Design Advisor Workshop

Session 2
Mass Estimation Fundamentals

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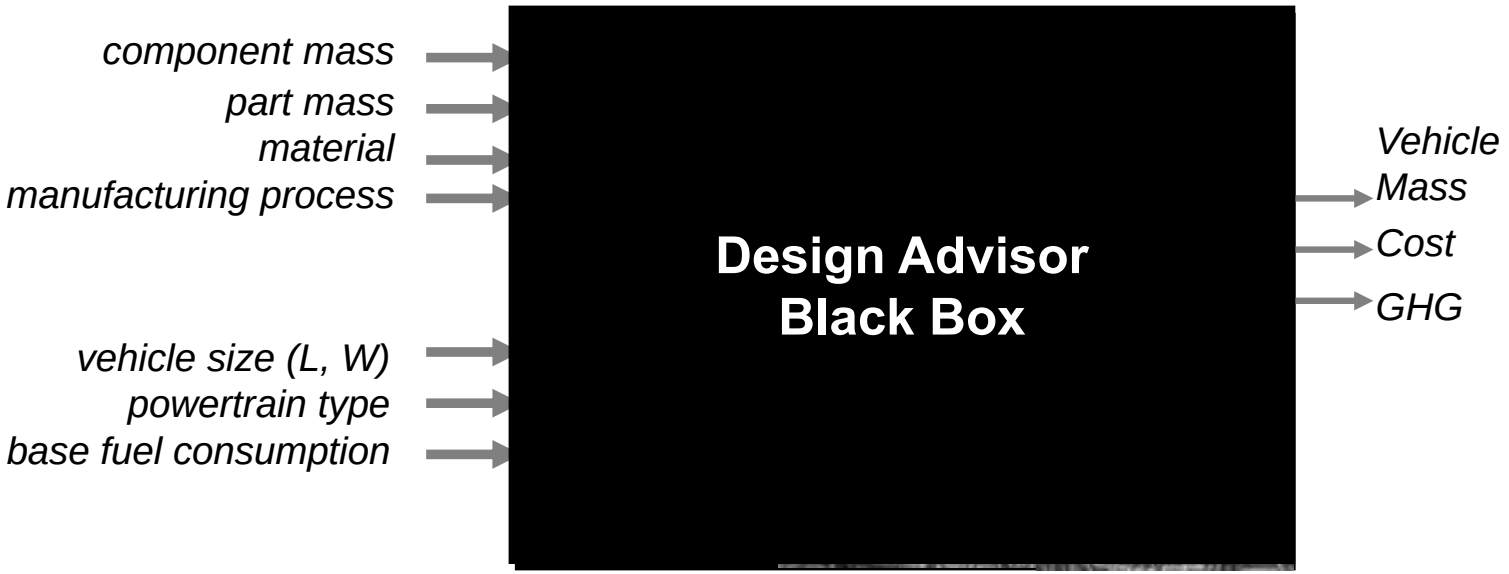
Understanding how it works



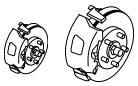
Importance of Mass

Mass is primary determinate of:

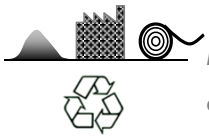
material cost

equipment and tool cost

energy consumption



resizing subsystems



material production and recycling GHG

Questions to answer:
What is mass for a typical vehicle given length and width?

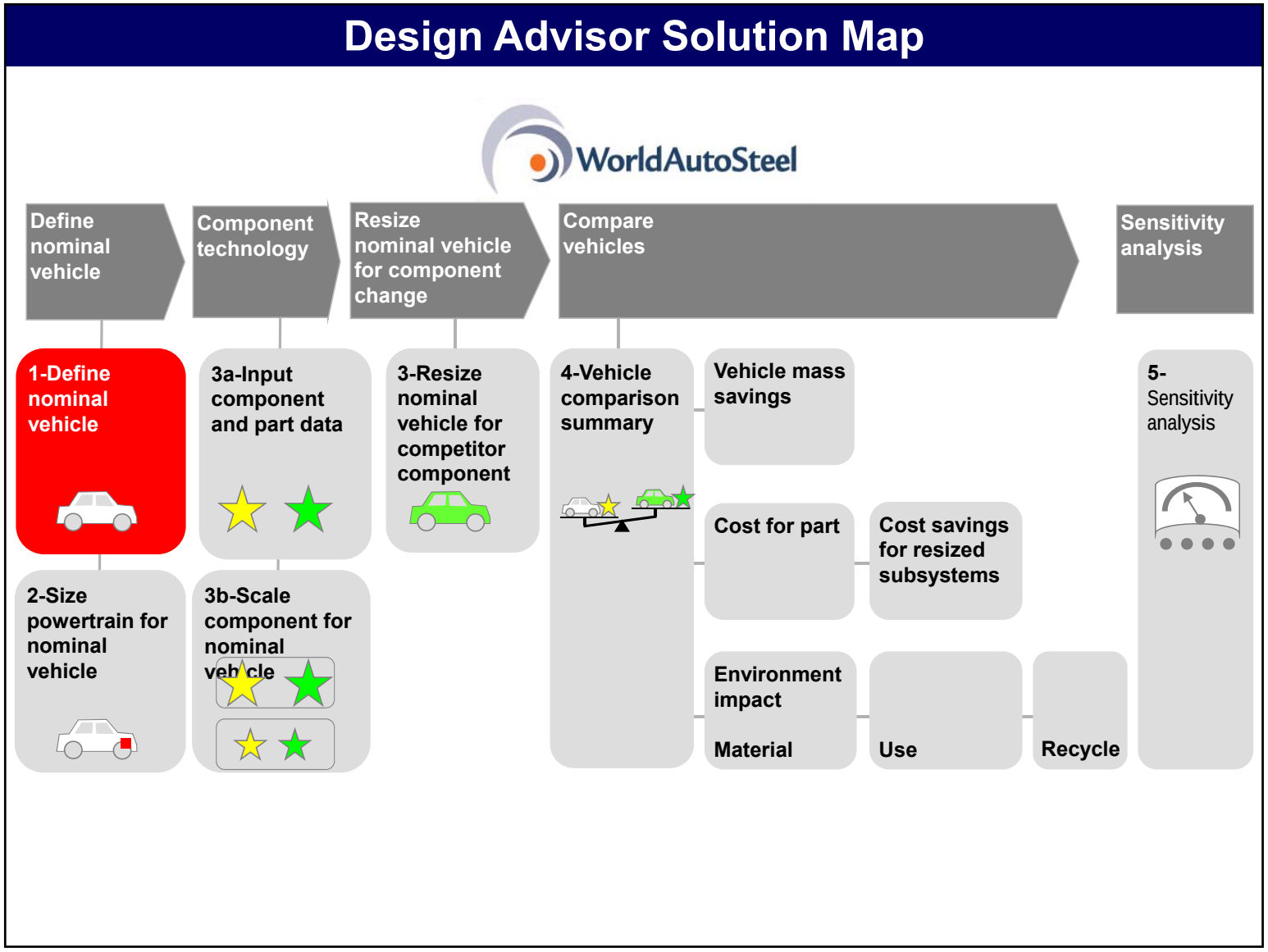
How does powertrain selection influence vehicle mass?

What is mass of materials for vehicle?

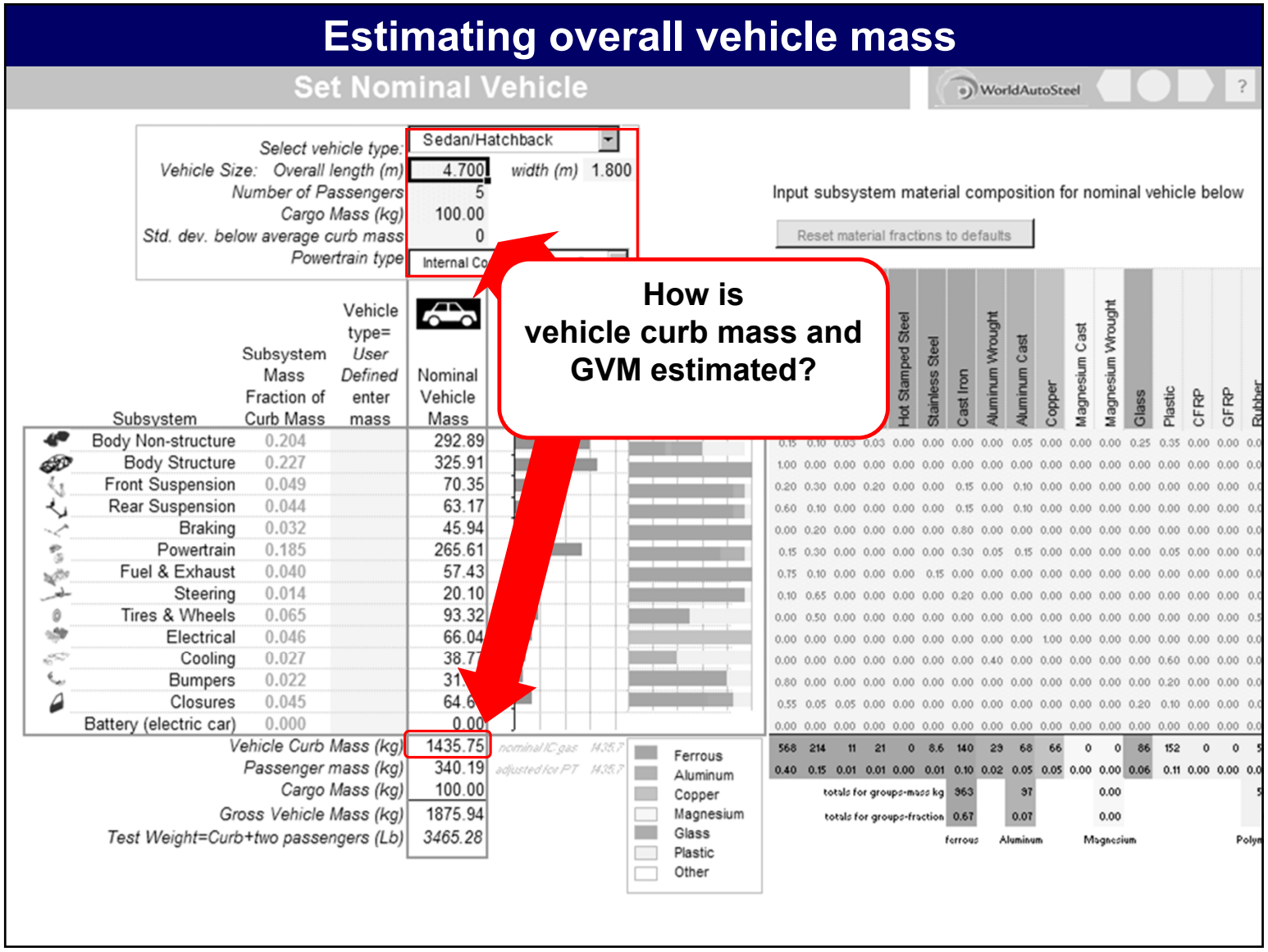
How does a change in component mass affect other subsystem's mass?

