Design Advisor Workshop

Session 6

Greenhouse Gas
Life Cycle Assessment

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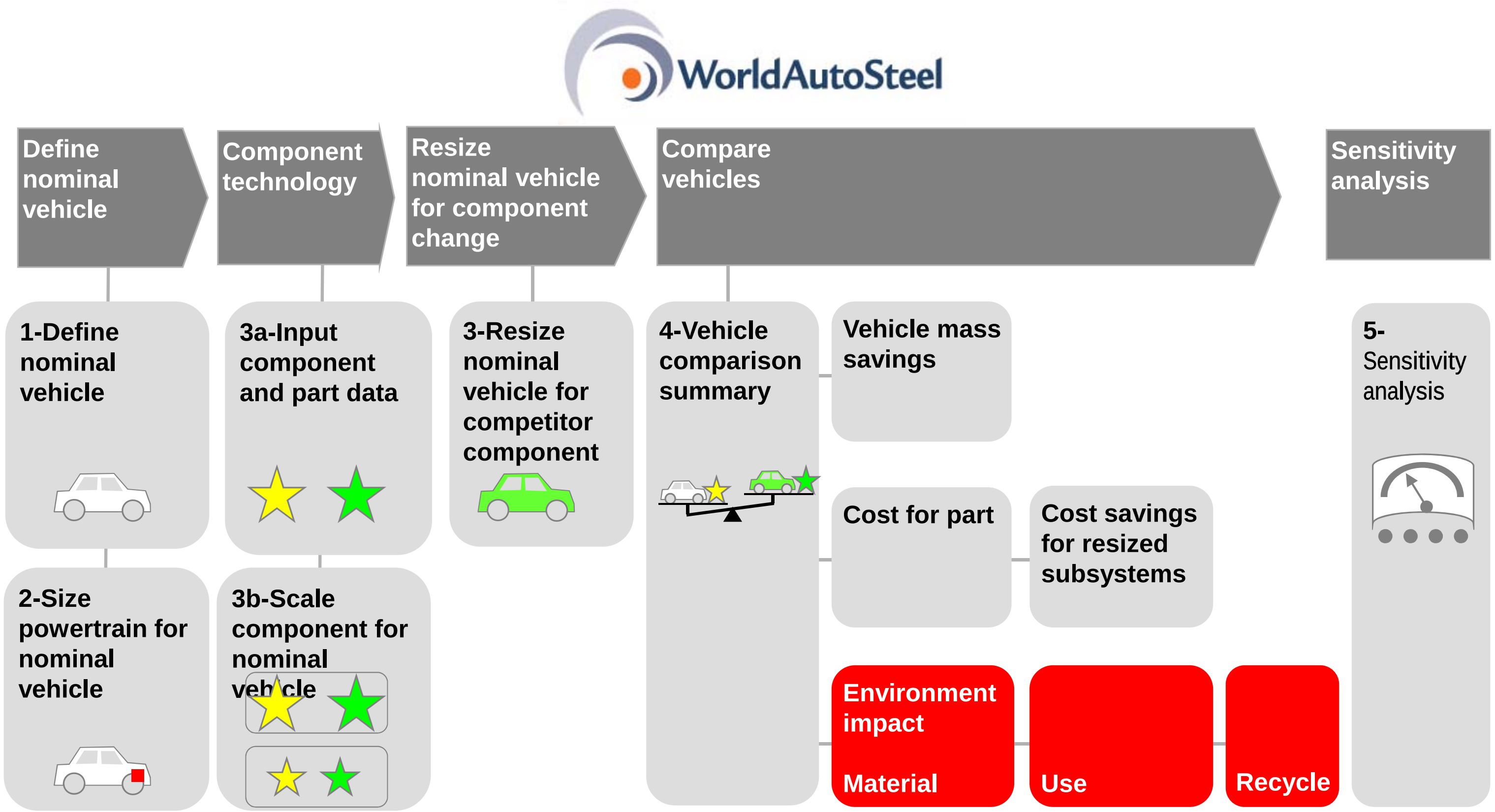
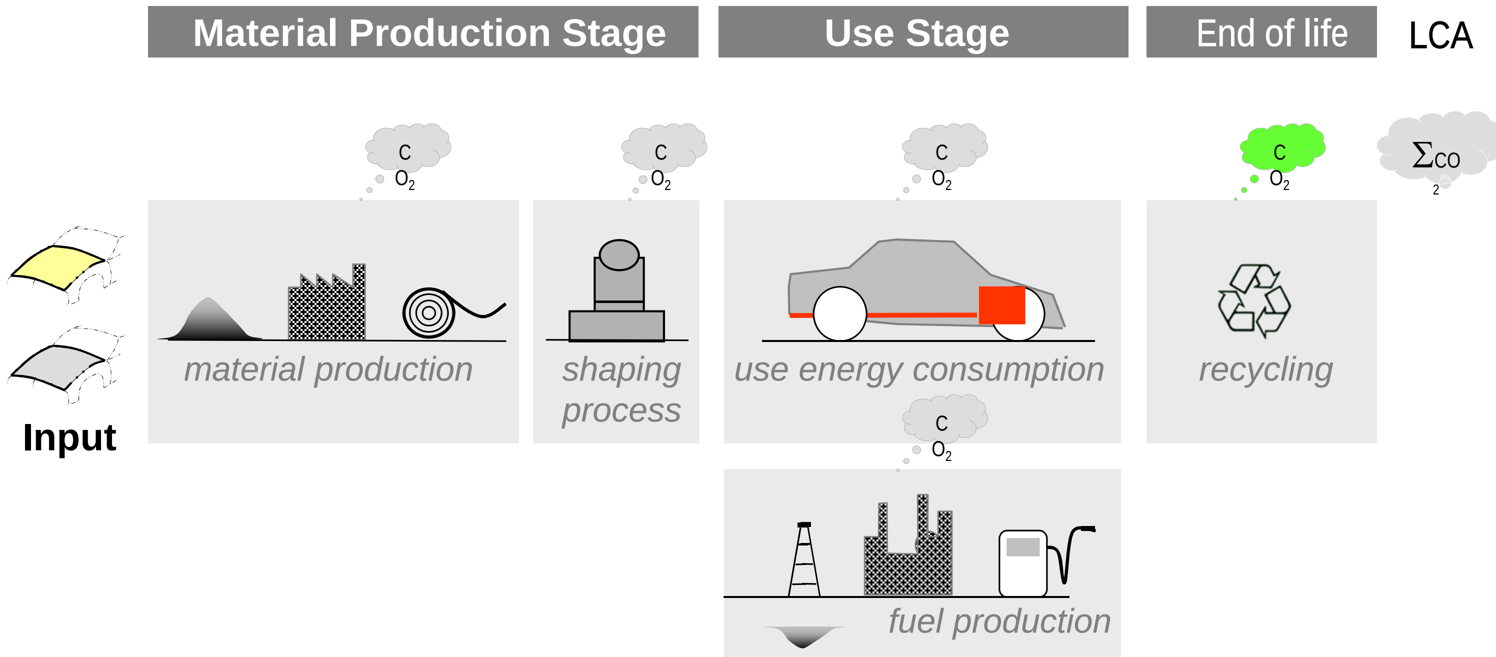
Design Advisor Solution Map



