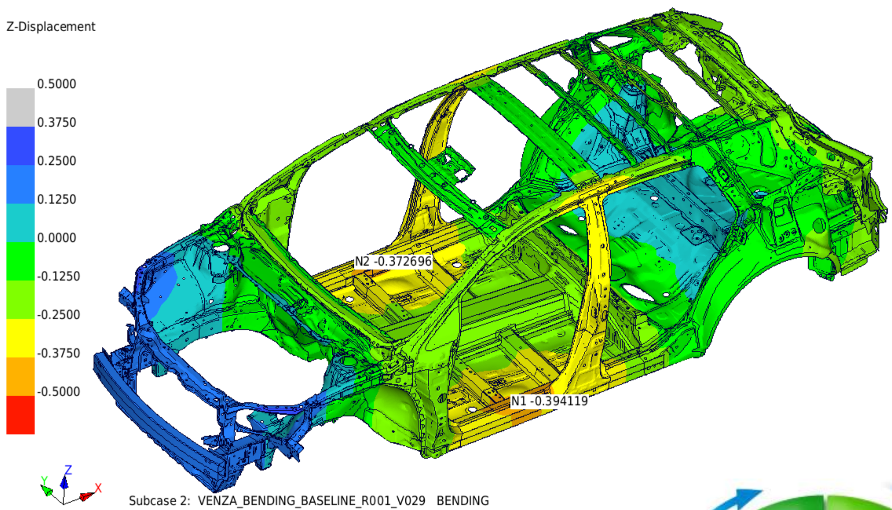
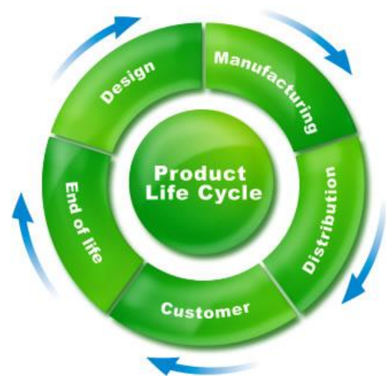
Life Cycle Assessment - Energy and CO_2 Emissions of Aluminum-Intensive Vehicles



