ANALYSIS OF MATERIAL USE IN LIGHT-DUTY VEHICLES ACROSS POWERTRAINS

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Argonne overview

http://www.anl.gov/

- Located 25 miles from the Chicago Loop, Argonne was the first national laboratory, chartered in 1946
- Operated by the University of Chicago for the U.S. Department of Energy
- Major research missions include basic science, environmental management, and advanced energy technologies
- About 3,500 employees, including 178 joint faculty, 1000 visiting scientists and 6500 facility users
- Annual operating budget of about $750 million (≈80% from DOE)
- Research collaboration and partnerships are highly valued

Material substitution and lightweighting for LDVs

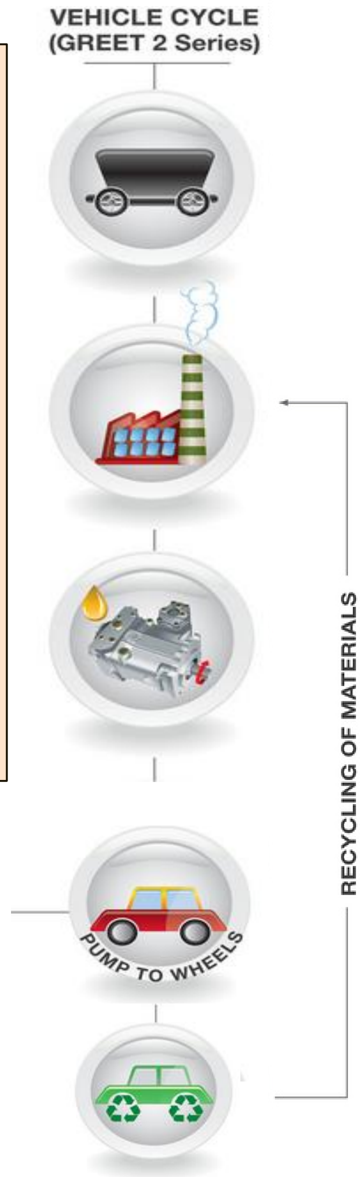
- Lightweighting of LDVs is a trend to achieve vehicle fuel efficiency
- Switch from ICEVs to EVs results in powertrain changes and changes in vehicle materials
- Energy and environmental effects of material switches and vehicle operations need to be addressed from life cycle point of view

The GREET® (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model

- Argonne has been developing the GREET LCA model since 1995.
- It is available at greet.es.anl.gov

GREET 1 model:
Fuel-cycle (or well-to-wheels, WTW) modeling of vehicle/fuel systems

GREET 2 model:
Vehicle cycle modeling for vehicles



-------- Vehicle Cycle --------

-------- Fuel Cycle ---------

Life cycles of 60+ materials are included in GREET2

Material Type	Number in GREET	Examples
Ferrous Metals	3	Steel, stainless steel, iron
Non-Ferrous Metals	12	Aluminum, copper, nickel, magnesium
Plastics	23	Polypropylene, nylon, carbon fiber reinforced plastic
Vehicle Fluids	7	Engine oil, windshield fluid
Others	17	Glass, graphite, silicon, cement
Total	**62**	

GREET outputs include energy use, greenhouse gases, criteria pollutants and water consumption for vehicle and energy systems

❑ Energy use

- Total energy: fossil energy and renewable energy
  - Fossil energy: petroleum, natural gas, and coal (they are estimated separately)
  - Renewable energy: biomass, nuclear energy, hydro-power, wind power, and solar energy

❑ Greenhouse gases (GHGs)

- CO_2, CH_4, N_2O, black carbon, and albedo
- CO_{2e} of the five (with their global warming potentials)