Life Cycle Assessment of Green House Gas



The Math

Use Stage

$$I_{USE} = I_{WELL\_TANK} + I_{TANK\_WHEELS}$$

$$I_{WELL\_TANK} = [i_{FUEL\_PRODUCTION}]R_L(ED)$$

$$I_{TANK\_WHEELS} = [i_{FUEL\_COMBUSTION}]R_L(ED)$$

Where

ED= *Energy demand per unit distance (MJ/100km)*

$ED_{NOMINAL\ VEHCILE}$ *=f(vehicle mass, schedule) from fka simulations*

$ED_{RESIZED\ VEHCILE} = (ED)_{NOM} + (\Delta m)(FRV)$

(Δm) *=Difference in mass between resized and nominal vehicles (kg)*

(FRV) *=Fuel Reduction Value-Change in fuel consumption (MJ/100km/100kg)*

R_L *=life time range (km)*

I_{USE} $=CO_2$ *resulting from vehicle use over life (kg* CO_2eq*)*

$i_{FUEL\_PRODUCTION}$ $=CO_2$ *resulting from production of 1 unit of fuel (kg* CO_2eq/MJ*)*

$i_{FUEL\_COMBUSTION}$ $=CO_2$ *resulting from combustion of 1 unit of fuel (kg* CO_2eq/MJ*)*

note: Gasoline equivalent energy demand (liter/100km)=ED/ $Q_{LHV}^{GASOLINE}$

Q_{LHV} *=Lower Heating Value of fuel (MJ/liter) (for gasoline* Q_{LHV}*=31.88 MJ/liter)*

Correlation- Use Stage CO_2

~500 possible combinations of vehicles, powertrains, fuels, resizing/not resizing ∴sampling used-38

less than 1%

less than 4%

Nominal

	UCSB Model GHG CO2 HYZEM	NEDC	US	UCSB Model MJ total MJ HYZEM	NEDC	US	Design Advisor GHG CO2 HYZEM	NEDC	US	Design Advisor MJ total MJ HYZEM	NEDC	US	CO2 HYZEM	NEDC	US	total MJ HYZEM	NEDC	US
ICEV gas	34675		28778	466873		387478	34662		28789	466682		387616	-0.04%		0.04%	-0.04%		0.04%
ICEV diesel		29992			386775			29938			386081			-0.18%			-0.18%	
ICEV E85	30755			637468			30739			636384			-0.05%			-0.17%		
HEV			21783			293296			21771			293123			-0.06%			-0.06%
FCV		20922			280548			21038			282094			0.55%			0.55%	
BEV	15709			198788			15729			199155			0.13%			0.18%		
150000km																		
PHEV20		13005			170422			13462			176256			3.51%			3.42%	
PHEV40		13858			181609			14380			188286			3.77%			3.68%	

