSS, AHSS, UHSS Closures: HSS, Al	~4%	1.0% - 1.5%	Mass Market 2025-2030
Scenario Two	High	High	Low	$4.0 -$6.0 C.Y.: 2030	Body: Aluminum, AHSS, UHSS Closures: Al, CFRP, Mag	~37%	12 - 14% (with secondary)	Premium Vehicles 2025-2030
Scenario Three	High	Low	Low	$1.5 - $3.5 CY: 2035	Body: AHSS, UHSS, low Al Closures: Al	~12%	4 - 6%	Mass Market 2030-35
Scenario Four	High	Low	High*	-	AHSS intensive	not in scope		Low



Material Penetration - Cars and Unibody SUVs

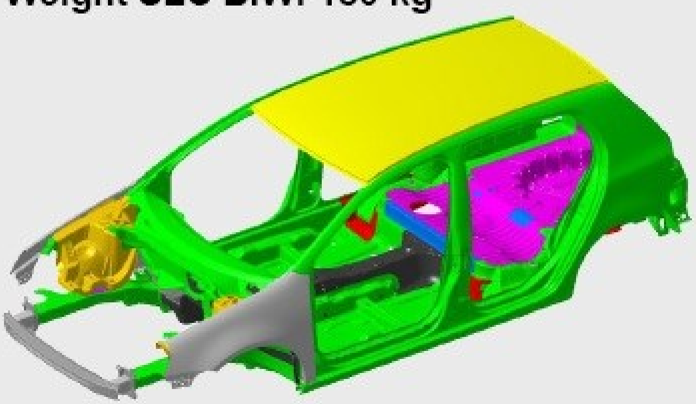


	2020 Baseline	Scenario 1 Mass Market 2025-2030	Scenario 2 Premium 2025-2030	Scenario 3 Mass Market 2030-35
Mild	10%	0%	0%	0%
HSS	44%	35%	0%	18%
AHSS	40%	52%	22%	49%
UHSS	2%	7%	6%	15%
Al	4%	6%	65%	18%
Mag	0%	0%	3%	0%
Comp	0%	0%	4%	0%

Super Light Car (SLC)

- Multi-material concepts design and optimization
  - Multi-material vehicle concept 35% (101 Kg) weight reduction compared to the reference (VW Golf V, 2004 benchmark)

Weight SLC BIW: 180 kg



Materials

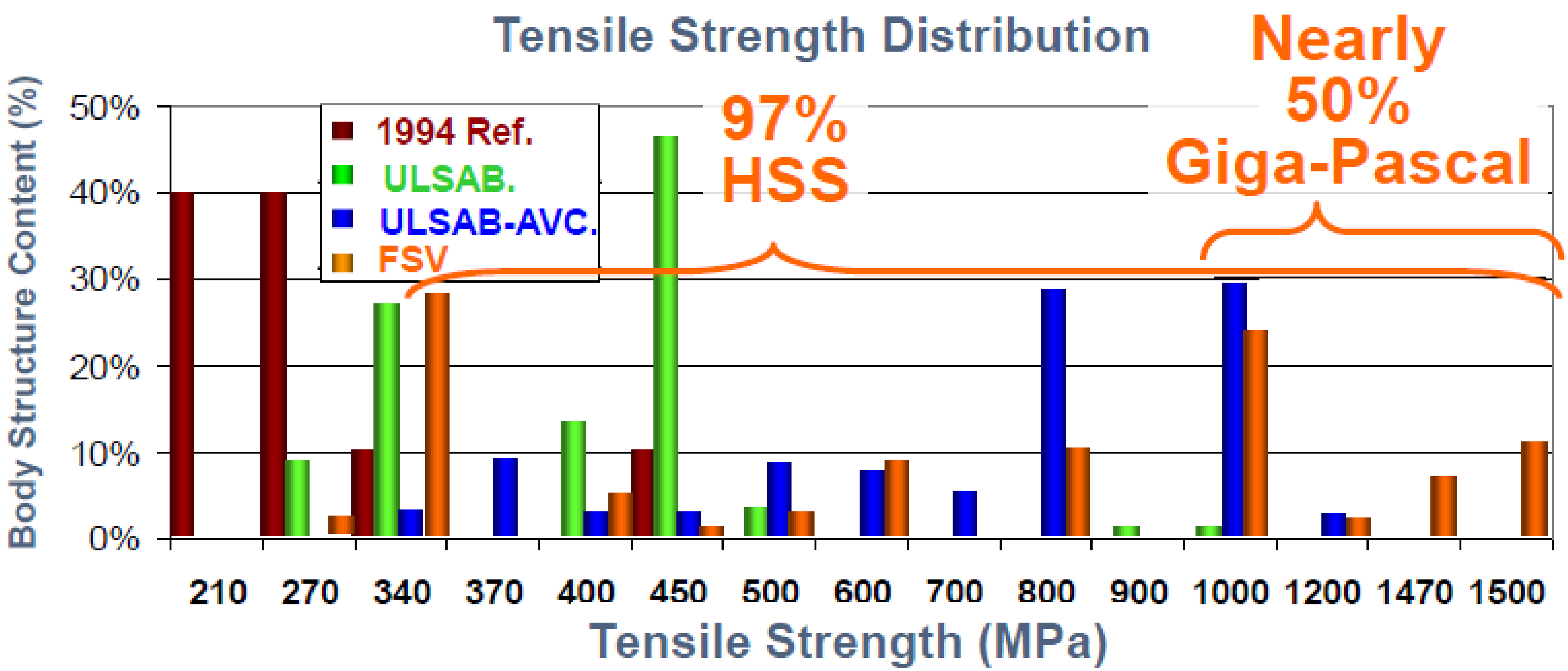
- Aluminium sheet
- Aluminium die-casting
- Aluminium extrusion
- Steel
- Hot-formed steel
- Magnesium sheet
- Magnesium die-casting
- Fiberglas thermoplastic