Sujit Das

September 2013



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

LCA Study Goals

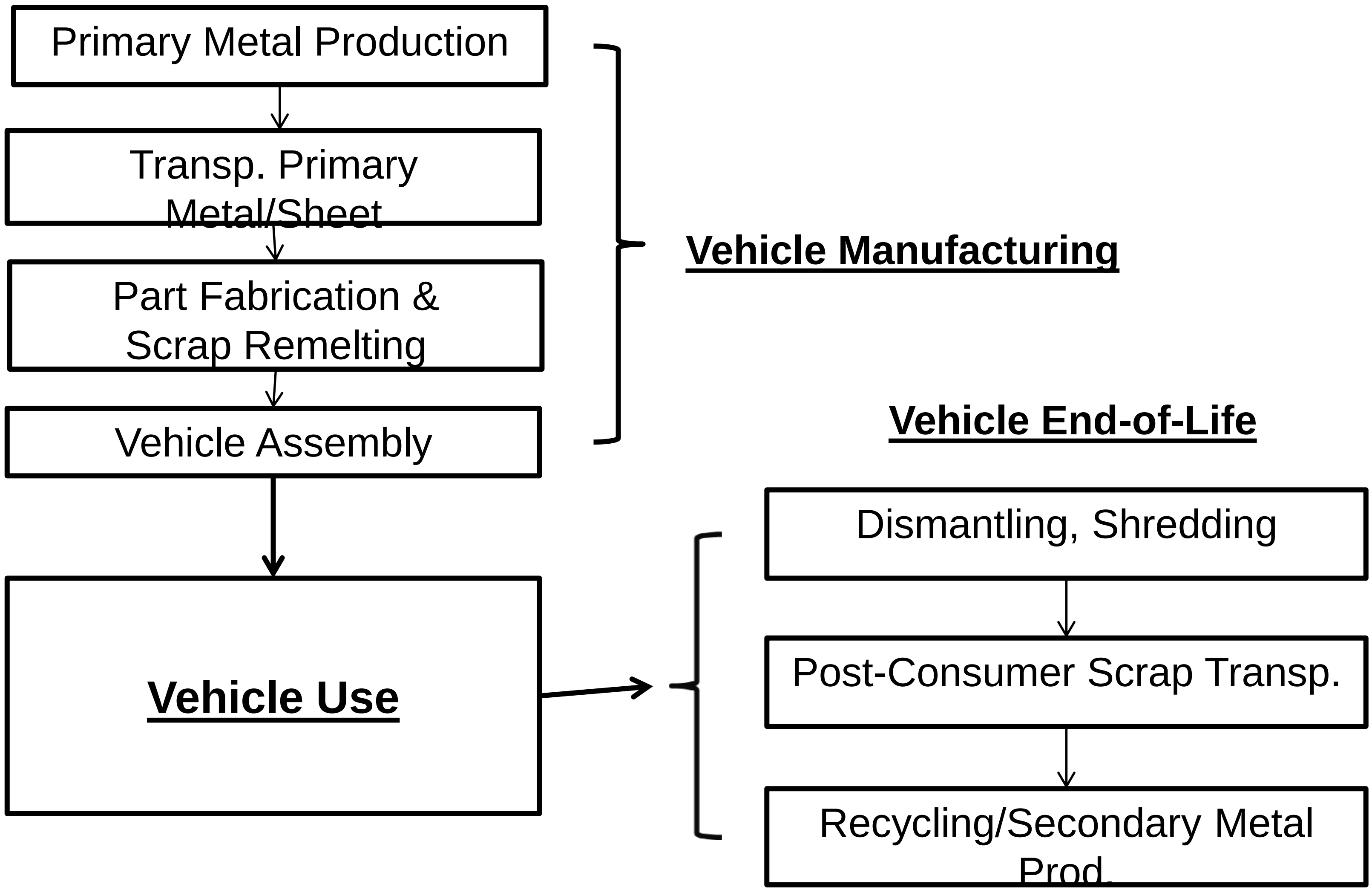
- **End-of-Life Recycling:**
  - **closed-loop approach ISO 14044:2006**
    - **Avoided primary production equals recovered scrap**
- **Life cycle impacts (Ecoinvent V. 1.02)**
    - **Total Primary energy**
    - **Cumulative Energy Demand**
    - **Global Warming Potential (CO2e)**
    - **Acidification Potential**
    - **Eutrophication Potential**
    - **Photo Chemical Smog Potential**
    - **Respiratory Effects Potential,**
    - **Ozone Depletion Potential -- TRACI 2.1 Version 1.00**

LCA – Functional Unit Materials

Material	Baseline	LWSV	AIV
Steel (kg)	1011	794	366
Pickled Hot Rolled (SP)	242	181	172
Electro-Galvanized (BIW, SP)	684	344	138
Hot-Dip Galvanized (BIW, SP)	59	45	34
Engg. Steel (Other)	27	224	22
Aluminum (kg)	157	194	459
Sheet	12	55	296
Cast (A356)	128	125	125
Extrusion	17	14	38
Vehicle Weight (kg)	1711	1399	1236

