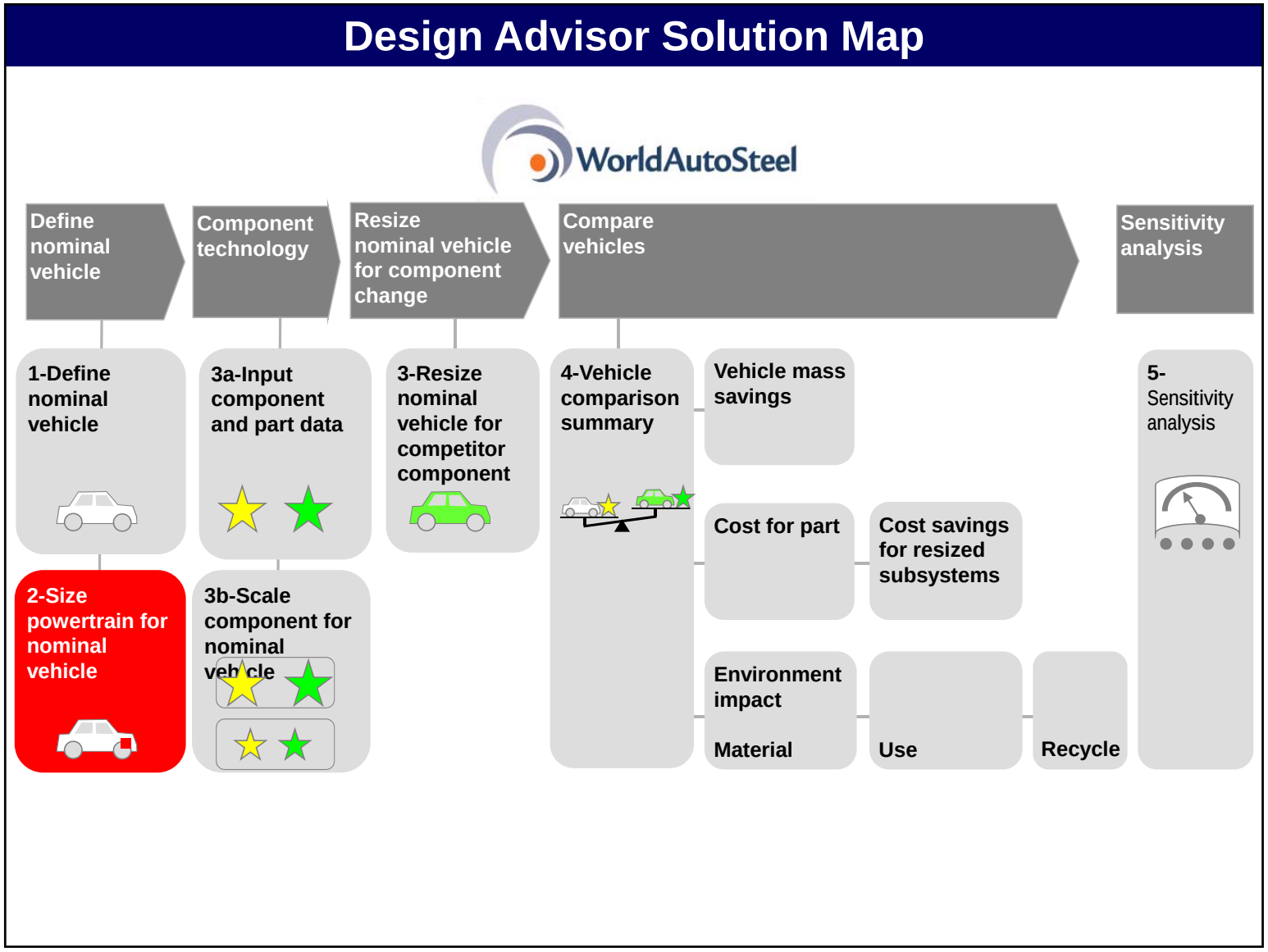
Design Advisor Workshop

Session 5

Powertrain Sizing

Donald E Malen, dmalen@umich.edu

Design Advisor Solution Map



Design Advisor- Nominal Vehicle Fuel Consumption

Powertrain Sizing for Nominal Vehicle

WorldAutoSteel

Life time range (km) 200000

Fuel type Gasoline

fuel compatible with powertrain selection

Powertrain Technology Selected Internal Combustion-gasoline

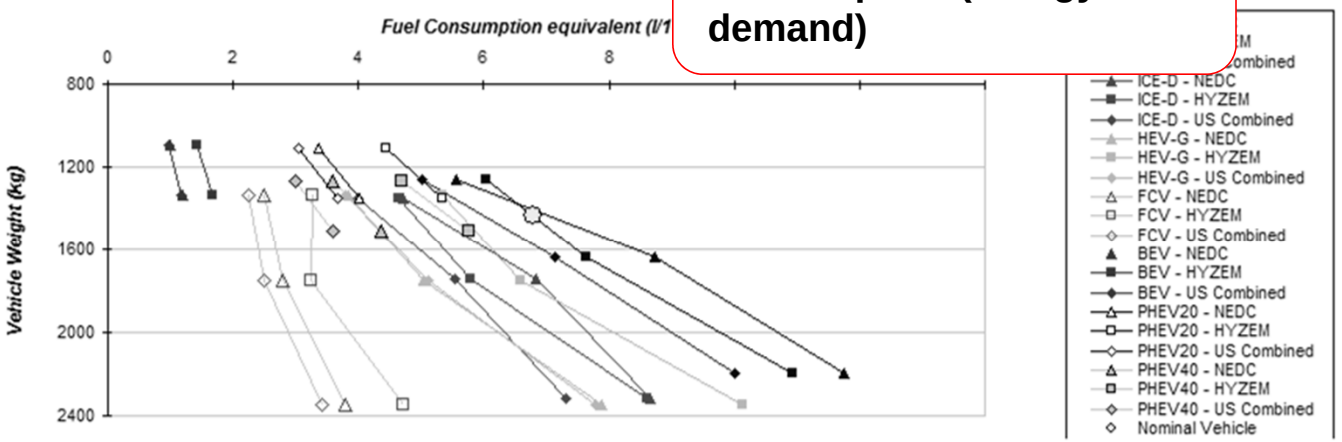
Driving schedule HYZEM

Fuel consumption of nominal vehicle (l/100 km)eq 6.80

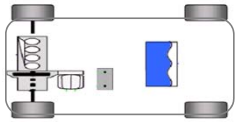
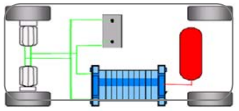
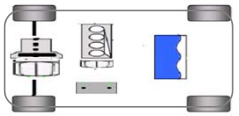
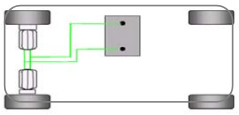
use chart below (MJ/100 km) 216.75

(kWh/100 km) 60.21

Determining the base fuel consumption (energy demand)

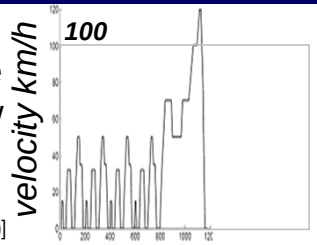


fka Powertrain Modeling

			Vehicle Size				
			A class	C class	Compact	Midsize	SUV
			11-13	11-13	9.8	6.9	6.5 0-100km/h time
Internal combustion		*Gasoline*			1260 kg	1640	2195
		Diesel			1350	1740	2320
Parallel Hybrid					1335	1752	2345
Fuel Cell					1335	1752	2345
Plug-in Hybrid Electric		*20 mile*	1107 kg	1349			
		40 mile	1268	1512			
Battery Electric		*55 mile*	1097	1334			

Fuel Consumption Schedules

NEDC, (New European Driving Cycle 2000), standard cycle in Europe. Low acceleration
Cycle length=6.8 mi (11 km)
[4(Elementary Urban Cycle ECE15)+1(Extra Urban Driving Cycle EUDC)]



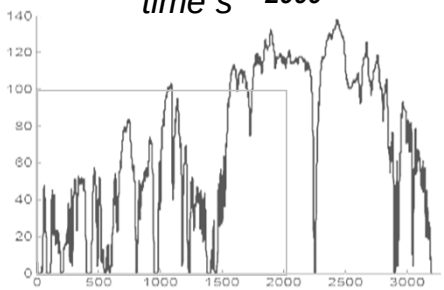
fka source report

Project #55510 NEDC HYZEM
2007 ICE-gas, HEV and FCV

Project #67270 NEDC HYZEM
ICE-diesel

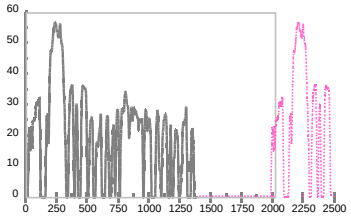
Project #99280 NEDC HYZEM
2010 BEV and PHEVs

HYZEM derived from real driving patterns in Europe. Consists of an urban, an extra-urban, and highway cycle.
Cycle length=37.8 mi (60.9 km)



SAE J1711

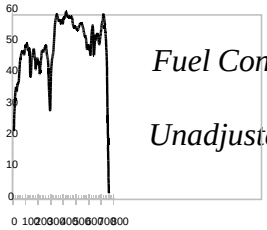
UDDS (Urban Dynamometer Driving Schedule) Also referred to as LA4 or city test.
Represents city driving conditions.
Cycle length=7.45 mi (12 km)



Project #105621 SAE J1711, SAE J2841
2011 ALL PT types

hot start portion of FTP75 not included in UDDS

HFEDS (Highway Fuel Economy Driving Schedule) represents highway driving conditions under 60 mph.
Cycle length=10.26 mi (16.5 km))



repeated for HWFET

$$Fuel\ Consuption_{COMPOSITE} = 0.55FC_{URBAN} + 0.45FC_{HIGHWAY}$$

$$Unadjusted\ Composite\ FE = \frac{1}{\frac{0.55}{FE_{URBAN}} + \frac{0.45}{FE_{HIGHWAY}}}$$

http://www.fueleconomy.gov/feg/fe_test_schedules.shtml

About the Ratings
Your Mileage Will Still Vary
Fuel Economy Tests
Which Vehicles Are Tested
Detailed Test Information

Detailed Test Information

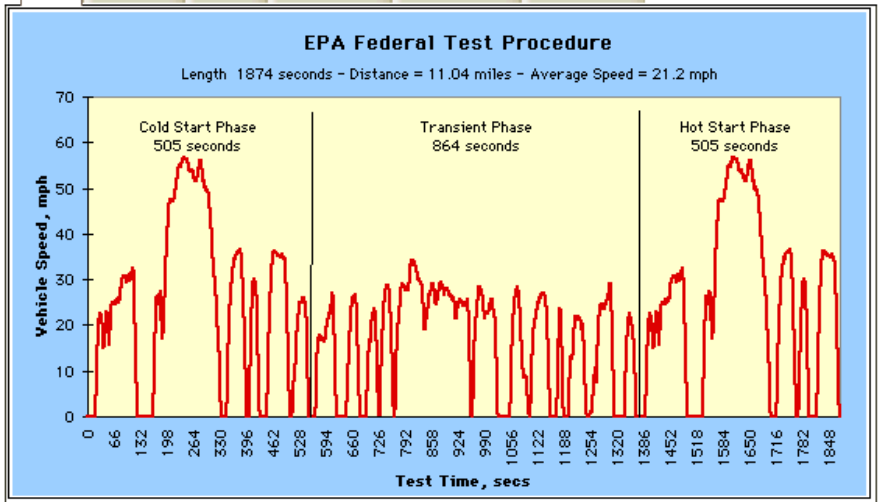
Share

EPA tests vehicles by running them through a series of driving routines, also called *cycles* or *schedules*, that specify vehicle speed for each point in time during the laboratory tests. For 2007 and earlier model year vehicles, only the *city* and *highway* schedules were used. Beginning with 2008 models, three additional tests will be used to adjust the city and highway estimates to account for higher speeds, air conditioning use, and colder temperatures.