How can component mass be scaled to 'fit' a vehicle?

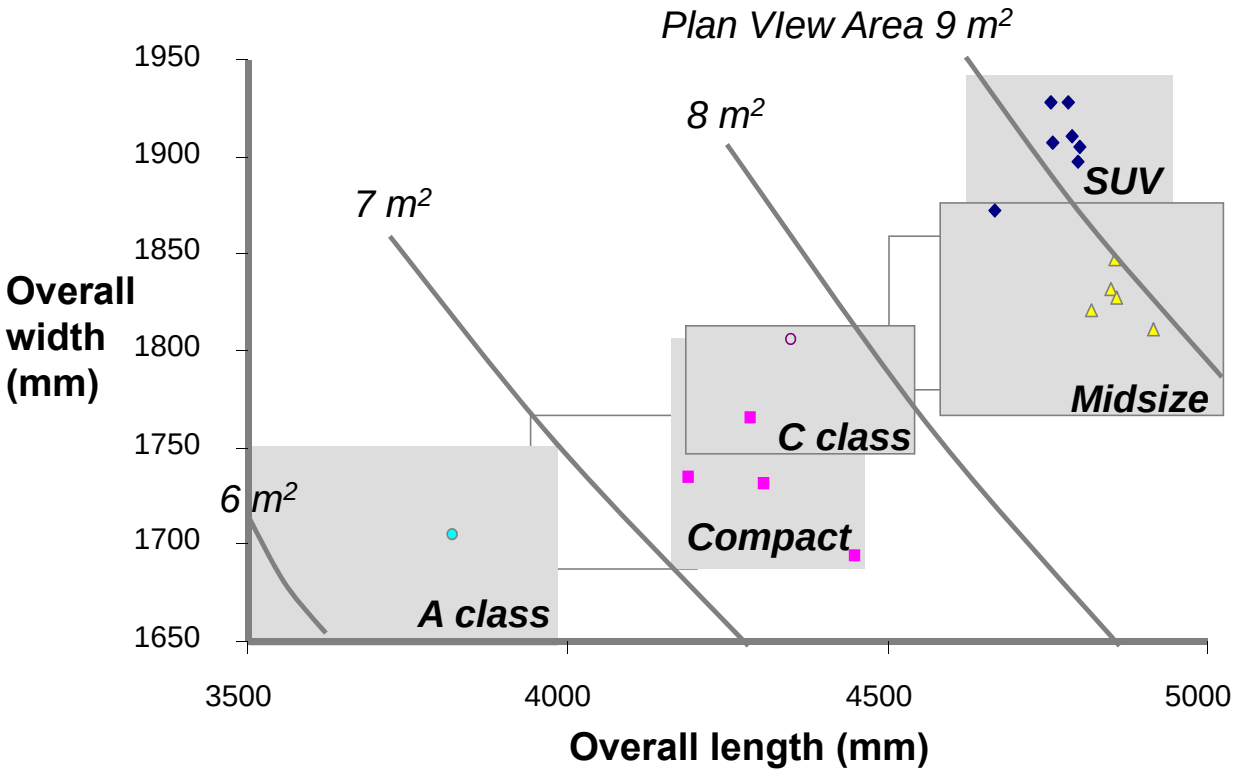
Design Advisor Solution Map



Estimating overall vehicle mass



Plan View Area Describes Vehicle Size



SUV	
Porsche	Cayenne
Volkswagen	Touareg
BMW	X5
Volvo	XC90
Mercedes	M-Class
Compact	
Volkswagen	Golf V
Opel	Astra
Audi	A3
BMW	1-Series
Ford	Focus
Mid Size	
Audi	A6
Mercedes	E-Class
BMW	5-Series
Volvo	S80
Peugeot	607