-100kg, 0.3 secondary, No PT Resizing

No PT resizing

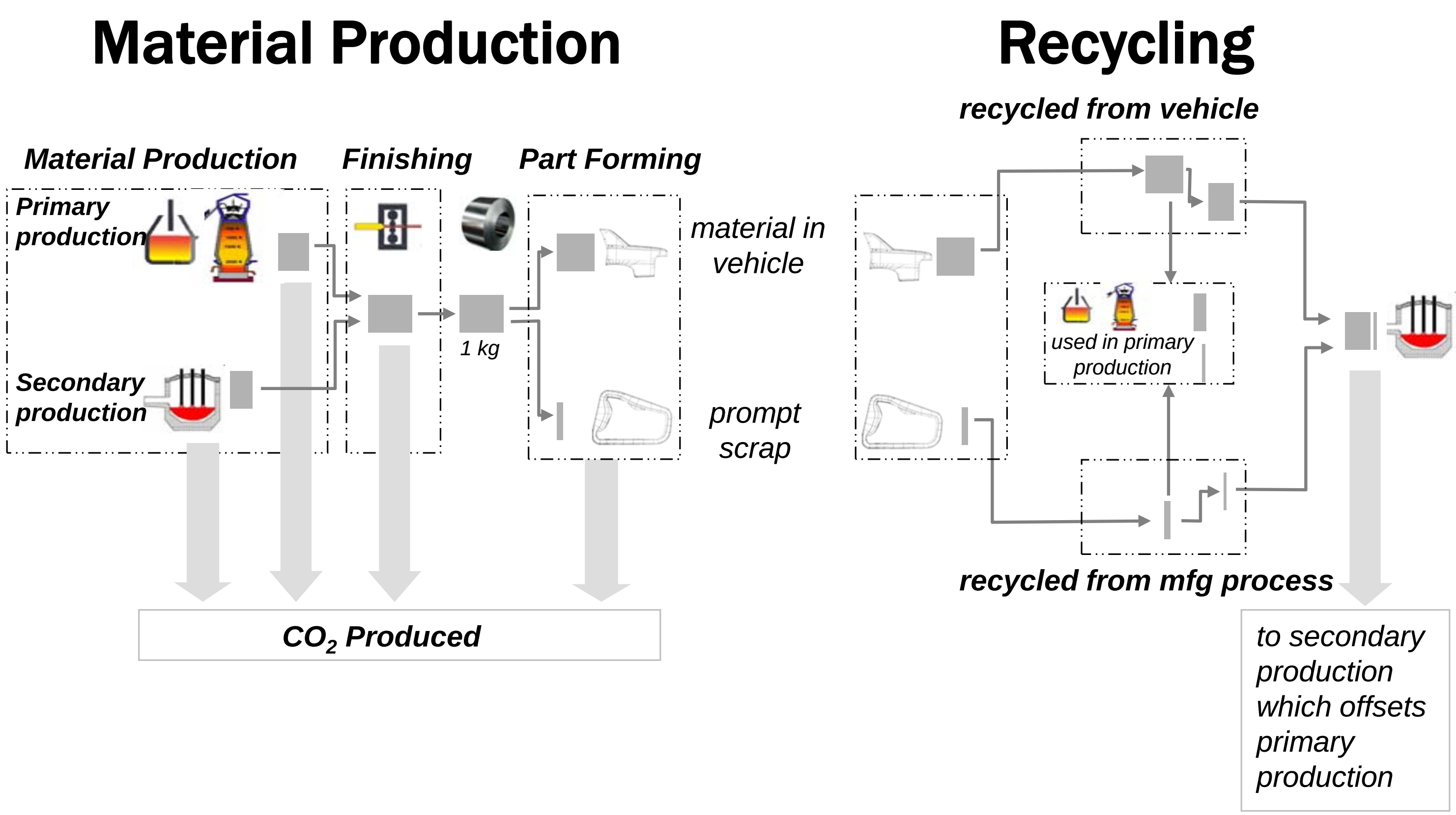
	UCSB Model GHG CO2 HYZEM	NEDC	US	UCSB Model MJ total MJ HYZEM	NEDC	US	Design Advisor GHG CO2 HYZEM	NEDC	US	Design Advisor MJ total MJ HYZEM	NEDC	US	CO2 HYZEM	NEDC	US	total MJ HYZEM	NEDC	US
ICEV gas	33744		27940	454343		376197	33709		28011	453855		377138	-0.10%		0.25%	-0.11%		0.25%
ICEV diesel		28949			373319			28905			372762			-0.15%			-0.15%	
ICEV E85	29930			620359			29894			618893			-0.12%			-0.24%		
HEV			21084			283877			21049			283404			-0.16%			-0.17%
FCV		20020			268445			20254			271587			1.17%			1.17%	
BEV	15088			190932			15088			191040			0.00%			0.06%		
PHEV20		12459			163295			12348			161723			-0.88%			-0.96%	
PHEV40																		