Note: EPA has established testing criteria for electric vehicles and plug-in hybrids that are slightly different than those for conventional vehicles.

New Tests

City | Highway | High Speed | Air Conditioning | Cold Temperature | Detailed Comparison



City: Represents urban driving, in which a vehicle is started with the engine cold and driven in stop-and-go rush hour traffic.

fka, Determination of Weight Influence on the Energy Consumption under EPA Conditions,

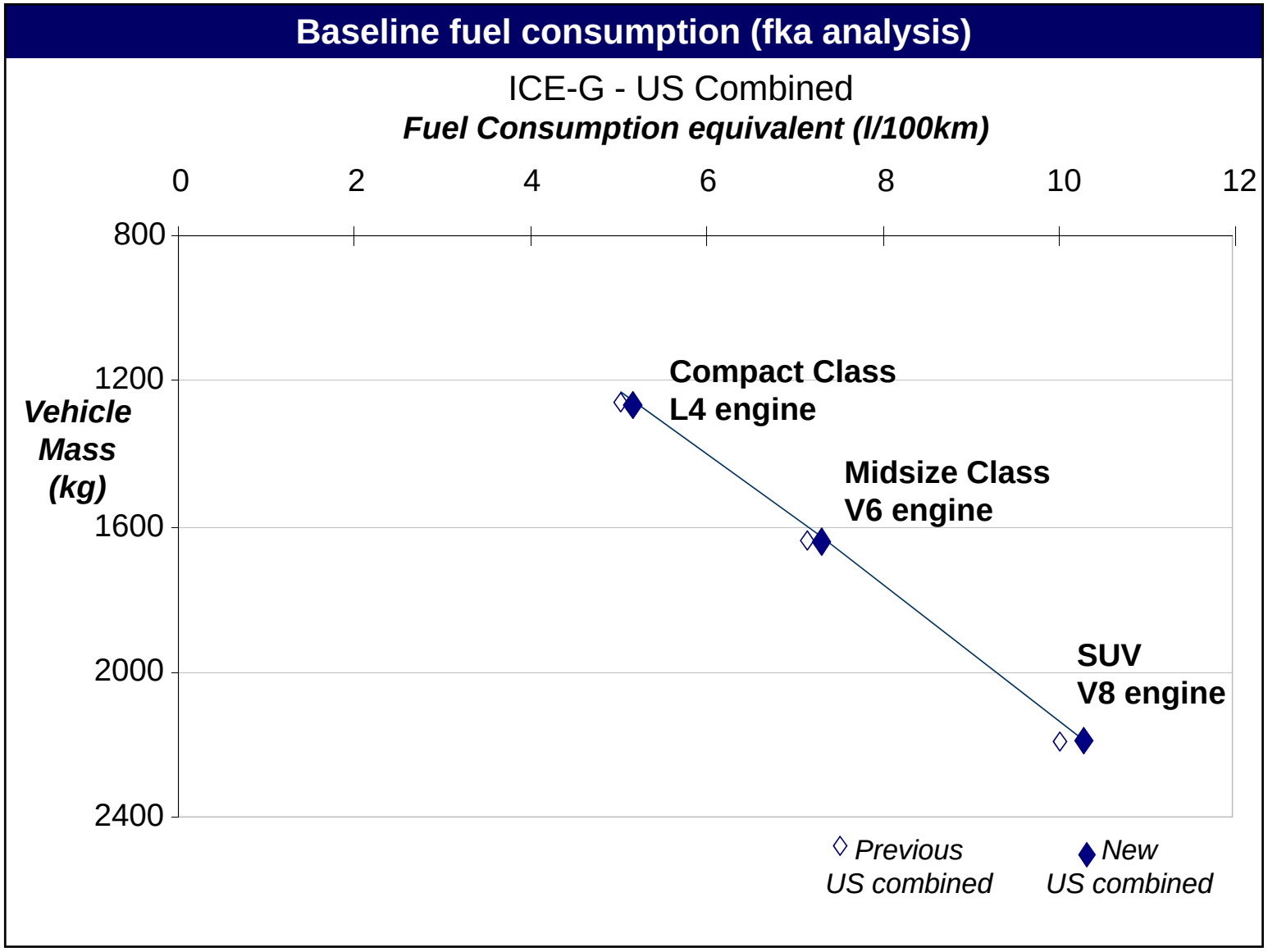
Project Number 124960, November 2012

Modified by R. Balzar

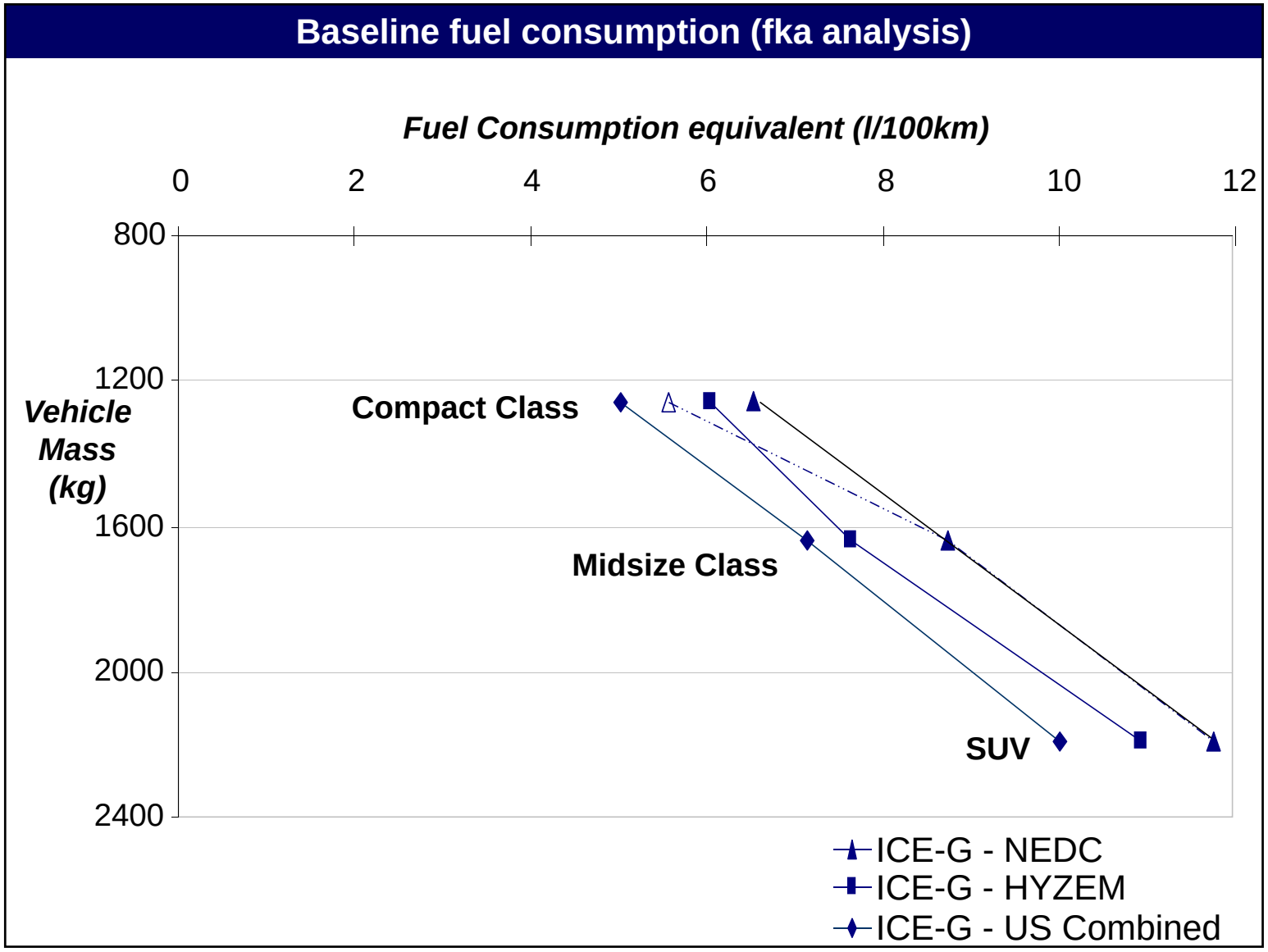
		ICE-G								
		Compact			Midsize			SUV		
		Base	reduce weight	down sized power-train	Base	reduce weight	down sized power-train	Base	reduce weight	down sized power-train
Vehicle Parameters										
Vehicle weight	**[kg]**	1260			1640			2195		
ICE power	**[kW]**	85			181			235		
c_D	**[-]**	0.31			0.27			0.36		
A	**[m²]**	2.16			2.24			2.78		
f_R	**[-]**	0.007			0.007			0.007		
Acceleration 0 - 100 km/h	**[s]**	8.98			5.58			5.51		
City fuel demand (FTP75 warm		5.65			9.28			12.09		
Highway fuel demand (HWFET)		4.39			5.78			8.28		
Combined fuel consumption (0.45 City + 0.55 Hwy)		5.08	*162.1 MJ*		7.70	*245.6 MJ*		10.38	*330.9 MJ*	

Gasoline heating value 31.9 MJ / liter

Baseline fuel consumption (fka analysis)



Baseline fuel consumption (fka analysis)



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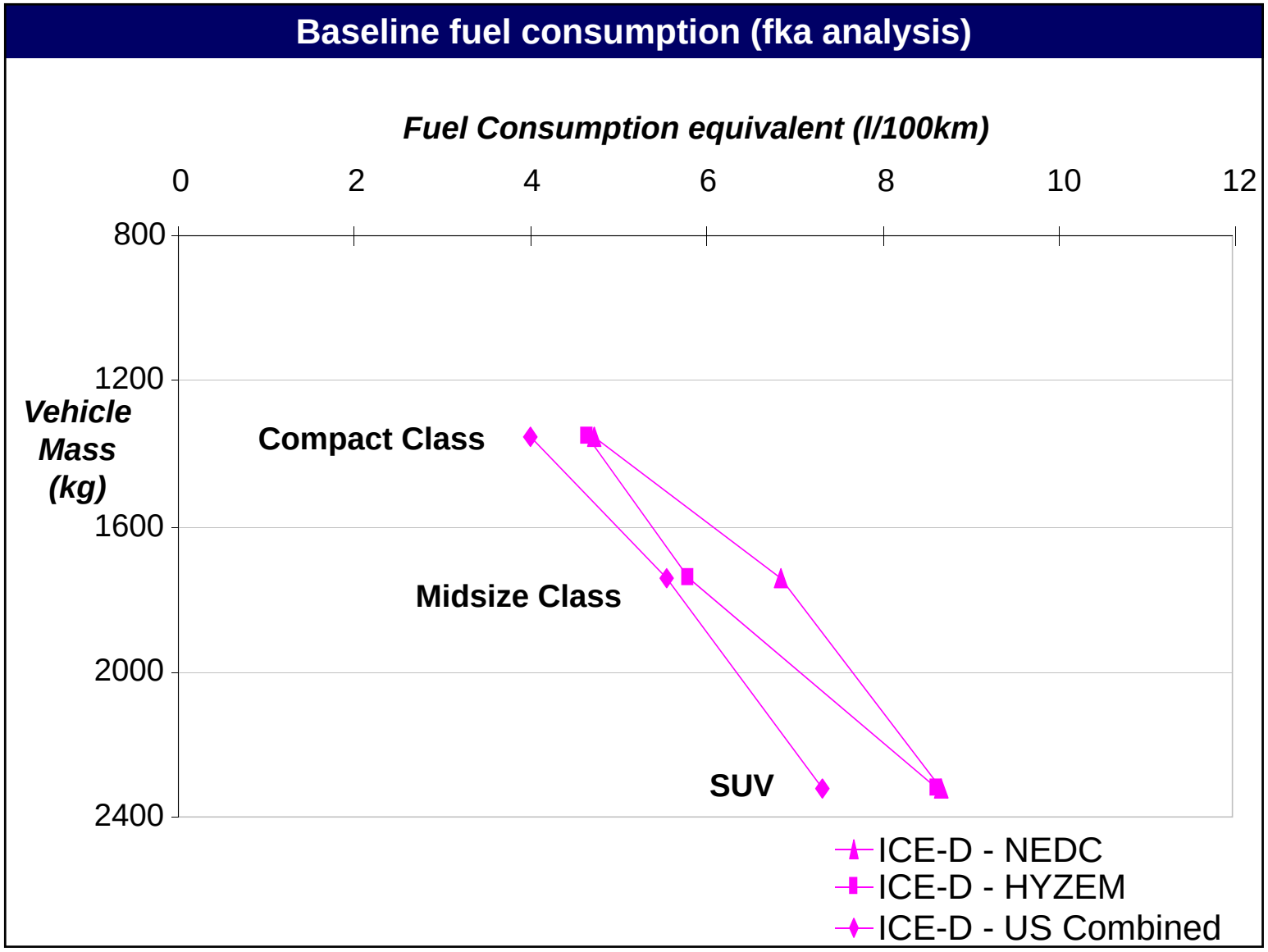


