THE EVALUATION OF VEHICLE MASS REDUCTION AND MATERIAL CHOICE IN LIFE CYCLE ASSESSMENTS

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SAE INTERNATIONAL

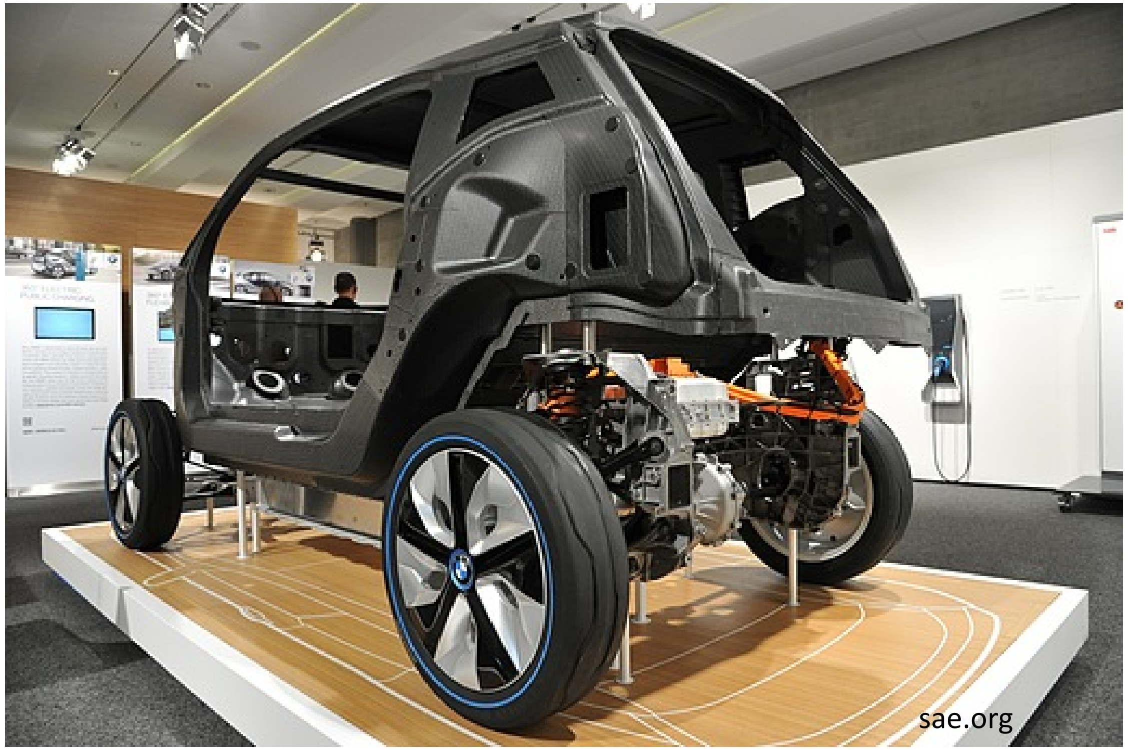
EPA United States Environmental Protection Agency

Overview

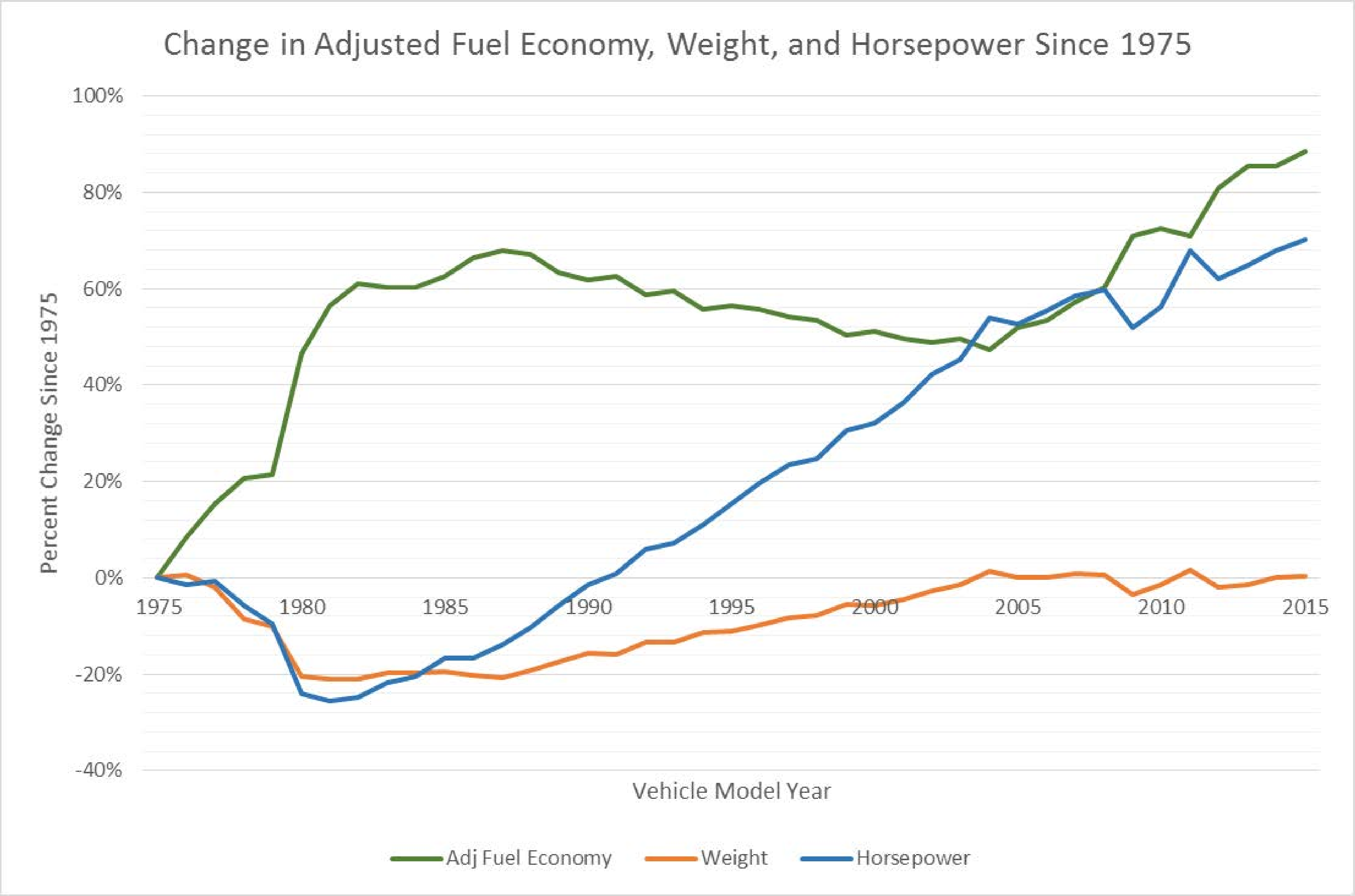
- The role of vehicle mass reduction (VMR) in improving fuel economy
- Life cycle assessment (LCA) as a tool to understand impacts of changing materials and designs
- Results of a literature review of LCAs of VMR
- Six key factors in LCAs for VMR
- Final thoughts for LCA moving forward