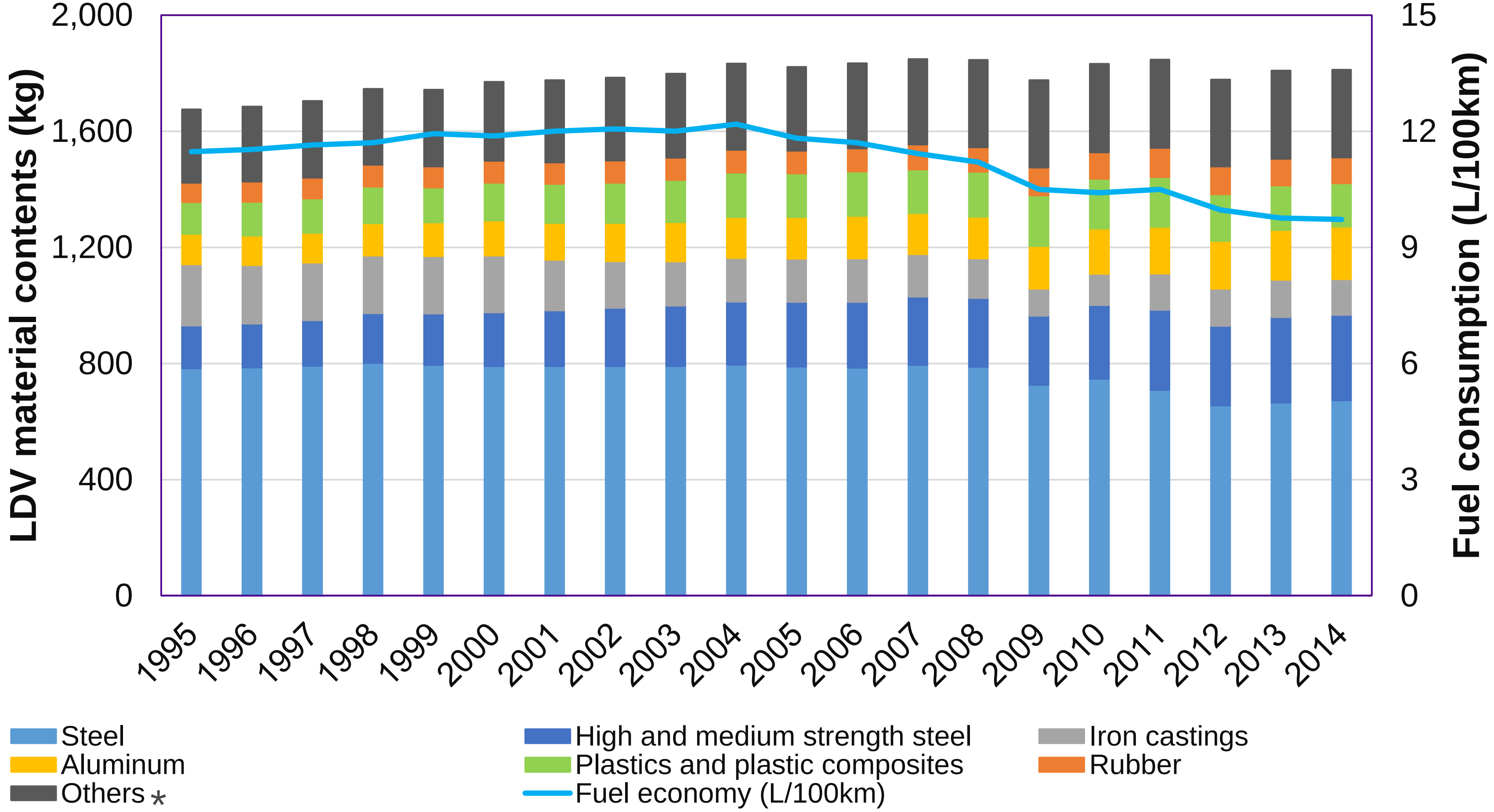
❑ Air pollutants

- VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
- They are estimated separately for
  - Total (emissions everywhere)
  - Urban (a subset of the total)

❑ Water consumption

U.S. LDV Material Use Trends (1995-2014)

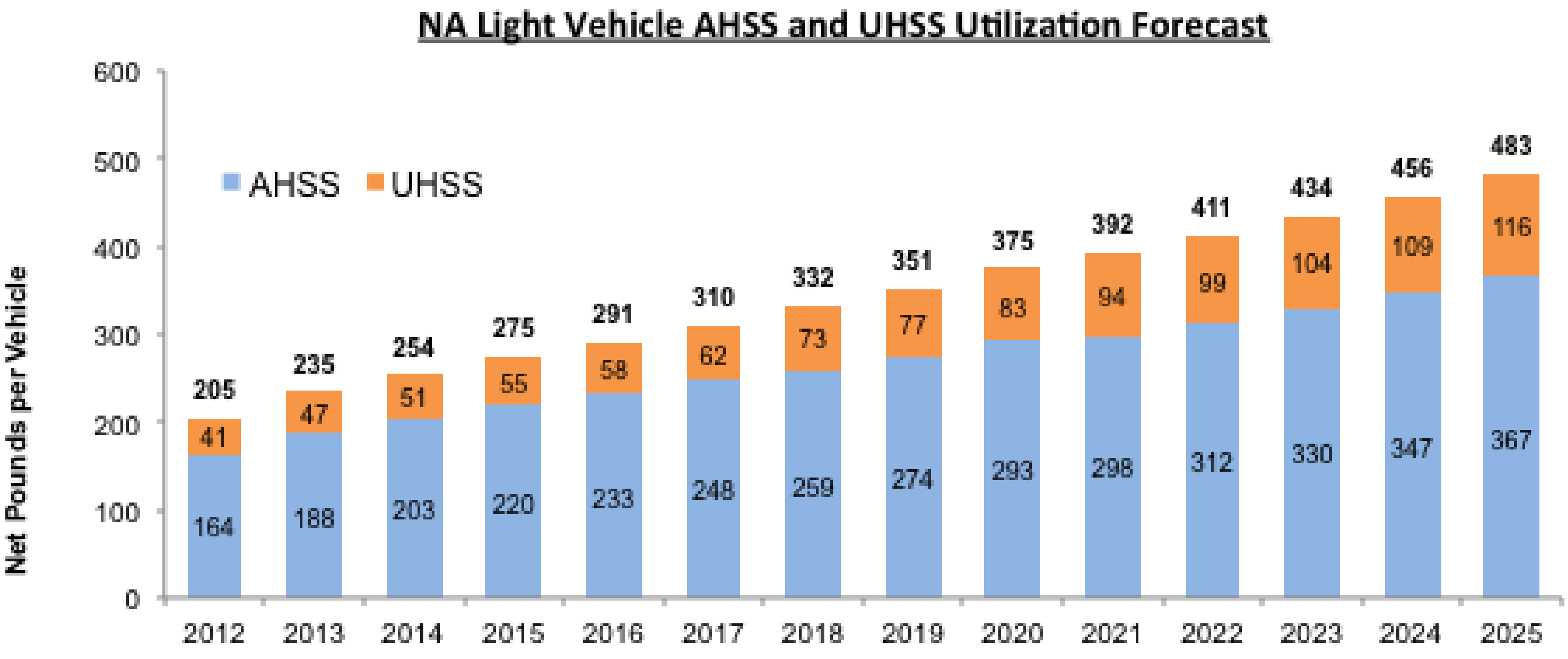
- **The contents of high-strength steel (HSS) and Al increase substantially, while the contents of conventional steel and cast iron decrease**



* Others include other metals such as copper, lead, magnesium, etc., as well as other nonmetallic materials such as textiles, glass, fluids, etc.