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

Vehicle Life Cycle Stages



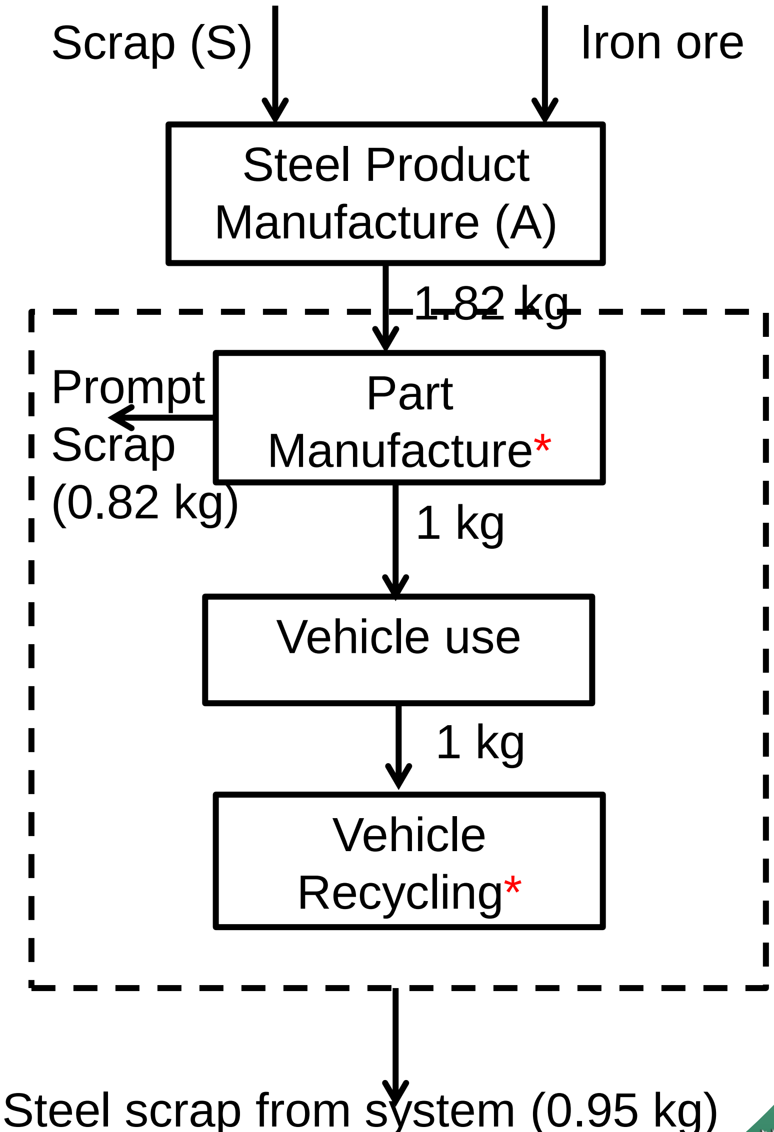
Avoided Primary Metal Production Occurs at Manufacturing (prompt scrap) and End-of-Life (post-consumer scrap)

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]



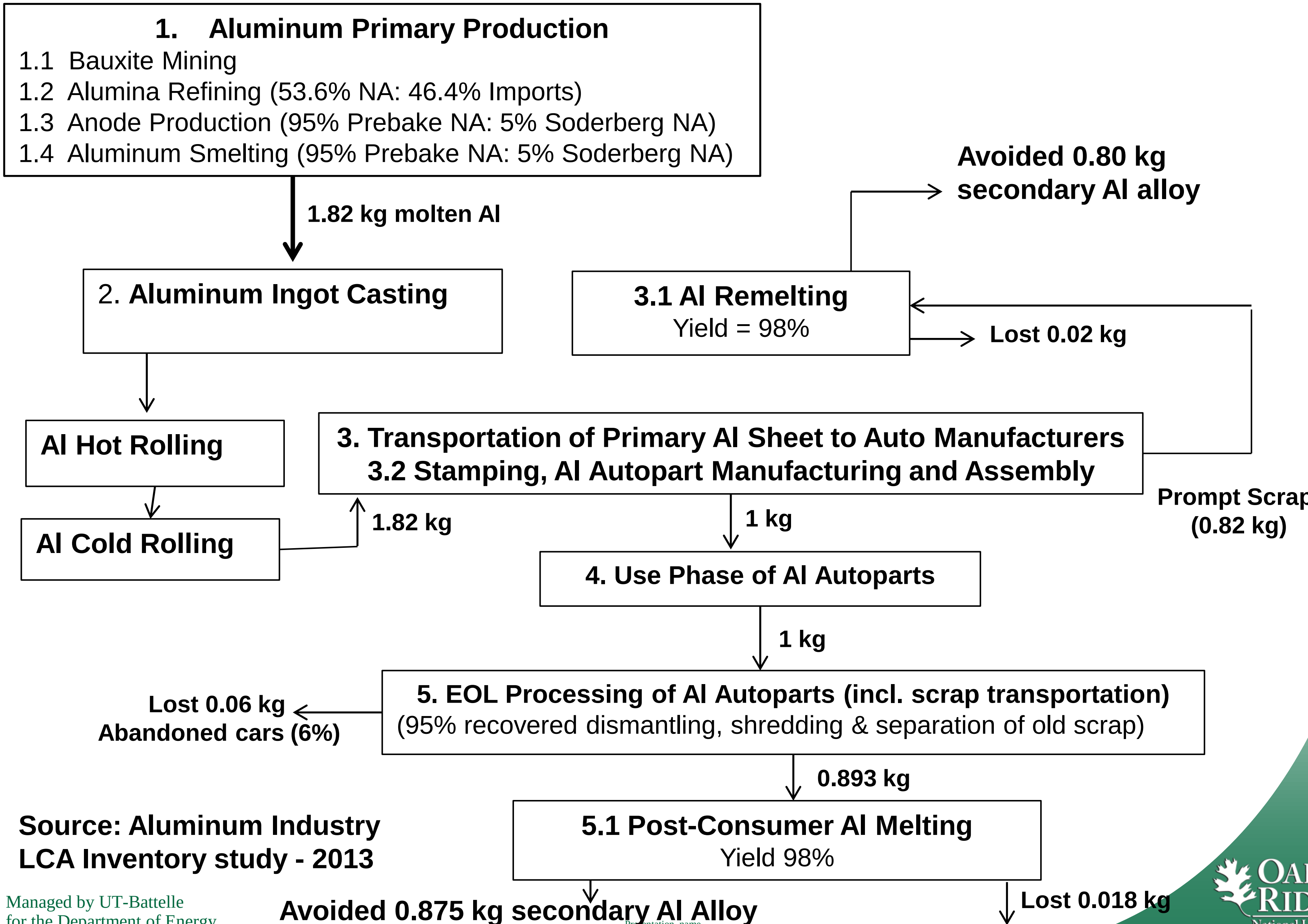
*Including transportation of steel products and post consumer scrap