Based on work in review titled: “Critical factors affecting life cycle assessments of material choice for vehicle mass reduction”

Vehicle Mass Reduction in the Market

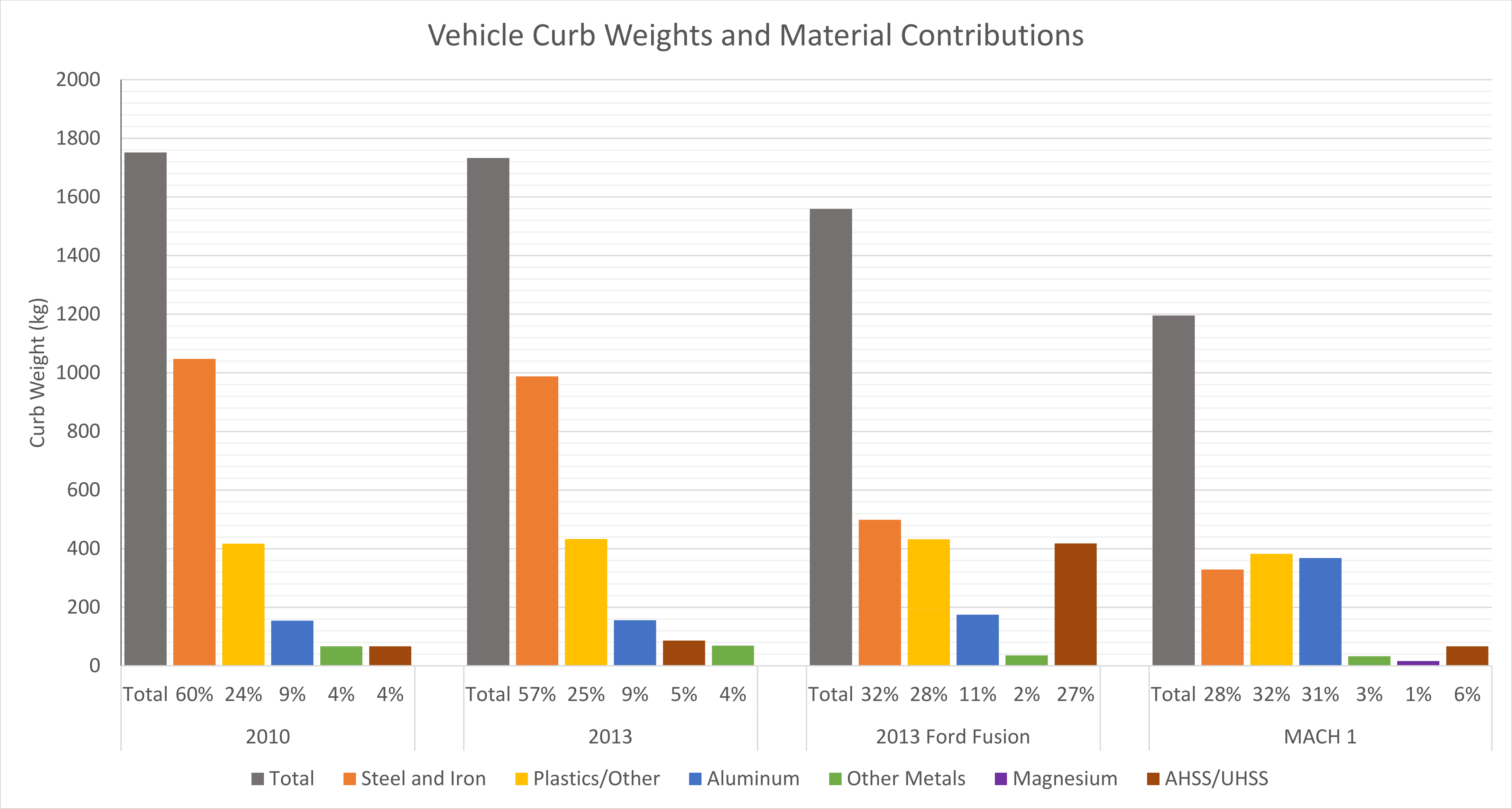


Fuel Economy and Weight Trends



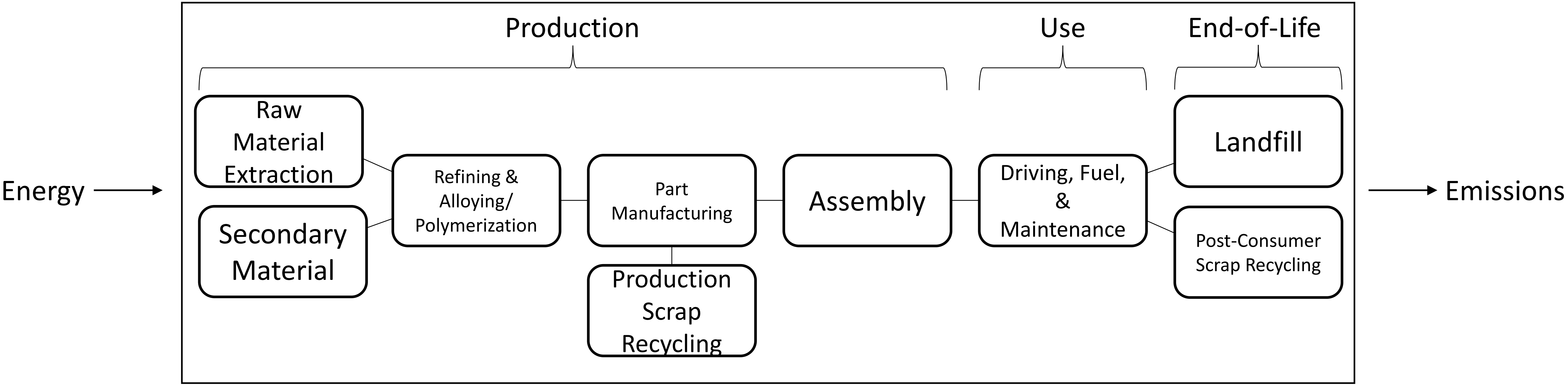
Based on data from: Hula, A., A. Bunker, and J. Alson, *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2015*. 2015, United States Environmental Protection Agency.

