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

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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
  - Autoparts manufacturing and assembly
  - Use
  - Semi-fabrication material production
  - Transportation
  - End-of-life metals recycling

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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,**
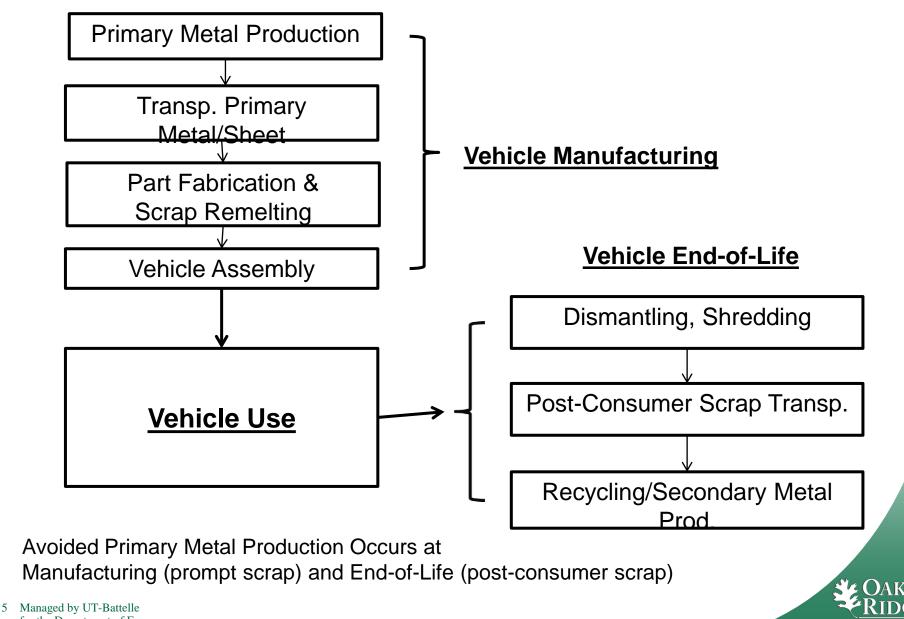   - **Ozone Depletion Potential -- TRACI 2.1 Version 1.00**

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LCA – Functional Unit Materials

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

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

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Vehicle Life Cycle Stages

Primary Metal Production

↓

Transp. Primary Metal/Sheet

↓

Part Fabrication & Scrap Remelting

↓

Vehicle Assembly

Vehicle Manufacturing

↓

Vehicle Use

→

Vehicle End-of-Life

Dismantling, Shredding

↓

Post-Consumer Scrap Transp.

↓

Recycling/Secondary Metal Prod.

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

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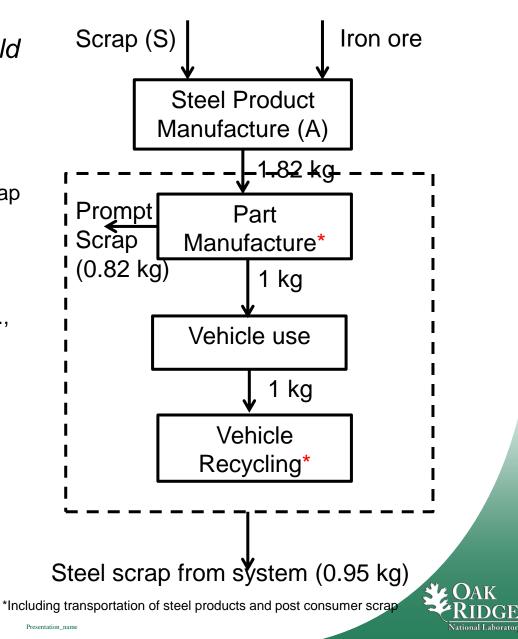
Steel LCI Data Methodology

- **LCI = X – (RR-S)Y(Xpr – Xre)**
  [Applicable for when scrap could be both inputs and outputs]

Where:

- X = Cradle-to-gate product LCI

- 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%)

- Xpr – Xre = Difference in energy between primary and secondary metal production

- Prompt scrap generated (45% for stamping and 15% eng. steel) [Krupitzer 2013]