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.**

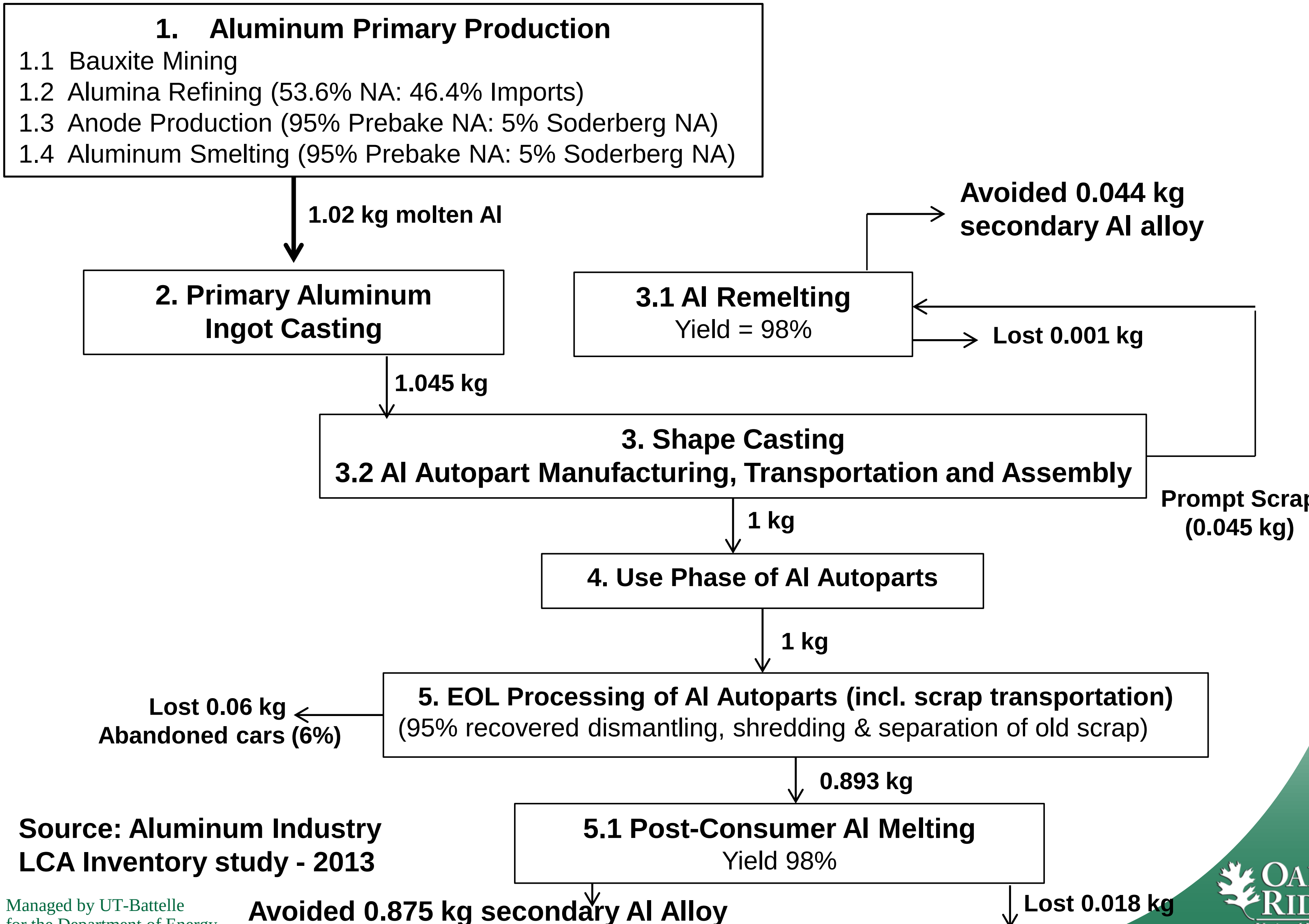
Source: World Autosteel