Materials and Designs



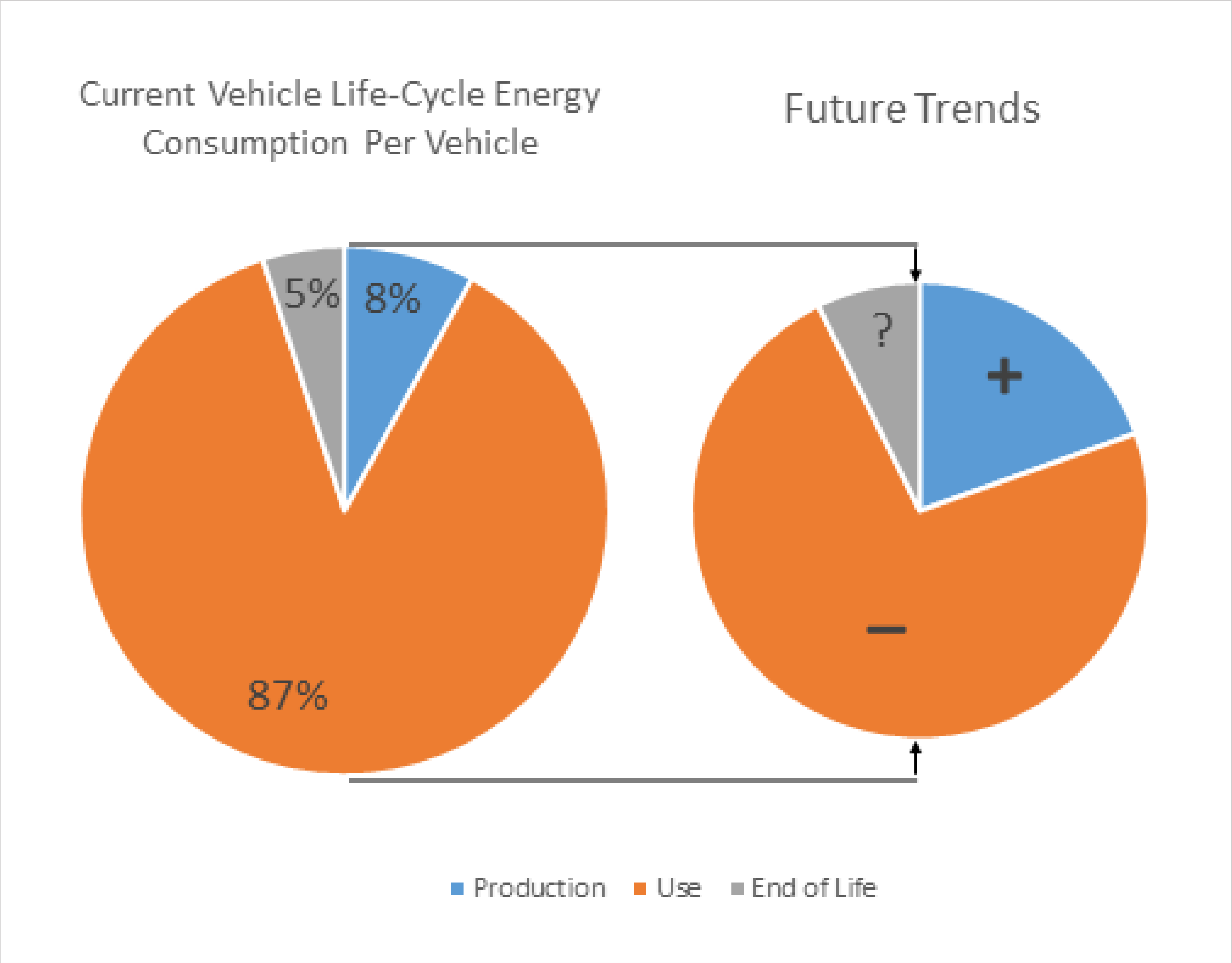
Based on data from: Ducker Worldwide, *Metallic Material Trends in North American Light Vehicle*. 2015;
Bushi, L., T. Skszek, and D. Wagner, *Comparative LCA Study of Lightweight Auto Parts of MMLV Mach-I Vehicle as Per ISO 14040/44 LCA Standards and CSA Group 2014 LCA Guidance Document for Auto Parts*, in *Engineering Solutions for Sustainability*. 2015, John Wiley & Sons, Inc. p. 193-208.