Key materials for substitution: Advanced / Ultra / High Strength Steel

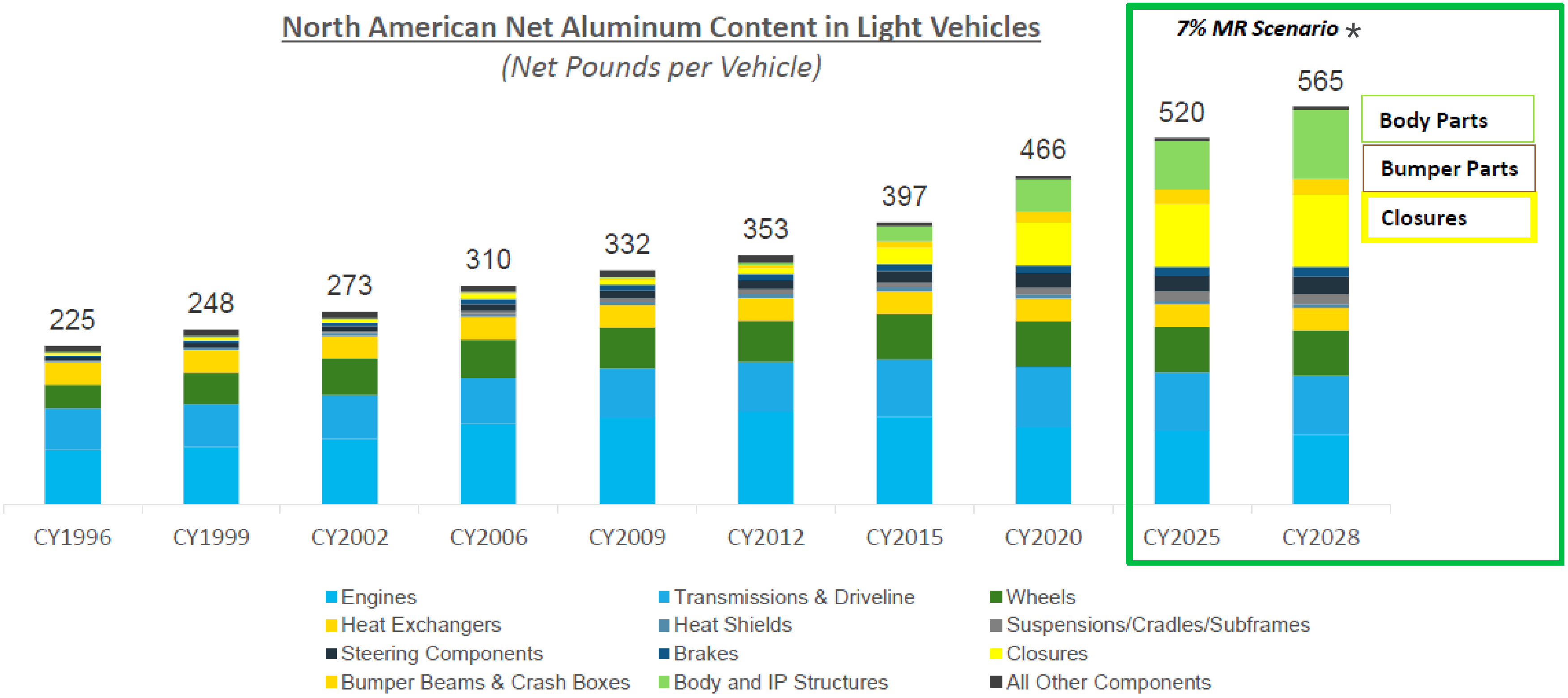
- A/U/HSS classifications are based on strength and deformation properties
- Wide applications available in: body sheet, A/B pillars, closures, cross members, roof bows, door beams, and control arms



Source: Abraham, Ducker Worldwide, 2015

Key materials for substitution: Aluminum

- **Engine and transmission parts account for over 50% of current aluminum use in LDVs**
- **Significant growth is expected for aluminum use in body and closure parts**



Source: Ducker Worldwide, 2017

* Assuming 7% vehicle mass reduction (MR) by 2028. EPA and NHTSA target an industry-average MR of 7% for LDVs from 2015 to 2025 and beyond. Ducker believes that achieving the 7% MR goal is likely to be delayed to 2028.

Key materials for substitution: Magnesium

- Presently account for less than 0.5% of average vehicle weight due to technological and economical barriers
- Applications have included instrument panels, steering wheels, engine cradles, seats, transfer cases and various housings

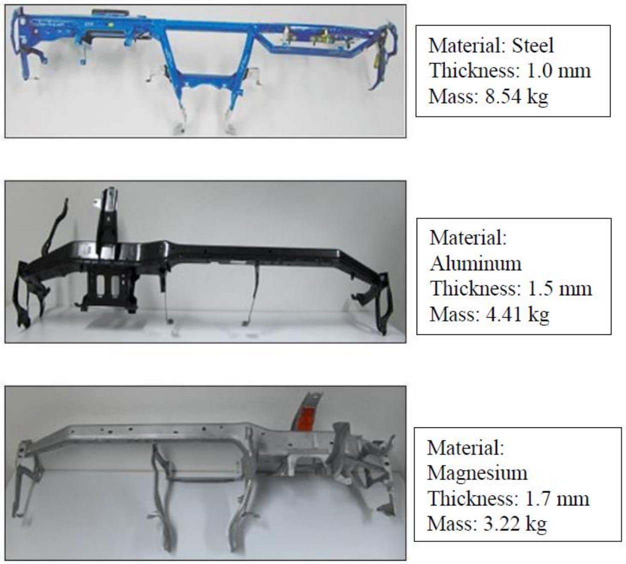


Image F.5-26: CCB Examples Compared by the Stolfig® Group

(Source: Stolfig http://www.stolfig.com/lang/en/services/carbeam.php)

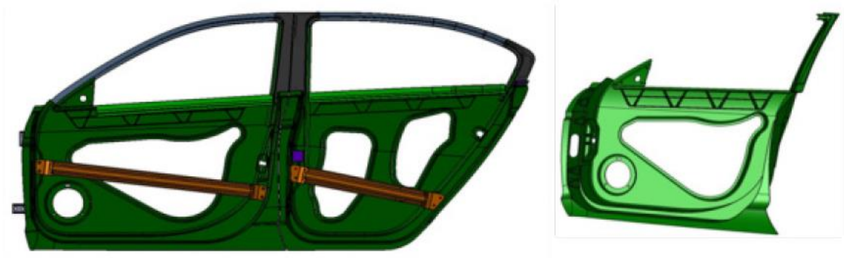


Figure 215: Cast Magnesium I/P Beam (GM Epsilon shown)

Sources: Joost & Krajewski, 2017; NHTSA, 2012; FEV-EPA, 2012.