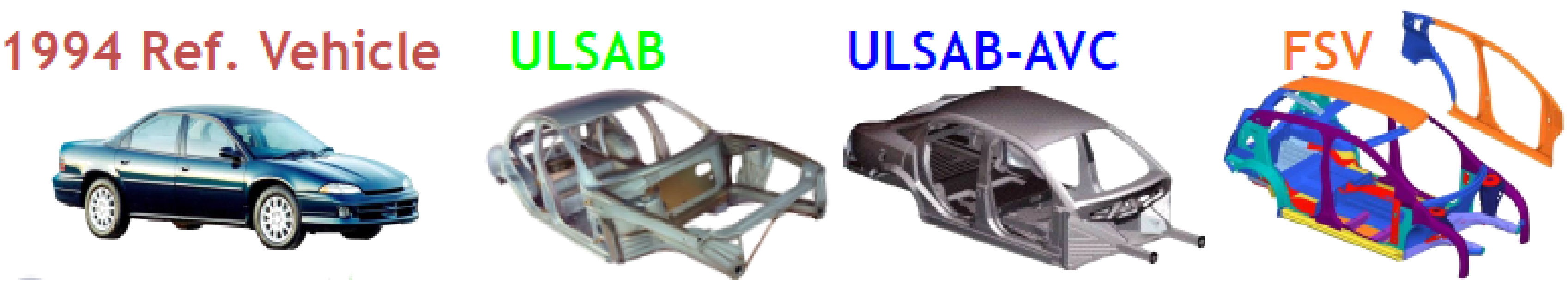
Weight distribution

Aluminium	96 kg	(53%)
Steel	66 kg	(36%)
Magnesium	11 kg	(7%)
Plastic	7 kg	(4%)

www.superlightcar.com (2009)

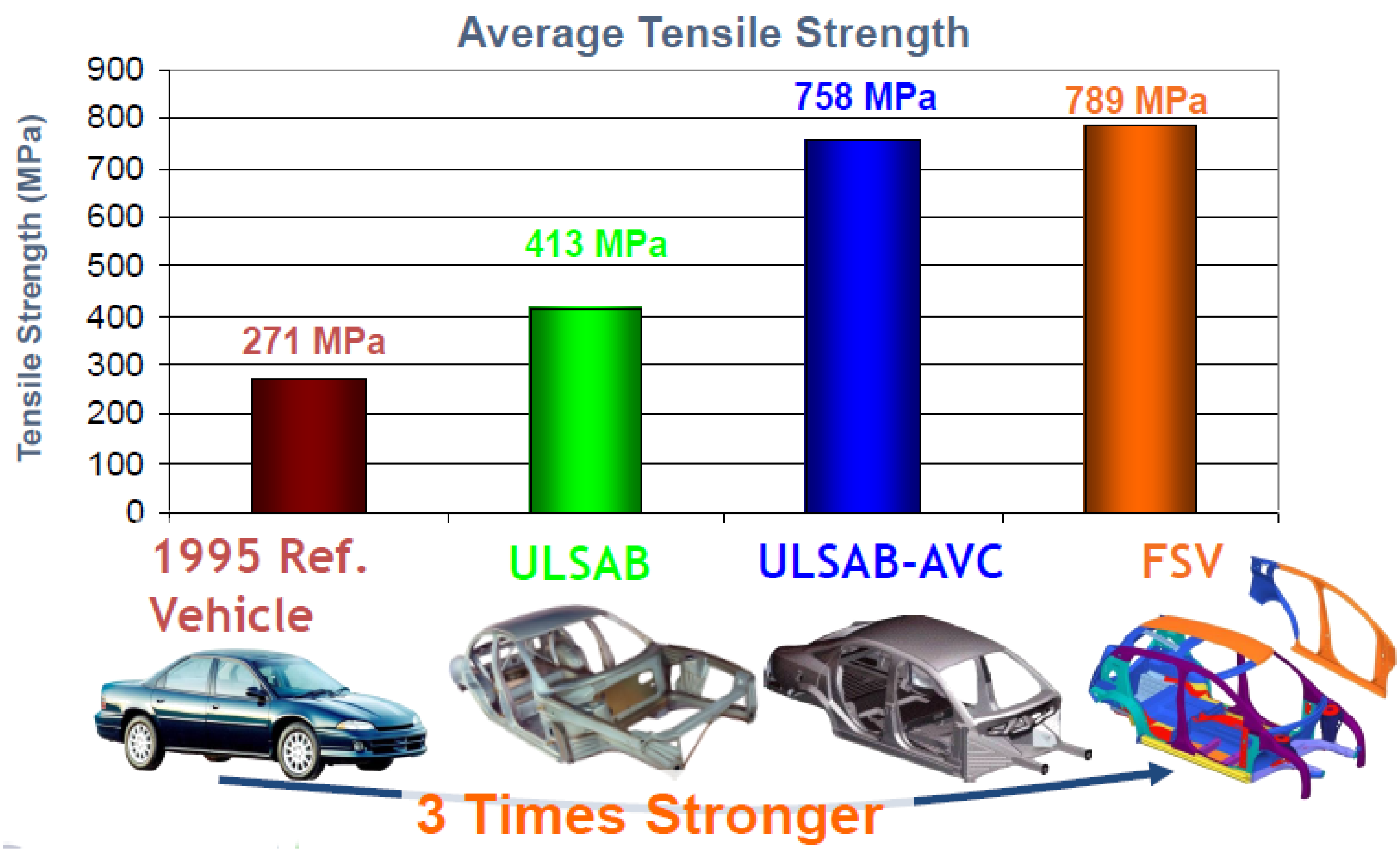
FSV vs. UltraLight: Tensile Strength (1)