Energy, Power Units

	Metric Units	Conversions
Work/Energy: ***Force over a distance***	*1 Joule= Nm* *1 kW hr=3.6 MJ*	*1 ft lb = 1.356 J* *1 BTU = 1055 J*
Power: ***Rate of doing work***	*Watt=J/s*	*1 hp=746 W* *1 BTU/sec=1055 W*

Fuel	***Lower heating value MJ/liter***
gasoline	*31.9*
diesel	*36.0*
biodiesel	*32.6*
ethanol	*21.1*
E85	*22.7*
H_2-Liq	*8.5*
LPG	*23.7*
methanol	*16.0*

$$1kWhr\left(\frac{J/s}{W}\right)\left(\frac{3600s}{hr}\right)=3.6MJ$$

When fuel is not Gasoline
Gasoline equivalent fuel consumption

Liquid fuels

$$(Fuel\ Consumption)e\quad (liter/100km) = \frac{\left(\frac{Total\ Energy\ Consumed\ (MJ)}{energy\ of\ \ one\ unit\ of\ \ gasoline\ (MJ/liter)}\right)}{Distance\ (km)}$$

Electric

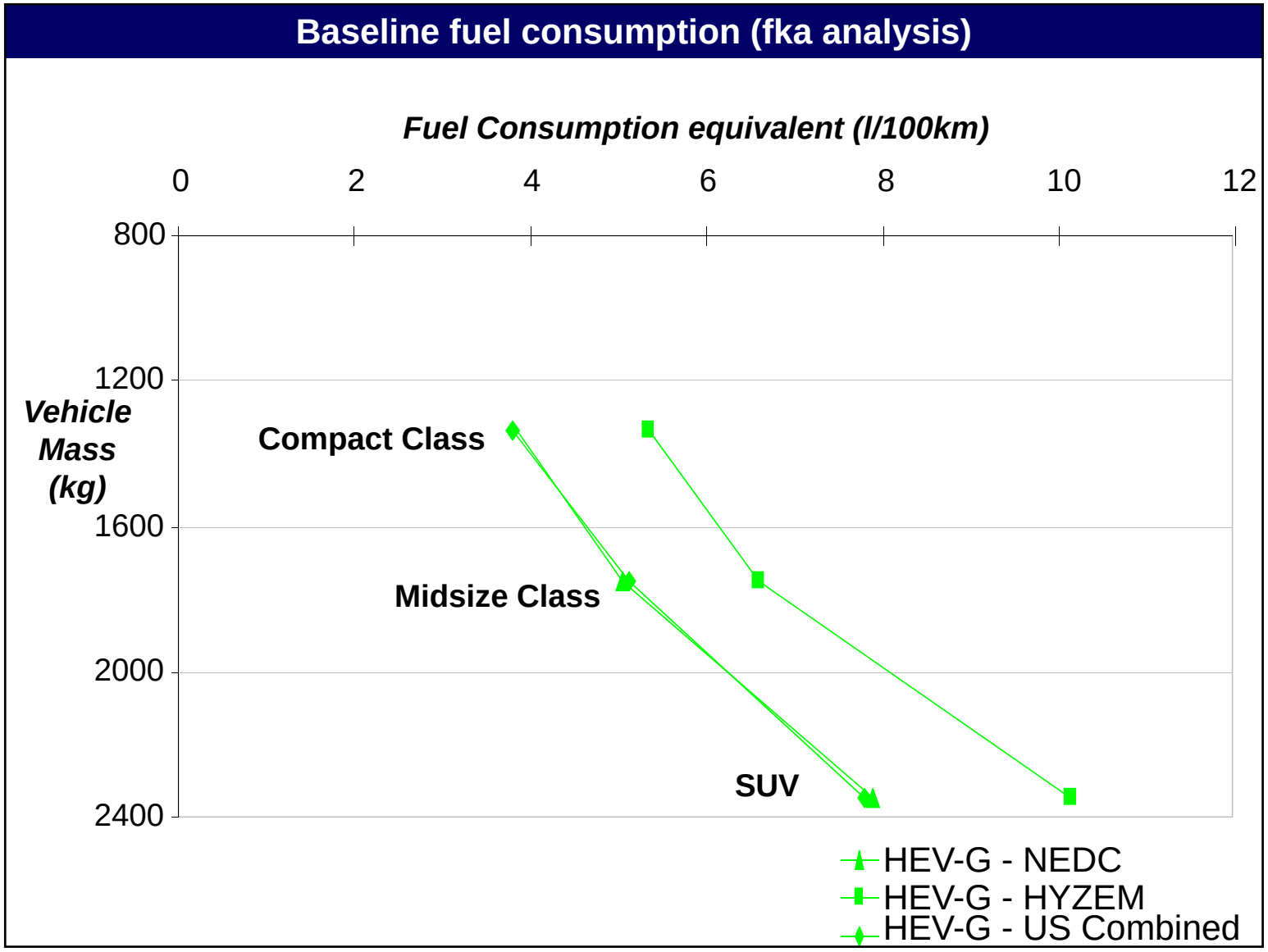
$$(Fuel\ Consumption)e\quad (liter/100km) = \left(\frac{E_M \cdot E_E}{E_G}\right)$$

E_M=*battery-to-wheel electrical energy consumed per 100 km (kWhr)*

E_E=*energy per unit of electricity (3.6 MJ/kWhr)*

E_G=*energy content per unit volume of gasoline MJ/liter.*

Baseline fuel consumption (fka analysis)



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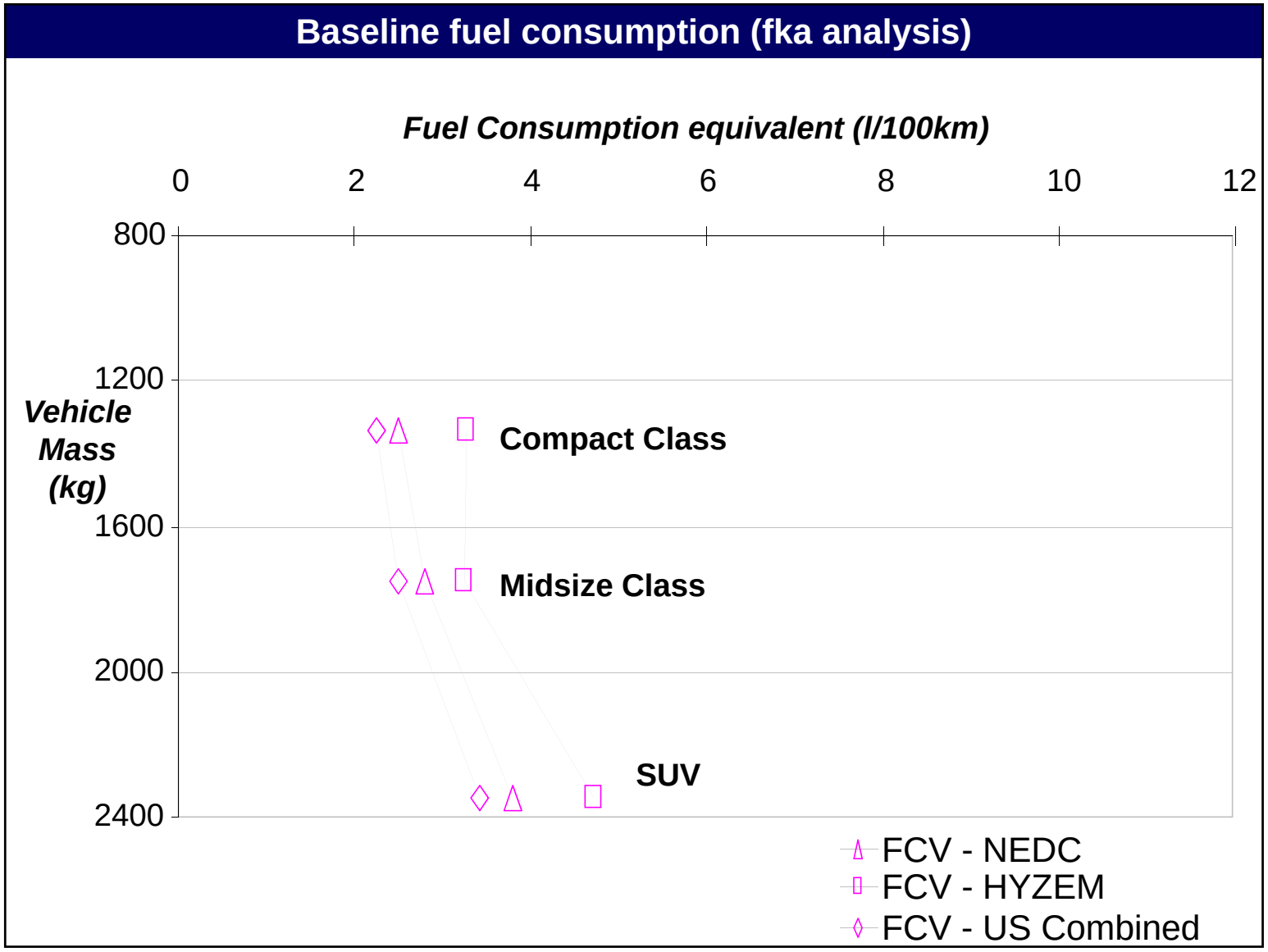