Key materials for substitution: Carbon Fiber

- Race cars have been using carbon fiber for a long time
- Carbon fiber reinforced polymer composites have been successfully integrated into numerous, typically low volume, vehicles. The BMW i3 has extensive carbon fiber use, as does the Chevrolet Corvette Stingray
- Likely applications include: closures, seats, instrument panels, engine cradles, pans, and covers
- Major challenges include material costs and long cycle times

Sources: Joost & Krajewski, 2017; Automotive World 2016.

Material Substitution Ratios are Key for Energy and GHG Emissions Estimates

- Generally, increased energy and GHGs for lightweight material production on a lb/lb basis
  - But, no consideration of actual lightweighting
- Substitution ratios, $f_{\beta\alpha}$
  - Replace material β with material α within a given part, component, or system
  - Through material properties (strength, density, etc.), can reduce mass of part through substitution

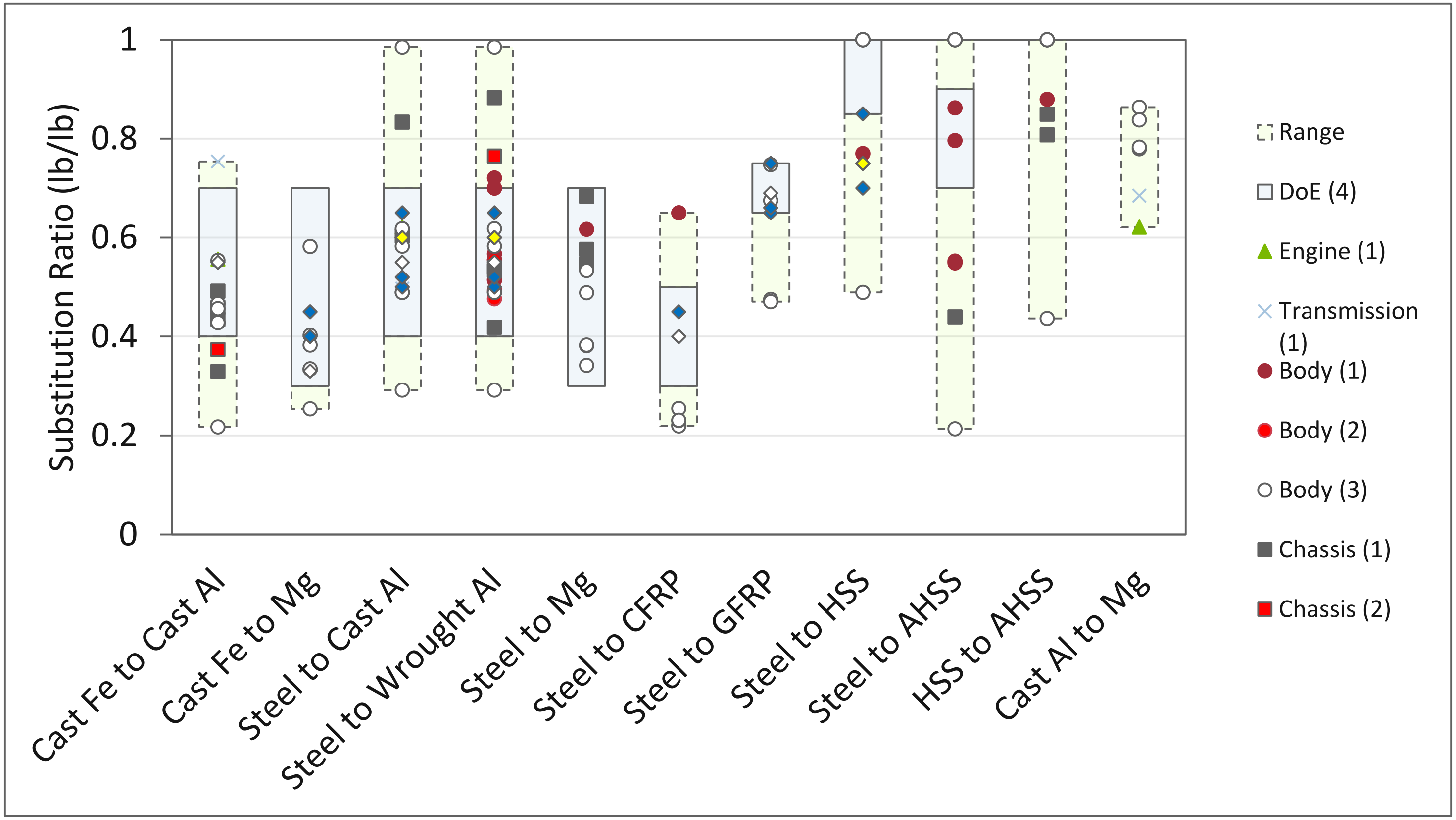
Baseline Knuckle (Iron)– 12.3 kg

LWV Knuckle Design (Al) – 4.6 kg

Singh, Harry. (2012, August). *Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025.* (Report No. DOT HS 11 666). Program Reference: DOT Contract DTNH22-11-C-00193. Contract Prime: Electricore, Inc.