Life Cycle - Al Stamped Part



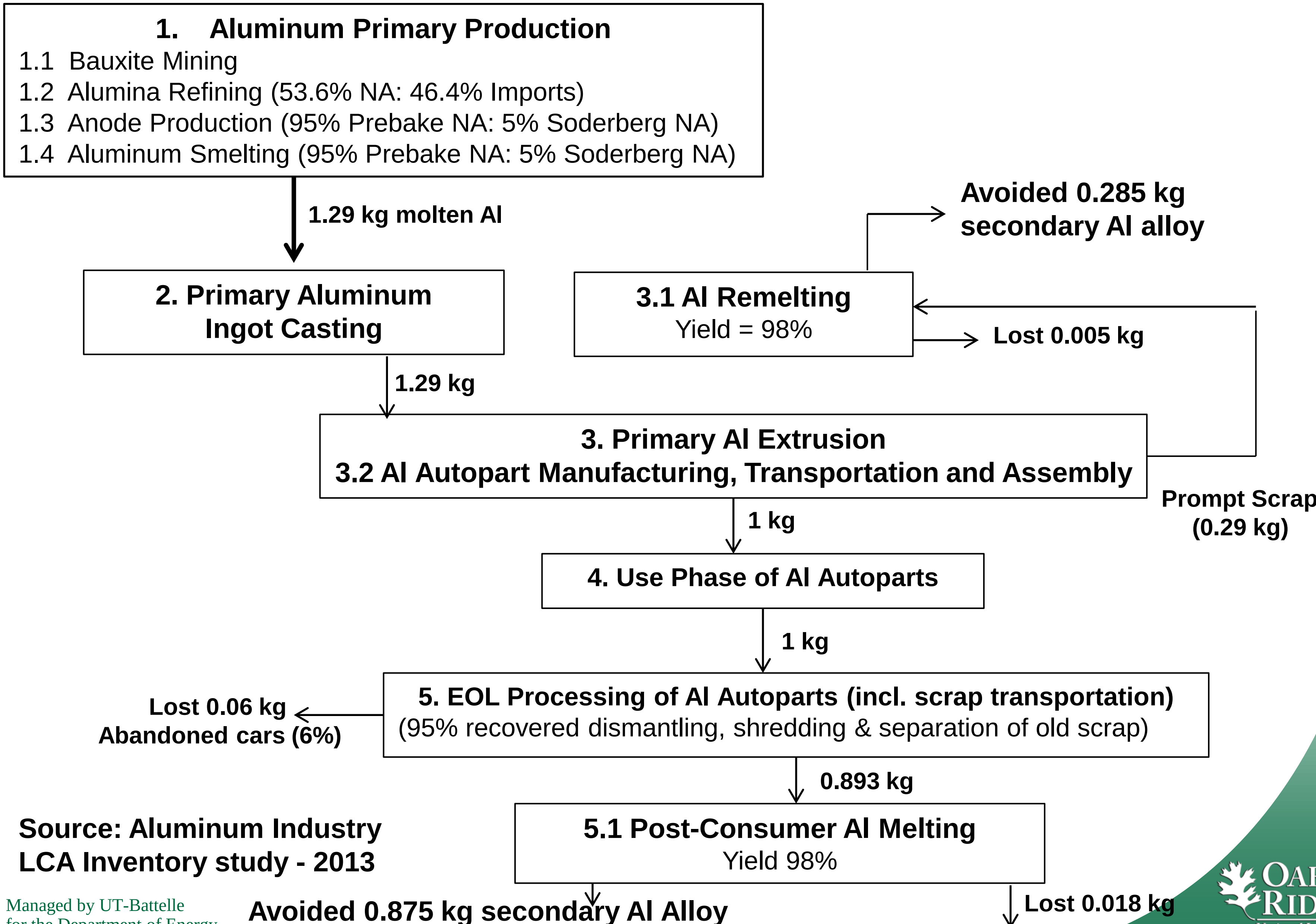
Source: Aluminum Industry LCA Inventory study - 2013

