Vehicle materials modelling in the IEA Mobility Model

Jacob Teter and Tiffany Vass

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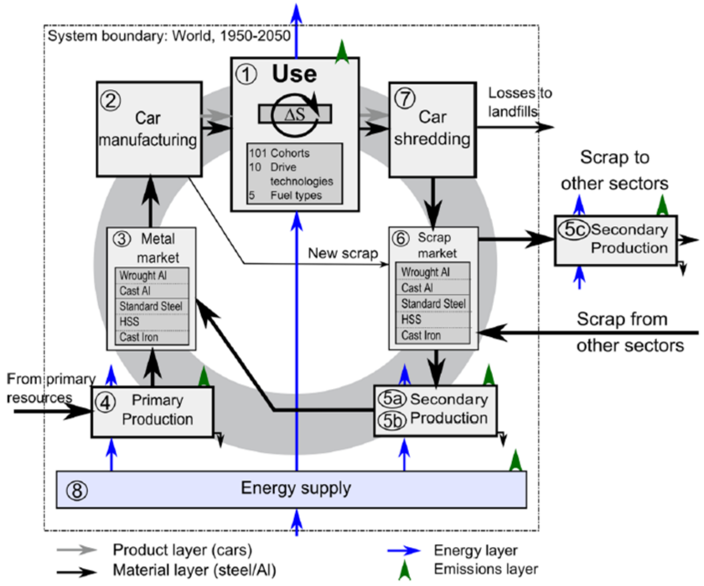
Vehicle materials modelling

Bottom-up
- Focus on light-duty passenger vehicles (passenger cars, light trucks)
- HDVs (trucks and buses) – structure adopted from LDVs
- Rail, ships, aircraft TBD

Top-down
- Focus on Steel and Aluminum



Source: Modaresi et al., 2014

Comparing the approaches – initial results

Future material use – in the *Reference* and *Low-Carbon Scenarios*

Key remaining uncertainties and areas for improvement

The IEA Mobility Model and estimation of materials requirements

Historic regional sales data:
- 27 countries and regions (G20 coverage)
- Passenger Cars & Light Commercial Vehicles

LDV materials estimates:
- Based on GREET
- Differences across regional markets

HDV materials update:
- Builds upon the LDV materials module
- Also draws upon 2015 Ricardo-AEA study

No detailed modelling of materials requirements for other modes
- aircraft, rail cars, ships

- **MoMo must balance national & regional detail with global data coverage**
- **<u>Key parameters</u>: vehicle sales & scrappage and infrastructure build-out, maintenance, and retirement**
- **MoMo members inform modelling and ensure model is maintained and developed**

Light-duty vehicles (LDVs) – sales and material composition

Summary of material composition (current products, 2015, passenger cars)   [upper:body   middle:Conventional PT(ICE)   lower: Electric PT(Motor)]

		Gasoline ICE		Gasoline HEV		Diesel ICE		Diesel HEV		LPG/CNG		FCV		EV		Plug-in Gasoline HEV		Plug-in Diesel HEV	
	Ferrous Metals	73.240%	53.3%	71.2%	49.9%	73.2%	53.3%	71.2%	49.9%	73.2%	53.3%	63.6%	54.6%	55.3%	47.9%	63.4%	43.1%	63.4%	43.1%
			20.0%		18.9%		20.0%		18.9%		20.0%		0.0%		0.0%		17.9%		17.9%
			0.0%		2.3%		0.0%		2.3%		0.0%		9.0%		7.4%		2.4%		2.4%
	Aluminum	6.4%	0.6%	7.0%	0.5%	6.4%	0.6%	7.0%	0.5%	6.4%	0.6%	5.9%	0.6%	9.3%	0.5%	9.6%	0.5%	9.6%	0.5%
			5.8%		4.2%		5.8%		4.2%		5.8%		0.0%		0.0%		3.7%		3.7%
			0.0%		2.3%		0.0%		2.3%		0.0%		5.3%		8.8%		5.4%		5.4%
	Copper	1.9%	1.2%	3.9%	1.1%	1.9%	1.2%	3.9%	1.1%	1.9%	1.2%	3.4%	1.2%	6.7%	1.0%	5.8%	0.9%	5.8%	0.9%
			0.7%		1.5%		0.7%		1.5%		0.7%		0.0%		0.0%		1.4%		1.4%
			0.0%		1.4%		0.0%		1.4%		0.0%		2.2%		5.7%		3.5%		3.5%
	CFRP	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		6.0%		0.0%		0.0%		0.0%
Battery	NiMH battery	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
			0.0%		0.8%		0.0%		0.8%		0.0%		0.0%		0.0%		0.0%		0.0%
	Li-ion battery	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	11.9%	0.0%	6.3%	0.0%	6.3%	0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.4%		11.9%		6.3%		6.3%
	Plastics	11.3%	8.8%	10.6%	7.9%	11.3%	8.8%	10.6%	7.9%	11.3%	8.8%	12.1%	8.9%	10.4%	7.4%	9.2%	6.5%	9.2%	6.5%
			2.6%		1.9%		2.6%		1.9%		2.6%		0.0%		0.0%		1.8%		1.8%
			0.0%		0.9%		0.0%		0.9%		0.0%		3.2%		2.9%		0.9%		0.9%
	Glass	3.0%	3.0%	2.7%	2.7%	3.0%	3.0%	2.7%	2.7%	3.0%	3.0%	3.0%	3.0%	2.5%	2.5%	2.2%	2.2%	2.2%	2.2%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
			0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%		0.0%
	Others	4.2%	3.3%	3.8%	3.0%	4.2%	3.3%	3.8%	3.0%	4.2%	3.3%	5.5%	3.3%	3.9%	2.9%	3.6%	2.6%	3.6%	2.6%
			0.9%		0.5%		0.9%		0.5%		0.9%		0.0%		0.0%		0.5%		0.5%
			0.0%		0.3%		0.0%		0.3%		0.0%		2.1%		1.0%		0.6%		0.6%
	TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: ANL, GREET2 2017

