ANALYSIS OF MATERIAL USE IN LIGHT-DUTY VEHICLES ACROSS POWERTRAINS

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Argonne overview

- 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

http://www.anl.gov/
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
Life cycles of 60+ materials are included in GREET2

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Number in GREET</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrous Metals</td>
<td>3</td>
<td>Steel, stainless steel, iron</td>
</tr>
<tr>
<td>Non-Ferrous Metals</td>
<td>12</td>
<td>Aluminum, copper, nickel, magnesium</td>
</tr>
<tr>
<td>Plastics</td>
<td>23</td>
<td>Polypropylene, nylon, carbon fiber reinforced plastic</td>
</tr>
<tr>
<td>Vehicle Fluids</td>
<td>7</td>
<td>Engine oil, windshield fluid</td>
</tr>
<tr>
<td>Others</td>
<td>17</td>
<td>Glass, graphite, silicon, cement</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62</strong></td>
<td></td>
</tr>
</tbody>
</table>
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)**
  - \( \text{CO}_2, \text{CH}_4, \text{N}_2\text{O}, \) black carbon, and albedo
  - \( \text{CO}_2e \) of the five (with their global warming potentials)

- **Air pollutants**
  - \( \text{VOC}, \text{CO}, \text{NO}_x, \text{PM}_{10}, \text{PM}_{2.5}, \) and \( \text{SO}_x \)
  - They are estimated separately for
    - Total (emissions everywhere)
    - Urban (a subset of the total)

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

**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

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**Chopped Carbon (40%) / Nylon Composite**

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight (kg)</th>
<th>Steel Weight (kg)</th>
<th>Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cushion</td>
<td>1.9</td>
<td>2.5</td>
<td>26%</td>
</tr>
<tr>
<td>Back</td>
<td>2.0</td>
<td>2.1</td>
<td>6%</td>
</tr>
<tr>
<td>Total</td>
<td>3.9</td>
<td>4.6</td>
<td>17%</td>
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</tbody>
</table>

**Source:** Ford Motor Company

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 $\beta$ with material $\alpha$ within a given part, component, or system
  - Through material properties (strength, density, etc.), can reduce mass of part through substitution

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**Vehicle Lightweighting: Substitution Ratios**

- How does one material substitute another to reduce vehicle weight is another important step.

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

![Graph showing energy use and GHG emissions for various automotive materials](image-url)
# GHG Emissions Ratios, Based on GREET Data

*lb-to-lb for parts*

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Engine (1)</th>
<th>Transmission (1)</th>
<th>Body (1)</th>
<th>Body (2)</th>
<th>Body (3)</th>
<th>Chassis (1)</th>
<th>Chassis (2)</th>
<th>Even GHG Line</th>
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<td><strong>DoE (4)</strong></td>
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<td><strong>General (7)</strong></td>
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(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

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

- GREET models
- GREET documents
- LCA publications
- GREET-based tools and calculators