Life Cycle Stages - Al Cast Part



Source: Aluminum Industry LCA Inventory study - 2013

Life Cycle Stages - Al Extrusion Part



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*) x VA x LTDD, where,

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

  mpart, n = mass in kg of new design autoparts (i.e., 1399 kg LWSV, 1236 kg AIV)

  mpart, b = mass in kg of baseline autoparts (baseline, replaced with the new design), i.e., 1711 kg

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

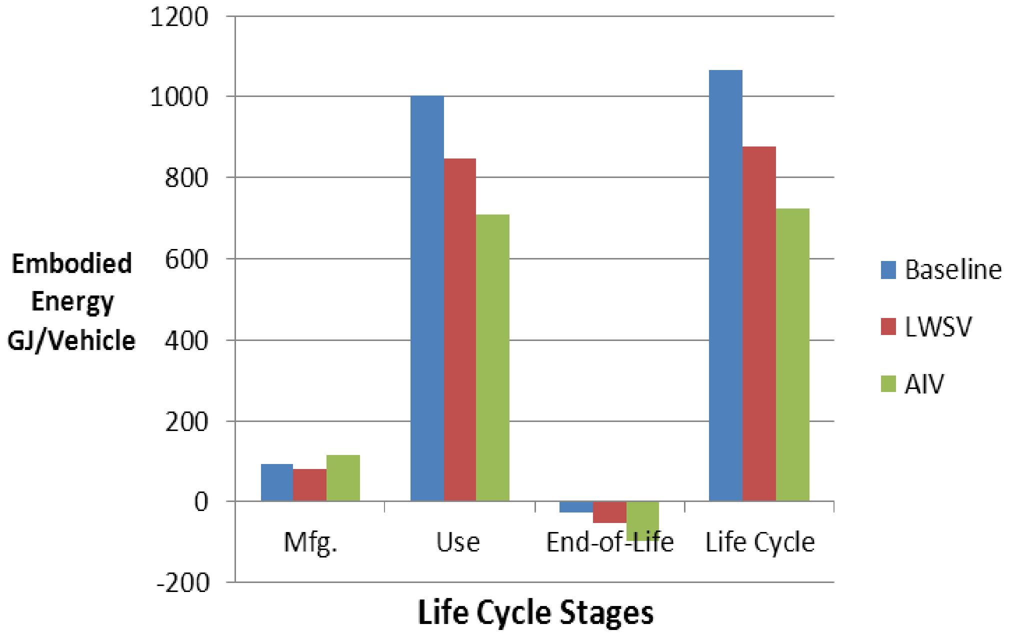
  LTDD = baseline life-time driving distance (250,000 km, 155,000 mi.)