- **Annual vehicle sales taken from publically available data**
- **Materials composition from GREET (US focus based on Dai, Kelly & Elgowainy, 2016)**

Key regional and powertrain specific characteristics

Regional Passenger Car (PC) kerb weights

Gasoline car weight by region (kg) (not including LT)			
	2005	2010	2015
OECD_NA	1662	1623	1517
OECD_Europe	1373	1401	1375
OECD_Pac & Others	1513	1441	1447
RUS & ATE	1522	1457	1490
East_Eur (EU6+OETE)	1528	1474	1478
China	1368	1495	1506
Oth_Asia(ASEAN + ODA)	1481	1486	1461
India	1097	1320	1323
Mid_East	1528	1474	1425
Lat Am (BRA, OCSA)	1393	1398	1423
Africa	1469	1506	1468

Global PC:LT kerb weight ratios by powertrain

Weight ratio by type	
Gasoline=1.0	
Gasoline	1.00
GHEV	1.21
Diesel	1.14
DHEV	1.21
LPG/CNG	0.97
FCV	1.27
EV	1.11
P-GHEV	1.30
P-DHEV	1.30

Global PC to Light Truck kerb weight ratios

	Gasoline ICE	**Gasoline HEV**	**Diesel ICE**	**Diesel HEV**	**LPG/CNG**	**FCV**	**EV**	**Plug-in**
Total	**1.18**	**1.09**	**1.17**	**1.09**	**1.30**		**1.02**	**1.02**
Ferrous Metals	1.19	1.10	1.18	1.10	1.31	1.01	0.98	1.03
Aluminum	1.08	1.04	1.08	1.04	1.19	1.04	1.07	1.04
Copper	1.16	1.07	1.16	1.07	1.28	1.02	1.00	1.05
CFRP						1.03		
NiMH battery		1.41		1.41				
Li-ion battery						1.19	1.29	1.27
Plastics	1.15	1.07	1.14	1.07	1.26	0.93	0.93	0.81
Glass	1.15	1.06	1.15	1.06	1.27	0.88	0.93	0.68
Others	1.19	1.11	1.18	1.11	1.31	1.00	1.00	1.04

- **Sales-weighted parameters extracted from *Global Fuel Economy Initiative* (GFEI) database**
- **Modelling captures: sales-weighted kerb weights; kerb weight ratios (by powertrain-fuel type); TBD**

HDVs – material composition

Ricardo-AEA designation		IEA Mobility Model
Heavy van (5t GVW)	→	LCV (< 3.5 t GVW)
Rigid truck (12t GVW)	→	MFT (3.5 – 15 t GVW)
Artic truck (40t GVW)	→	HFT (> 15 t GVW)
City bus (12t GVW)	→	Minibus
Coach (19t GVW)	→	Bus