Life Cycle Assessment



- Flexible methodology
- Guided by ISO-14040 and 14044
- Enables a comparison of different phases in the life cycle
- Can help identify tradeoffs and unintended consequences

Shifting Life Cycle Impacts



- VMR is meant to improve use phase impacts
- High-tech nascent technologies may have increased production-phase impacts
- The EOL-phase is largely dependent upon the recyclability of a material
- Electric vehicles add more complexity and uncertainty to the use-phase

Based on data from: Keoleian, G.A. and J.L. Sullivan, *Materials challenges and opportunities for enhancing the sustainability of automobiles.* MRS Bulletin, 2012. **37**(04): p. 365-373.

Reviewed Studies

Ref.	Author	Year	Publication	Country / Affiliation / Funding	Explicitly ISO compliant	Component Specific	Component(s)	Body-in-white explicit	Steel	Al	Mg	Composites
20	Simões	2016	Journal of Cleaner Production	EU / University & Bosch / Nat. & Bosch	y	n	-	n	y	y	n	y
21	Steel Market Dev. Inst.	2016	Report	USA / Industry / -	n	n	-	n	y	y	n	n
8	Bushi	2015	SAE International	USA / Ford Magna / -	y	n	-	n	y	y	y	y
22	Ding	2015	Journal of Industrial Ecology	China / Nat. / Nat.	y	y	various	n	y	y	n	n
12	Kelly	2015	Environmental Science and Tech	USA / Nat. Lab / DOE	y	n	-	n	y	y	y	y
23	Li	2015	Resources, Conservation, and Recycling	China / Nat. / Nat.	n	n	-	n	y	y	y	n
24	Raugei	2015	Journal of Cleaner Production	UK / University / Research grant	y	n	-	n	y	y	y	y
25	Das	2014	SAE International	USA / Nat. Lab / -	y	n	-	y	y	y	n	n
26	Dhingra	2014	Journal of Cleaner Production	USA / University & Lab / -	n	y	engine	n	y	y	y	n
27	Lewis	2014	Applied Energy	USA / University / CERC, DOE	n	n	-	y	y	y	n	n
28	Ehrenberger	2013	Report	EU / Institute / -	y	y	steering wheel	n	n	y	y	n
29	Koffler	2013	Int Journal of Life Cycle Assessment	USA / Consultant / -	y	y	step assist, front end bolster	n	y	n	n	y
30	Baroth	2012	SAE International	India / GE & SABIC / -	y	y	fender	n	y	n	n	y
31	Dubreuil	2012	SAE International	Global / Universities & Labs / -	y	y	front end	n	y	y	y	n
32	Marretta	2012	Conference on LC Engineering	EU & USA / Universities & GM / -	n	y	fender, hood	y	y	y	n	n
33	Mayyas	2012	Energy	USA / University / -	y	n	-	y	y	y	y	y
34	PE International[a]	2012	Report	USA / Consultant / ACC	y	y	step assist	n	y	n	n	y
35	PE International[b]	2012	Report	USA / Consultant / ACC	y	y	bolster	n	y	n	n	y
36	Stasinopoulos	2012	Int Journal of Life Cycle Assessment	AU / University / Nat.	n	n	-	y	y	y	n	n
37	Das	2011	Int Journal of LCA	USA / Nat. Lab / -	n	y	floor pan	n	y	n	n	y
38	Tempelman	2011	Transportation Research Part D	EU / University / -	n	n	-	y	y	y	n	y
39	Witik	2011	Composites: Part A	EU / University / Research Network	y	y	rear bulkhead	y	y	n	y	y
40	Du[a]	2010	Journal of Cleaner Production	China / University / Ford & Shanghai	y	n	-	n	y	n	y	n
41	Du[b]	2010	Energy	China / University / Ford & Shanghai	n	n	-	n	y	y	n	n
42	Kim	2010	Journal of Industrial Ecology	USA / University / NSF Alcoa	n	n*	-	y	y	y	n	n
43	Tharumarajah	2010	Resources, Conservation, and Recycling	AU / CSIRO / -	y	y	instrument panel	n	y	n	y	y