Vehicle Lightweighting: Substitution Ratios

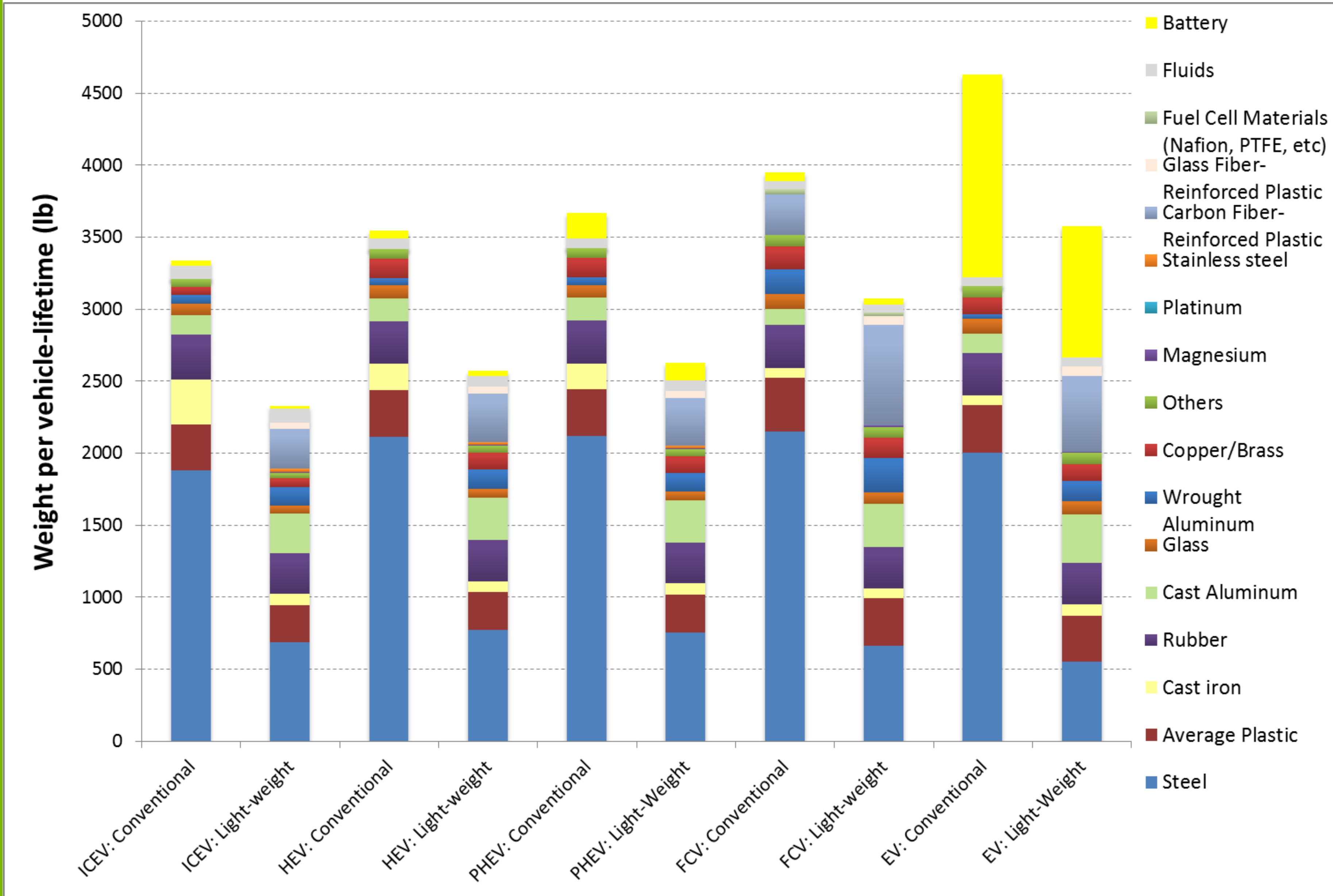
- ***How does one material <u>substitute</u> another to reduce vehicle weight is another important step***



$$Substitution\ Ratio = \frac{Lightweight\ part\ weight}{Conventional\ part\ weight}$$

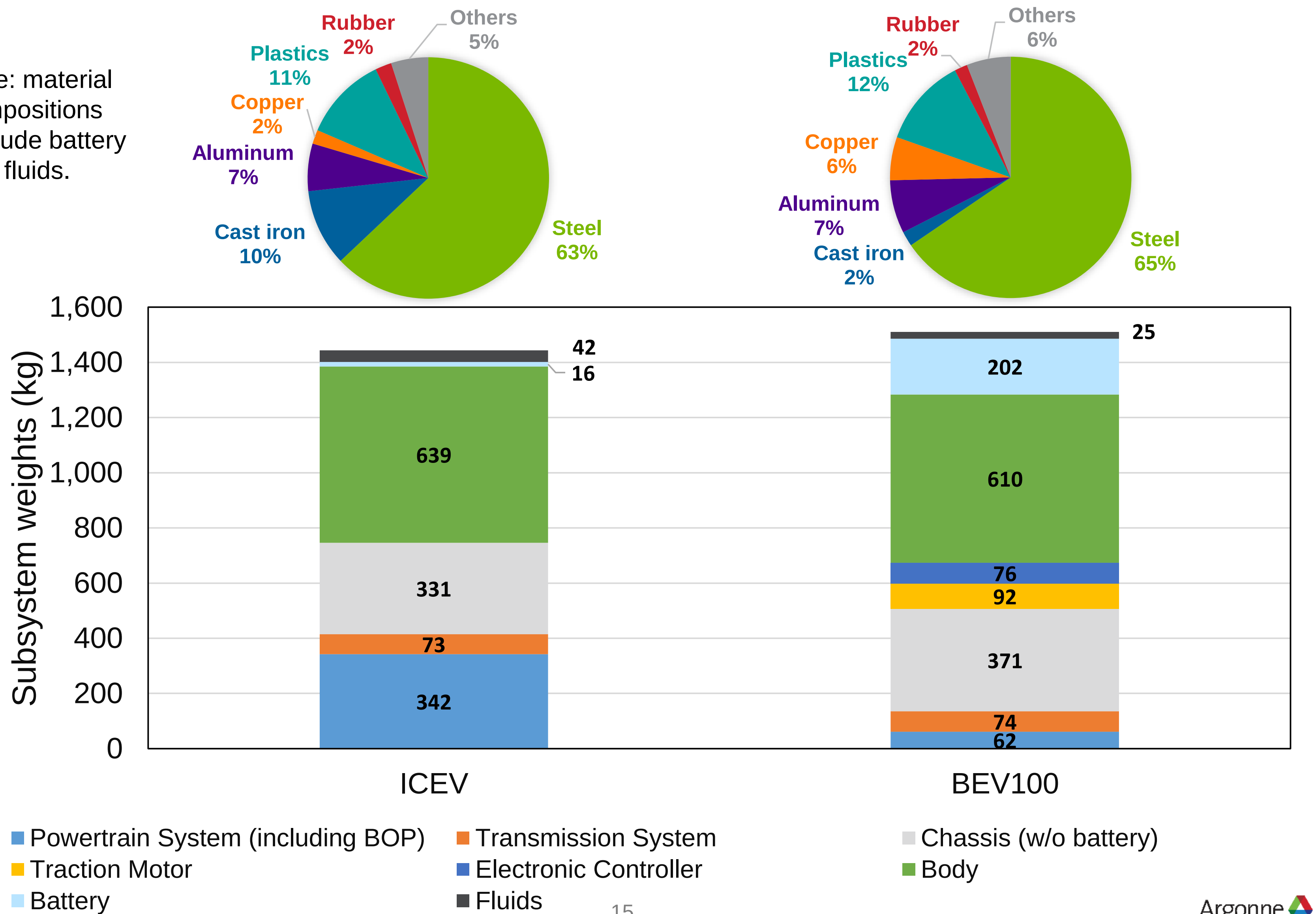
- ***Substitution ratios vary among studies (reflecting materials strength understanding and other assumptions) and with vehicle parts applications***