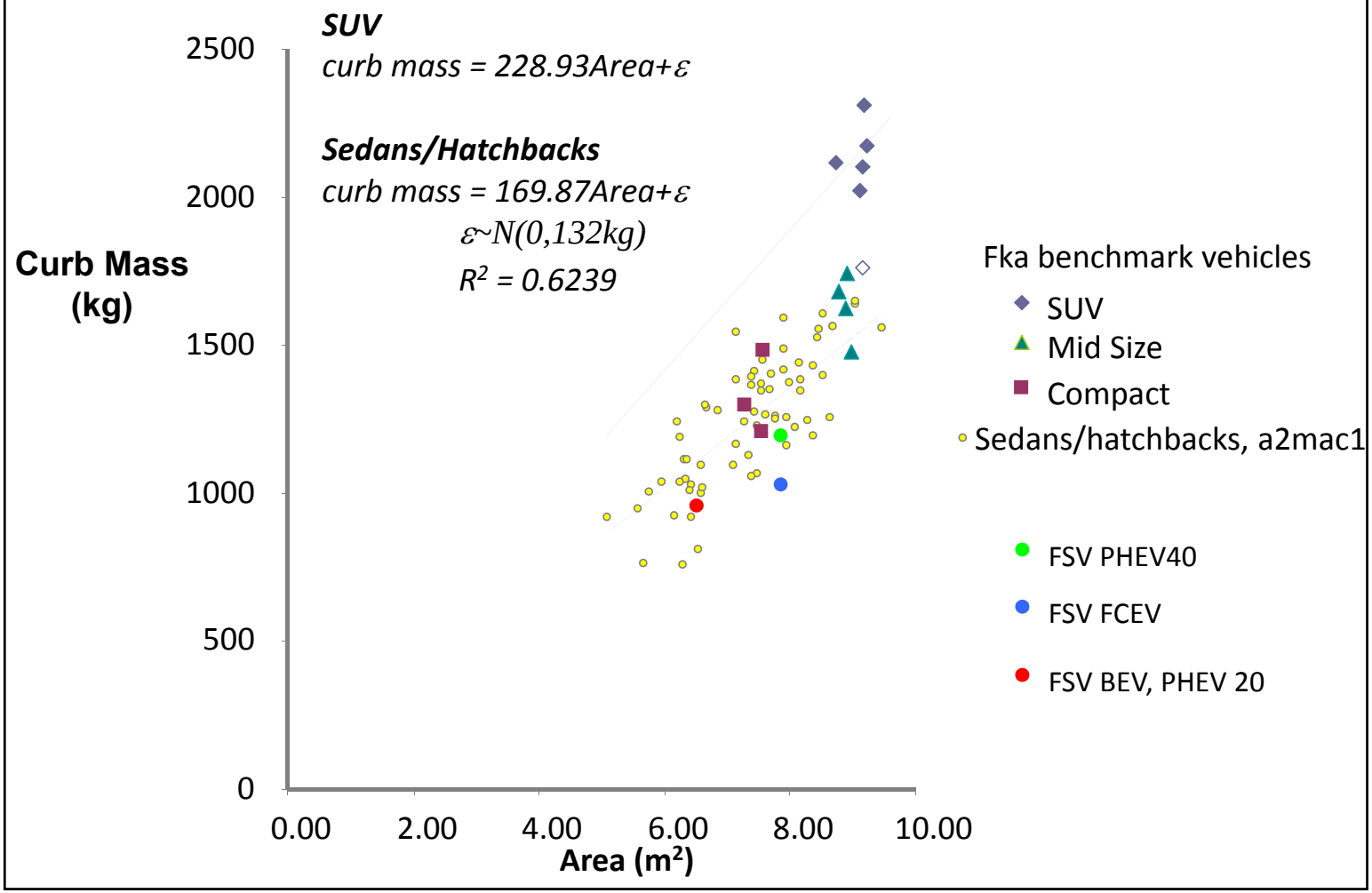
A-Mini/micro
2-4 passengers

B-Subcompact
4 passengers

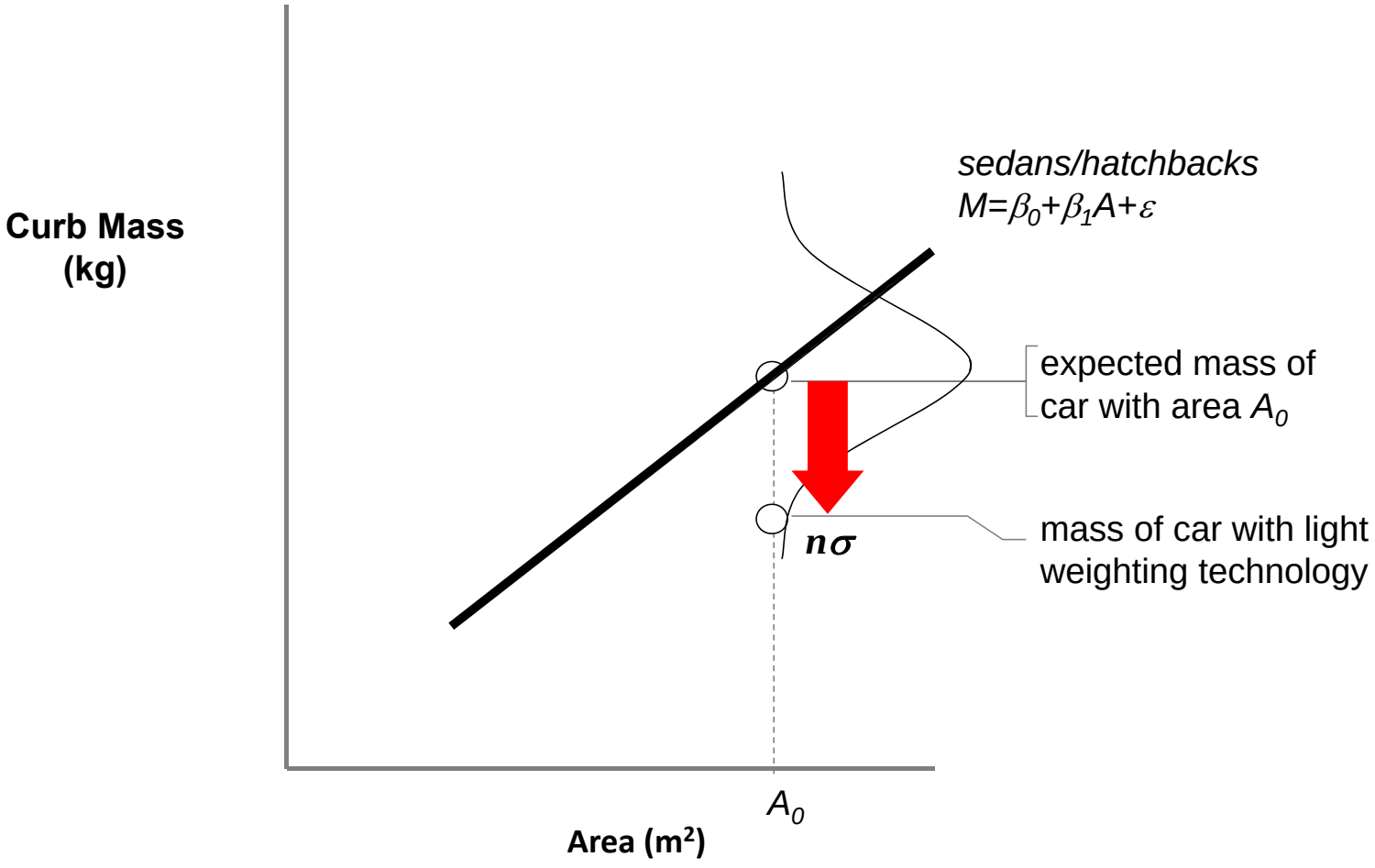
C-Compact
5- passengers

D-Midsize
5 passengers

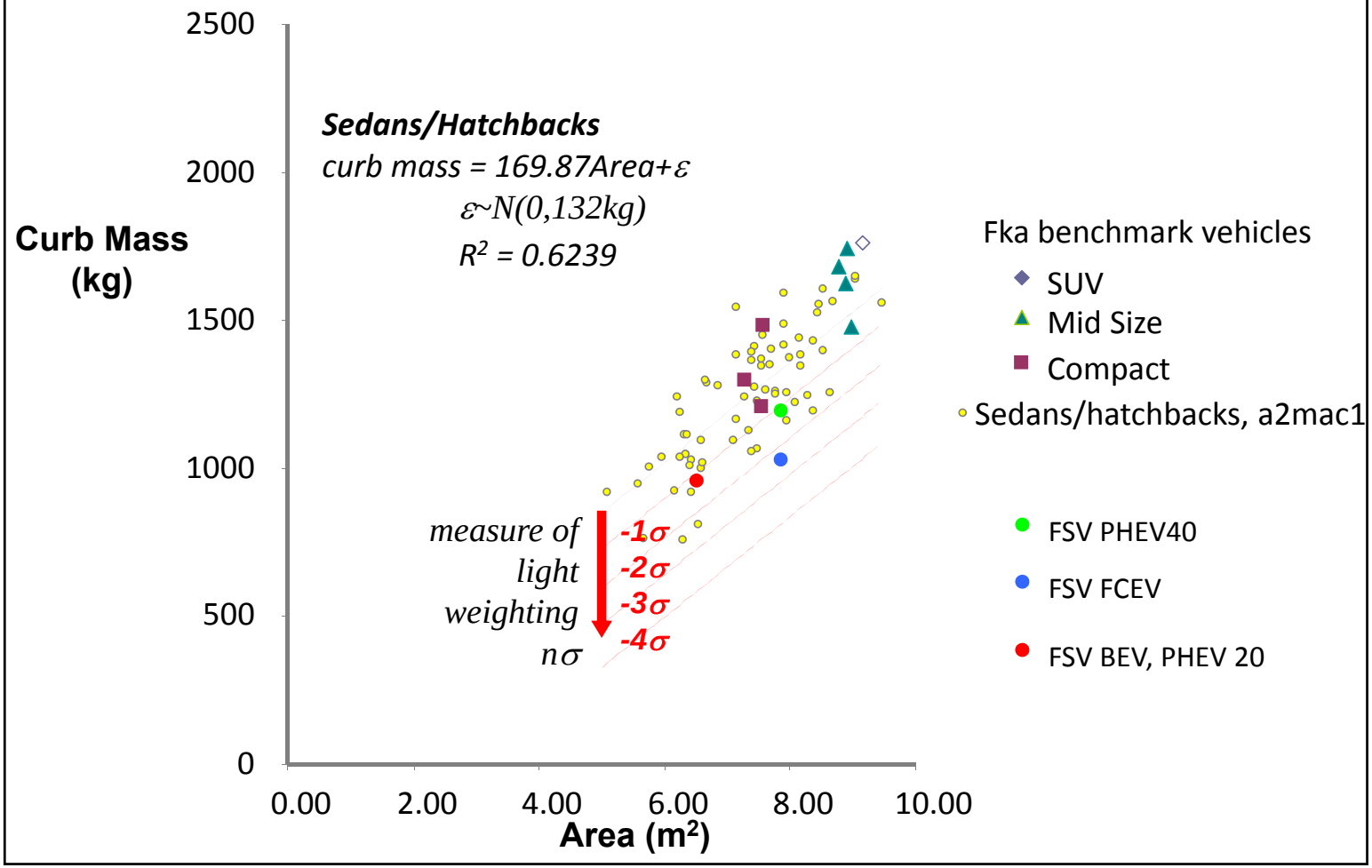
Benchmark Curb Mass Data



Adjusting nominal vehicle mass for technology/timeframe



Curb Mass to plan view area relationship



The math

Curb mass

$$m_{CURB} = \beta_0 + \beta_1 A_{PLAN} + \varepsilon$$

where

m_{CURB}	=*estimated curb mass (kg) **
A_{PLAN}	=*Plan view area of vehicle (length x width) (m^2)*
β_0, β_1	=*coefficients estimated by regression*
ε	=*residual error N(0,σ)*

****base gasoline IC, Sedan/hatchbacks, FWD, BFI***

Mass Estimation: Size and mass comparison

	unit	Toyota IQ
length	mm	2985
width	mm	1552
height	mm	1480
manufacturers mass	kg	885

estimate: 786

	unit	Toyota Yaris
length	mm	3810
width	mm	1694
height	mm	1524
manufacturers mass	kg	1061

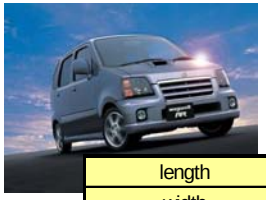
1095

	unit	Daimler Smart Fortwo
length	mm	2695
width	mm	1559
height	mm	1542
manufacturer's mass	kg	820

713

	unit	Honda Fit
length	mm	4105
width	mm	1694
height	mm	1524
manufacturers mass	kg	1129

1180



	unit	Suzuki Wagon R
length	mm	3295
width	mm	1395
height	mm	1640
manufacturers mass	kg	855