-100kg, 0.3 secondary, With PT Resizing

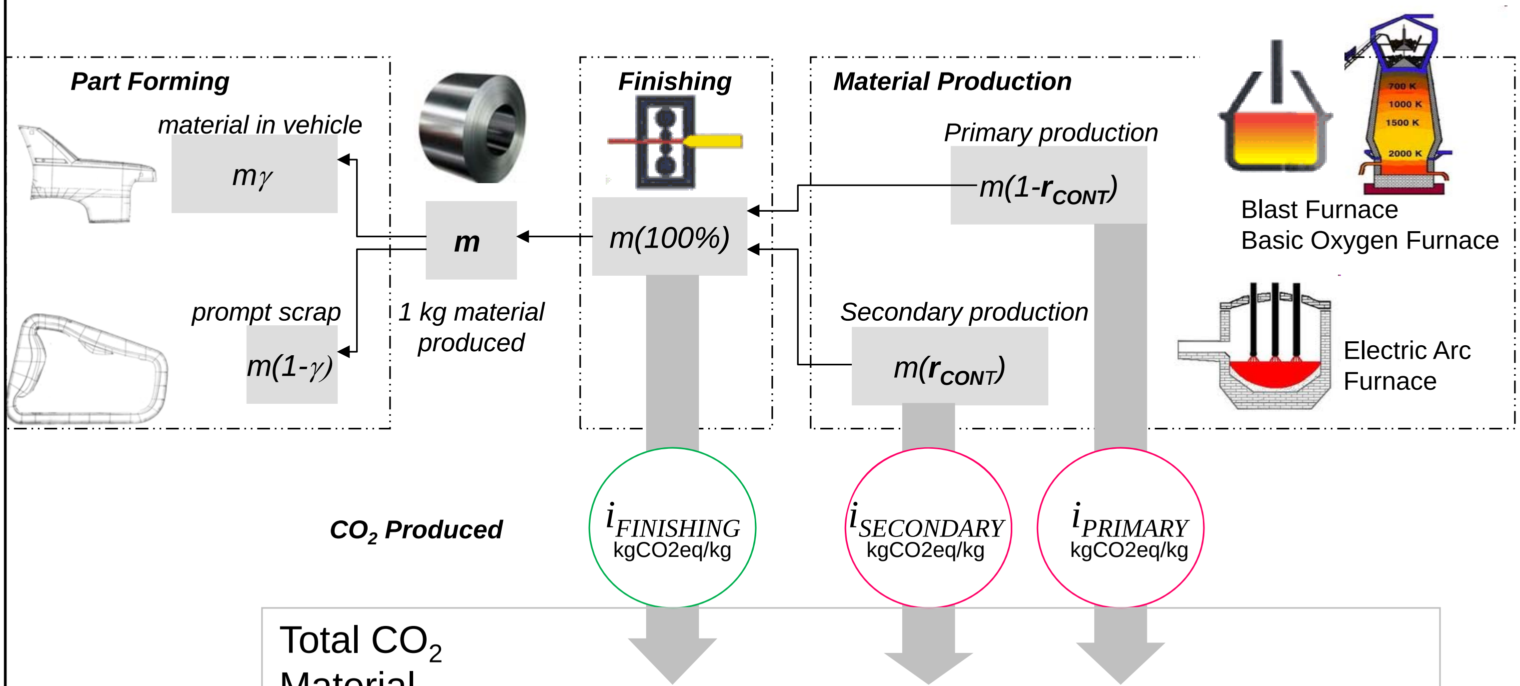
PT resizing

	UCSB Model GHG CO2 HYZEM	NEDC	US	UCSB Model MJ total MJ HYZEM	NEDC	US	Design Advisor GHG CO2 HYZEM	NEDC	US	Design Advisor MJ total MJ HYZEM	NEDC	US	CO2 HYZEM	NEDC	US	total MJ HYZEM	NEDC	US
ICEV gas	32769		26901	441214		362204	32587		26625	438754		358470	-0.55%		-1.03%	-0.56%		-1.03%
ICEV diesel																		
ICEV E85																		
HEV																		
FCV																		
BEV																		
PHEV20																		
PHEV40																		

Material Production and Recycling GHG



Material production



Total CO_2 Material Production= CO_2 Finishing Process + CO_2 Secondary Production + CO_2 Primary Production

r_{CONT} =*Fraction of unfinished material from secondary production*

γ =*Forming yield*

The Math

Material Production Stage

Total CO_2 Material Production =

[CO_2 Primary Production] + [CO_2 Secondary Production] + [CO_2 Finishing Process]

$$I_{MAT} = [m(1 - r_{CONT})i_{PRIMARY}] + [mr_{CONT}i_{SECONDARY}] + [mi_{FINIFSHING}]$$

$$I_{MAT} = m[\underbrace{(1 - r_{CONT})i_{PRIMARY} + r_{CONT}i_{SECONDARY} + i_{FINIFSHING}}]$$

$$I_{MAT} = m[i_{TOTAL\_PRODUCTION}]$$

Where

m =*mass of material produced*

I_{MAT} =CO_2 *resulting from production of m kg of finished material (kg CO_2eq)*