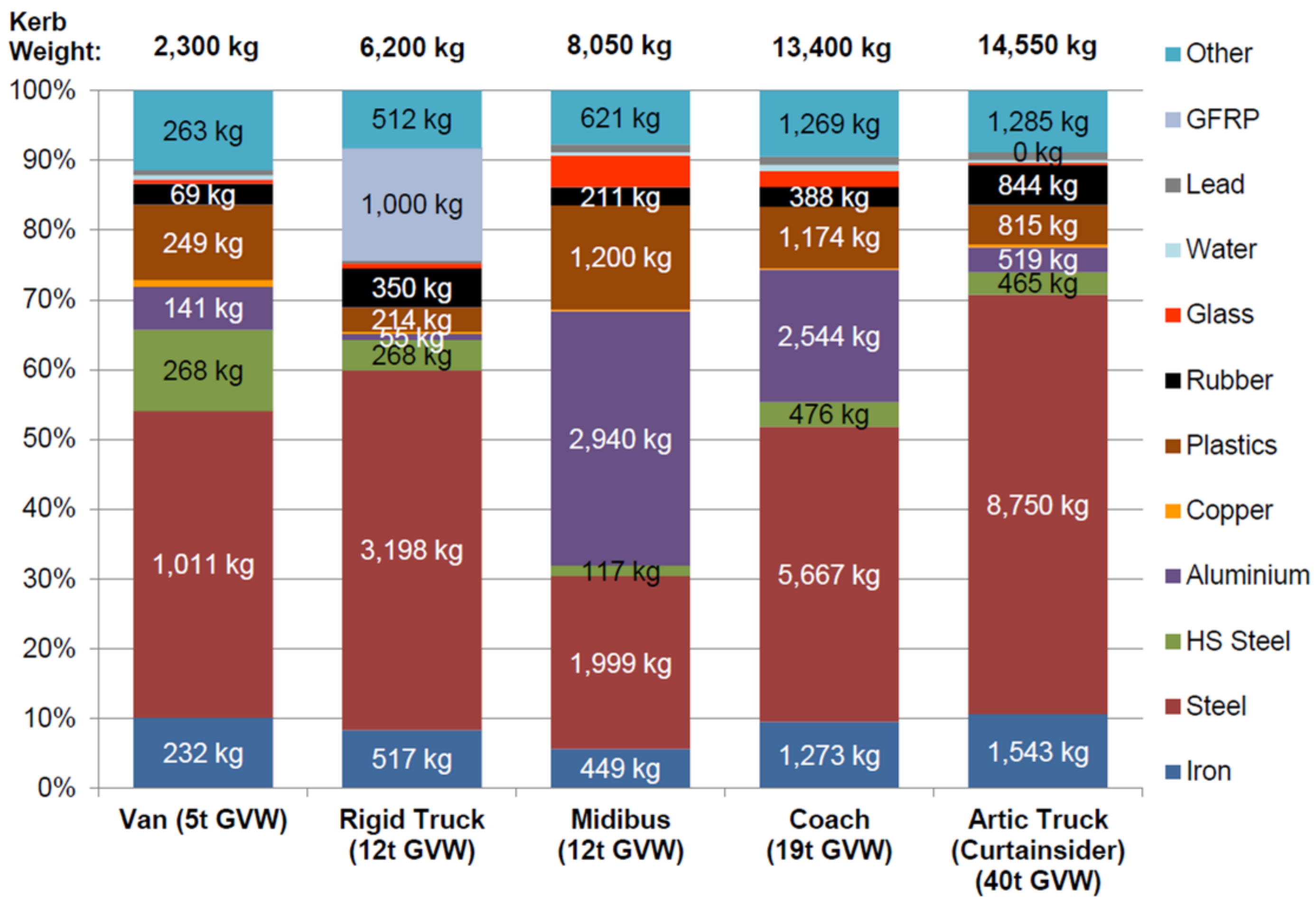


Figure 2.5: Breakdown of vehicle composition by material type

Main data source: **“Lightweighting as a means of improving Heavy Duty Vehicles’ energy efficiency and overall CO_2 emissions” (Ricardo-AEA, 2015)**

Key limitations

Material mass shares based on GREET 2016

- Weights and powertrain shares based on regional data
- Actual material composition shares likely more dependent on regulatory environment and consumer preferences
- Definition / split of *Passenger Cars* versus *Light Commercial Vehicles* also regionally specific (subject to data availability)

Uncertainties

- *Bottom-up*: evolution of material shares over time also varies across regions
- *Top-down*: steel disaggregation from four sector categories:
    - Transportation (vehicles); Machinery; Construction (infrastructure); Products

Scenarios - key sensitivity parameters include:

- Capacity for avoid-shift strategies to delivers (and "ACES" evolutions)
- Regulatory developments (e.g. ICE & diesel bans, electrification targets & support)
- Speed and extent of electrification in various regional markets
- Lightweighting and material substitution strategies

Projections – Low Carbon Scenario (2DS)

Near-term (Present - 2025):

Taken from U.S. DOE – Vehicle Technologies Office 2016 targets

- 30% weight reduction from 2012 baseline for LDVs by 2022
- Primarily achieved through advanced high-strength steel (AHSS) & aluminum (Al)
- Also limited uptake of carbon fiber reinforced plastic (CFRP) and magnesium
- All have the potential of mass production by 2025
- Material compositions of recent studies (by EPA & NHTSA) have been incorporated into GREET

Mid- to Long-term (2025-2050):

Taken from U.S. DOE – Vehicle Technologies Office 2013 targets (for 2050)