780

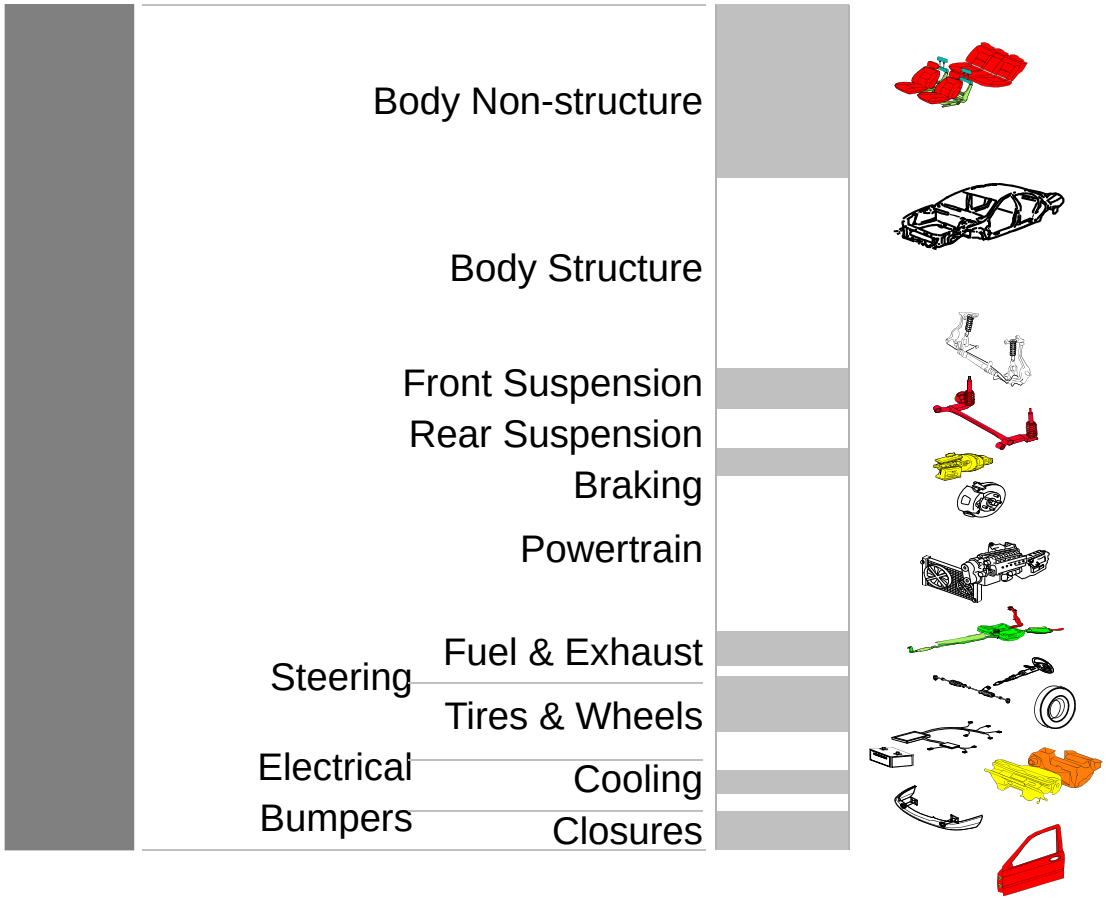
	unit	Suzuki 2008 SX4
length	mm	4135
width	mm	1755
height	mm	1605
manufacturers mass	kg	1271

1232

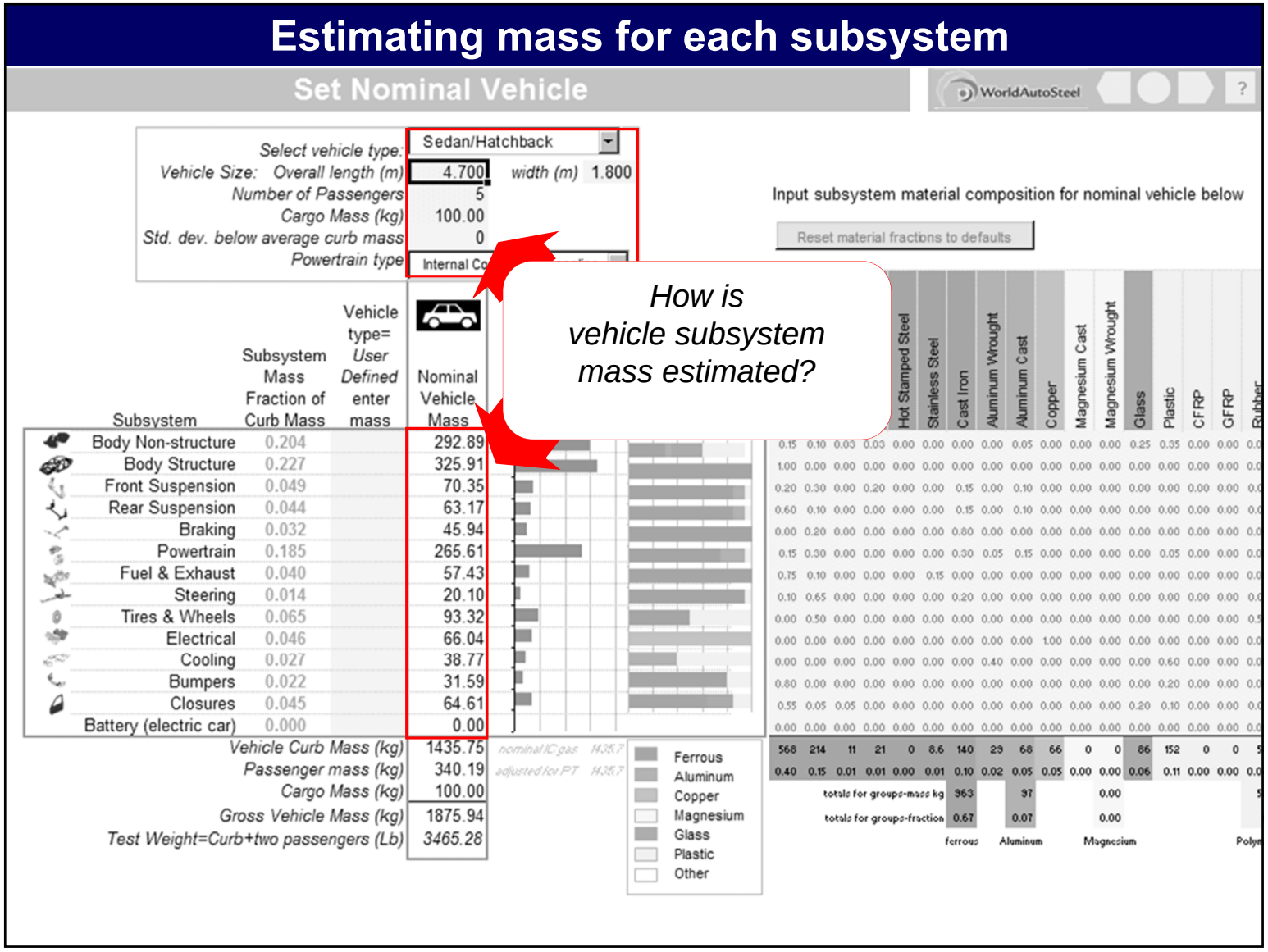
Determining mass of subsystems

Curb Mass

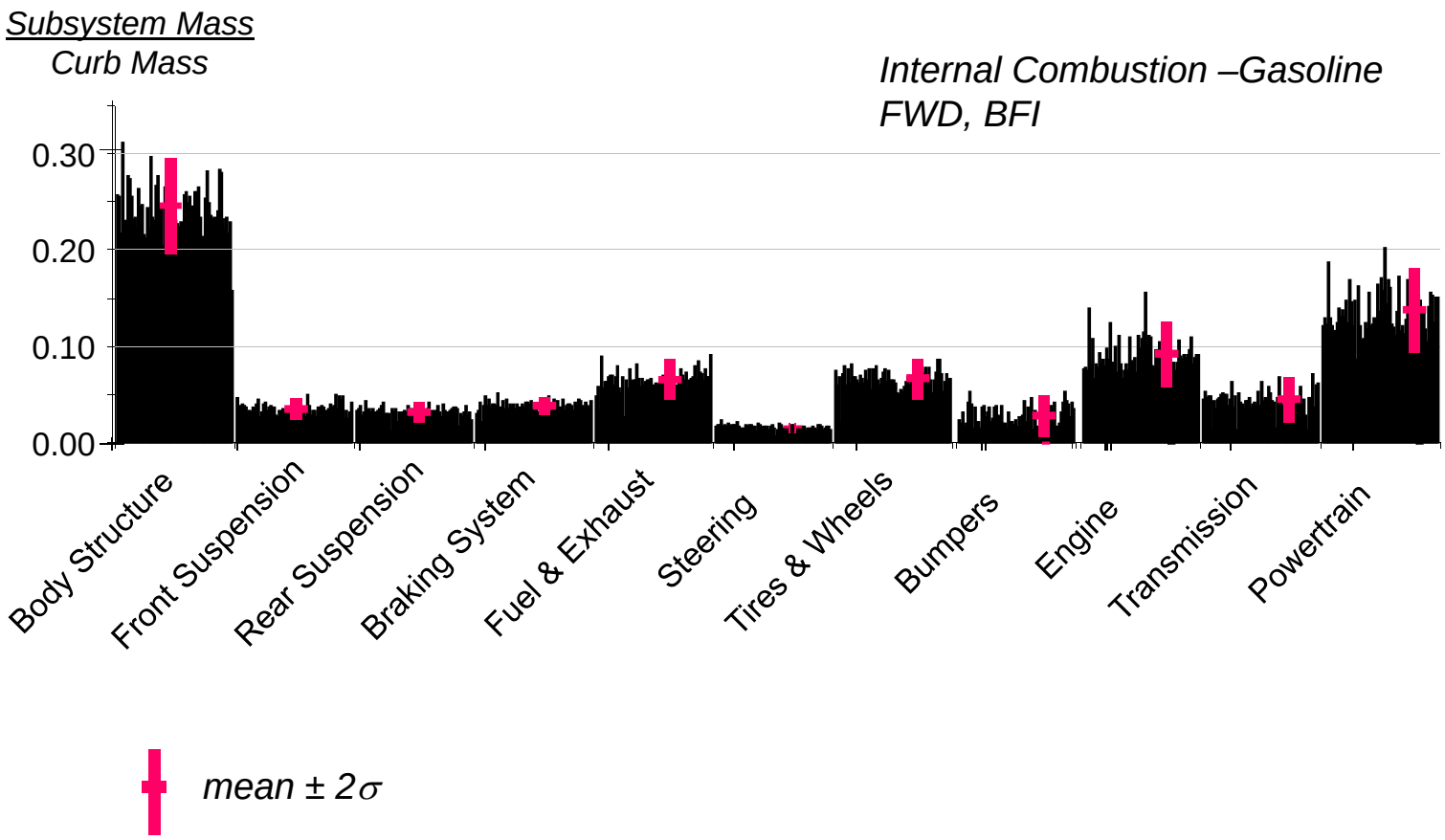
$$m_{CURB} = \beta_0 + \beta_1 A_{PLAN}$$



