Life Cycle Assessment - Energy and CO2 Emissions of Aluminum-Intensive Vehicles

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January 15, 2014
LCA Study Scope

- Standards Compliance:
  - ISO 14040 and ISO 14044
  - Draft 2012 CSA-PCR-2012:1 (environmental performance of autoparts)

- Functional Unit:
  - 2010 Toyota Venza Vehicle
  - Conventional powertrain
  - Vehicle configurations
    - current production steel vehicle
    - lightweight steel (LWSV) - EPA Body-in-White, Sept. 2012 Study
    - Aluminum-intensive (AIV) vehicle - FEV/EDAG, Jan 2013 Study

- Cradle-to-grave approach
  - Primary metal production - Semi-fabrication material production
  - Autoparts manufacturing and assembly - Transportation
  - Use - End-of-life metals recycling
LCA Study Goals

- **End-of-Life Recycling:**
  - closed-loop approach ISO 14044:2006
    - Avoided primary production equals recovered scrap

- **Life cycle impacts (Ecoinvent V. 1.02)**
  - Total Primary energy
  - Cumulative Energy Demand
  - Global Warming Potential (CO2e)
  - Acidification Potential
  - Eutrophication Potential
  - Photo Chemical Smog Potential
  - Respiratory Effects Potential,
  - Ozone Depletion Potential -- TRACI 2.1 Version 1.00
# LCA – Functional Unit Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Baseline</th>
<th>LWSV</th>
<th>AIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>127</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Steel (Kg)</td>
<td>1,011</td>
<td>794</td>
<td>366</td>
</tr>
<tr>
<td>Pickled Hot Rolled (SP)</td>
<td>242</td>
<td>181</td>
<td>172</td>
</tr>
<tr>
<td>Electro-Galvanized (BIW, SP)</td>
<td>684</td>
<td>344</td>
<td>138</td>
</tr>
<tr>
<td>Hot-Dip Galvanized (BIW, SP)</td>
<td>59</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>Eng. Steel (Other)</td>
<td>27</td>
<td>224</td>
<td>22</td>
</tr>
<tr>
<td>Iron</td>
<td>127</td>
<td>49</td>
<td>49</td>
</tr>
<tr>
<td>Aluminum (kg)</td>
<td>157</td>
<td>194</td>
<td>459</td>
</tr>
<tr>
<td>Sheet</td>
<td>12</td>
<td>55</td>
<td>296</td>
</tr>
<tr>
<td>Cast (A356)</td>
<td>128</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>Extrusion</td>
<td>17</td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>Other materials</td>
<td>416</td>
<td>416</td>
<td>416</td>
</tr>
<tr>
<td>Vehicle Total Weight (Kg)</td>
<td>1,711</td>
<td>1,399</td>
<td>1,236</td>
</tr>
</tbody>
</table>

Mass distribution includes impacts on secondary part mass changes due to primary mass reduction
SP = Structural Part
Vehicle Life Cycle Stages

Primary Metal Production

Transp. Primary Metal/Sheet

Part Fabrication & Scrap Remelting

Vehicle Assembly

Vehicle Use

Vehicle Manufacturing

Dismantling, Shredding

Post-Consumer Scrap Transp.

Recycling/Secondary Metal Prod.

Vehicle End-of-Life

Avoided Primary Metal Production Occurs at Manufacturing (prompt scrap) and End-of-Life (post-consumer scrap)
Steel LCI Data Methodology

- \[ \text{LCI} = X - (\text{RR-S})Y(X_{\text{pr}} - X_{\text{re}}) \]
  
  [Applicable for when scrap could be both inputs and outputs]

Where:

- \( X \) = Cradle-to-gate product LCI
- \( \text{RR} \) = Recovery rate, i.e., steel scrap from system, 95% for stamped automotive steel – SRI 2011
- \( S \) = Scrap input into primary production process (44%, 20%, 6.5%, and 100.1% for hot dip galv., pickled hot rolled coil, electro-galvanized, and eng. steel respectively)
- \( Y \) = Process Yield (EAF for steel, i.e., 91.6%)
- \( X_{\text{pr}} - X_{\text{re}} \) = Difference in energy between primary and secondary metal production
- Prompt scrap generated (45% for stamping and 15% eng. steel) [Krupitzer 2013]
2012 Steel LCI Data

- **Primary steel production - unavailable**
  - all LCI data contain ferrous scrap input
  - S factor (LCI data provided represent X part of the formula, excludes recycling)

- **North America data:**
  - Pickled hot rolled (Structural Part)
  - Hot dip galvanized coil (BIW, Structural Part)

- **Global data:**
  - Electro-galvanized (BIW, Structural Part)
  - Engineering steel (Other)

- **Value of scrap data in terms of Y(Xpr-Xre) available for global only**
  - 91.6% EAF global melting efficiency (lower than 98% assumed for aluminum)