Key Factors Used in LCAs

Critical factor	Phase(s) Influenced	Influence on results
Secondary mass reduction	Use	• Reduction of impacts through production and use • Magnifies use phase reductions • Introduces additional uncertainty
Recycling allocation	Production & EOL	• Determines amount of material considered • May favor different materials based on method
Powertrain reduction and fuel reduction values (FRVs)	Use	• Reduction of impacts through use phase efficiency • Magnifies use phase reductions • Introduces additional uncertainty
Material substitution rates	Production	• Estimated values in lieu of actual component masses • Introduces additional uncertainty
Lifetime vehicle travel distances	Use	• Can vary based on driving trends and vehicle durability • Determines the magnitude of use phase reductions
Production location and grid mix	Production	• Impacts associated with energy use during production • Industries may have different sources of energy • Consequential impacts may alter energy sourcing

Secondary Mass Reduction

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- Not all studies include secondary mass reduction
- Materials with higher production impacts may need to reduce the vehicle mass enough to trigger systemic changes in weight dependent systems

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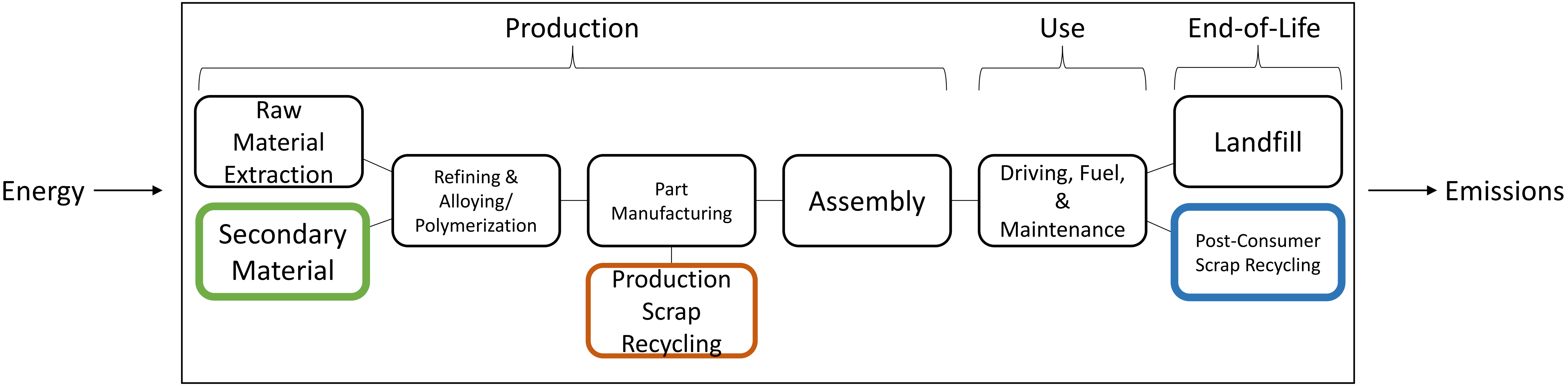
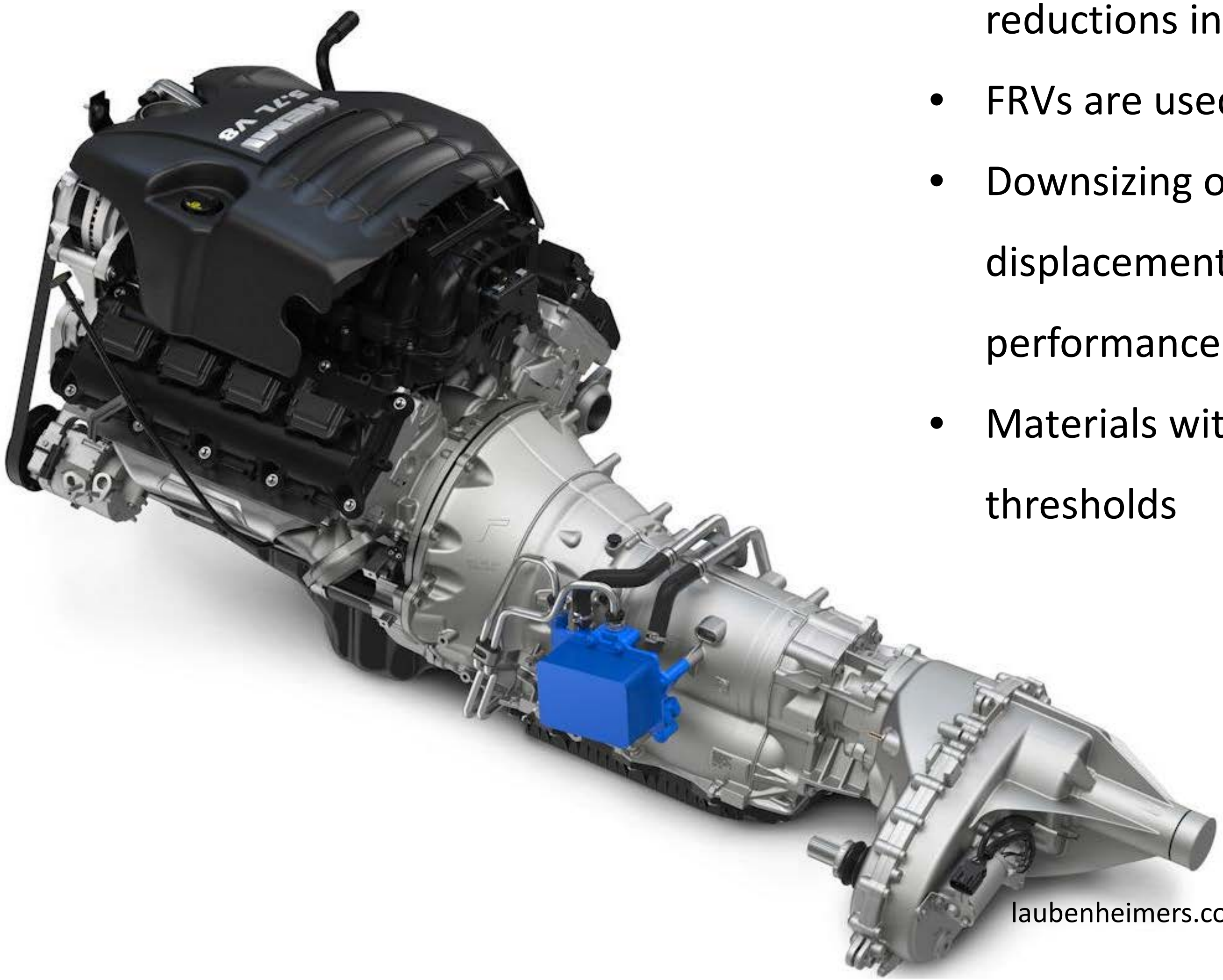
Recycling Allocation