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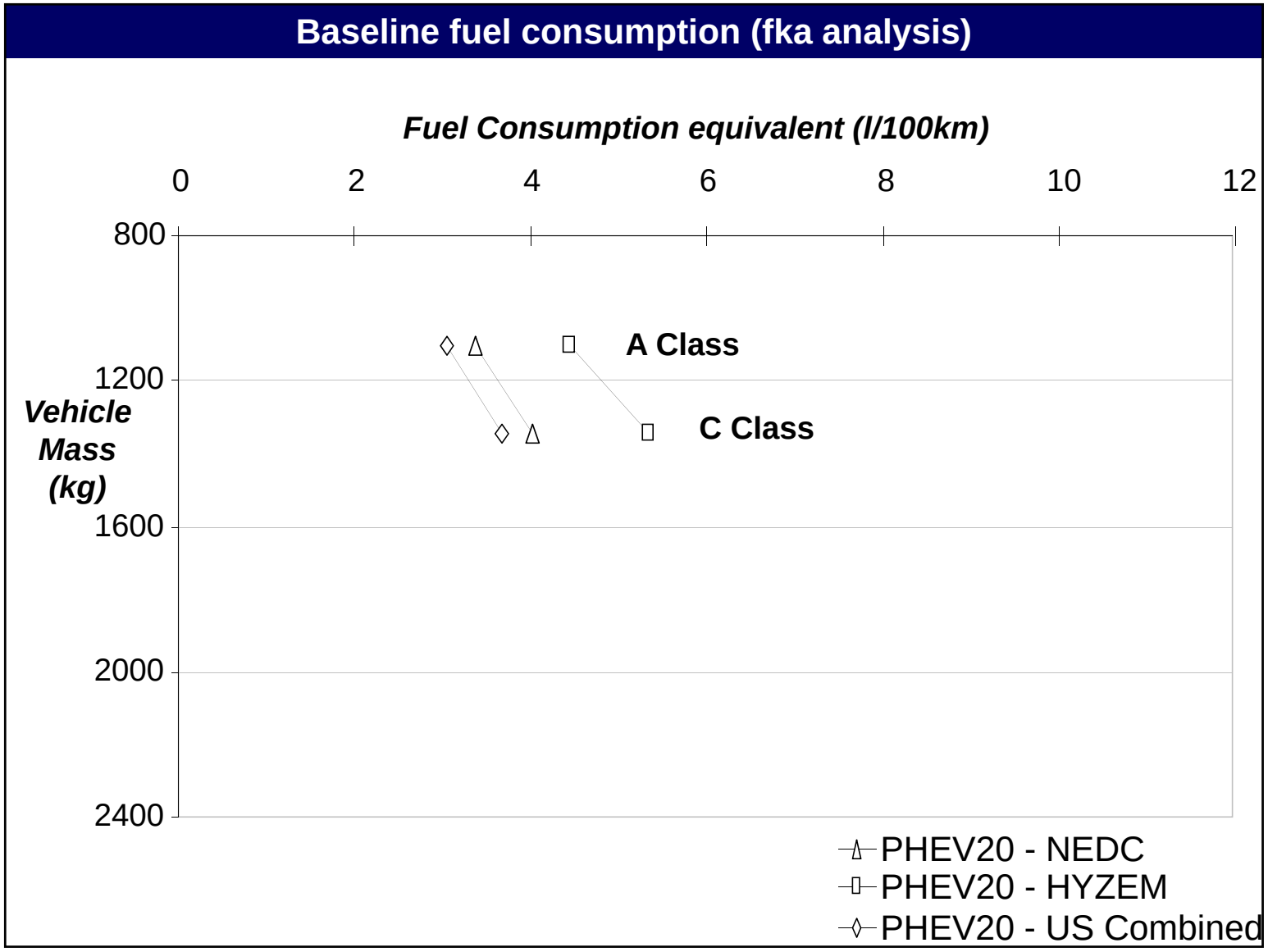

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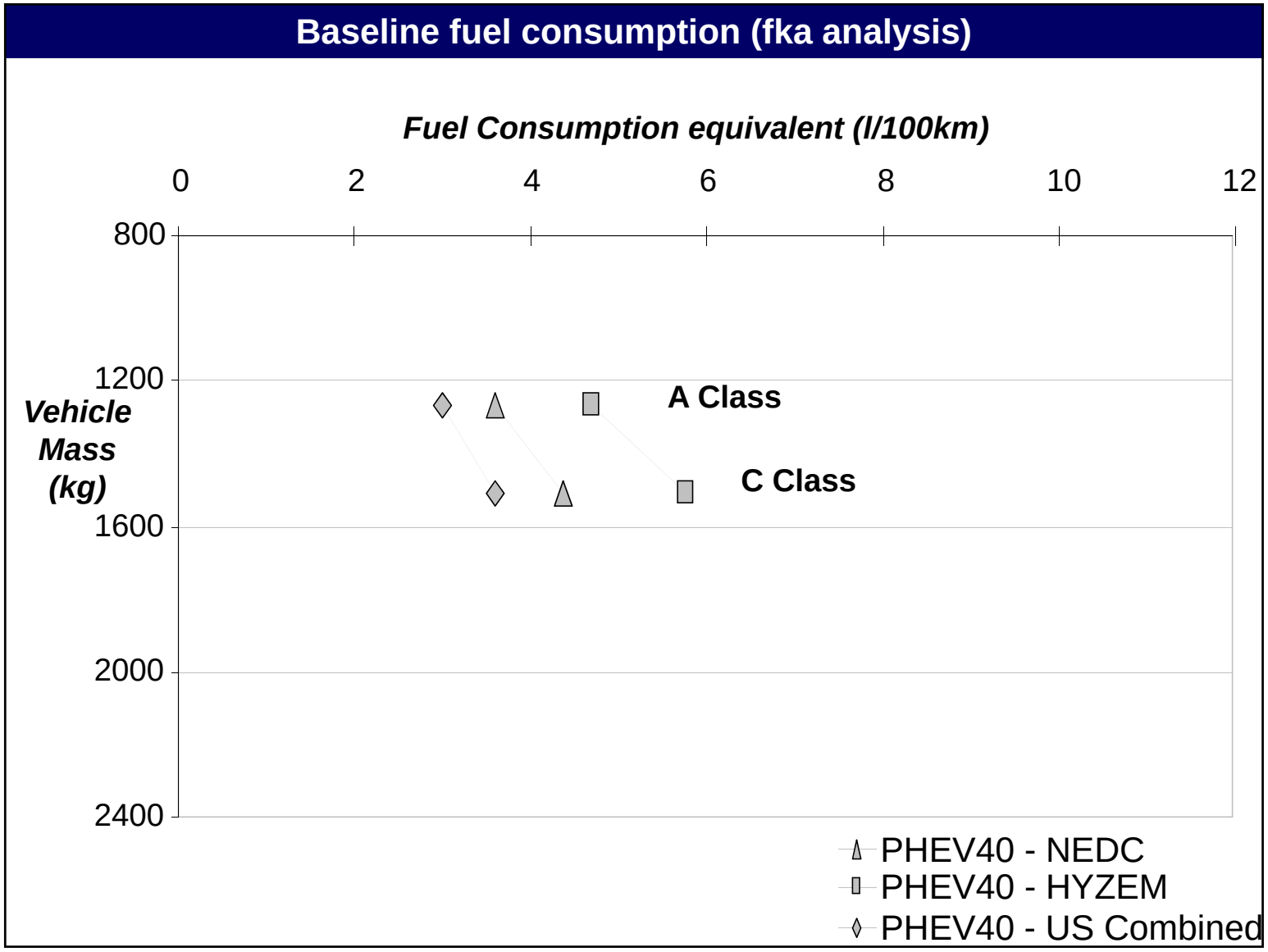

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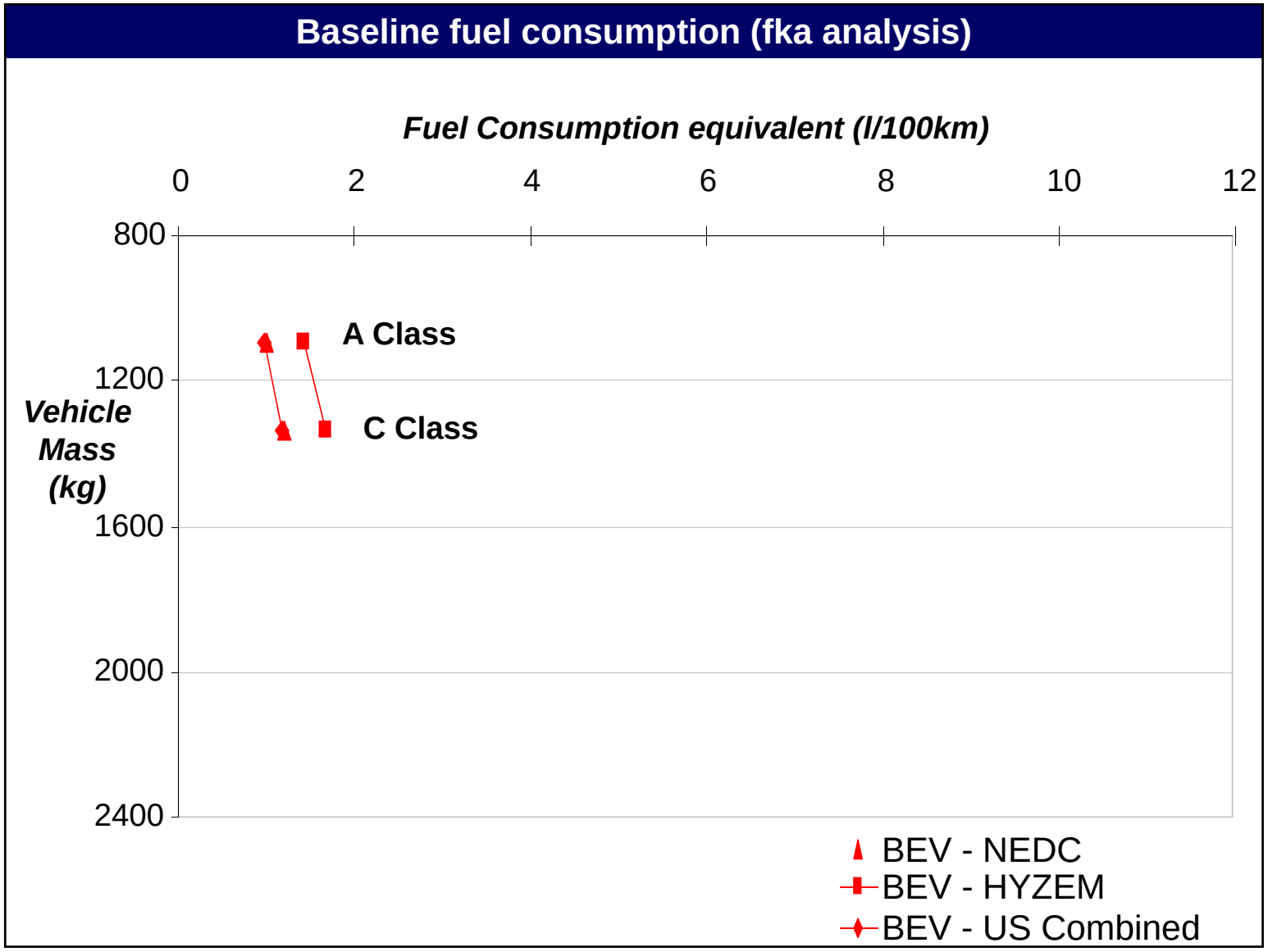