r_{CONT} =*fraction of material from secondary process*

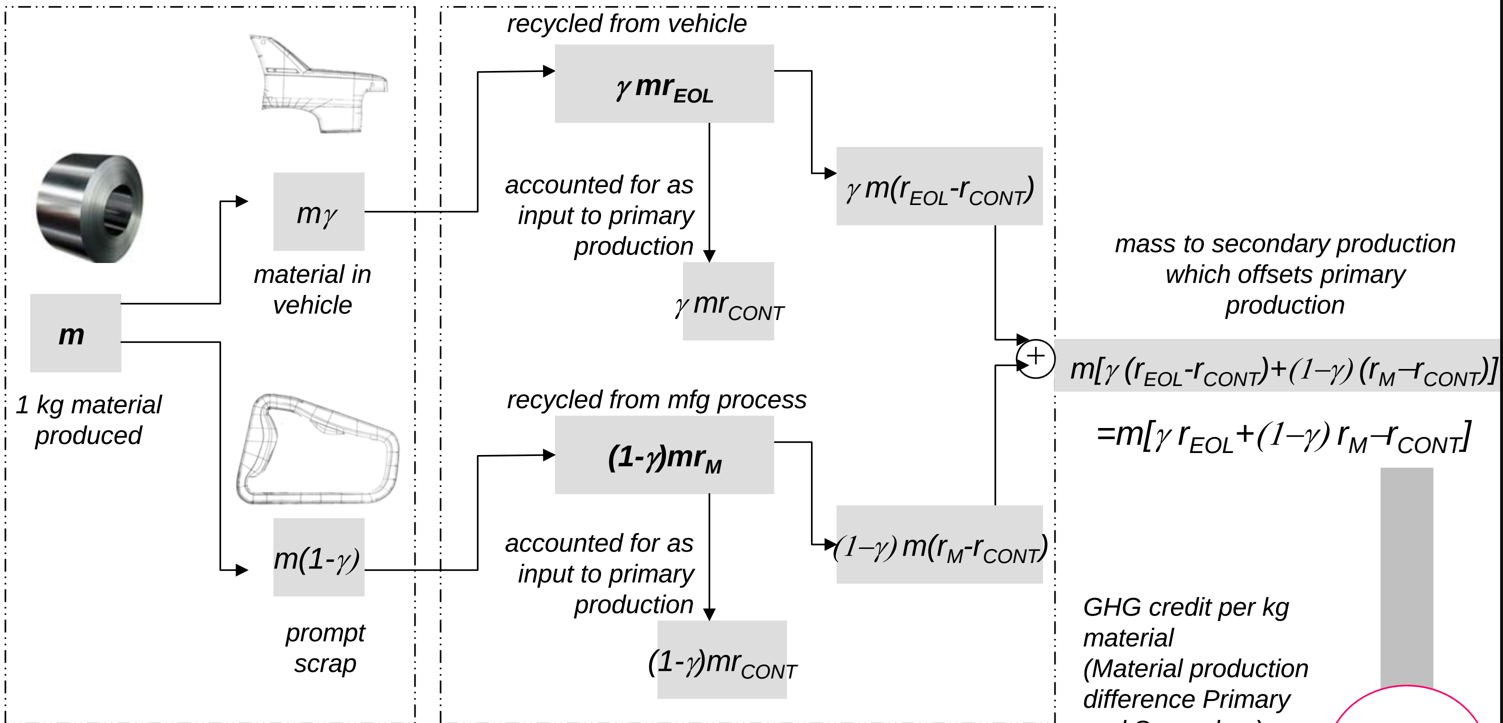
$i_{PRIMARY}$ =CO_2 *resulting from primary production of 1 kg (kg CO_2eq/kg material)*

$i_{SECONDARY}$=CO_2 *resulting from secondary production of 1 kg (kg CO_2eq/kg material)*

$i_{FINISHING}$ =CO_2 *resulting from finishing process of 1 kg (kg CO_2eq/kg material)*

$i_{TOTAL\_PRODUCTION}$=CO_2 *resulting from complete production of 1 kg (kg CO_2eq/kg material) (resource extraction (cradle) to factory gate)*

Material recycle



Where

$I_{RECYCLE}$	$=CO_2$ credit from end of life of $(m\gamma)$ kg of material from vehicle (kg CO_2eq)
r_M	=Prompt scrap recycling rate
r_{EOL}	=recycle rate for vehicle
r_{CONT}	=Fraction of unfinished material coming from secondary production
γ	=vehicle production forming yield (from material mass of m, part mass of $m\gamma$ results)
i_{CREDIT}	=GHG credit per kg material (Material production difference between Secondary and Primary)

The Math

End of Life Stage

$$I_{RECYCLE}=(1-\alpha)\ m[\gamma\,(r_{EOL}-r_{CONT})+(1-\gamma)\ (r_M-r_{CONT})](i_{SECONDARY}-i_{PRIMARY})$$

Where

m	=mass of material produced (kg)
$I_{RECYCLE}$	$=CO_2$ credit from end of life of $(m\gamma)$ kg of material from vehicle (kg CO_2eq)
r_M	=Prompt scrap recycling rate
r_{EOL}	=End of Life recycle rate for vehicle
r_{CONT}	=Scrap input to primary production
γ	=vehicle production forming yield (from material mass of m, part mass of $m\gamma$ results)
i_{CREDIT}	=GHG credit per kg material (Material production difference between Secondary and Primary)
$i_{PRIMARY}$	=Environmental impact of primary material production per unit mass
$i_{SECONDARY}$	=Environmental impact of secondary material production per unit mass