- 50% reduction in kerb weight of entire vehicle from 2010 baseline
- Excludes BEV penetration weight effects on brakes, fuel/exhaust systems)
- Content of magnesium and CFRP predicted to increase in next few decades

Based on recent targets (DOE VTO 2013 & 2016)
and analyses (EPA 2012 and 2015; NHTSA 2012 – both incorporated into GREET)

HDV Projections

Default lightweighting scenario

Default	Baseline (2015)	2020	2025	2030	2040	2050
Trucks, Urban	0.0%	1.2%	2.1%	2.7%	3.0%	3.0%
Trucks, Utility	0.0%	1.5%	1.6%	1.8%	1.8%	1.8%
Trucks, Regional	0.0%	1.1%	1.9%	2.3%	2.3%	2.4%
Trucks, Construction	0.0%	1.4%	3.1%	3.7%	4.4%	4.9%
Trucks, Long Haul	0.0%	0.8%	1.6%	1.7%	2.1%	2.2%
Trucks <7.5t (All Cycles)	0.0%	0.8%	1.9%	2.2%	2.5%	2.6%
Trucks 7.5-16t (All Cycles)	0.0%	1.6%	2.6%	3.1%	3.5%	3.6%
Trucks 16t-32t (All Cycles)	0.0%	1.3%	2.3%	2.6%	2.7%	2.8%
Trucks >32t (All Cycles)	0.0%	0.8%	1.3%	1.7%	2.2%	2.4%
Bus	0.0%	2.8%	5.8%	6.6%	6.6%	17.1%
Coach	0.0%	0.8%	0.9%	1.4%	1.2%	1.6%
Average all HDVs	*0.0%*	*1.1%*	*2.0%*	*2.4%*	*2.6%*	*3.3%*
Average Trucks	*0.0%*	*1.1%*	*1.9%*	*2.2%*	*2.6%*	*2.7%*
Average Buses/Coaches	*0.0%*	*1.6%*	*2.8%*	*3.4%*	*3.3%*	*7.5%*

Calculated cost-effective weight reduction potential (%) versus 2015 baseline

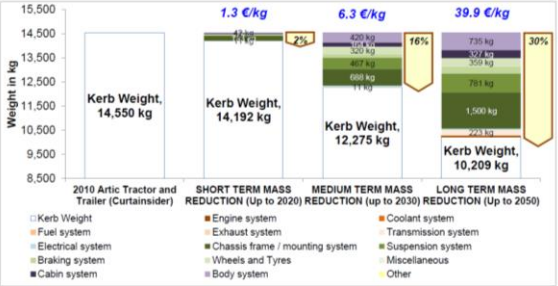
Vehicle type	2020	2025	2030	2040	2050
Average Truck	**4.1%**	**7.4%**	**8.6%**	**9.8%**	**10.2%**
Urban	4.4%	8.4%	10.3%	11.5%	11.8%
Utility	3.7%	4.0%	4.6%	4.6%	4.6%
Regional	4.9%	8.6%	9.9%	10.1%	10.2%
Construction	3.8%	8.2%	9.9%	12.0%	13.5%
Long Haul	4.1%	7.6%	8.0%	10.1%	10.6%
Average Bus	**2.8%**	**4.2%**	**5.4%**	**5.1%**	**10.5%**
Bus	3.5%	7.1%	8.0%	8.0%	20.5%
Coach	2.3%	2.4%	3.8%	3.3%	4.2%

Key sensitivities (modelled as a change of ±25%):

(1) Reduction in cost of lightweighting measures
(2) Share of weight limited operations
(3) Annual mileage assumption
(4) Fuel prices

Figure 2.6: large van

Figure 2.8: articulated truck



- **Lightweighting & material substitution based on potential estimated in Ricardo-AEA 2015**
- **Powertrain shifts based on 'The Future of Trucks' (IEA, 2016)**

Uncertainties and key areas for development

- **Key historic parameters & modelling assumptions**
  (e.g. current approach for LDVs / HDVs, development of methods for shipping, rail cars, aviation)

- **Parameters & modelling assumptions for future scenario projection**
  (e.g. capacity for lightweighting via HSS and AHSS, Aluminum, CFRP)

- **Regional Differences in materials composition by region**
  (e.g. due to fuel economy or safety standards; or consumer preferences, expectations & purchasing power)

- **Capacity for improvement in manufacturing yields**
  - <u>Room for improved manufacturing yields in vehicle manufacturing?</u>
    (e.g. yields tend to increase from steel to HSS to AHSS – what potential exists for each of these to improve further, and to what extent does substitution lead to higher manufacturing yields?)
  - <u>Design (modularity / alloys) that can be more easily recovered / recycled</u>
    (and more economically / flexibly reused not only for buildings but also for vehicles)

We aim to follow-up on specific areas with experts on a targeted basis, above are two examples