- **No significant difference in LCI data for advanced steels, i.e., AHSS, UHSS etc.**

  **Source:** World Autosteel
Life Cycle - Al Stamped Part

1. Aluminum Primary Production
   1.1 Bauxite Mining
   1.2 Alumina Refining (53.6% NA: 46.4% Imports)
   1.3 Anode Production (95% Prebake NA: 5% Soderberg NA)
   1.4 Aluminum Smelting (95% Prebake NA: 5% Soderberg NA)

2. Aluminum Ingot Casting
   3.1 Al Remelting
      Yield = 98%

3. Transportation of Primary Al Sheet to Auto Manufacturers
   3.1 Al Remelting
   3.2 Stamping, Al Autopart Manufacturing and Assembly
   3.3 Al Hot Rolling
   3.4 Al Cold Rolling

4. Use Phase of Al Autoparts

5. EOL Processing of Al Autoparts (incl. scrap transportation)
   5.1 Post-Consumer Al Melting
      Yield 98%

Source: Aluminum Industry
LCA Inventory study - 2013
Life Cycle Stages - Al Cast Part

1. Aluminum Primary Production
   1.1 Bauxite Mining
   1.2 Alumina Refining (53.6% NA: 46.4% Imports)
   1.3 Anode Production (95% Prebake NA: 5% Soderberg NA)
   1.4 Aluminum Smelting (95% Prebake NA: 5% Soderberg NA)

   1.02 kg molten Al

2. Primary Aluminum Ingot Casting

3.1 Al Remelting
   Yield = 98%

   1.045 kg

3. Shape Casting
   3.2 Al Autopart Manufacturing, Transportation and Assembly

   1 kg

4. Use Phase of Al Autoparts

   1 kg

5. EOL Processing of Al Autoparts (incl. scrap transportation)
   (95% recovered dismantling, shredding & separation of old scrap)

   0.893 kg

5.1 Post-Consumer Al Melting
   Yield 98%

   Avoided 0.875 kg secondary Al Alloy

Prompt Scrap (0.045 kg)

Lost 0.001 kg

Abandoned cars (6%)

Lost 0.06 kg

Source: Aluminum Industry LCA Inventory study - 2013
Life Cycle Stages - Al Extrusion Part

1. Aluminum Primary Production
   1.1 Bauxite Mining
   1.2 Alumina Refining (53.6% NA: 46.4% Imports)
   1.3 Anode Production (95% Prebake NA: 5% Soderberg NA)
   1.4 Aluminum Smelting (95% Prebake NA: 5% Soderberg NA)

   1.29 kg molten Al

2. Primary Aluminum Ingot Casting
   1.29 kg

3. Primary Al Extrusion
   3.2 Al Autopart Manufacturing, Transportation and Assembly

   1 kg

4. Use Phase of Al Autoparts
   1 kg

5. EOL Processing of Al Autoparts (incl. scrap transportation)
   (95% recovered dismantling, shredding & separation of old scrap)
   0.893 kg

5.1 Post-Consumer Al Melting
   Yield 98%

   0.875 kg secondary Al Alloy

   Lost 0.018 kg

Source: Aluminum Industry LCA Inventory study - 2013
Aluminum LCI Data

- 2013 Aluminum LCI data – Al ingot
  - No distinction made for Al alloy compositions used for cast or wrought materials
  - Data represent production-weighted average data for North America
    - Primary, secondary production - US & Canada
    - Semi-fabricated products – US, Canada, & Mexico
- Forming technology - stamping, extrusion, and casting
  - Shape Casting (Die Casting: 60%; Permanent Mold Casting: 30%; Sand Casting: 9%)
- Electricity profile based on North America Al producer production mix
- Electricity used for electrolysis based on domestic aluminum smelters (Hydropower: 75%, Coal: 24%, Oil+Natural Gas+Nuclear Power: 1%)
  - Share of electrolysis (Pre-baked – 95% vs. Soderberg – 5%)
- Prompt scrap recovery
  - Sheet: 45% [same as steel stamping]; Cast: 4.3%; and Extrusion: 22.5%
- Scrap melting efficiency – 98% (based on scrap and subsequent dross/salt cake recycling)

SimaPro software by Pré Consultants for LCA
Vehicle Use Phase

- Mass-induced fuel consumption improvement due to lightweight steel and aluminum designs (constant performance)

\[ CA,n = (mpart,n - mpart,b) \times VA \times LTDD, \]

where,

\[ CA,n = \text{the total life cycle mass-induced fuel change} \]
\[ \text{(decrease/or increase) of new autoparts designs in liters} \]

\[ mpart, n = \text{mass in kg of new design autoparts} \]
\[ \text{(i.e., 1399 kg LWSV, 1236 kg AIV)} \]

\[ mpart, b = \text{mass in kg of baseline autoparts} \]
\[ \text{(baseline, replaced with the new design), i.e., 1711 kg} \]

\[ VA = \text{mass-induced fuel consumption reduction value with} \]
\[ \text{powertrain adaptation} \]
\[ - 0.38l/100km.100 \text{ kg} \]

\[ LTDD = \text{baseline life-time driving distance} \]
\[ (250,000 \text{ km, 155,000 mi.}) \]