www.worldautosteel.org (2011)

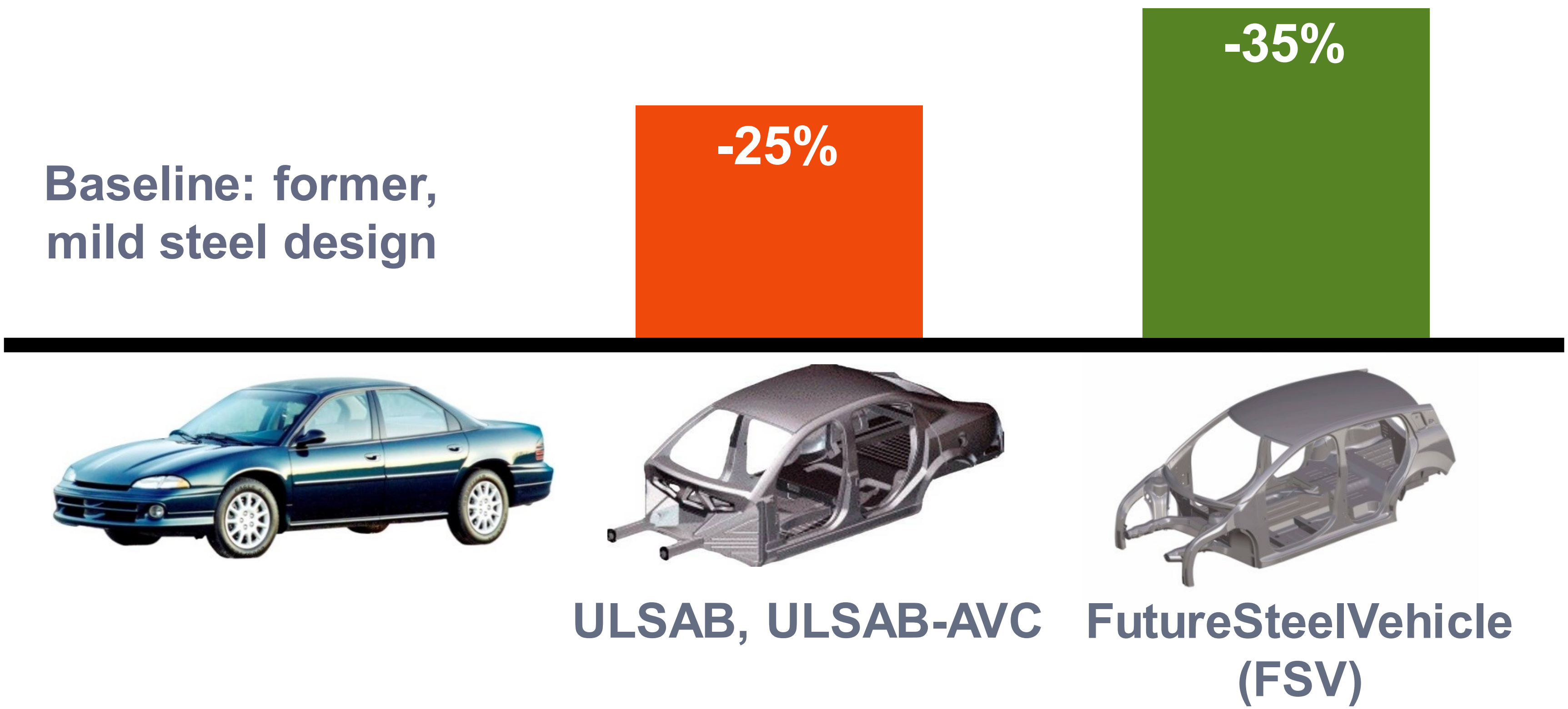
FSV vs. UltraLight: Tensile Strength (2)



www.worldautosteel.org (2011)