Estimating mass for each subsystem



Subsystem mass for 66 Sedans/Hatchbacks



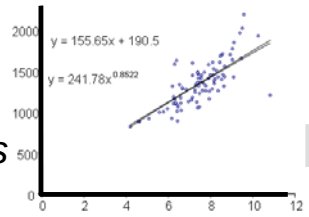
Mass Estimation Conventional TFWD, BFI, gasoline IC

$(Curb\ mass) = \beta_1\ (plan\ view\ area) + \beta_0\ )$

$(subsystem\ mass) = \phi_i\ (curb\ mass)$

Vehicle
•Length
•Width
•type

curb mass



foot print area (L x W)

curb mass

0.204	body Non-structure	
0.227	body structure	
0.049	front suspension	
0.044	rear suspension	
0.014	steering	
0.032	braking	
0.185	powertrain	
0.040	fuel/exhaust	
0.065	tires/wheels	
0.046	air conditioning	
0.027	electrical	
0.022	bumpers	
0.045	closures	

The math

Subsystem Mass

$$\bar{\phi} = \begin{bmatrix} \phi_1 \\ \phi_2 \\ . \\ \phi_n \end{bmatrix} \qquad m_{CURB}\bar{\phi} = \begin{bmatrix} m_1 \\ m_2 \\ . \\ m_n \end{bmatrix}$$

where

ϕ_i *=mass fraction relative to curb mass for subsystem i*

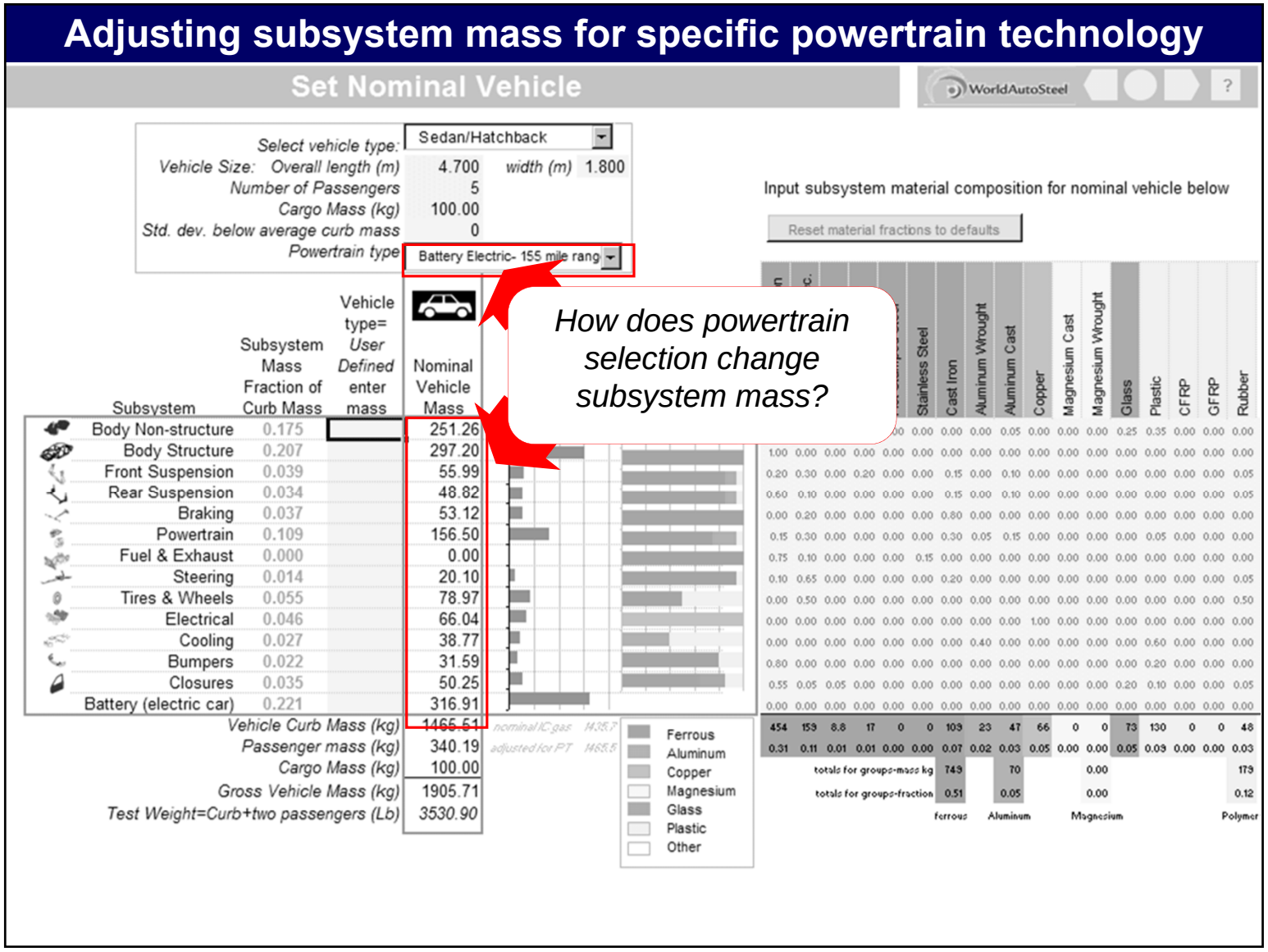
for the reference vehicle (IC gasoline), $\Sigma\phi_i=1$