- Lower impacts associated with the EOL allocation approach, more so for materials with higher production impacts
- Recycled content approach is limited to the share of secondary material used in production, which may be limited by recyclability and/or availability

FRV and Powertrain Reductions



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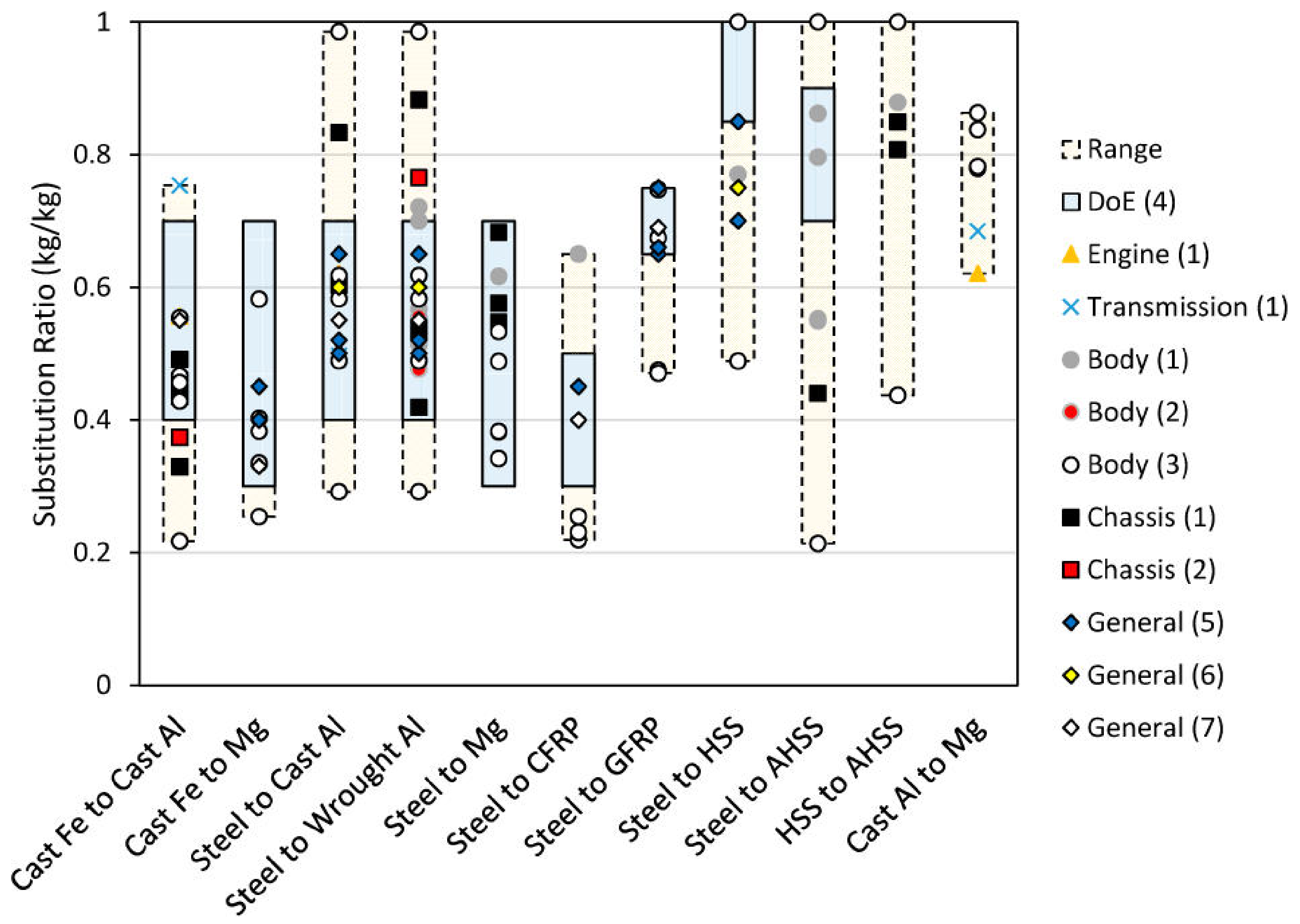
- Separate from secondary mass reduction estimates but reductions in the powertrain may contribute to mass reduction
- FRVs are used to estimate efficiency gains from mass reductions
- Downsizing of the powertrain (e.g., reducing cylinder displacement and/or cylinder count while maintaining performance) increases efficiency during use phase
- Materials with higher production impacts depend on meeting thresholds