Powertrain changes inevitably result in material composition changes (from GREET2)

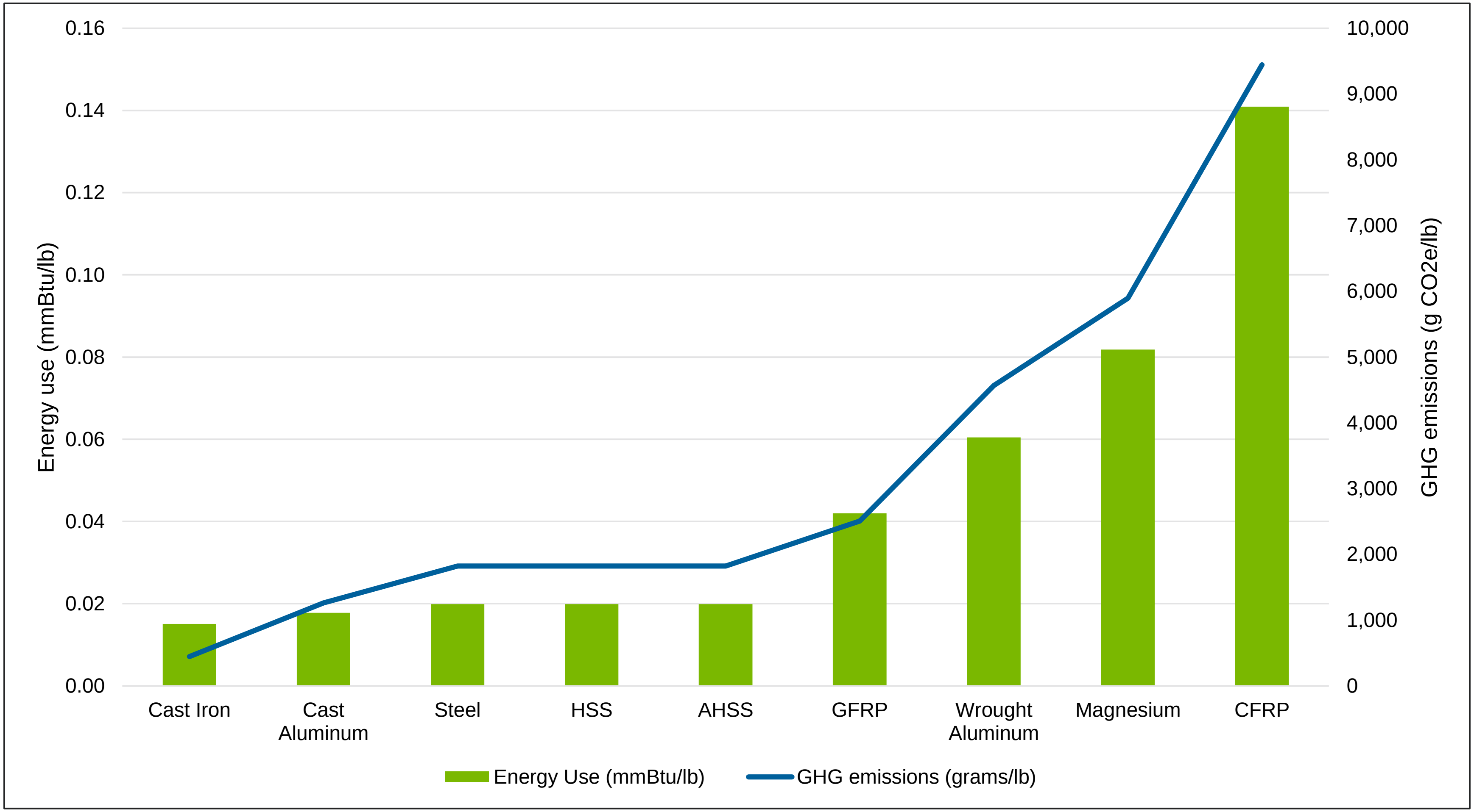


GREET2 passenger car weight distribution and material composition: ICEV vs. BEV100