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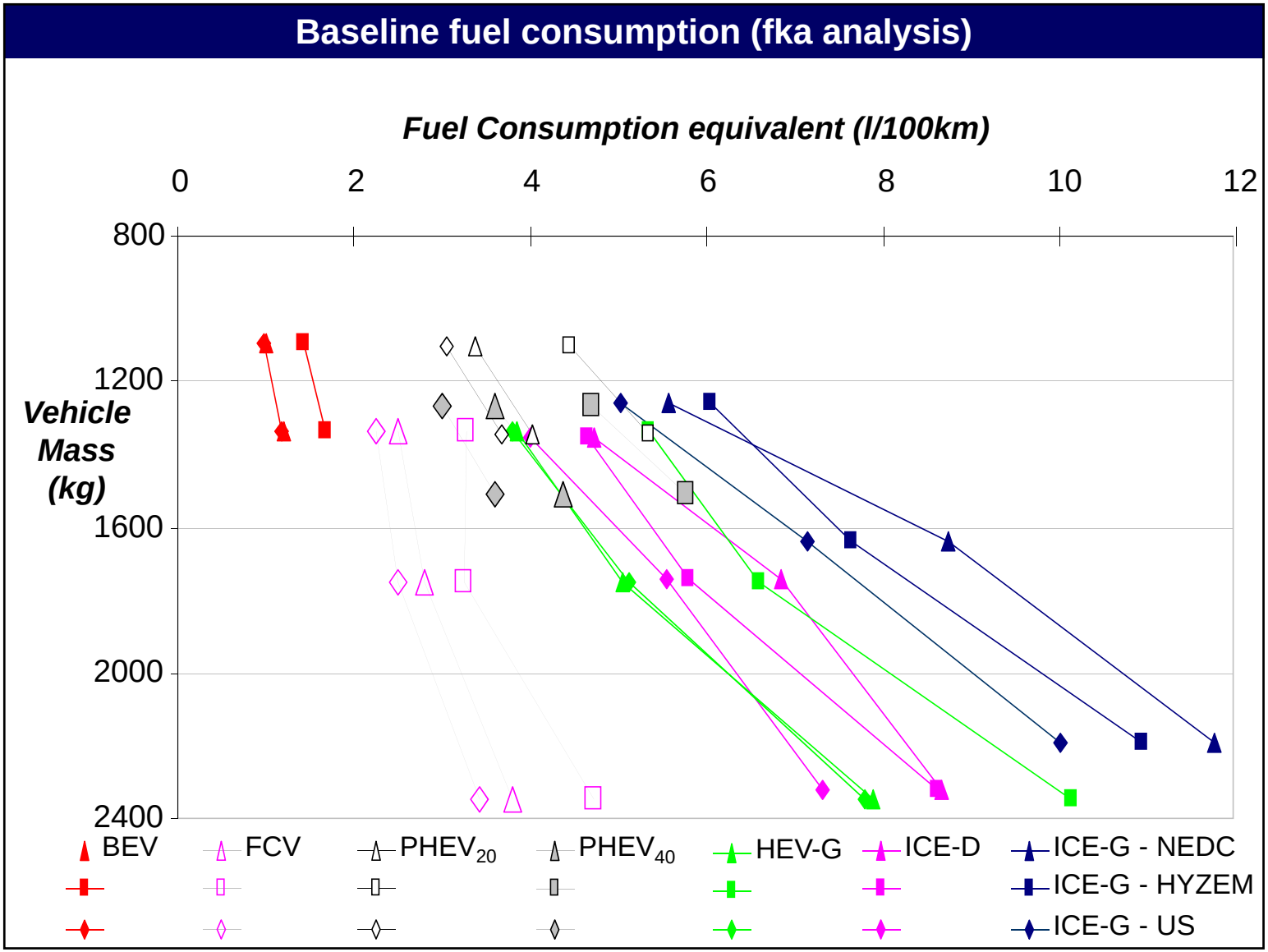
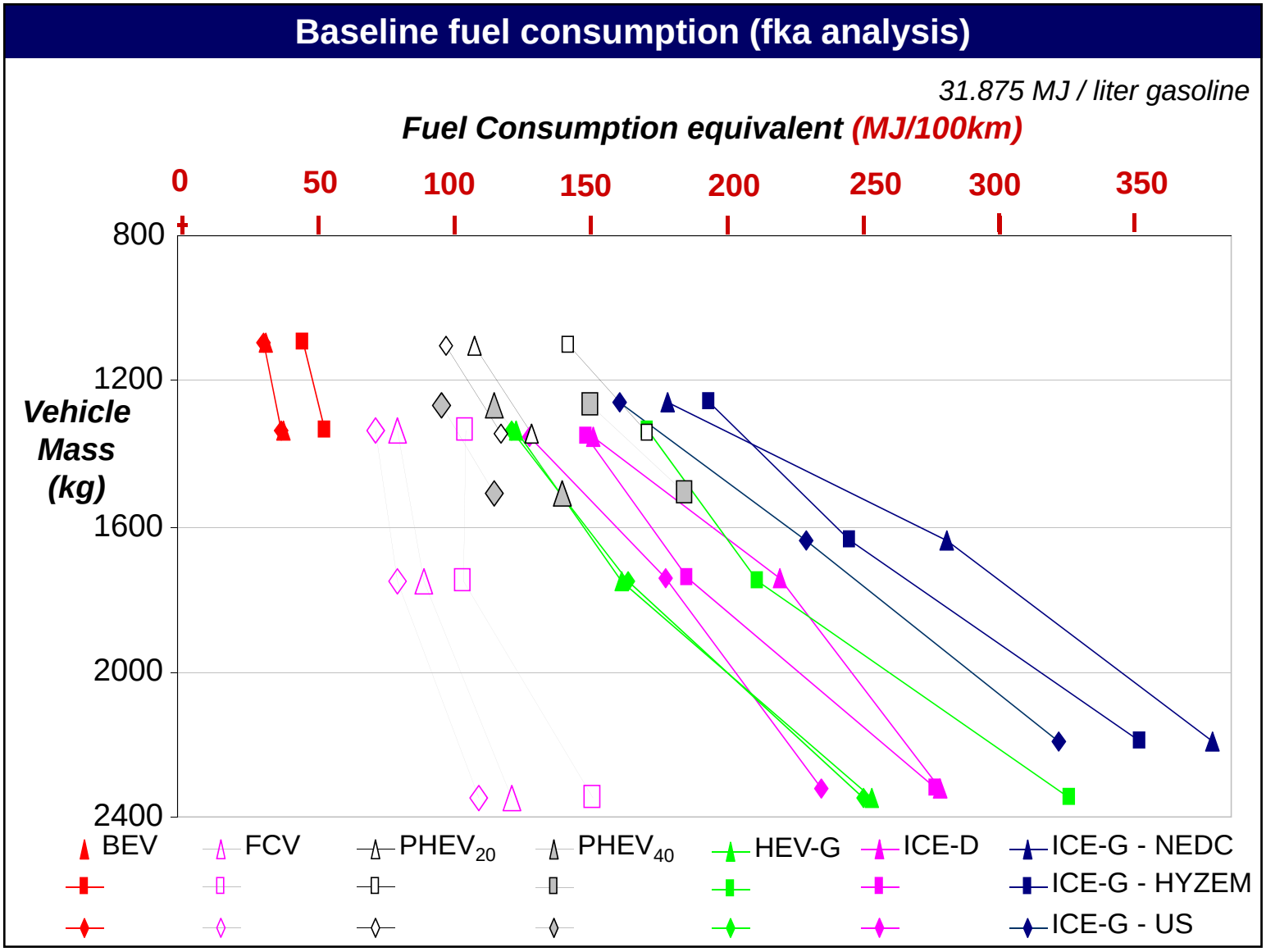
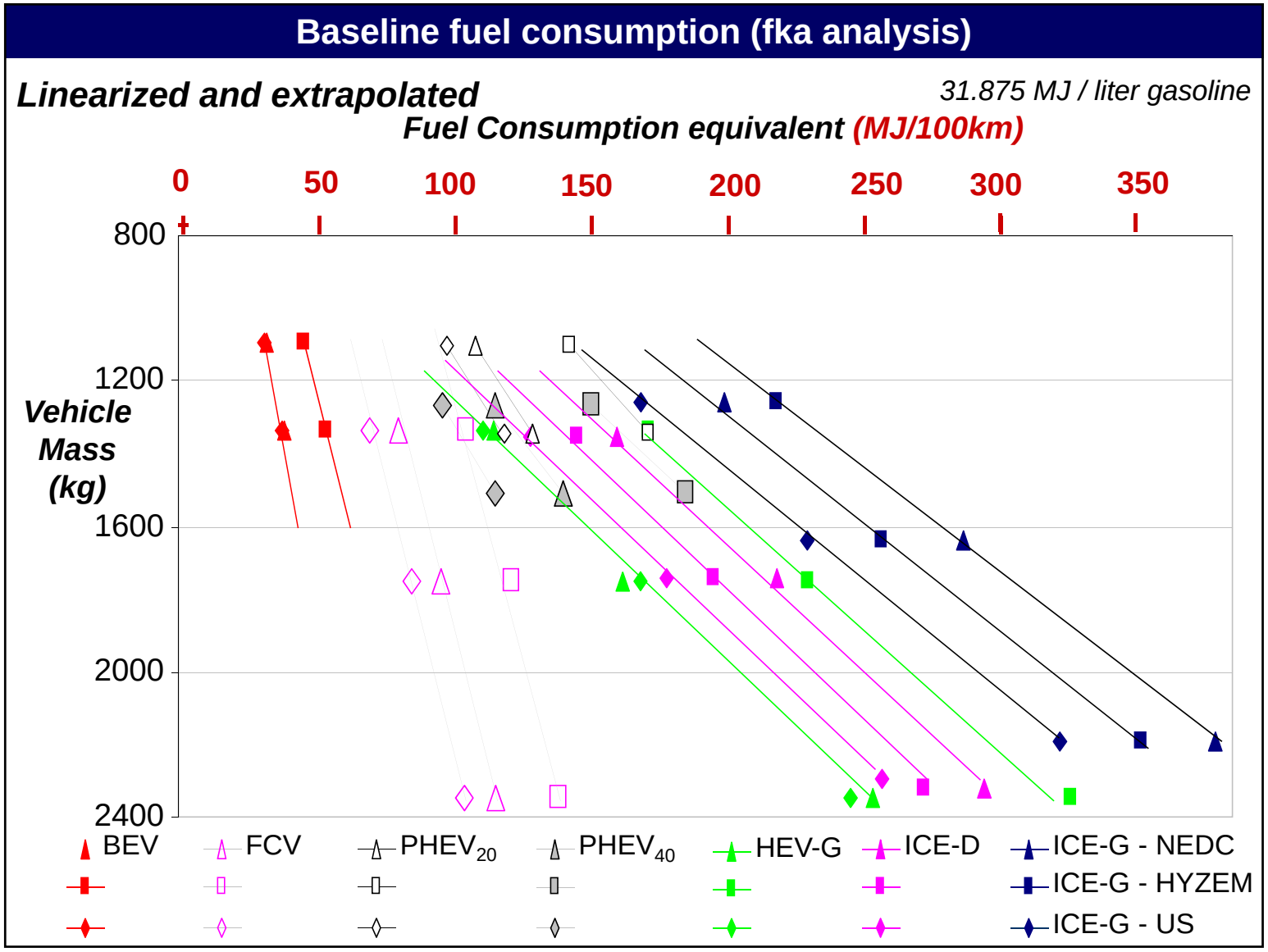


Baseline fuel consumption (fka analysis)



Baseline fuel consumption (fka analysis)

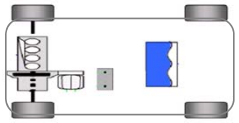


Powertrain Modeling

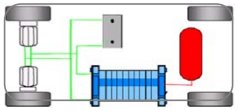
Internal combustion

Gasoline
E85
Diesel
Bio diesel

Parallel Hybrid

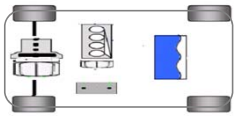


Fuel Cell



Hydrogen

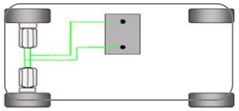
Plug-in Hybrid Electric



Electric
•USA
•Europe
•China
•Japan
•India

20 mile
40 mile

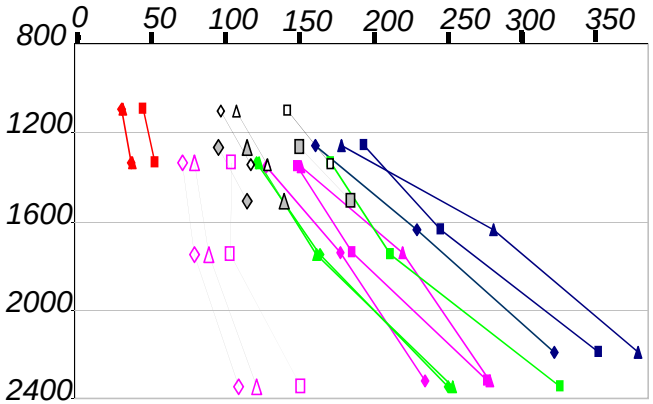
Battery Electric



55 mile

Fuel Consumption equivalent (MJ/100km)

Vehicle Mass (kg)



NEDC
HYZEM
US combined

fka, Matlab powertrain simulation

Design Advisor- Resized Vehicle Fuel Consumption

Results - LCA Use Comparison

WorldAutoSteel

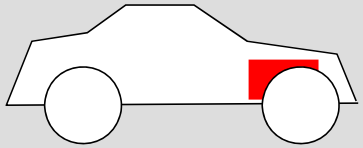
Selected fuel	Gasoline		
Selected powertrain technology	Internal Combustion-gasoline		
Selected driving schedule	HYZEM		
Selected fuel consumption	6.80 *l/100km eq*	216.75 *MJ/100km*	
Selected life time range	200000 *km*		
Liquid fuel consumption mass elasticity	0.1277 *l/100km eq/100kg*	4.0	
Electricity consumption mass elasticity	0.0000 *l/100km eq/100kg*	0.0	
Vehicle mass difference	-5.2100 *kg*		
Resize powertrain for equal performance?	FALSE		

How is fuel consumption estimated for Resized Vehicle?