for other powertrain types, $\Sigma\phi_i$ *may be smaller or larger than one*

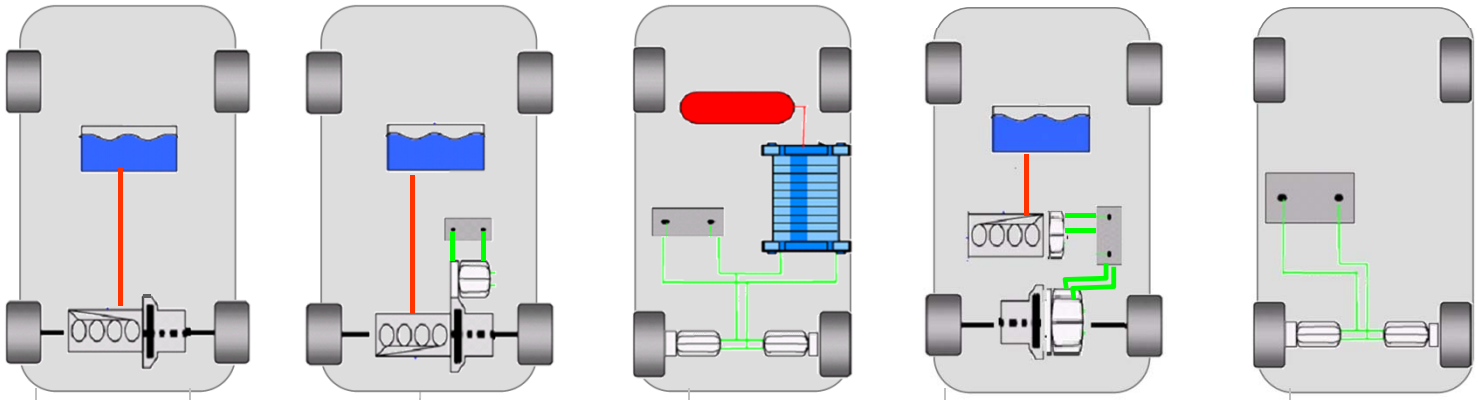
m_{CURB} *=curb mass (kg)*

m_i *=subsystem mass (kg)*

Adjusting subsystem mass for specific powertrain technology



Subsystem Changes for Powertrain Technology

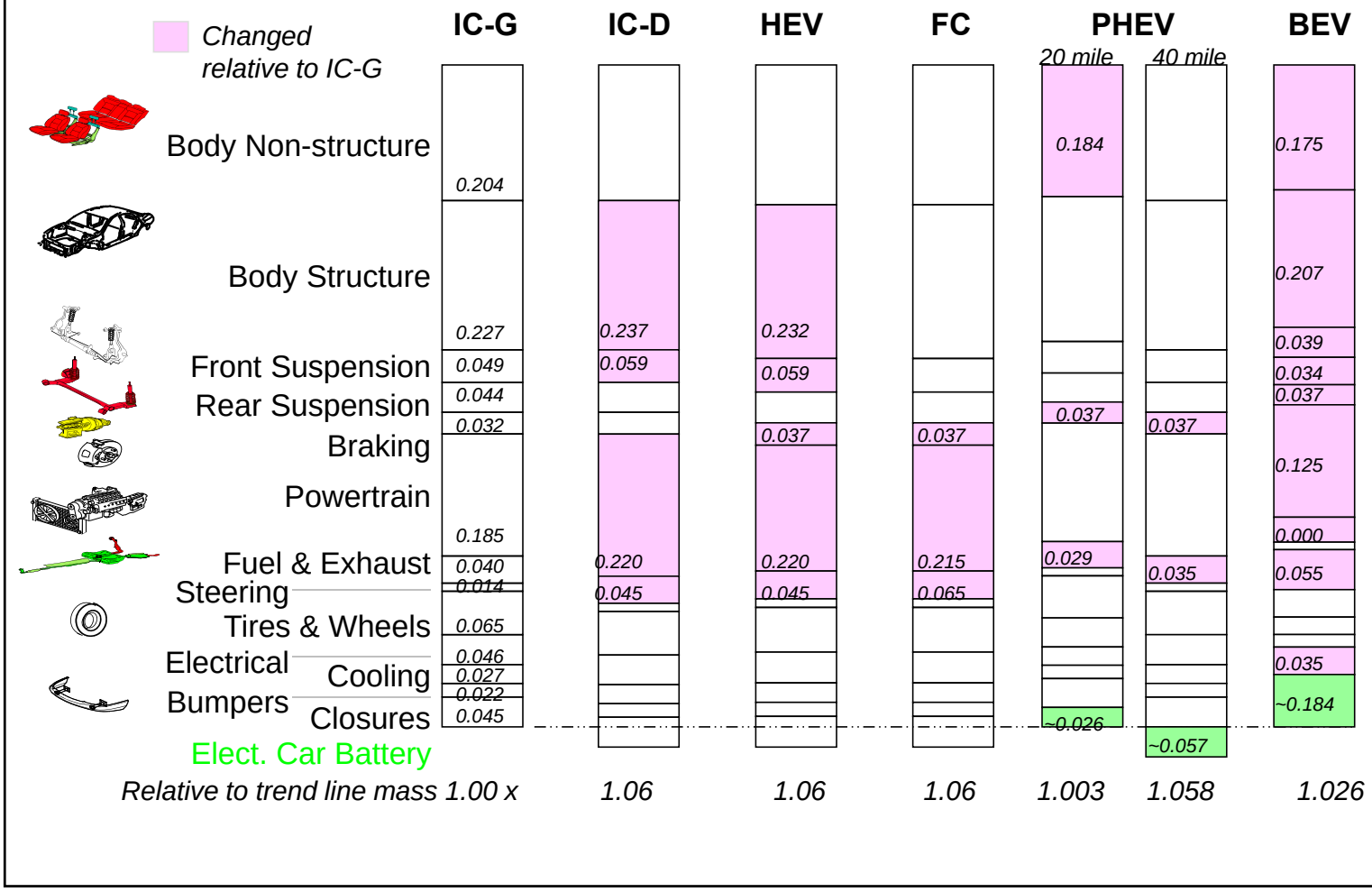


IC-G IC-D

Functional changes relative to Internal Combustion-Gasoline

IC-G	IC-D	Parallel HEV	Hydrogen Fuel Cell FC	Plug-in Hybrid Electric PHEV	Battery Electric BEV
Base subsystem masses	•combustion severity •noise isolation	•motor+IC •regenerative braking	•motor •fuel cell •regenerative braking •pressure tank	•motor+IC •regenerative braking •battery size •interior trim adjustments	•motor •regenerative braking •battery size •interior trim adjustments •improved noise source

Mass Estimation Other powertrain types



Battery Sizing

Nissan Leaf Battery Module

Power required

$$P_{BATTERY} = 0.0623 A_F \cdot R \cdot M_{CURB}$$

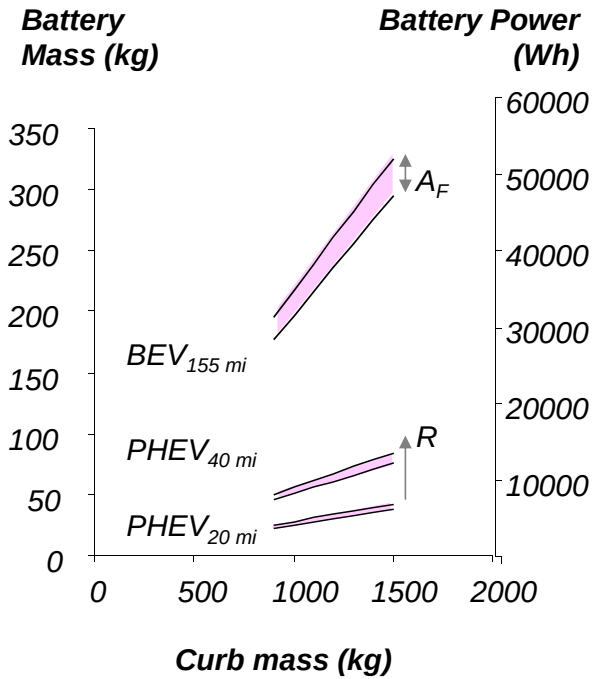
$P_{BATTERY}$ = required battery power (Wh)
A_F = vehicle frontal area (m^2)
R = range with fully charged battery (km)
M_{CURB} = vehicle curb mass (kg)

Battery Mass

$$m_{BATTERY} = \frac{P_{BATTERY}}{e_{DENSITY}}$$

$m_{BATTERY}$ = battery mass (kg)
$e_{DENSITY}$ = battery energy density (Wh/kg)
for Li-ion technology, $e_{DENSITY}$=155 Wh/kg

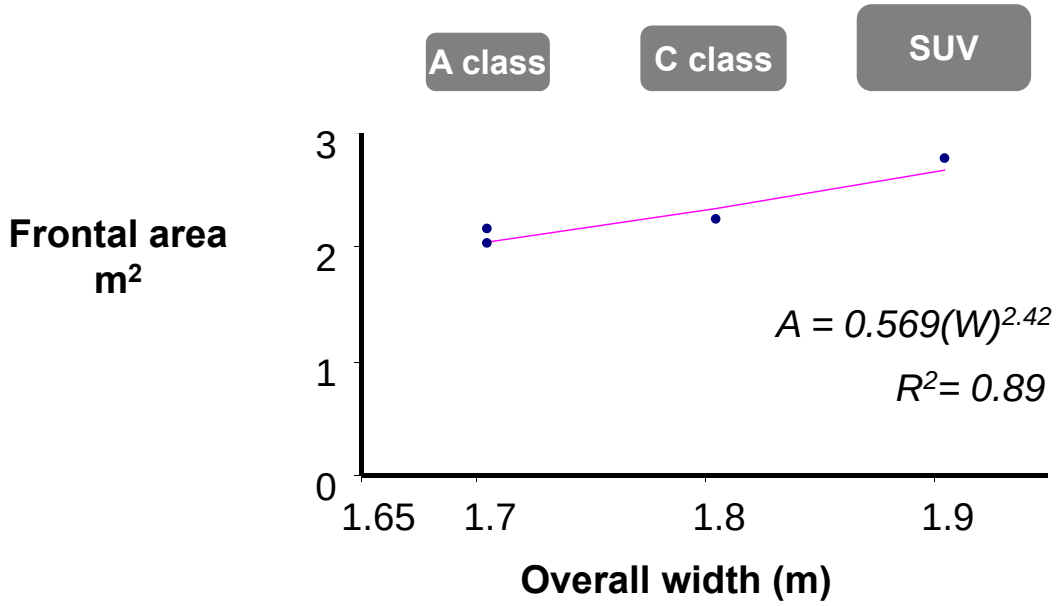
Li-ion technology



	Battery mass
BEV	20-22 % curb
$PHEV_{40}$	5.1-5.6 %
$PHEV_{20}$	2.5-2.8 %
	2.03 m^2<A_F<2.24 m^2

User Guide for Version 3 of the WorldAutoSteel Energy and GHG Model, Roland Geyer, WorldAutoSteel, 1/6/2011, page 24.

Frontal Area (battery sizing)



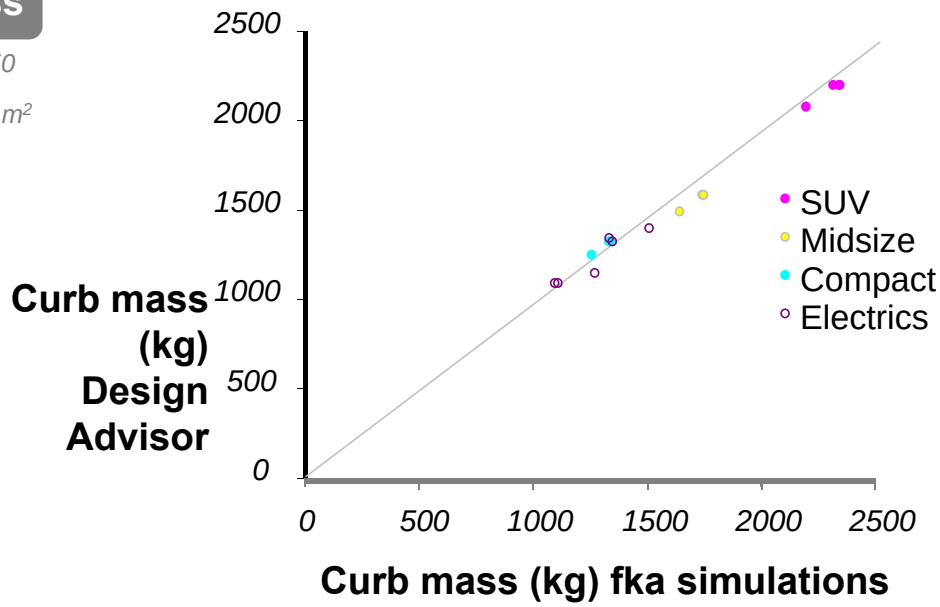
	OAW m	Area m²
BEV	1.705	2.03
A class	1.705	2.16
C class	1.805	2.24
SUV	1.905	2.78