*Including transportation of steel products and post consumer scrap

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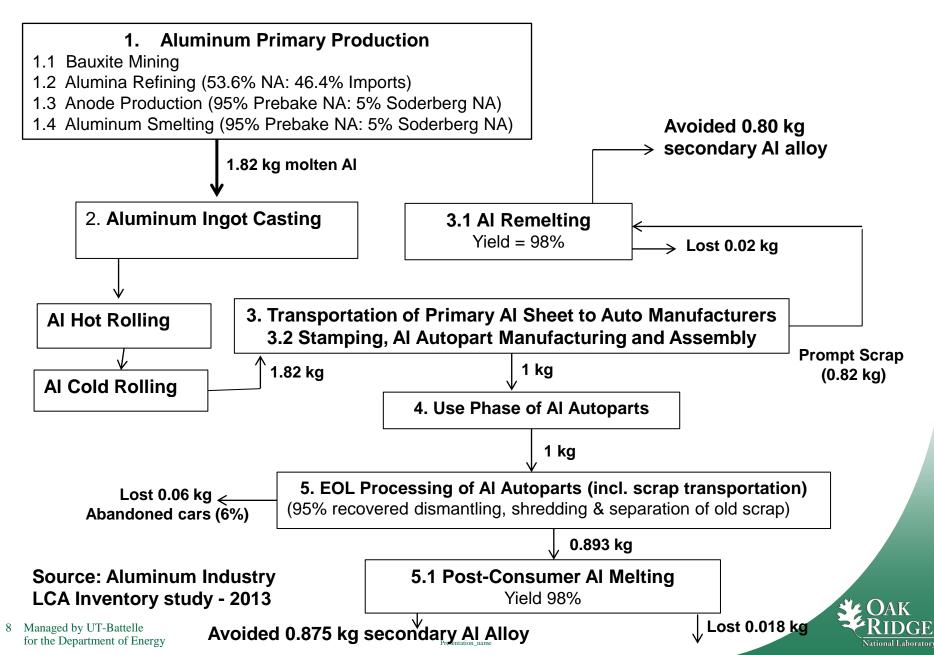 - Electro-galvanized (BIW, Structural Part)
  - Engineering steel (Other)

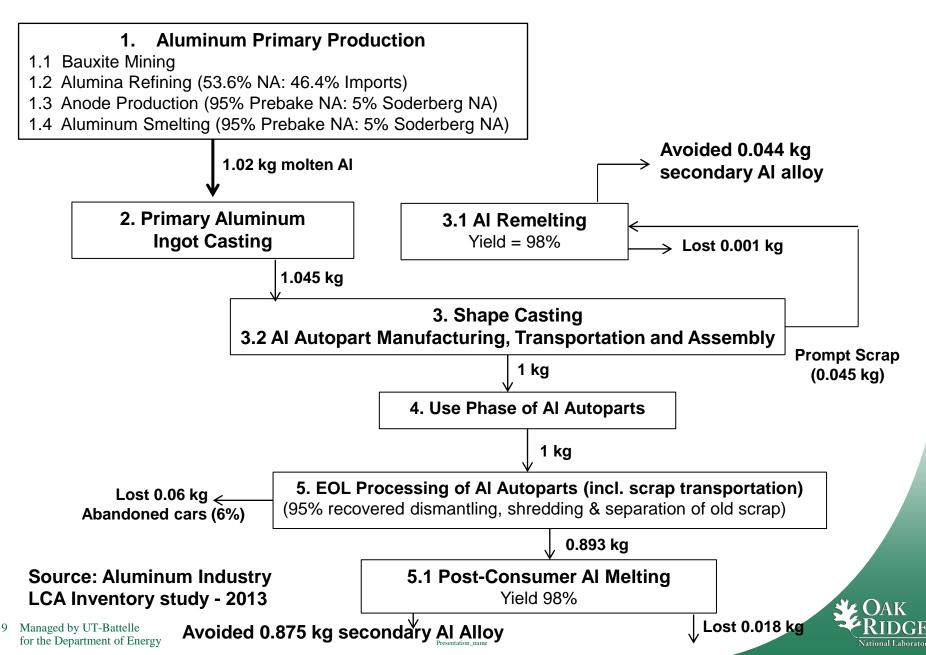- **Value of scrap data in terms of Y(Xpr-Xre) available for global only**
  - 91.6% EAF global melting efficiency (lower than 98% assumed for aluminum)