$(1-\alpha)$ =Factor for Consequential System Expansion method, where α=0.1 for all materials
Each kg of scrap reduces scrap collection by 0.1 kg with the remaining 0.9 kg increasing secondary material production resulting in a reduction of primary material production.
(User Guide for Version 3 of the WorldAutoSteel Energy and GHG Model, p 12, R. Geyer, 2012)

WorldAutoSteel

Life Cycle Assessment Case Study
GM/MIT Lift Gate Study

September, 2010

Table 1: GM Liftgate Study: Compact Car, ICE-G, 7L/100km, VCW 1260 kg, Hyzem, 200,000 km, Recycling - alpha = 0.1, no powertrain adjustments

Liftgate Material	Mass	Material	Recycling	Use	Vehicle Life Cycle	Design Advisor
		In kg of CO2eq				
Conv Steel	12.32 kg	2,713	(1,135)	40,103	41,681	42,848
AHSS	7.81 kg	2,691	(1,125)	40,053	41,619	42,793
Aluminium	6.77 kg	2,786	(1,193)	40,041	41,634	42,809
SMC Comp	8.05 kg	2,778	(1,114)	40,055	41,719	42,908

Table 2: GM Liftgate Study: Compact Car, ICE-G, 7L/100km, VCW 1260 kg, Hyzem, 200,000 km, Recycling – alpha = 0.1; Powertrain re-sized for equivalent performance

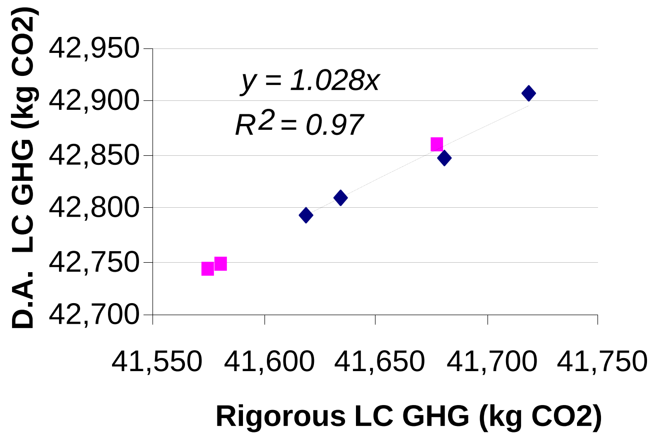
Liftgate Material	Mass	Material	Recycling	Use	Vehicle Life Cycle	Design Advisor
		In kg of CO2eq				
Conv Steel	12.32 kg	2,713	(1,135)	40,103	41,681	42,848
AHSS	7.81 kg	2,691	(1,125)	40,009	41,575	42,742
Aluminium	6.77 kg	2,786	(1,193)	39,987	41,581	42,747
SMC Comp	8.05 kg	2,778	(1,114)	40,014	41,678	42,860

Use vehicle length=4.4m, width=1.7m mass=1269kg

WorldAutoSteel

Life Cycle Assessment Case Study
GM/MIT Lift Gate Study

Correlation of estimates



Pairwise Comparisons

Rigorous no resize

		Conv Steel	AHSS	Alum	SMC
		41,681	41,619	41,634	41,719
Conv Steel	41,681		-62	-47	38
AHSS	41,619			15	100
Alum	41,634				85
SMC	41,719				

Design Advisor no resize

		Conv Steel	AHSS	Alum	SMC
		42,848	42,793	42,809	42,908
Conv Steel	42,848		-55	-39	60
AHSS	42,793			16	115
Alum	42,809				99
SMC	42,908				

Rigorous with resize

		Conv Steel	AHSS	Alum	SMC
		41,681	41,575	41,581	41,678
Conv Steel	41,681		-106	-100	-3
AHSS	41,575			6	103
Alum	41,581				97
SMC	41,678				

Design Advisor with resize

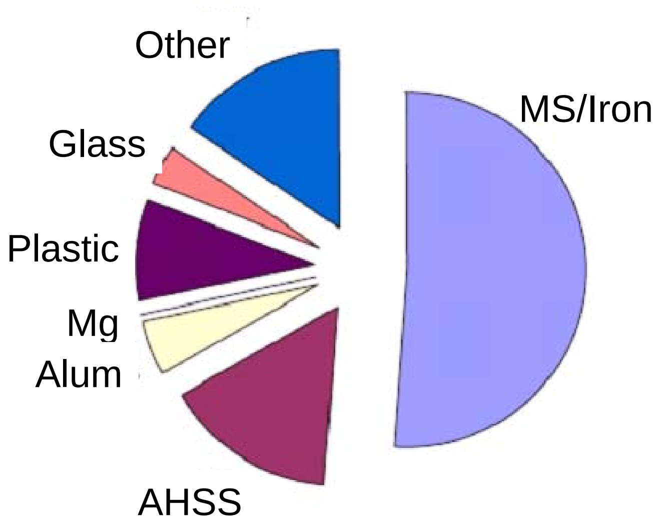
		Conv Steel	AHSS	Alum	SMC
		42,848	42,742	42,747	42,860
Conv Steel	42,848		-106	-101	12
AHSS	42,742			5	118
Alum	42,747				113
SMC	42,860				