Mass Targets

Raising the Bar in Vehicle Mass Reduction



	WorldAutoSteel		FSV-1
	ULSAB	ULSAB AVC C Class	BEV
	1997	2004	2015-2020
Vehicle Mass kg	1350	966	1232
Powertrain Mass kg		195	449
		20%	36%
References	1994 Ford Taurus (1450kg)	243	268
Reference/Benchmark BIW Mass	271	268	290
ULSAB - Achieved BIW Mass	203		
	25%		
***Mass reduction from ULSAB for C-class target		20	
*Additional mass - Crash requirements for 2004		25	
ULSAB AVC - Target BIW Mass		208 (=203-20***+25*)	
ULSAB AVC - Achieved BIW Mass		202	
		3%	
ULSAB AVC - Achieved BIW Mass relative to Reference Benchmark		25%	
Updates to ULSAB-AVC			
Additional mass - Crash requirements 2020			5
Additional mass for: Higher Mass Powertrain (mass compounding)			38
Mass reduction for 2020 Technology Implementation			-10
Mass reduction Efficient Front-end Package			-11
** Total Updates to ULSAB-AVC for 2020			22
FSV-1 - Interim BIW Mass Target (Current AHSS Steel Solution)			224 (=202+22**)
			-23%
Additional Mass Reduction Advanced Steel Technology	-15%		-33.6
FSV-1 - Final BIW Mass Target (Advanced Steel Solution)			190
			-34%