Mass Estimation Other powertrain types

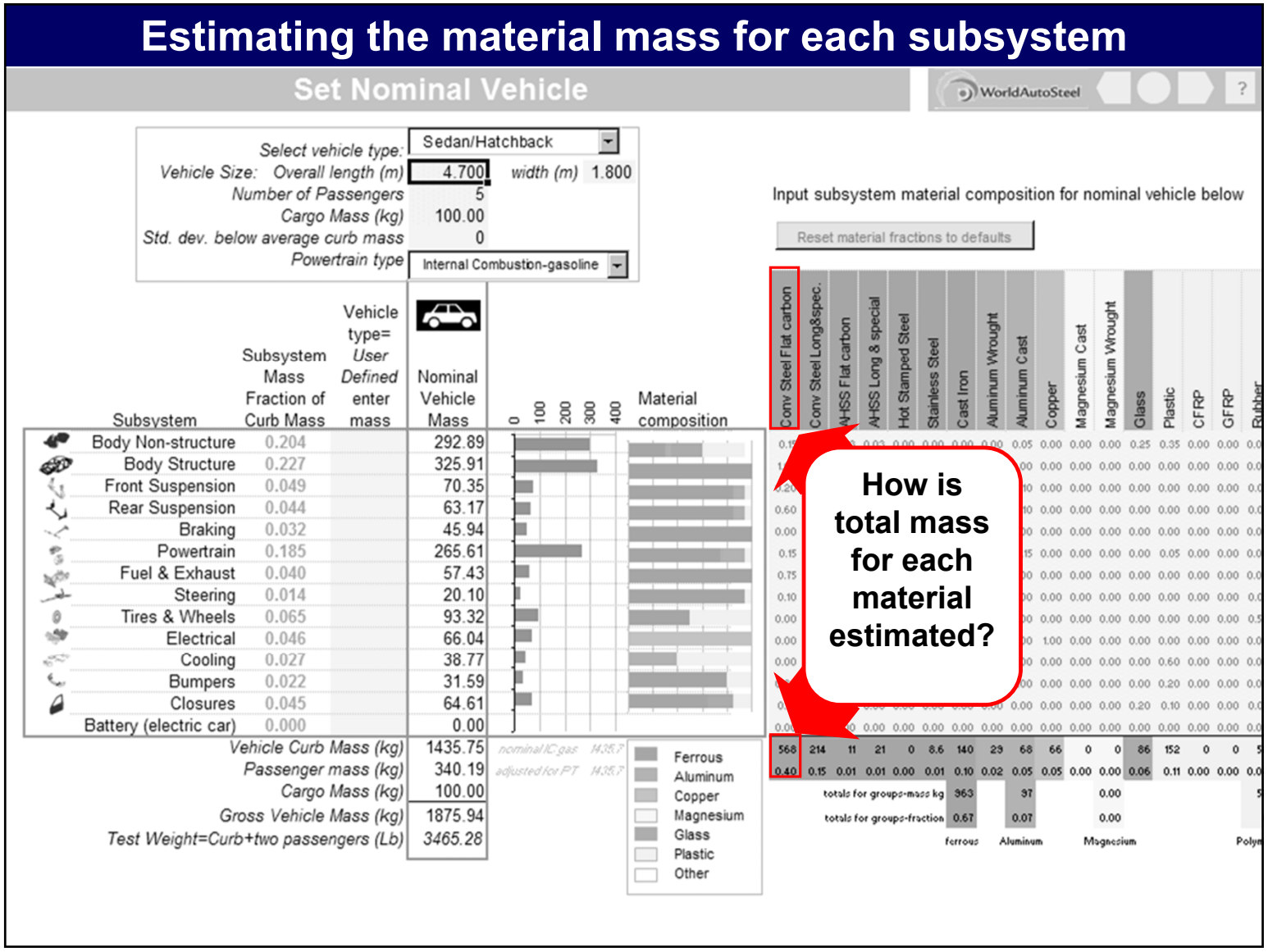
fka simulations

	Compact	Midsize	SUV
	w= 1731 mm, L=4308 mm,	*1827 x 4859*	*1907 x 4758*
	A=7.46 m²	*A=8.88 m²*	*A=9.14 m²*
IC-G	1260 kg	1640	2195
IC-D	1350	1740	2320
HEV	1335	1752	2345
FCV	1335	1752	2345

	A class	C class
	1705 x 3820	*1805 x 4350*
	A=6.51 m²	*A=7.85 m²*
$PHEV_{20}$	1107	1349
$PHEV_{40}$	1268	1512
BEV_{155}	1097	1334

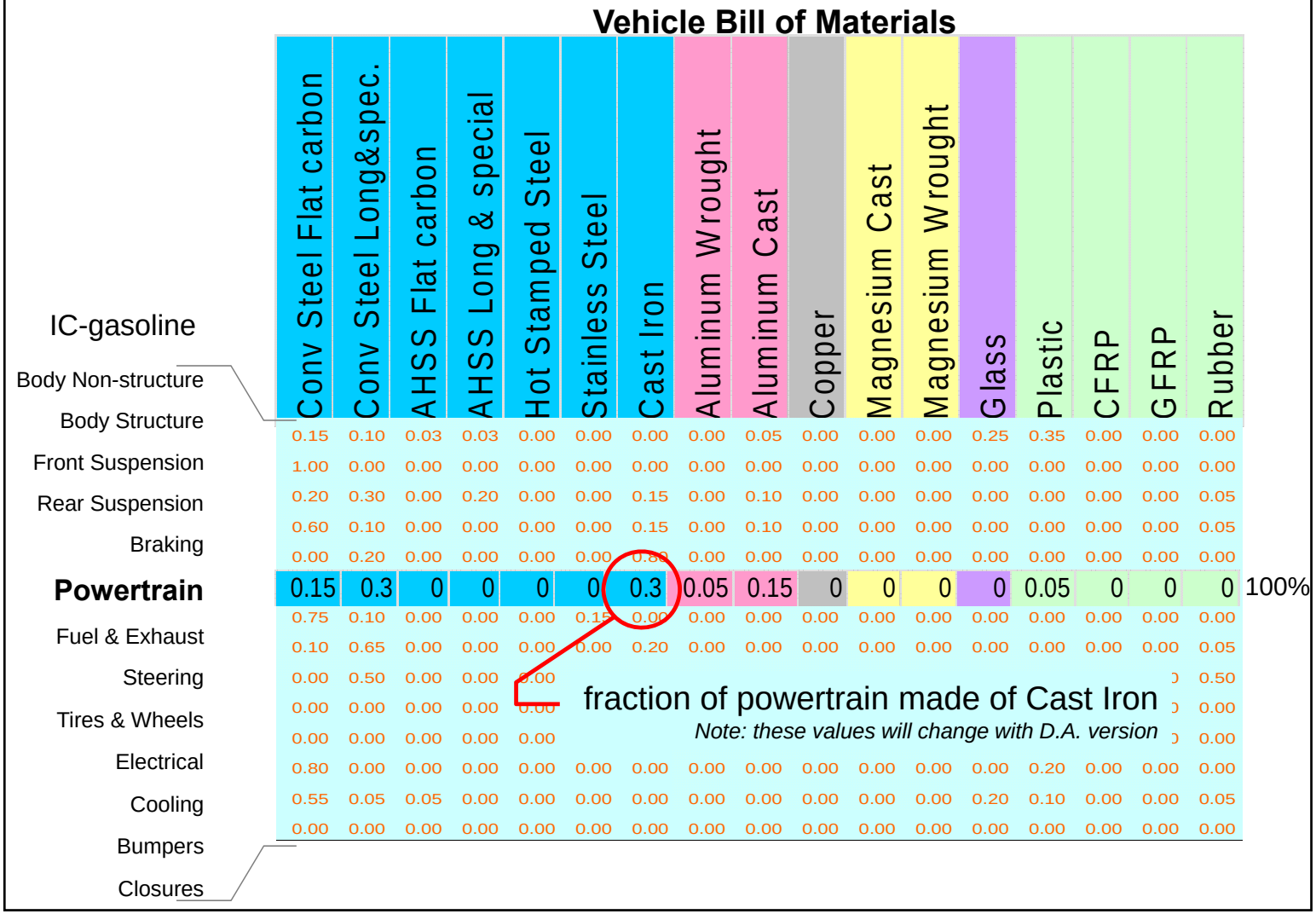


Estimating the material mass for each subsystem



Material composition of vehicle

Vehicle Bill of Materials



Material composition of vehicle

Vehicle Bill of Materials

	Conv Flat Carbon Steel	Conv Steel Long&spec.	AHSS Flat carbon	AHSS Long & special	Hot Stamped Steel	Stainless Steel	Cast Iron	Aluminum Wrought	Aluminum Cast	Copper	Magnesium Cast	Magnesium Wrought	Glass	Plastic	CFRP	GFRP	Rubber
Body Non-structure	0.15	0.10	0.03	0.03	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.25	0.35	0.00	0.00	0.00
Body Structure	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Suspension	0.20	0.30	0.00														
Rear Suspension	0.60	0.10	0.00														
Braking	0.00	0.20	0.00														
Powertrain	0.15	0.30	0.00														
Fuel & Exhaust	0.75	0.10	0.00														
Steering	0.10	0.65	0.00														
Tires & Wheels	0.00	0.50	0.00														
Electrical	0.00	0.00	0.00														
Cooling	0.00	0.00	0.00														
Bumpers	0.80	0.00	0.00														
Closures	0.55	0.05	0.05														
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	596	225	11.1	22.5	0	9.04	147	30.2	71.2	69.3	0	0	90.4	159	0	0	60.4
	0.40	0.15	0.01	0.01	0.00	0.01	0.10	0.02	0.05	0.05	0.00	0.00	0.06	0.11	0.00	0.00	0.04