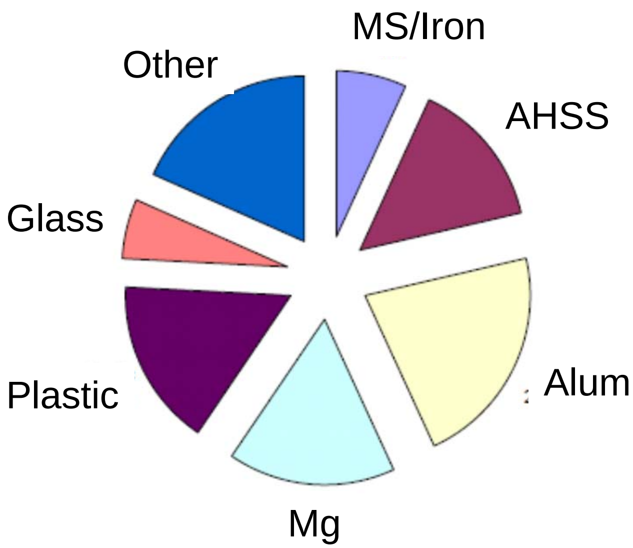
Case Study 5- BOM, Data

An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program, Lotus Engineering Inc., The International Council on Clean Transportation, March 2010, Rev 006A

2009 Toyota Venza
Curb mass=1709 kg
length 4800 mm
width 1900

High Development Vehicle
Curb mass=1060 kg





Case Study 5 – Changing Bill of Materials

Ferrous	Aluminum	Magnesium	Plastics including fiber reinforced	
0.21	0.26	0.16	0.26	
0.63	0.10	0.00	0.16	

advanced material BOM.xls

Reduces Vehicle Mass by 4σ

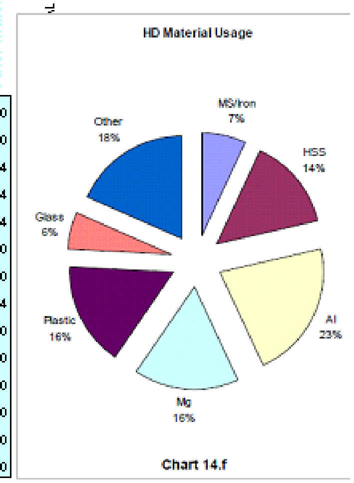
Design Advisor Default

Vehicle Mass as estimated

Case Study 5 – Changing Bill of Materials

Approximation of HDV BOM data provided as Excel sheet

	Conv Steel Flat carbon	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	Battery (electric car)	Other Material
Body Non-structure	0.04	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.20	0.35	0.00	0.19	0.00	0.00	0.00
Body Structure	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.16	0.15	0.00	0.00	0.04	0.20	0.00	0.00	0.00
Front Suspension	0.00	0.00	0.20	0.21	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.14
Rear Suspension	0.00	0.00	0.20	0.21	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.14
Braking	0.00	0.00	0.20	0.21	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.14
Powertrain	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.05	0.45	0.00	0.15	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Fuel & Exhaust	0.75	0.00	0.10	0.00	0.00	0.15	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
Steering	0.00	0.00	0.20	0.21	0.00	0.00	0.00	0.00	0.20	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.14
Tires & Wheels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00
Electrical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cooling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.20	0.00	0.60	0.00	0.00	0.00	0.00	0.00
Bumpers	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Closures	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.33	0.00	0.20	0.10	0.00	0.08	0.00	0.00	0.00
Battery	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	0.00	1.00	0.00
	47.6	0	97.84	105.6	0	7.484	0	153.9	166.9	57.38	146.3	49.21	62.12	146.5	11.33	109.5	61.37		
	0.04	0.00	0.08	0.08	0.00	0.01	0.00	0.12	0.13	0.05	0.12	0.04	0.05	0.12	0.01	0.09	0.05		
						totals for groups-mass kg	259		321			195.53					170.8		



Case Study 5 – Changing Bill of Materials

Component	Vehicle Parameters

Original and competitor Component

Component: Other
Subsystem: Body non-structure
0 kg

Material and process do not matter

Sedan/Hatchback, L=4.8 m, W=1.9 m, no P.T. resize, HYZEM

Conventional BOM

Vehicle mass
+1σ heavier than average

Run 1 ***IC-Gasoline***

Run 2 ***IC-Diesel BioDiesel fuel***

High Development BOM

Reduced vehicle mass by
-4σ relative to average

Run 3 ***IC-Gasoline***

Run 4 ***IC-Diesel BioDiesel fuel***

Purpose: To see how an advanced BOM affects GHG,
to see how advance powertrains and fuel changes the preferred materials

1. ***Input component data***
   Components and parts will have zero mass

2 ***Set Nominal Vehicle***
   Set dimensions to those given (select *1σ* above average mass)
   Leave BOM at default values
   Select IC gasoline