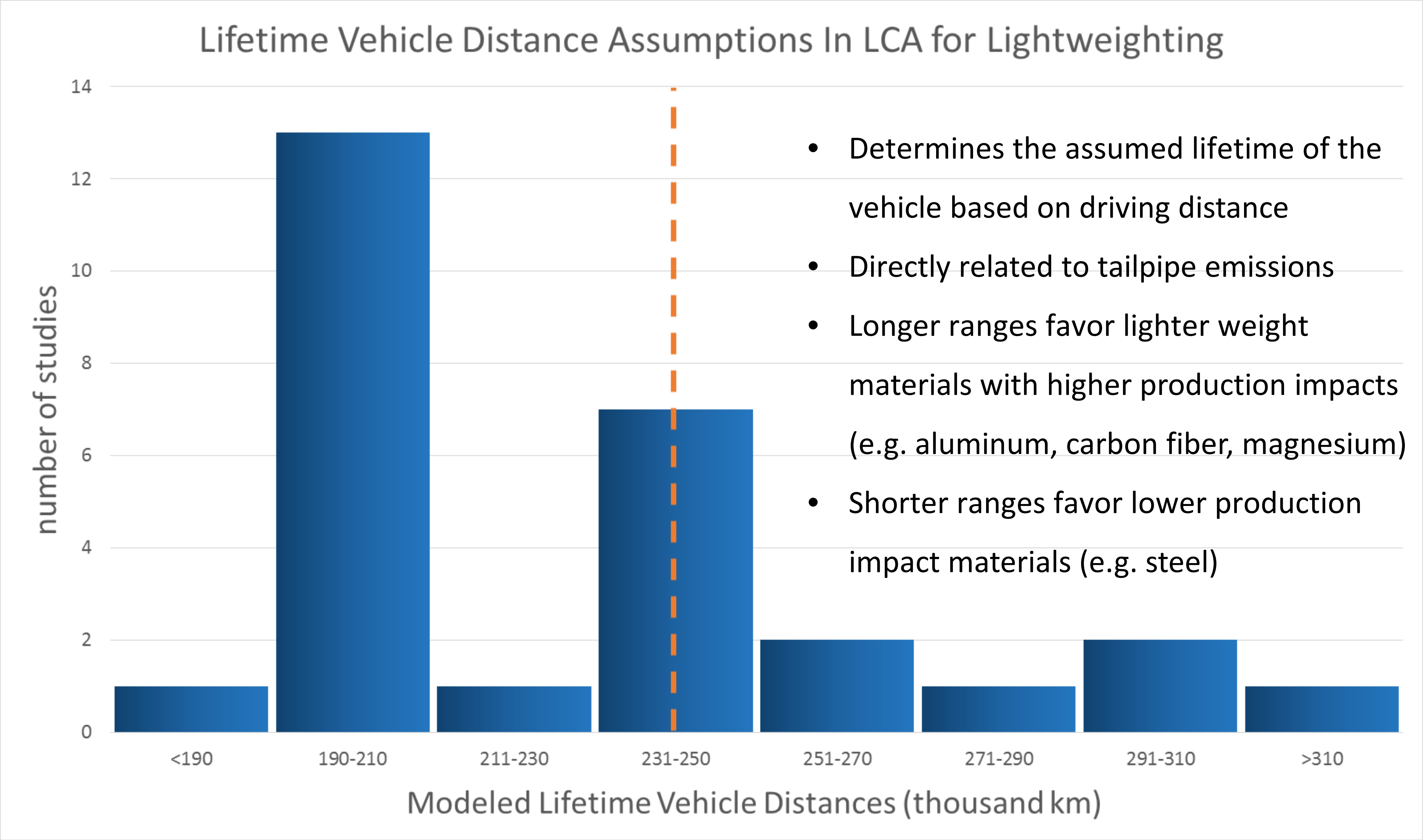
Material Substitution Rates

- Used to calculate how much of one material must be used to replace another
- In lieu of component specific data where actual material masses are known
- Tend to be generic and lack application specific data



Graph from: Kelly, J.C., et al., *Impacts of Vehicle Weight Reduction via Material Substitution on Life-Cycle Greenhouse Gas Emissions.* Environ Sci Technol, 2015. **49**(20): p. 12535-42.