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

        Source: World Autosteel

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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)

1.82 kg molten Al

2. Aluminum Ingot Casting

3.1 Al Remelting
Yield = 98%

Lost 0.02 kg

Avoided 0.80 kg secondary Al alloy

Al Hot Rolling

3. Transportation of Primary Al Sheet to Auto Manufacturers
3.2 Stamping, Al Autopart Manufacturing and Assembly

Prompt Scrap (0.82 kg)

Al Cold Rolling

1.82 kg

1 kg

4. Use Phase of Al Autoparts

1 kg

Lost 0.06 kg
Abandoned cars (6%)

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

0.893 kg

Source: Aluminum Industry LCA Inventory study - 2013

5.1 Post-Consumer Al Melting
Yield 98%

Avoided 0.875 kg secondary Al Alloy

Lost 0.018 kg

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

Avoided 0.044 kg secondary Al alloy

3.1 Al Remelting
Yield = 98%

Lost 0.001 kg

1.045 kg

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

Prompt Scrap (0.045 kg)

1 kg

4. Use Phase of Al Autoparts

1 kg

Lost 0.06 kg
Abandoned cars (6%)

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

0.893 kg

Source: Aluminum Industry LCA Inventory study - 2013

5.1 Post-Consumer Al Melting
Yield 98%

Avoided 0.875 kg secondary Al Alloy

Lost 0.018 kg

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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

Avoided 0.285 kg secondary Al alloy

2. Primary Aluminum Ingot Casting

3.1 Al Remelting
Yield = 98%

Lost 0.005 kg

1.29 kg

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

Prompt Scrap (0.29 kg)

1 kg

4. Use Phase of Al Autoparts

1 kg

Lost 0.06 kg
Abandoned cars (6%)

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

0.893 kg

Source: Aluminum Industry LCA Inventory study - 2013

5.1 Post-Consumer Al Melting
Yield 98%

Avoided 0.875 kg secondary Al Alloy

Lost 0.018 kg

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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)

    $C_{A,n} = (m_{part,n} - m_{part,b}) \times VA \times LTDD$, where,

    $C_{A,n}$ = the total life cycle mass-induced fuel change (decrease/or increase) of new autoparts designs in liters

    $m_{part,\,n}$ = mass in kg of new design autoparts
    (i.e., 1399 kg LWSV, 1236 kg AIV)

    $m_{part,\,b}$ = mass in kg of baseline autoparts (baseline, replaced with the new design), i.e., 1711 kg

    VA = mass-induced fuel consumption reduction value <u>with powertrain adaptation</u> - 0.38l/100km.100 kg

    $LTDD$ = baseline life-time driving distance (250,000 km, 155,000 mi.)

- Gasoline primary energy:

    40.9 MJ/l (ANL GREET Model – Well-To-Pump and Pump-To-Wheels)

- Baseline Vehicle Fuel Economy – 24 mpg Label (30 MPG Test)

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Life Cycle Environmental Impacts
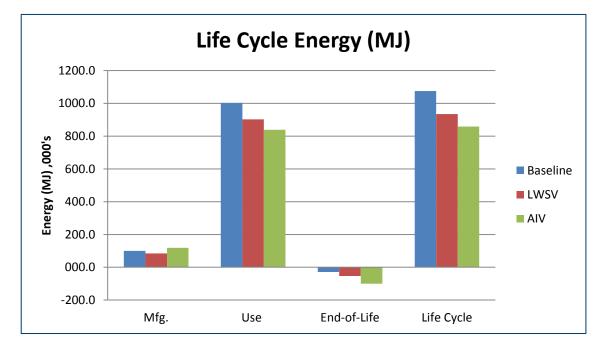
Parameter	Unit	Baseline	LWSV	AIV
Global warming	kg CO2 eq	76,397	67,777	63,412
Ozone depletion	kg CFC-11 eq	2.9 E-05	4.2 E-05	1.3 E-04
Smog	kg O3 eq	1,563	1,348	1,276
Acidification	kg SO2 eq	56	47	48
Eutrophication	kg N eq	3	2	2
Respiratory effects	kg PM2.5 eq	7	6	6