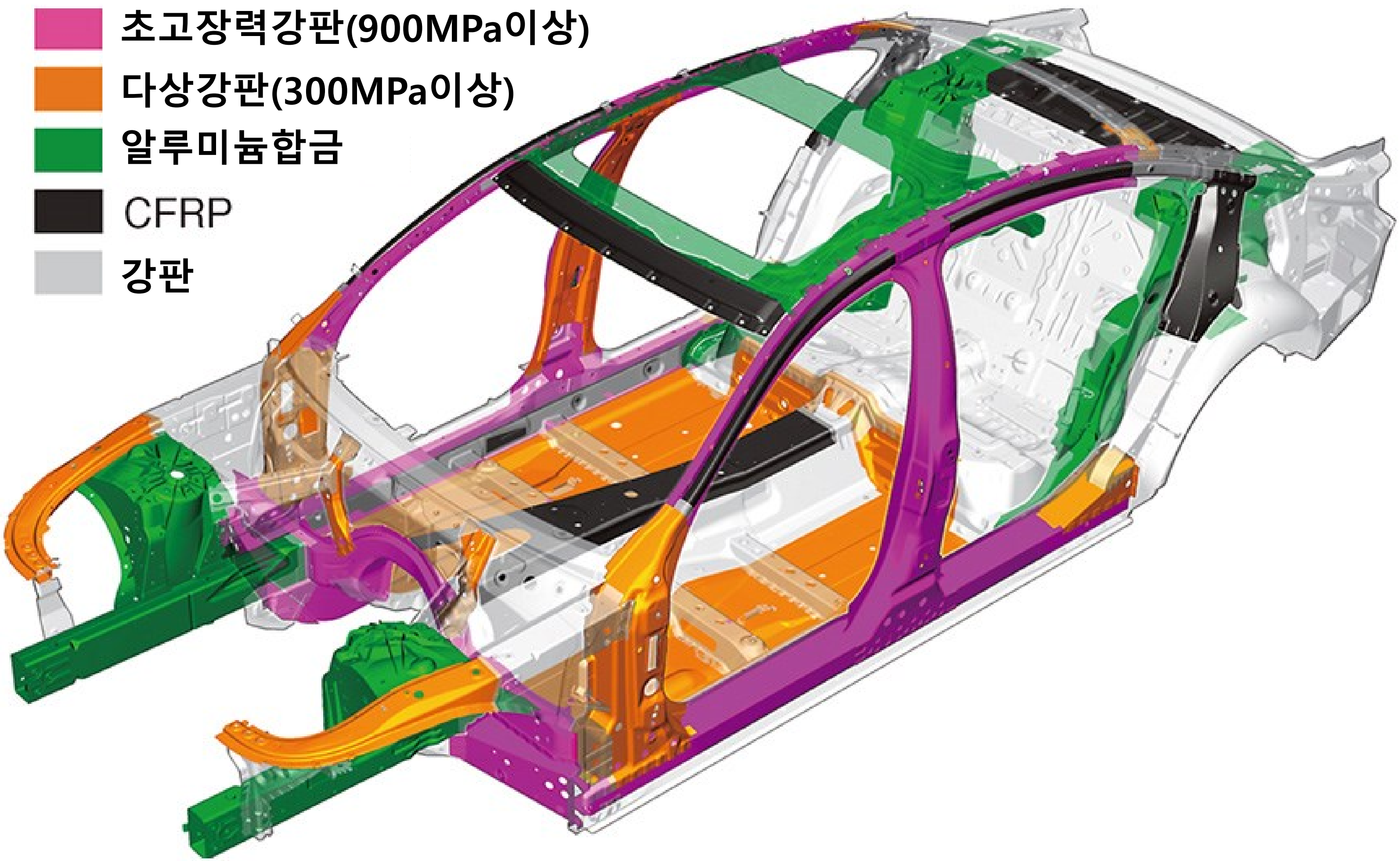
Nikkei Monozukuri 2016년 9월호

- 이종 복수재료를 복합적으로 조합해 바디를 제조하는 멀티머터리얼 설계를 실용화
  - BMW 7 시리즈: 차량중량 130kg 경감
  - Audi Q7: 차량중량 300kg 경감
- 자동차 및 자동차부품업계가 경량화기술을 찾는 이유
  - 연비경쟁이 매출과 직결
  - 연비규제(CO_2배출량규제) 시간한계 (2020년 문제) 근접
    - 105g/km(2020, 일본), 95g/km(2021, 유럽)
    - 고효율 엔진개발, 파워트레인 전동화만으로는 불가능
- 경량화기술의 2가지 방향
  - 구조 변경: 멀티머터리얼화, 이종재료 접합·접착
    - 경량재료를 적재적소에 배치
    - 강판 두께 감소, 보강재 사용 (총중량 감소하면서 필요 강도 확보)
    - 체결부품(볼트/너트), 주변부품(플랜지) 없는 간소한 구조
  - 재료 교체: CFRP, 고내열성 수지(PES), Polymer Alloy(PP+PA)

BMW 7 Series
고장력강판을 CFRP골격으로 보강

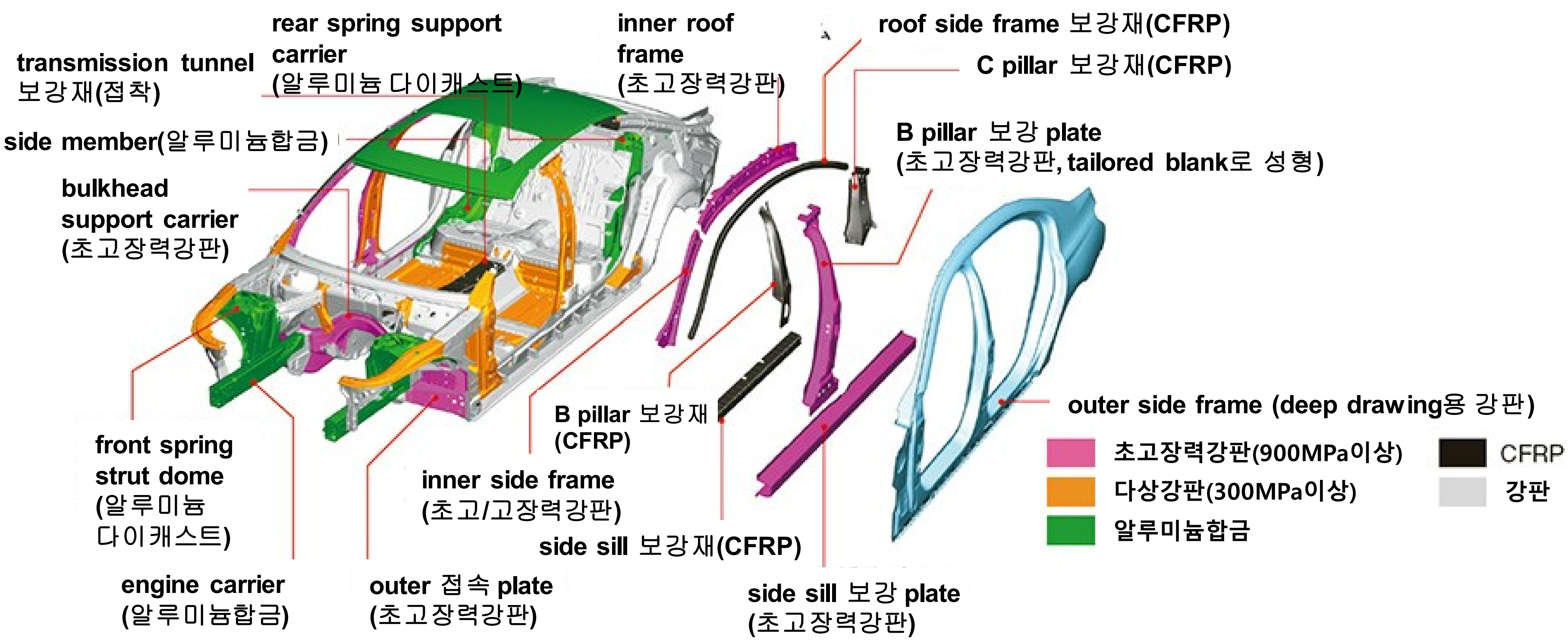
- 차량질량을 130kg 경감
- Carbon Core 바디 구조: 40kg 경감
- CFRP: 강(철)대비 강도 10배, 질량 1/4
- 저중심→주행성능 향상