	Liquid fuel	*Electricity*	*Liquid fuel*	*Electricity*	*Liquid fuel*	*Electric*
Fuel Consumption						
Fuel Consumption	6.800 *l/100km eq*	0.000 *kWh/100km*	6.793 *l/100km eq*	0.000 *kWh/100km*		
	216.750 *MJ/100km*	0.000 *MJ/100km*	216.538 *MJ/100km*	0.000 *MJ/100km*		
Life time fuel use by source	13600 *liter*	0 *kWh*	13587 *liter*	0 *kWh*	-13.30	0.
	433500 *MJ*	0 *MJ90%charge eff*	433076 *MJ*	0 *MJ90%charge eff*		
Total vehicle fuel demand-all sources	**433500** *MJ*		**433076** *MJ*		-424.02	
Fuel Cost						
Unit fuel cost	0.97 *$/l*	0.97 *$/kwhr*	0.97 *$/l*	0.97 *$/kwhr*		
Life time fuel cost	$13,192 *$*	$0 *$*	$13,179 *$*	$0 *$*		
Total Life time cost	**$13,192** $		**$13,179** $		-12.90	
Discount rate %/yr	5.0%					
Present value fuel cost (10yr)	$10,187 *$*		$10,177 *$*		-9.96	
Tank to Wheel CO2 eq						
Tank to wheels CO2 per unit fuel	0.072 *kg CO2eq/MJ*		0.072 *kg CO2eq/MJ*			
Life time CO2 from liquid fuel use	**31169** *kg CO2eq*		**31138** *kg CO2eq*		-30.49	0.
Well to Tank CO2 eq						
Fuel production energy per unit output	0.210 *MJ/MJ*	0.210 *MJ/MJ*	0.210 *MJ/MJ*	0.210 *MJ/MJ*		
CO2 per unit energy production	0.018 *kg CO2eq/MJ*	0.018 *kg CO2eq/MJ*	0.018 *kg CO2eq/MJ*	0.018 *kg CO2eq/MJ*		
Fuel production energy	91035 *MJ*	0 *MJ*	90946 *MJ*	0 *MJ*		
CO2 from fuel production by type	7790 *kg CO2eq*	0 *kg CO2eq*	7782	0 *kg CO2eq*		
Life time CO2 from fuel production	**7790** *kg CO2eq*		**7782** *kg CO2eq*		-7.62	
Well to Wheel Grand total	**38959** *kg CO2eq*		**38921** *kg CO2eq*		-38.11	
	524535 *MJ*		524022 *MJ*		-513.07	

Fuel Consumption Mass Sensitivity

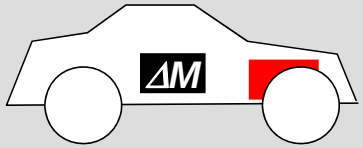
Nominal vehicle



$M_{NOMINAL}$

Fuel consumption=6.2 l/100 km

Resized vehicle



$M_{RESIZED}=M_{NONMINAL} + \Delta M$

Fuel consumption$_{RESIZED}$*=?*

What is fuel consumption for resized vehicle?

Fuel Reduction Value

Fuel Reduction Value=

$$\frac{\text{Change in fuel consumption}}{\text{Change in mass}} \qquad \text{(liter/100 km)/100kg)}$$

Or more generally

$$\frac{\text{Change in Energy Demand}}{\text{Change in mass}} \qquad \text{(MJ/100 km)/100kg)}$$

$$fc_{RESIZED} = fc_{NOMINAL} + \frac{\Delta M\,(FRV)}{100}$$

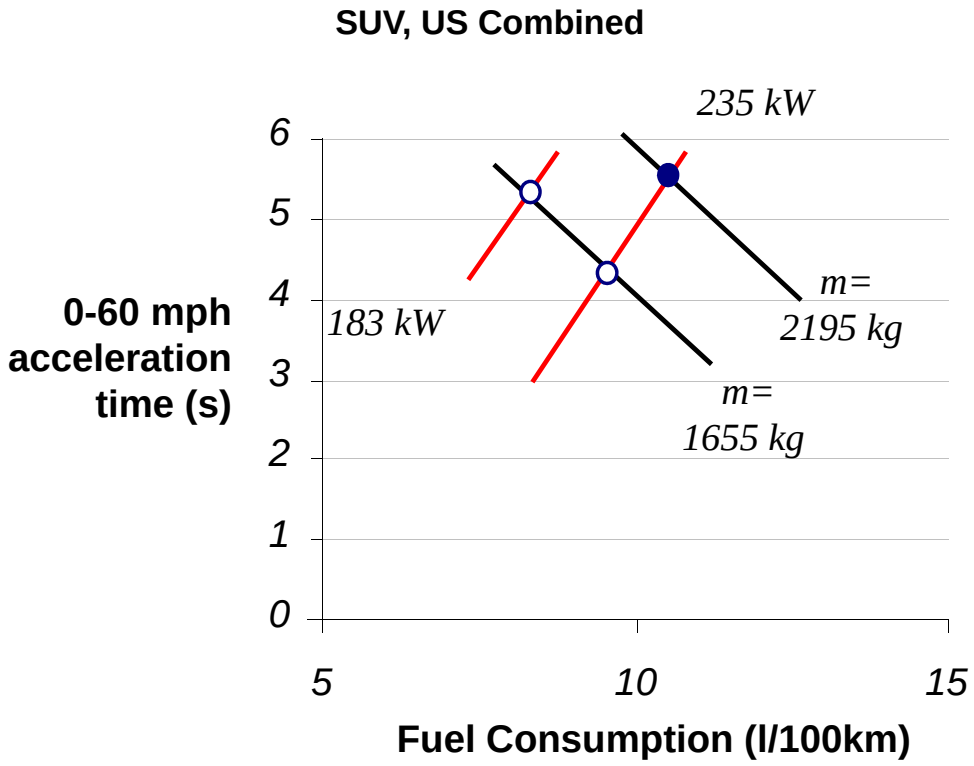
fka, Determination of Weight Influence on the Energy Consumption under EPA Conditions,

Project Number 124960, November 2012

Modified by R. Balzar

		ICE-G								
		Compact			Midsize			SUV		
		Base	reduce weight	down sized power-train	Base	reduce weight	down sized power-train	Base	reduce weight	down sized power-train
Vehicle Parameters										
Vehicle weight	**[kg]**							2195	1655	1655
ICE power	**[kW]**							235	235	183
c_D	**[-]**							0.36	0.36	0.36
A	**[m²]**							2.78	2.78	2.78
f_R	**[-]**							0.007	0.007	0.007
Acceleration 0 - 100 km/h	**[s]**							5.51	4.32	5.33
City fuel demand (FTP75 warm								12.09	11.05	9.62
Highway fuel demand (HWFET)								8.28	7.84	6.96
Combined fuel consumption (0.45 City + 0.55 Hwy)								10.38	9.60	8.42

Fuel Consumption Mass Sensitivity



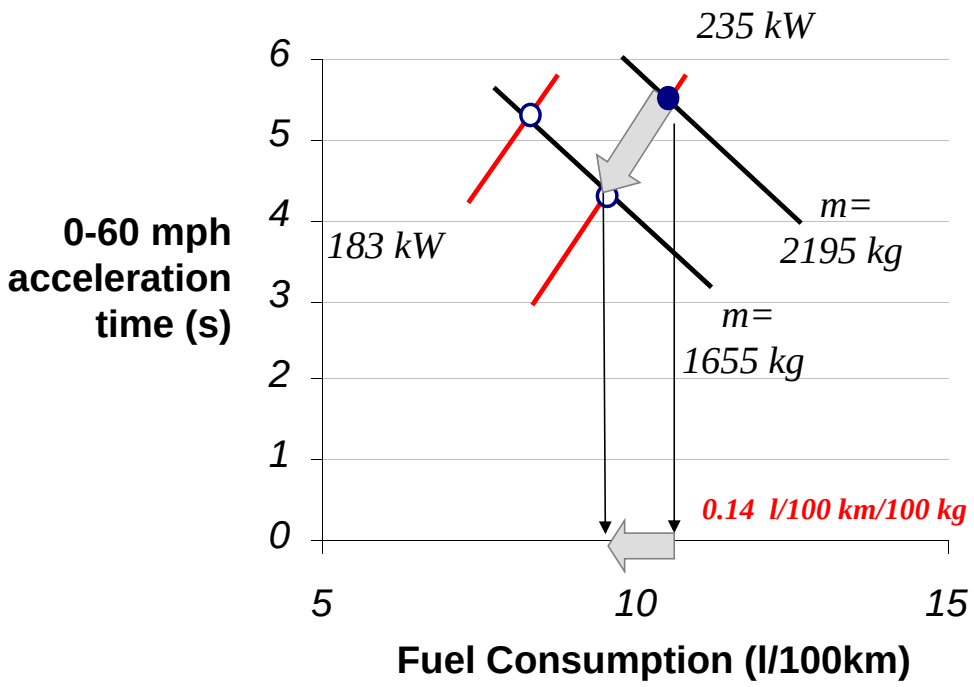
lines of same vehicle mass

lines of same engine power

vehicle mass *kg*	2195	1655	1655
Engine power *kW*	235	235	183
acceleration time s	5.51	4.32	5.33
combined fuel consumption *l/100km*	10.38	9.60	8.42