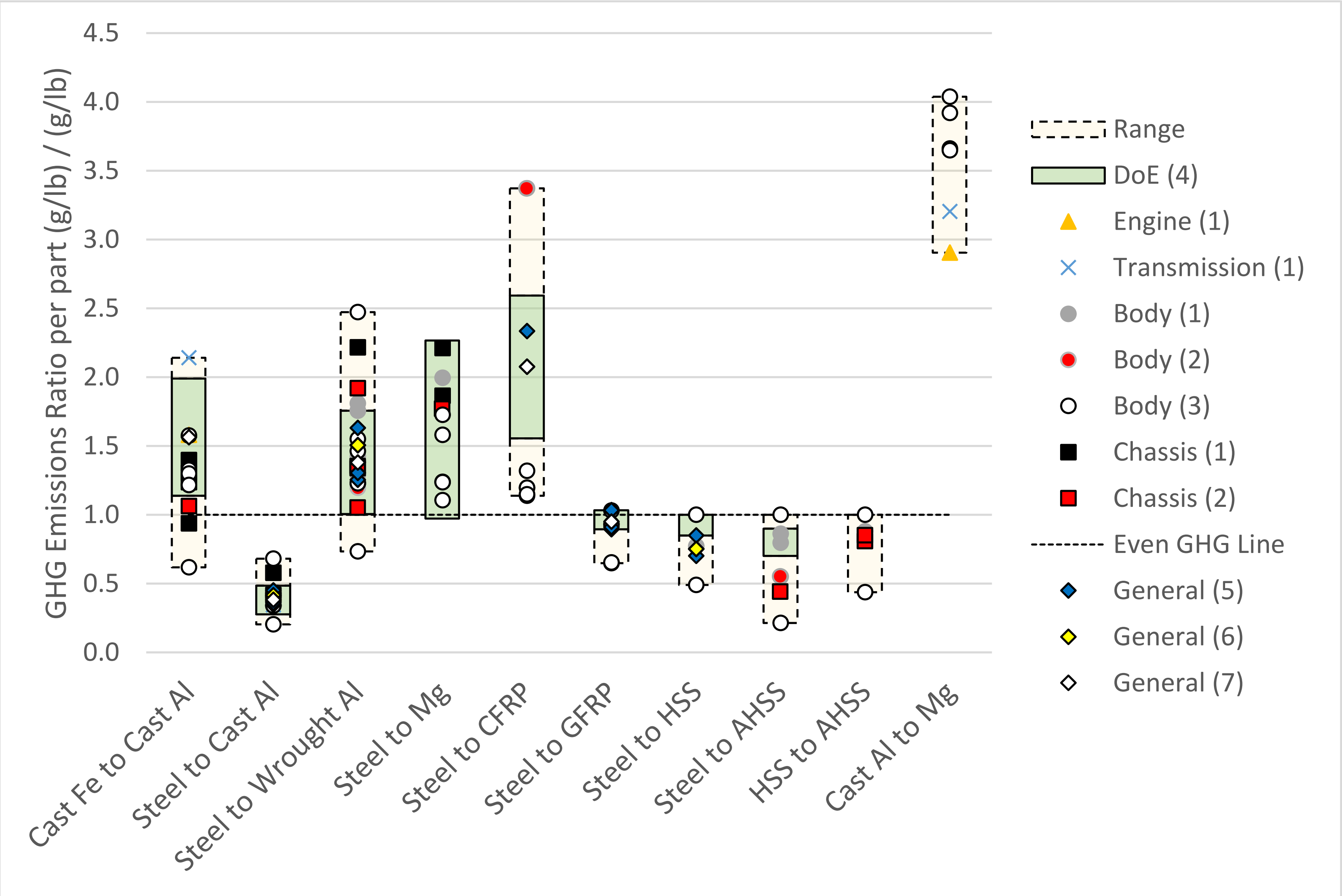
Note: material compositions exclude battery and fluids.



Life Cycle Energy Use and GHG Emissions for Automotive Materials



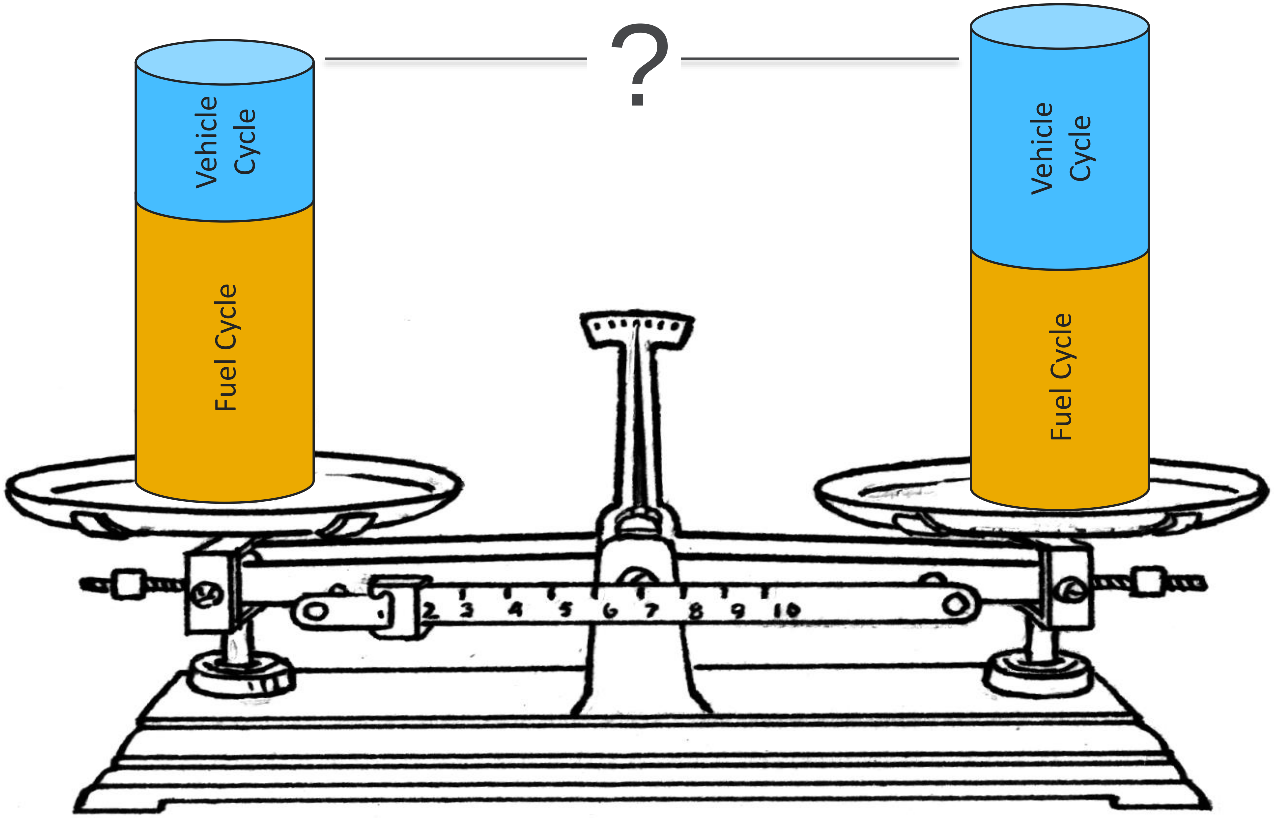
GHG Emissions Ratios, Based on GREET Data
(lb-to-lb for parts)