Total mass of conventional flat carbon steel in vehicle=

[*0.15·(mass of Body Non-structure)+***

+1.00·(mass of Body Structure)+

+...+

+0.15·(mass of Powertrain)+

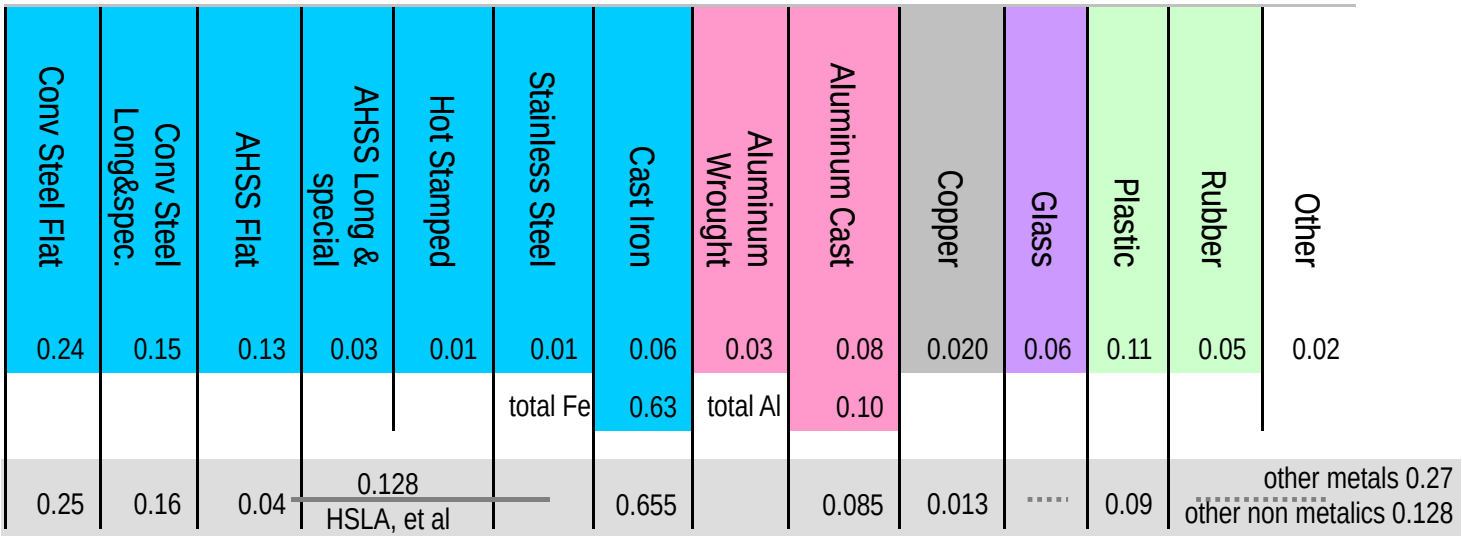
+...+

+0.55·(mass of Closures) **]**

Materials and the Environment, M. Ashby, 2009, p144

Material composition of vehicle

Design Advisor Materials Version 4.0



Aluminum in 2012 North American Light Vehicles

Executive Summary, September 7, 2011, Ducker Worldwide

The math

Vehicle Bill of Material and material mass

$$\bar{\alpha} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots \\ \alpha_{21} & \dots & \dots \\ \dots & \dots & \alpha_{ij} \end{bmatrix}$$

where

α_{ij} *=fraction of subsystem i composed of material j*

Note that rows will sum to 1

$$\bar{m} = \begin{bmatrix} m_1 \\ \dots \\ m_i \end{bmatrix}$$

where

m_i *=mass of subsystem i*

Total mass of material j in vehicle

$$\bar{\mathrm{m}} = \begin{bmatrix} \mathrm{m}_1 \\ \dots \\ \mathrm{m}_j \end{bmatrix} = \begin{bmatrix} m_1 & \dots & m_i \end{bmatrix} \begin{bmatrix} \alpha_{11} & \alpha_{12} & \dots \\ \alpha_{21} & \dots & \dots \\ \dots & \dots & \alpha_{ij} \end{bmatrix} = \left(\bar{m}\right)^T \left(\bar{\alpha}\right)$$

where

m_j *=total mass of material j in vehicle*

Case Study 1b Effect of vehicle size and powertrain selection on vehicle mass

Vehicle Parameters

2009
Toyota Venza
Cross over
5 passenger
100 kg cargo
OAL=*4.8 m*
OAW=*1.9 m*

I C-G

Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program, Lotus Engineering

2011
Honda Accord
Sedan/Hatchback
5 passenger
100 kg cargo
OAL=*4.938 m*
OAW=*1.831 m*

I C-G I C-D BEV

Mass Reduction for Light-Duty Vehicles for Model years 2017-2025, Singh, H.

Purpose: To see how vehicle size and powertrain selection will change vehicle curb mass and subsystem masses

Go to ***Solution Map*** and select ***Define Nominal Vehicle***

1. Change vehicle dimensions to Toyota with IC-G

Note: Toyota Venza is a cross-over vehicle which is slightly heavier than a Sedan/hatchback due to towing requirements. Account for this by increasing estimated mass by <u>one standard deviation</u> above a nominal Sedan/hatchback

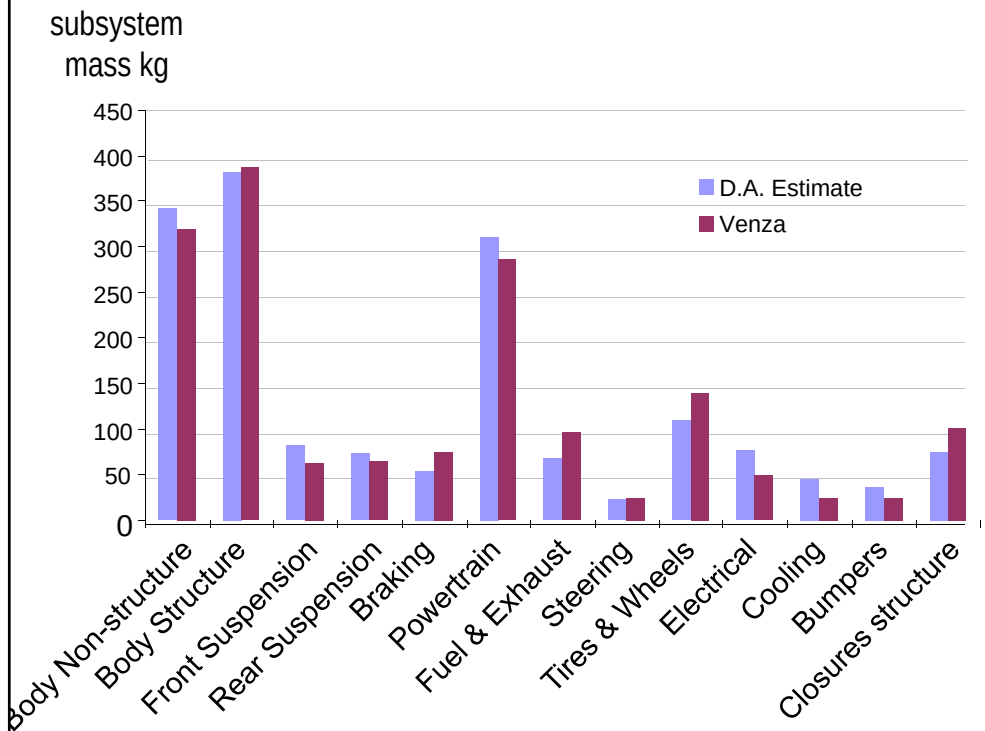
2a. Change vehicle dimensions to Honda (make use to set standard deviations back to zero)
2b. Change powertrain type

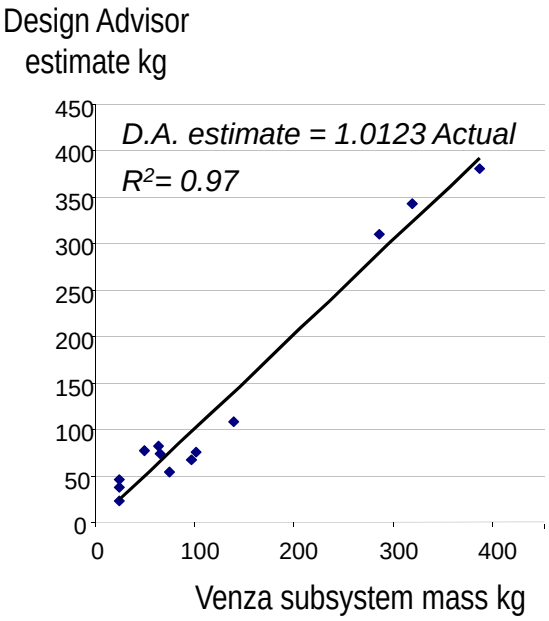
Vehicle	Powertrain type	Curb Mass	Powertrain mass	Body Structure mass	Ferrous content %/ (kg)
Toyota	IC-G	*1679.76*	*310.76*	*381.3*	*62.7 / 1053*
Honda	IC-G	*1534.43*	*283.87*	*348.32*	*62.7 / 962*
Honda	IC-D	*1626.50*	*337.57*	*363.66*	*63 .3 / 1030*
Honda	BEV	*1575.03*	*167.25*	*317.63*	*47.7 / 751*

Case Study 1b — Effect of powertrain selection on vehicle mass

Toyota Venza Mass Comparison

$$CurbMass: \quad \frac{Estimated}{Actual} = \frac{1680kg}{1700kg} = 0.99$$





Case Study 1b — Effect of powertrain selection on vehicle mass

Honda Accord Mass Comparison

$$CurbMass: \quad \frac{Estimated}{Actual} = \frac{1534kg}{1480kg} = 1.036$$