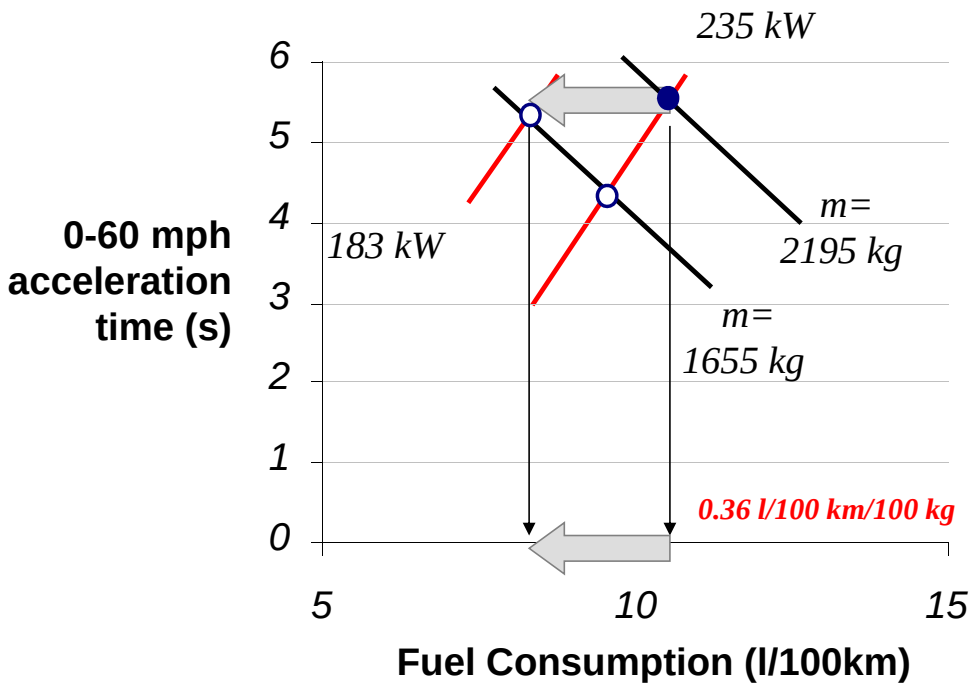
Fuel Consumption Mass Sensitivity

Powertrain displacement fixed

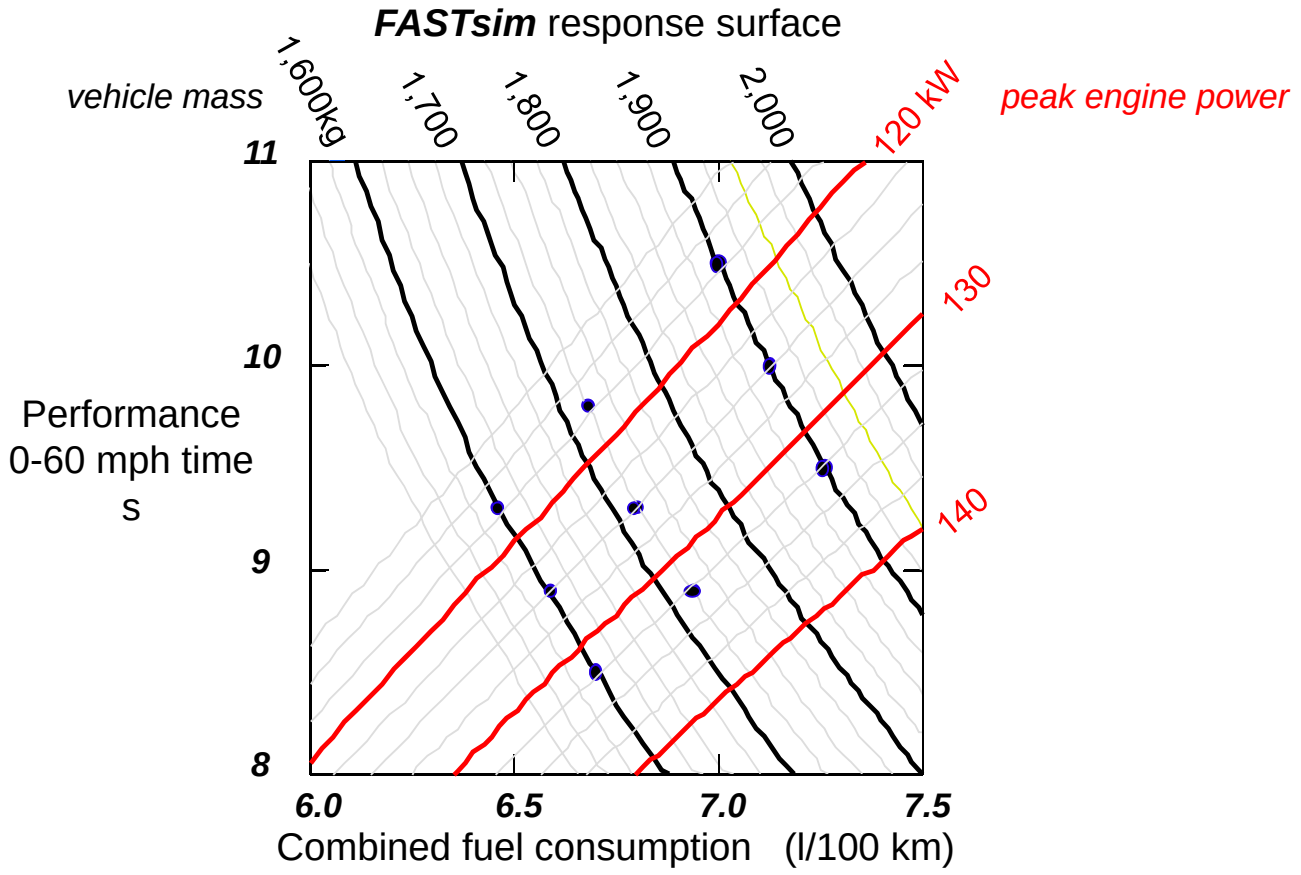


Fuel Consumption Mass Sensitivity

Acceleration fixed (engine downsized)



Example of expanded response surface



$$T_0 = 10.163 + 0.004\,mass - 0.057\,power \quad R^2 = 99.6$$

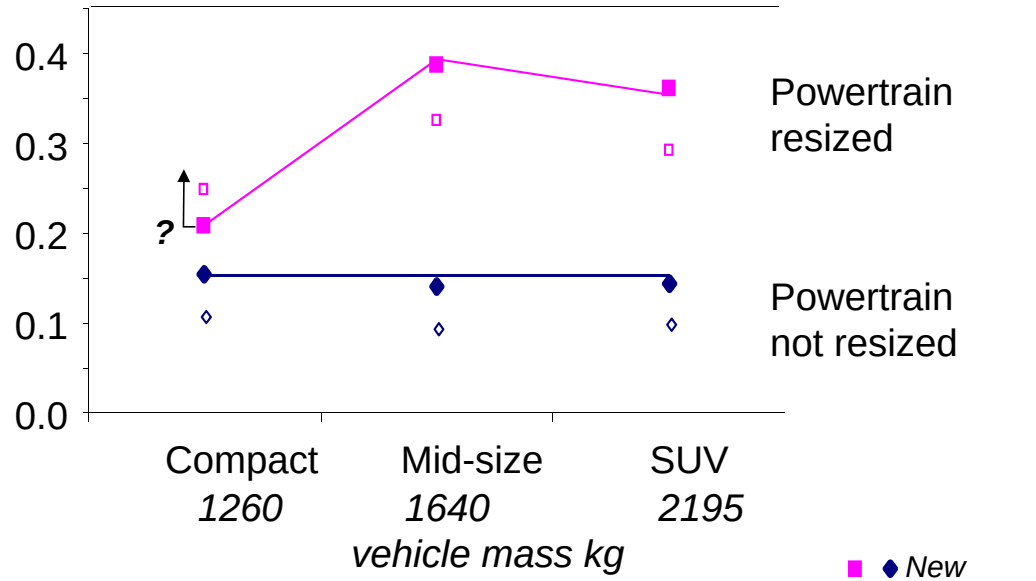
$$FC = 1.667 + 0.002\,mass + 0.016\,power \quad R^2 = 99.9$$

Fuel Reduction Value

US Combined schedule, IC gasoline

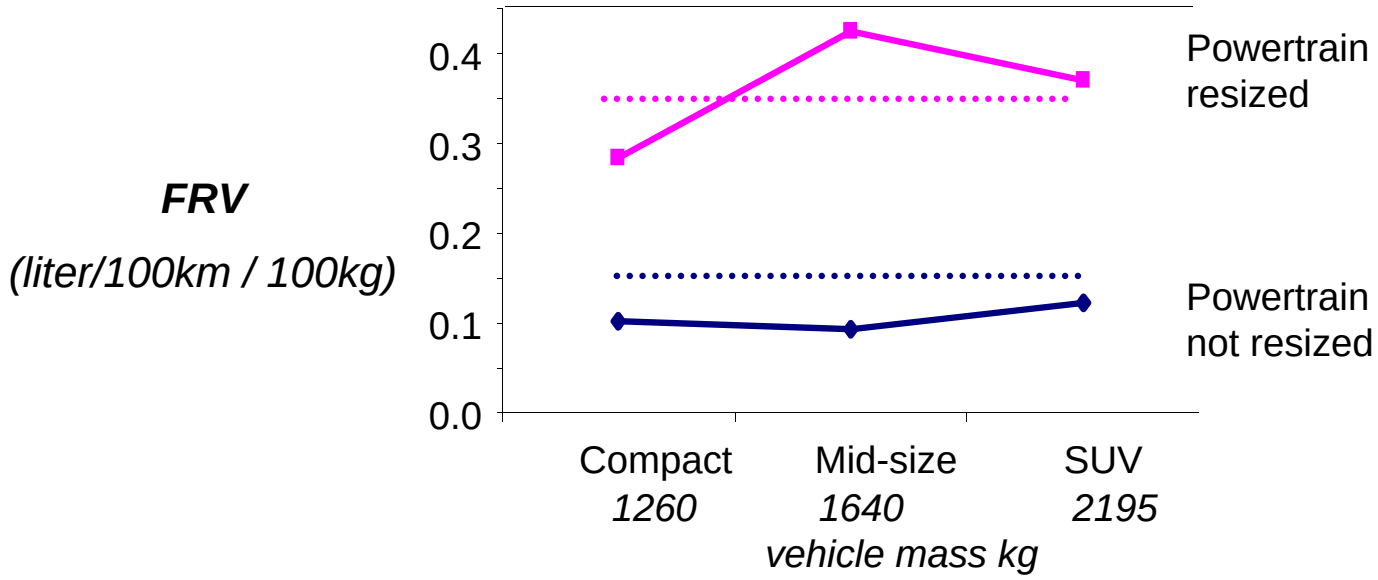
FRV

(liter/100km / 100kg)



Fuel Reduction Value

NEDC schedule, IC gasoline

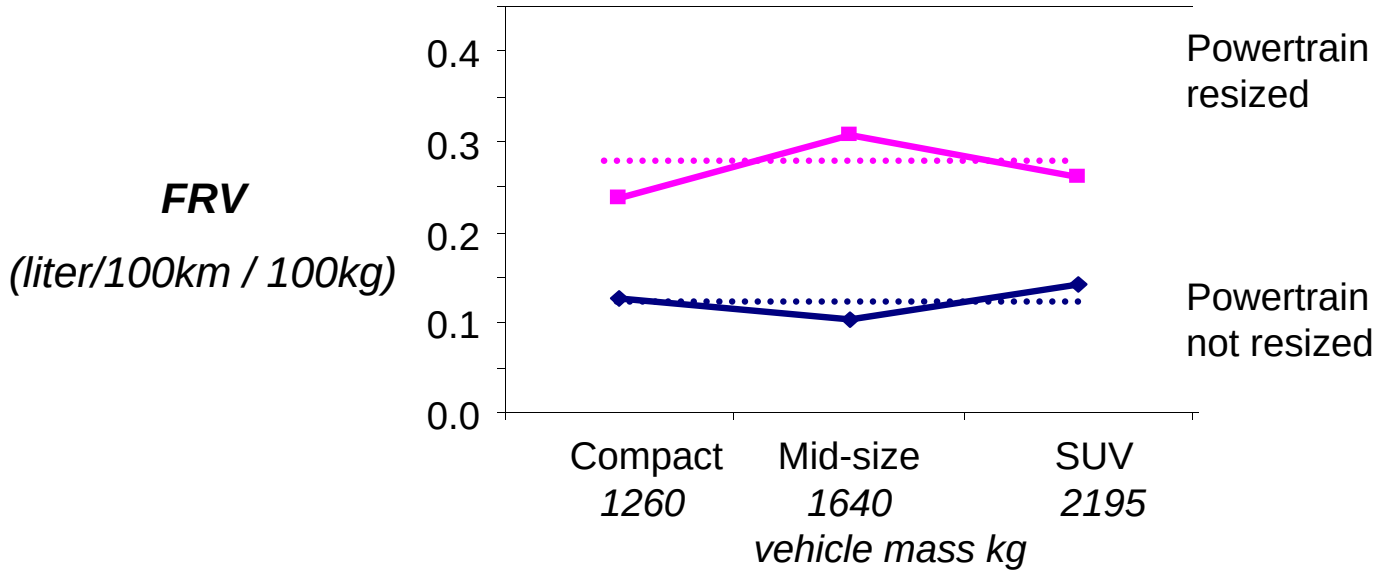


On the Calculation of Fuel Savings Through Lightweight Design in Automotive Life Cycle Assessments, Christoph Koffler & Klaus Rohde-Brandenburger, Int J Life Cycle Assess (2010) 15:128–135.