멀티머터리얼 바디의 구조



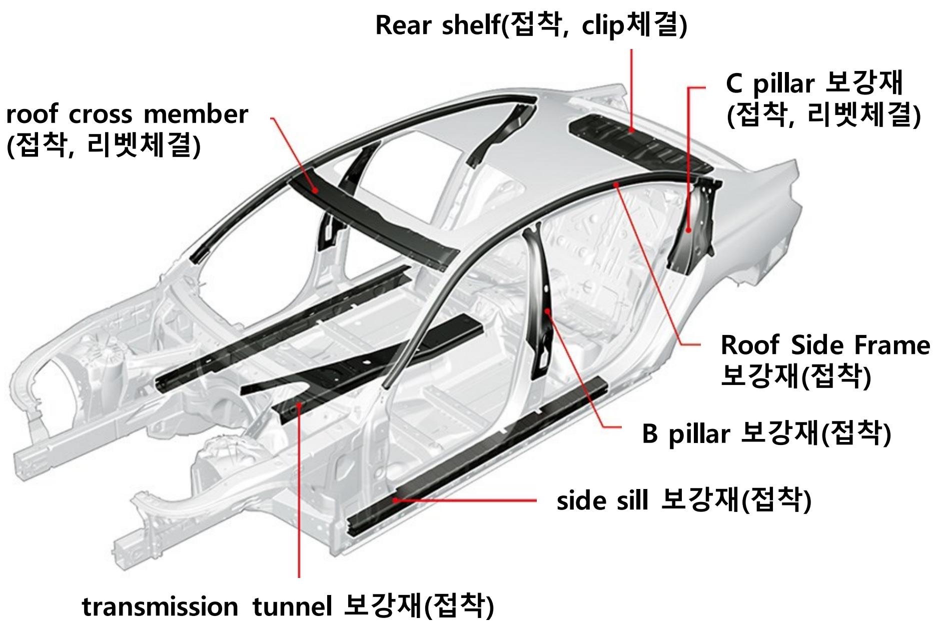
새로운 바디 구조

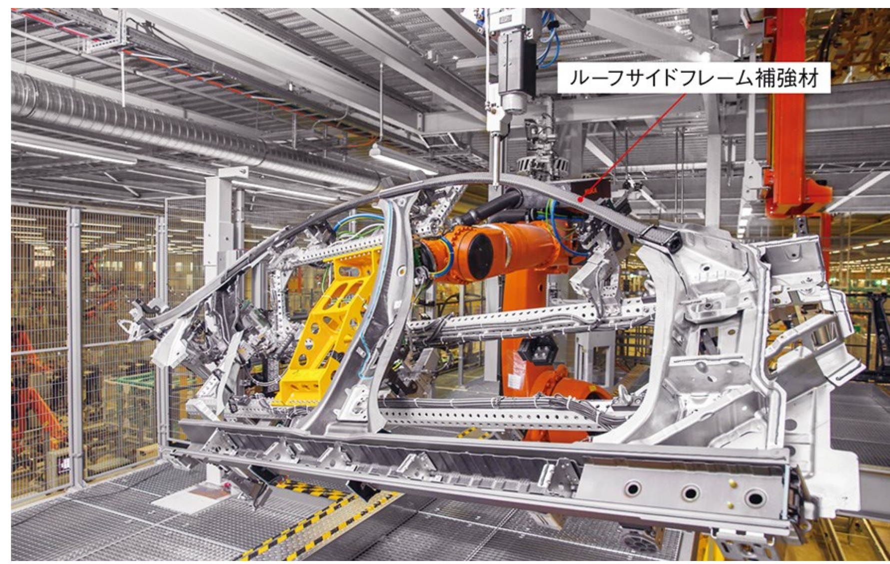
- 2장 강판으로 형성되는 중공부에 CFRP로 성형한 부품을 골격재로 통합
  - 초고장력강판이나 다상강판 사용 비중을 높여 판두께 줄여 중량 절감은 일반적
  - 판두께를 얇게 해서 강도/강성이 낮아진 곳에 CFRP로 성형한 부품을 통합
  - 접합문제? 접착제와 리벳