Vehicle Life



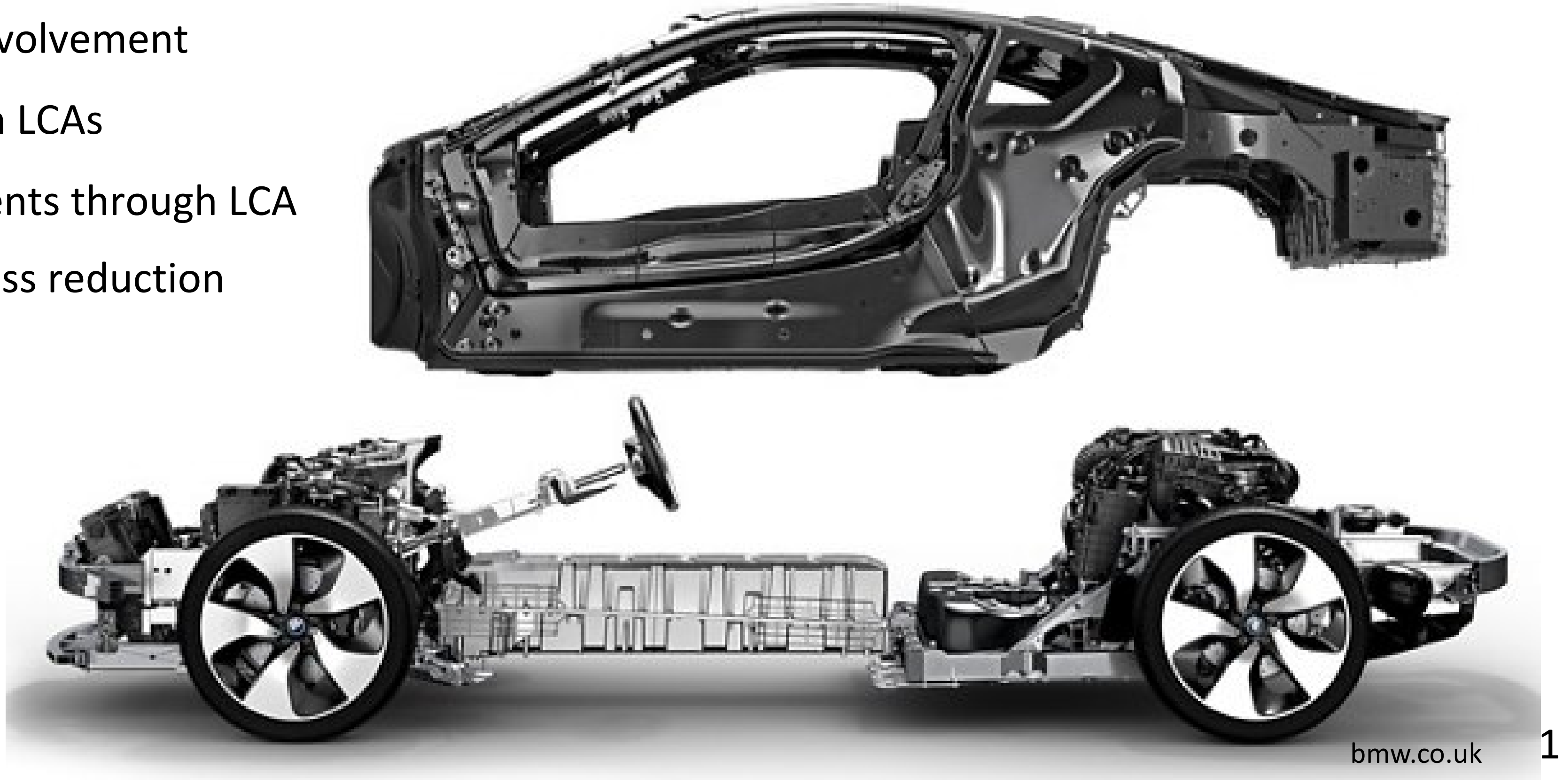
Based on data from the reviewed studies listed on page 8.

Production Location and Grid Mixes

- Location of material production is critical for energy intensive metallurgical processes
- Dictates upstream energy generation (e.g., hydroelectric vs coal) and the associated GHG emissions
- Changes in location or increases in quantities may have different impacts than existing inventories

Final Thoughts

- LCAs which compare complete vehicle redesigns help reduce uncertainty due to compounding assumptions
- Multimaterial designs are the reality and should be the focus in LCA to identify optimal material selections
- Consequential LCAs can help account for temporal factors required to understand larger shifts in major industries
- Iterative research with industry involvement
  - improving the temporal lag in LCAs
  - informed process improvements through LCA
  - improved data for vehicle mass reduction research



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Thank you for your time

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