diesel=0.12 and 0.28 l/100 km/100 kg
gasoline=0.15 and 0.35 l/ 100 km/100 kg
NEDC without and with engine displacement or gear ratio changes to achieve constant performance

Fuel Reduction Value

NEDC schedule, IC diesel



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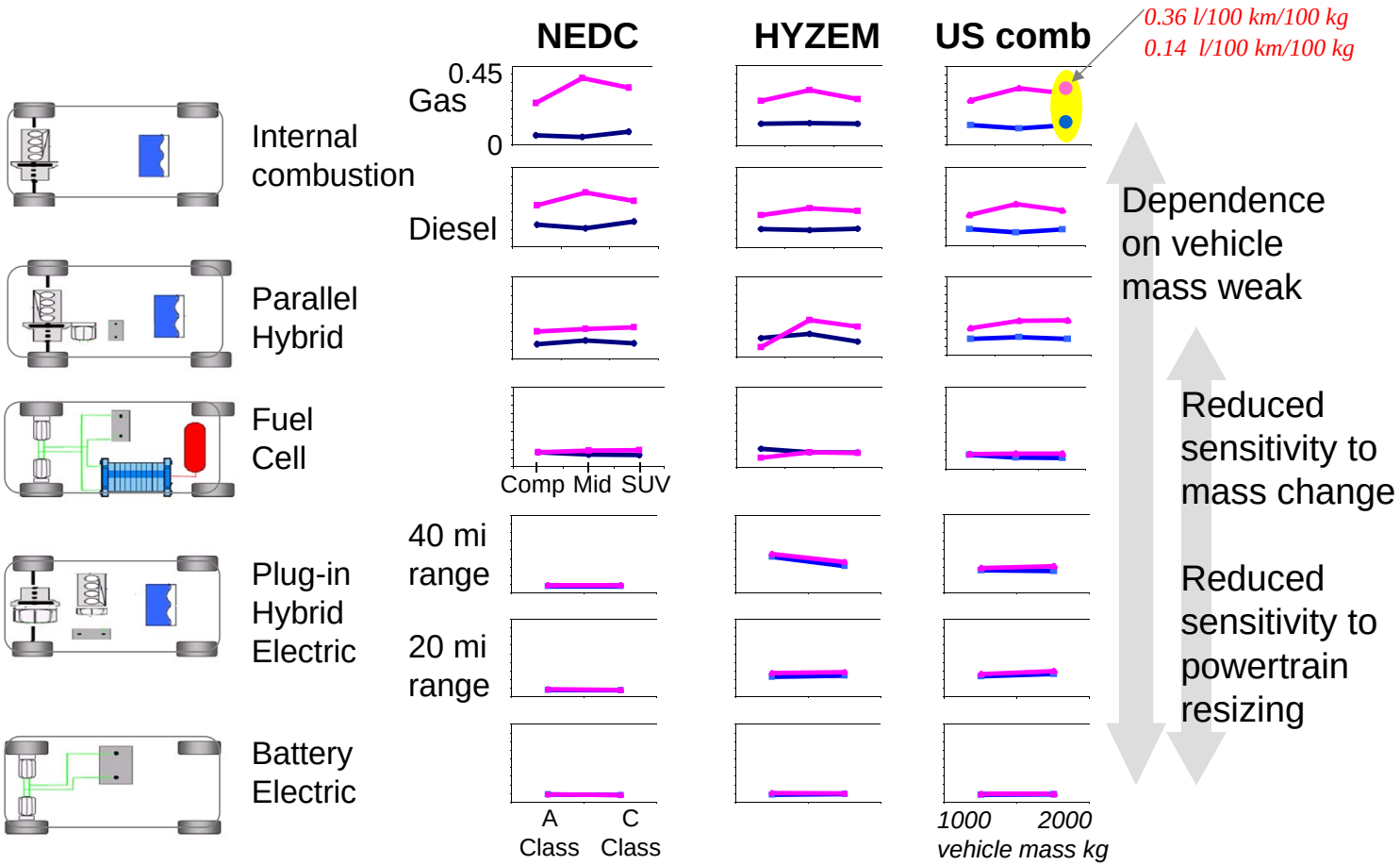
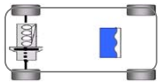
Fuel Reduction Values
liter/100km / 100kg



The Math

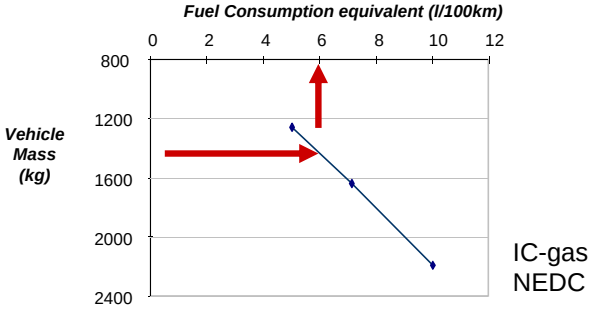
1. set nominal vehicle mass — *1400 kg*

2. select powertrain technology —  *IC-g*

3. select fuel consumption schedule — *NEDC*

4. select a consistent base fuel consumption (energy demand)

using energy demand graphs

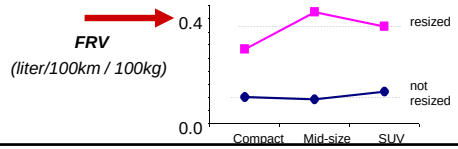


6 l/100km

5. resize nominal vehicle for component mass change — *1410 kg*

6. calculate change in vehicle mass between nominal and resized, ΔM — *10 kg*

7. use FRV to determine change in fuel consumption *Δ fuel consumption= (FRV)*ΔM*



Δfc=(0.4 L/100km/100kg)10 kg= 0.04 L/100km

resized fuel consumption=6+0.04= 6.04 L/100km

Note on Powertrain Resizing

The decision to resize powertrain in response to a vehicle mass change affects two areas

1. The resulting fuel consumption

2. The powertrain mass (secondary mass change)

In the Design Advisor, these areas are entered independently

1. Adjust fuel consumption change

LCA Use sheet>Resize powertrain for equal performance

2. Adjust Powertrain mass for secondary mass change

Mass Compounding sheet>check box for resize subsystem

		Resize powertrain for equal performance *(change fuel consumption)*	
		Yes	**No**
Resize powertrain for Secondary mass change *(change mass of engine)*	**Yes**	*All new engine sized to vehicle*	*No physical application. Useful for sensitivity study.*
	No	*Engine bore and final drive modification without significant powertrain mass change*	*Unchanged powertrain for Nominal and Resized vehicle*

Case Study 4 – Hatchback closure, powertrain influence

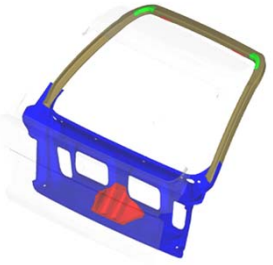
Plans for 20xx vehicle

Hatch door area=1 m²

Vehicle type: Hatchback
L=4.2 m
W=1.750 m
100 kg cargo

New architecture
Internal Combustion-gasoline
- Powertrain is fixed and will not change
- 6. liter/100 km (HYZEM schedule)
- Life time range =*155,000 km*

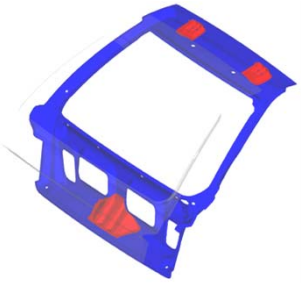
Component: Hatchback closure



Area=1 m²

Original Component

AHSS
Hydroformed
7.81 kg



Area=1 m²

Competitor 1 Component

Aluminum
Stamped
6.77 kg

Case Study 4 – Hatchback closure, powertrain influence

Purpose: To investigate the Use phase GHG analysis, to see how powertrain resizing affects results, to change powertrain and fuels and see how results change

Continue with the Hatchback closure case study

1. Use data for AHSS vs. Aluminum hatchback (Use *regression*, *simple* for secondary mass)
2. Record relative GHG, and material preference based on LCA
3. Click the bar for Use Phase GHG, this will take you to Use Phase GHG, click box ***Resize Powertrain for equal performance***
4. Click back arrow in upper right corner, this will take you back to results. Observe how PT resizing has affected results and record data for the IC-gasoline resized
5. Go back to Size Nominal Vehicle and *change the powertrain to a BEV –make sure you choose the fuel consumption value for BEV using the graph on Size Powertrain sheet*
6. *Repeat steps 3 and 4 for BEV*

Note: On* Mass Compounding *sheet- the powertrain and battery box should be checked (for resize), or unchecked (for no resize)

Powertrain Type	Powertrain Resizing	Fuel consumption Original vehicle / Resized vehicle	Relative LCA GHG (challenger relative to original)
IC-G	No PT resizing	/ *l/100km*	
IC-G	with PT resizing	/ *l/100km*	
BEV	with PT resizing	/ kWh/100 km	
BEV	No PT resizing	/ kWh/100 km	

Case Study 4 – Hatchback closure, powertrain influence

Purpose: To investigate the Use phase GHG analysis, to see how powertrain resizing affects results, to change powertrain and fuels and see how results change

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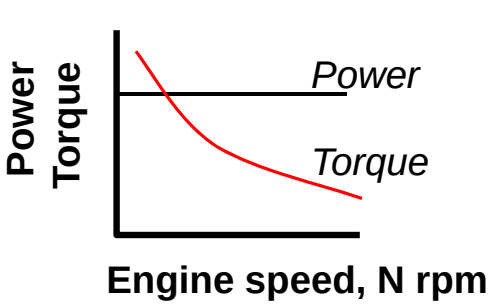
5. Go back to Size Nominal Vehicle and *change the powertrain to a BEV –make sure you choose the fuel consumption value for BEV using the graph on Size Powertrain sheet*
6. *Repeat steps 3 and 4 for BEV* *1.6 l/100km* $_{eq}$

Note: On* Mass Compounding *sheet- the powertrain and battery box should be checked (for resize), or unchecked (for no resize)

PT	Powertrain Resizing	Fuel consumption Original vehicle / Resized vehicle		Relative LCA GHG (challenger relative to original)	
IC-G	No PT resizing	*6 / 5.998*	*l/100km*	*-18.04*	*large*
IC-G	with PT resizing	*6 / 5.996*	*l/100km*	*-7.19*	*difference*
BEV	No PT or battery resizing	*14.167 / 14.161*	*kWh/100 km*	*-18.87*	*small*
BEV	with PT & battery resizing	*14.167 / 14.159*	*kWh/100 km*	*-12.87*	*difference*

Vehicle Powerplant Characteristics

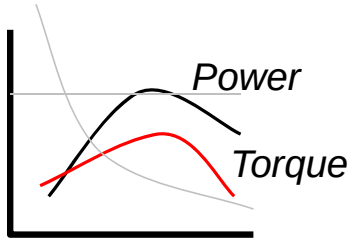
Ideal characteristics



1. Constant power output over usable speed range

2. Torque that peaks at low-speed where traction demands for grade climbing and acceleration are greatest

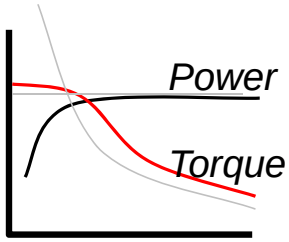
Internal Combustion Engine



Very low torque at low speeds

Requires torque multiplying transmission at low speeds

Series wound Electric Motor



Substantial torque at zero speed

Much closer to ideal

Mechanics of Vehicles, J. Taborek, Machine Design, Chapter 13.