CFRP재 부품과 탑재위치

– 강판재 인너판넬을 이어붙여 인너바디 제작
– 인너바디의 필요한 부분에 접착제 도포, CFRP제 보강재 접착 (강한 접합력이 필요한 곳은 기계적으로 체결)
– 강판제 아우터판넬을 인너바디에 용접으로 접합
  • B필러 보강플레이트, 사이드씰 보강플레이트



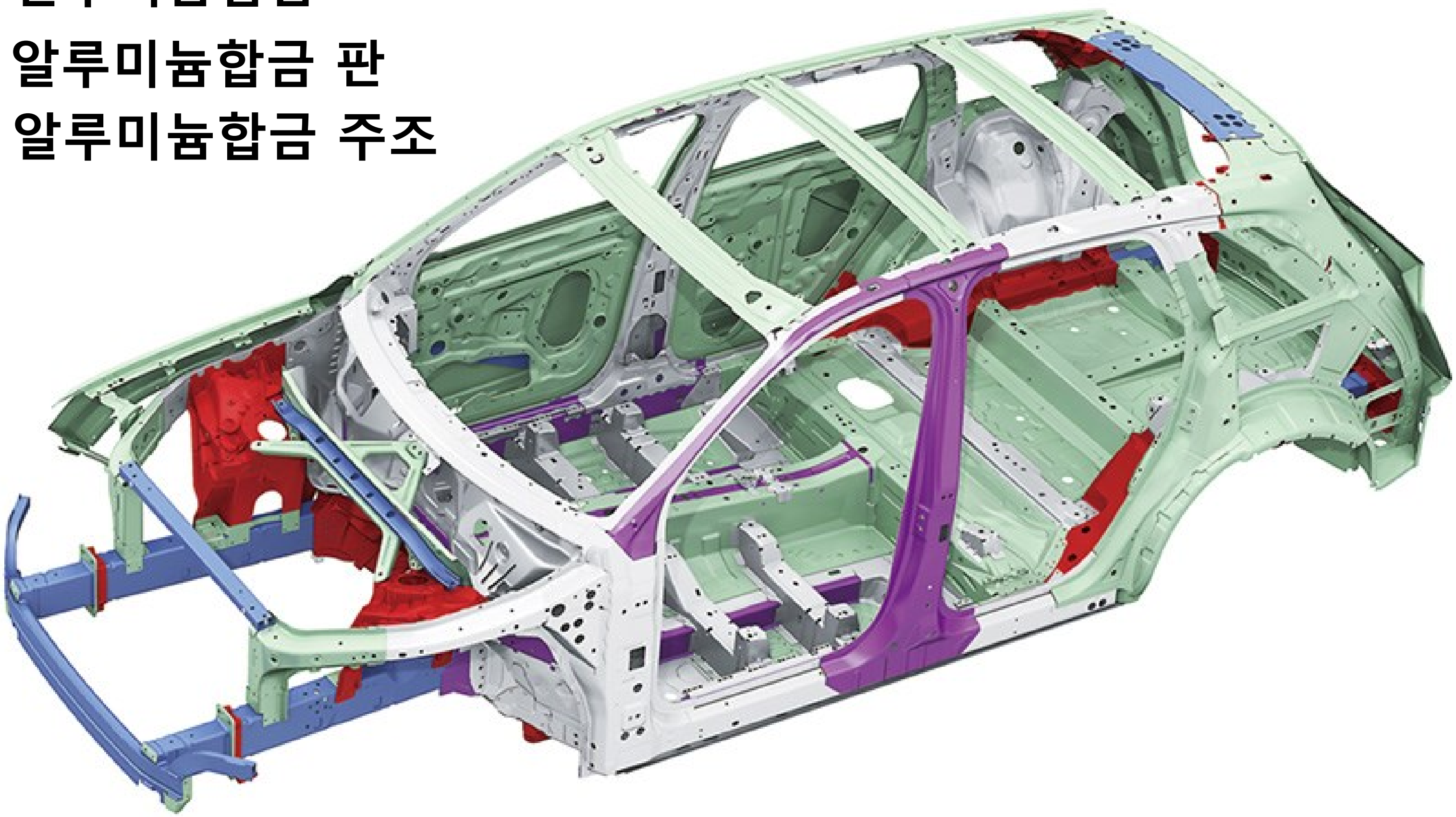


Audi Q7: 소재를 구분하여 300kg 경량화

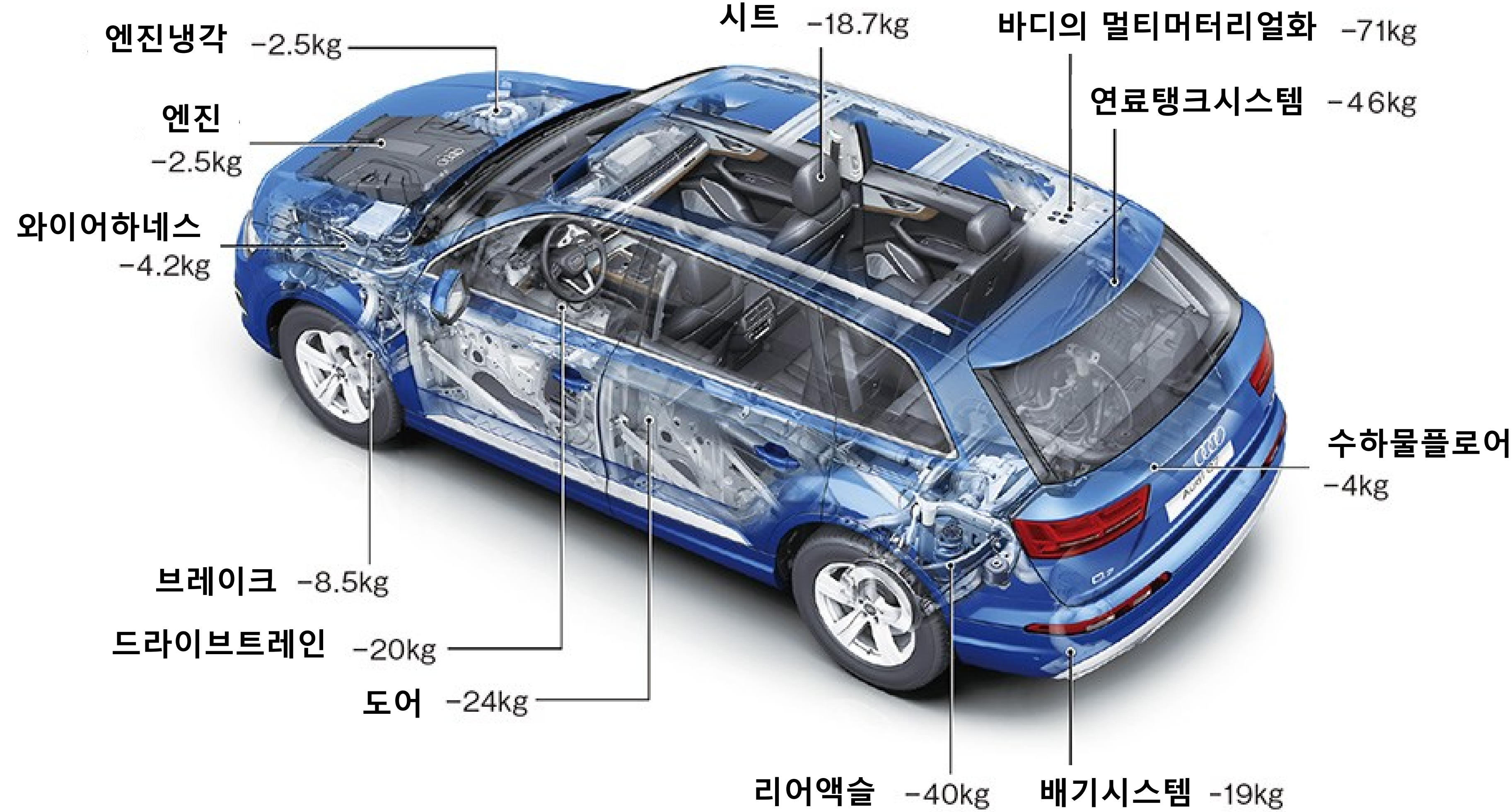
- 2016년 3월 일본에서 판매
- 적재적소적량을 인식하여 알루미늄합금이나 고장력강판 등 여러가지 소재를 구분하여 설계한 결과 대폭적인 경량화가 가능→연비효율 30%이상 개선
- 바디 전체질량의 41%에 해당하는 부분이 알루미늄합금
  - 고강도가 요구되는 부분: 프런트엔드, 리어엔드, 캐빈외피

바디를 구성하는 재료

- 초고장력강판(열간프레스강판)
- 일반 강
- 알루미늄합금
- 알루미늄합금 판
- 알루미늄합금 주조



300kg 경량화 내역



엔진냉각 -2.5kg
엔진 -2.5kg
와이어하네스 -4.2kg
브레이크 -8.5kg
드라이브트레인 -20kg
도어 -24kg
시트 -18.7kg
바디의 멀티머터리얼화 -71kg
연료탱크시스템 -46kg
수하물플로어 -4kg
리어액슬 -40kg
배기시스템 -19kg

Note

- System engineering approach to treat automobile body design
  - Breakdown of its physical parts or subsystems
  - Examining the functions the system must provide
- Design philosophy: primary design stage
  - Identify the small set of topology-defining structural requirements
  - Gain an intuitive feel for thin-walled structure behavior
  - Develop simple analytical models (first-order models) to approximate structure sizing
  - Gain an appreciation for the vehicle and manufacturing context of body design and the common trade-off issues which must be balanced