(1) derived from (U.S. Environmental Protection Agency 2012), (2) derived from (Singh 2012), (3) calculated from (Malen 2011), (4) (U.S. Department of Energy 2013, Gibbs, Joost, Schutte), (5) (Sullivan and Hu 1995), (6) (Geyer 2008), (7) automotive expert opinions

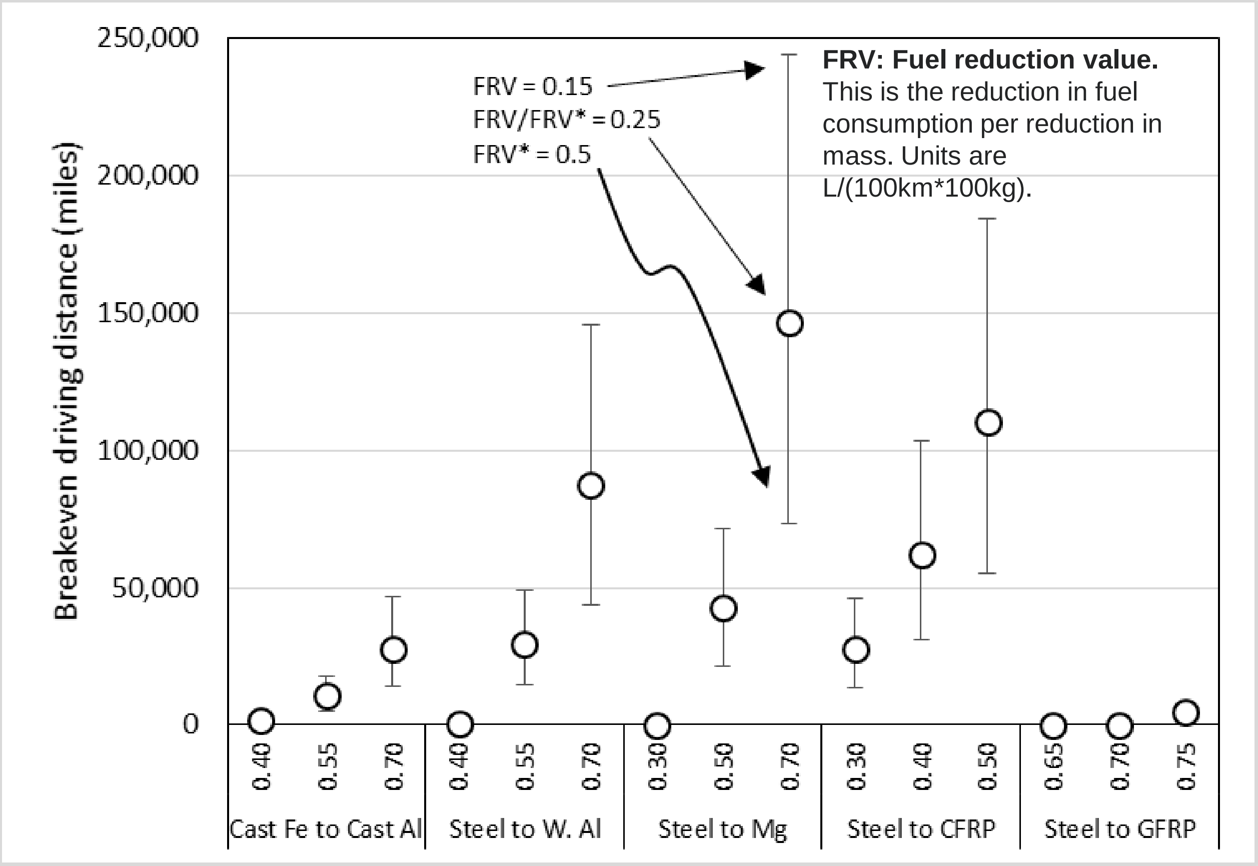
Material Burdens and Life Cycle Assessment

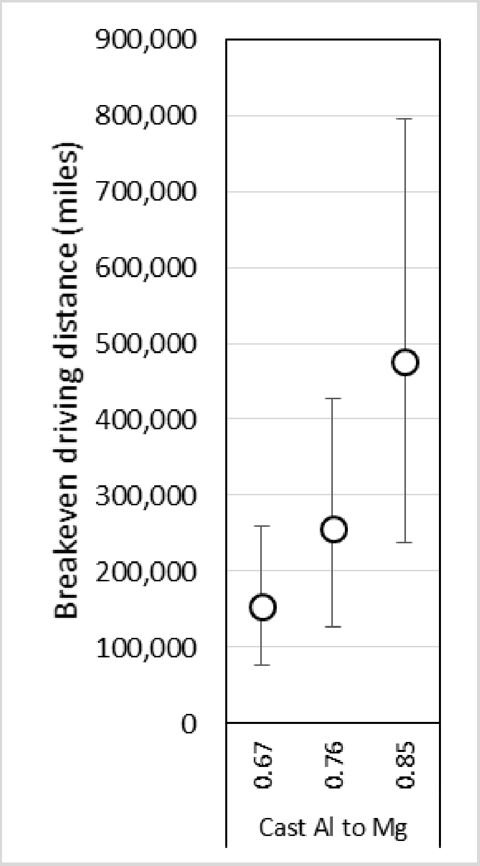
- We have examined the GHG burden of materials
  – Addressed the potential trade off between fuel cycle and vehicle cycle
  – Tailpipe GHG reduction vs. increased material embedded GHG burden



Vehicle Lightweighting: Breakeven Analysis

- ***Material substitution ratios strongly influence distance required to achieve breakeven life-cycle GHG emissions***
  → longer distance reflects greater GHG from material substitution





Kelly, J.C.; Sullivan, J.L; Burnham, A; Elgowainy, A. "Impacts of Vehicle Weight Reduction via Material Substitution on Life-Cycle Greenhouse Gas Emissions" *Environmental Science & Technology.* Article ASAP.
DOI: 10.1021/acs.est.5b03192

Please visit http://greet.es.anl.gov for:

- **_GREET models_**
- **_GREET documents_**
- **_LCA publications_**
- **_GREET-based tools and calculators_**