- Gasoline primary energy:

\[ 40.9 \text{ MJ/l (ANL GREET Model – Well-To-Pump and Pump-To-Wheels)} \]

- Baseline Vehicle Fuel Economy – 24 mpg Label (30 MPG Test)
## Life Cycle Environmental Impacts

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Baseline</th>
<th>LWSV</th>
<th>AIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming</td>
<td>kg CO2 eq</td>
<td>76,397</td>
<td>67,777</td>
<td>63,412</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>kg CFC-11 eq</td>
<td>2.9 E-05</td>
<td>4.2 E-05</td>
<td>1.3 E-04</td>
</tr>
<tr>
<td>Smog</td>
<td>kg O3 eq</td>
<td>1,563</td>
<td>1,348</td>
<td>1,276</td>
</tr>
<tr>
<td>Acidification</td>
<td>kg SO2 eq</td>
<td>56</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>kg N eq</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Respiratory effects</td>
<td>kg PM2.5 eq</td>
<td>7</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

**Impact Assessment Method:** TRACI 2.1 Version 1.00
## Life Cycle Energy Findings

### MJ/Vehicle

<table>
<thead>
<tr>
<th></th>
<th>Mfg.</th>
<th>Use</th>
<th>End-of-Life</th>
<th>Total Life Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>100,328</td>
<td>1,002,819</td>
<td>-28,710</td>
<td>1,074,438</td>
</tr>
<tr>
<td>LWSV</td>
<td>84,800</td>
<td>902,451</td>
<td>-52,815</td>
<td>934,436</td>
</tr>
<tr>
<td>AIV</td>
<td>116,350</td>
<td>839,040</td>
<td>-99,628</td>
<td>857,761</td>
</tr>
</tbody>
</table>

![Life Cycle Energy (MJ)](chart.png)
Energy Breakeven Analysis

Life Cycle Energy (MJ) BEP

- 20%

BEP - AIV:Base
19,000 Km
(12,000 Mi)

Distance traveled (Km)

Energy (MJ),000's

Baseline
LWSV
AIV
Life Cycle CO2e Findings

<table>
<thead>
<tr>
<th>CO2e - Kg</th>
<th>Mfg.</th>
<th>Use</th>
<th>End-of-Life</th>
<th>Total Life Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>7,599</td>
<td>71,136</td>
<td>-2,337</td>
<td>76,397</td>
</tr>
<tr>
<td>LWSV</td>
<td>6,102</td>
<td>64,016</td>
<td>-2,341</td>
<td>67,777</td>
</tr>
<tr>
<td>AIV</td>
<td>7,555</td>
<td>59,518</td>
<td>-3,661</td>
<td>63,412</td>
</tr>
</tbody>
</table>

Life Cycle CO2e Emissions (Kg)

- Baseline
- LWSV
- AIV
CO2 eq. Breakeven Analysis

Life Cycle CO2e Emissions BEP

- 17%

Distance Traveled (Km)

CO2e Emissions (kg), 000's

BEP - AIV: Base
900 Km
(600 Mi)

Baseline
LWSV
AIV
Conclusions – Auto. Aluminum LCA

- Aluminum Intensive Vehicle (AIV) technology offers the lowest life cycle Energy and CO₂ impact
  - Key factor – fuel economy improvement due to light-weighting
  - AIV reduces vehicle mass 25% (vs. baseline) significantly reducing vehicle use phase energy consumption (20%) and CO₂ emissions (17%)

- Use phase 250,000 KM (155,000 M) contributes over 90% of life cycle impacts for all vehicle configurations studied

<table>
<thead>
<tr>
<th></th>
<th>Use</th>
<th>Life Cycle</th>
<th>% Use Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>1,002,819</td>
<td>1,074,438</td>
<td>93%</td>
</tr>
<tr>
<td>LWSV</td>
<td>902,451</td>
<td>934,435</td>
<td>97%</td>
</tr>
<tr>
<td>AIV</td>
<td>839,040</td>
<td>857,761</td>
<td>98%</td>
</tr>
</tbody>
</table>

- Lightweight Steel Vehicle (LWSV) has the lower production phase environmental impact offset by higher use phase energy and CO₂

- AIV Energy Break-even distance:
  - AIV:Baseline vehicle 19,000 km (12,000 miles)
  - AIV:LWSV 76,000 km (47,000 miles)