Impact Assessment Method: TRACI 2.1 Version 1.00

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Life Cycle Energy Findings

Life Cycle Energy (MJ)
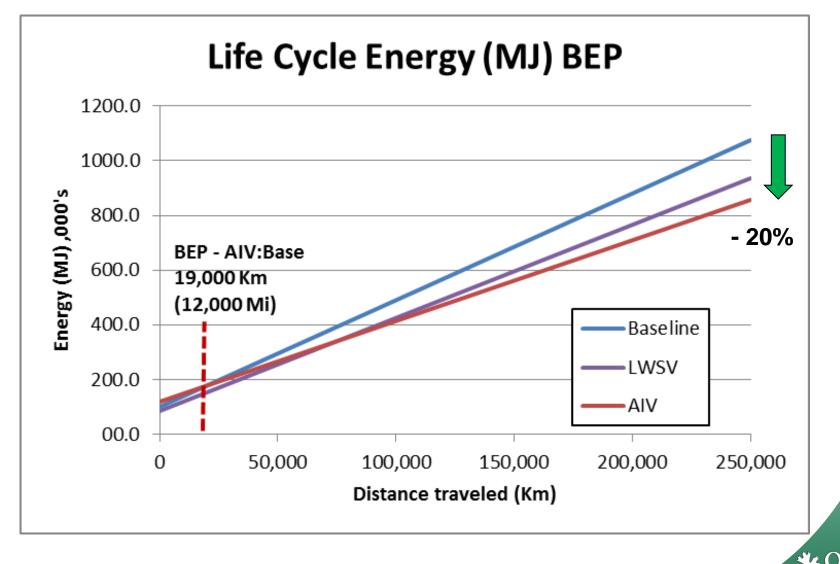
MJ/Vehicle

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

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Energy Breakeven Analysis

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Life Cycle CO2e Findings

Life Cycle CO2e Emissions (Kg)
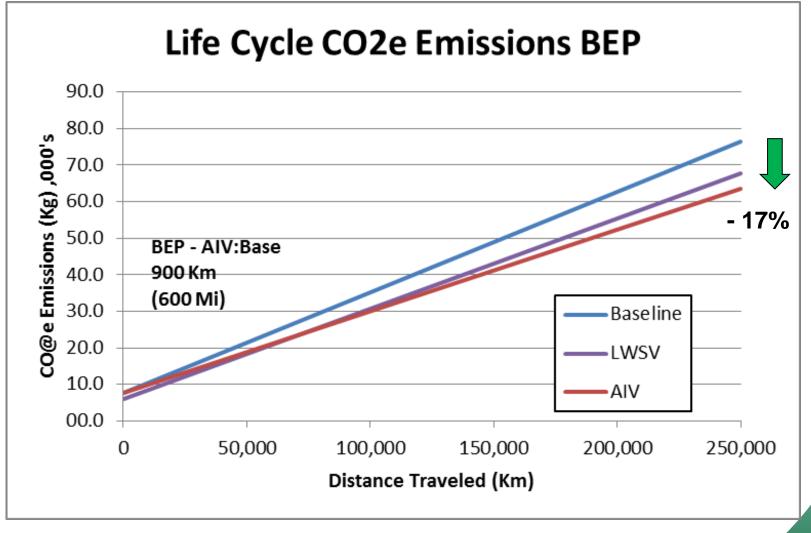
CO2e - Kg

	Mfg.	Use	End-of-Life	Total Life Cycle
Baseline	7,599	71,136	-2,337	76,397
LWSV	6,102	64,016	-2,341	67,777
AIV	7,555	59,518	-3,661	63,412

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CO2 eq. Breakeven Analysis

Managed by UT-Battelle
for the Department of Energy

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Conclusions – Auto. Aluminum LCA

- **Aluminum Intensive Vehicle (AIV) technology offers the lowest life cycle Energy and CO_2 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 CO_2 emissions (17%)**

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

	Use	Life Cycle	% Use Phase
Baseline	1,002,819	1,074,438	93%
LWSV	902,451	934,435	97%
AIV	839,040	857,761	98%

MJ/Vehicle

- **Lightweight Steel Vehicle (LWSV) has the lower production phase environmental impact offset by higher use phase energy and CO_2**

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

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