Comparison Summary - Difference between Nominal & Resized Vehicles
WorldAutoSteel
values are resized vehicle relative to nominal vehicle
relative performance
resized vehicle worse
resized vehicle better
Vehicle Mass kg
component mass 0.00
subsystem mass 0.00
total change 0.00
Vehicle Cost $
product cost part cost
subsystem cost
life time fuel savings $0.00
total $0.00
Life Cycle CO2 kg
LCA Material part CO2 0.00
subsystem CO2 0.00
LCA use 0.00
LCA recycle 0.00
total 0.00
For detailed result in each area click grey dot or bar
Trade-off Ratios
#DIV/0!
kg mass
kg CO2
$
Mass change
kg CO2
kg
-Cost is product cost
-Up and to the right indicates resized vehicle is
Life Cycle CO2 kg eq
40000
20000
0
nominal
resized
Recycle -8370.15 -8370.15
Use 10376.11 10376.11
Material production 20832.94 20832.94
Total 22838.89 22838.89

3. ***Size powertrain***

a. Select 155,000 km life time range
b. Select gasoline
c. Choose HYZEM
d. Determine fuel consumption from graph (also shown on case study sheet)

--Go to ***Vehicle Comparison Summary*** and record GHG results for nominal vehicle onto data sheet—

4. Repeat steps 2 to 3 for Diesel with Biodiesel fuel (This is done first with conventional BOM) . Be sure to size the powertrain fuel consumption on the size powertrain sheet-step 3b and 3d

6. Now open the spreadsheet ***advanced material BOM.xls*** and copy the blue range representing a high development BOM

7. Go to Design Advisor, ***Set Nominal Vehicle*** sheet and paste this into the blue range to change the BOM. Also set ***Std. dev. from average curb mass*** to *-4*
8. Now repeat steps 3 to 5 for the advance BOM

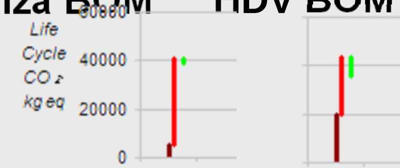
	IC-Gas		**Bio Diesel**	
	conventional BOM	High Dev BOM	conventional BOM	High Dev BOM
	m+1σ	*m-4σ*	*m+1σ*	*m-4σ*
Recycle				
Use				
Material				
LC GHG				

Case Study 5 – Changing Bill of Materials

	Venza BOM	HDV BOM

Updated

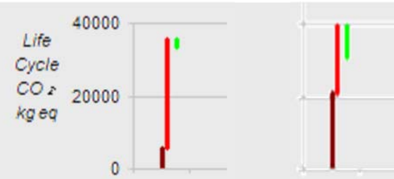
Gasoline IC



	Venza BOM: 8 l/100km	HDV BOM: 5.3 l/100km
	nominal	nominal
Recycle	-2000.18	-7909.04
Use	35521.12	23532.74
Material production	5593.87	19686.89
Total	39114.81	35310.59

Diesel IC

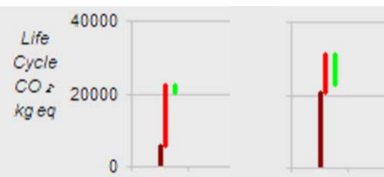
diesel fuel



	Venza BOM: 6 l/100 km	HDV BOM: 3.8 l/100 km
	nominal	nominal
Recycle	-2107.35	-8370.15
Use	29556.86	18719.34
Material production	5919.70	20832.94
Total	33369.21	31182.13

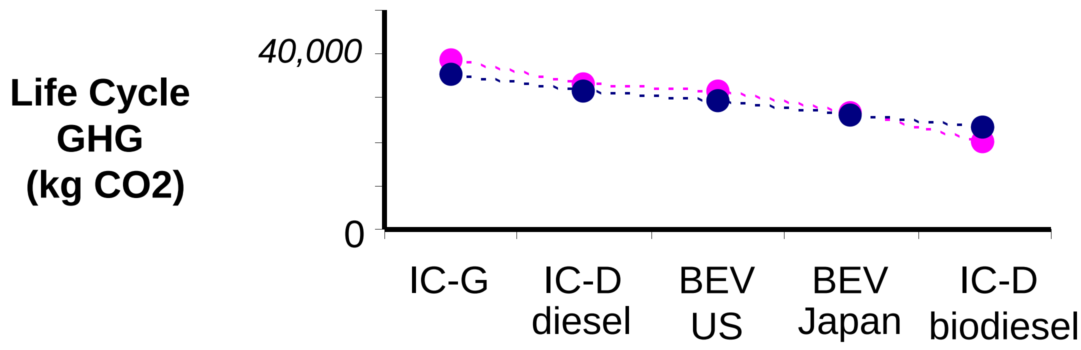
Diesel IC

bio diesel fuel



	Venza BOM: 6 l/100 km	HDV BOM: 3.8 l/100 km
	nominal	nominal
Recycle	-2107.35	-8370.15
Use	16383.33	10376.11
Material production	5919.70	20832.94
Total	20195.68	22838.89

Case Study 5 – Changing Bill of Materials



Venza ●	*8 l/100km* *1680 kg*	*5.3*	*2*	*2*	*5.3*
HDV ●	*6 l/100 km* *1020 kg*	*3.8*	*1.4*	*1.4*	*3.8*