- Gasoline primary energy:

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

- Baseline Vehicle Fuel Economy – 24 mpg

Life Cycle Energy Findings



Note: Based on Baseline 1168 kg Components of a 1711 kg Curb Weight Vehicle

MJ/Vehicle

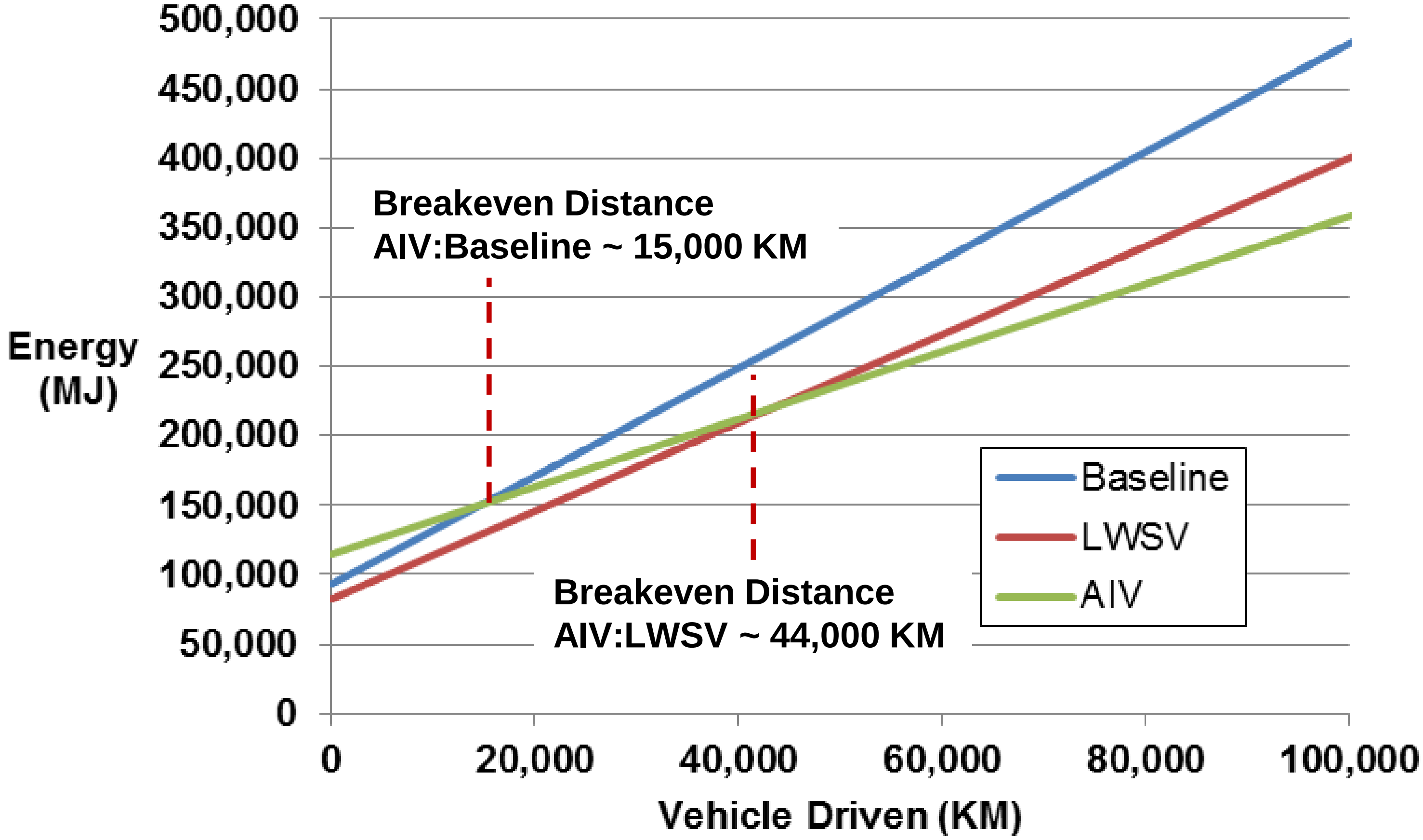
	Mfg.	Use	End-of-Life	Total Life Cycle
Baseline	93,275	100,2819	-27,983	1,068,111
LWSV	81,973	848,275	-52,311	877,938
AIV	115,084	708,327	-98,893	724,518

Life Cycle Environmental Impacts

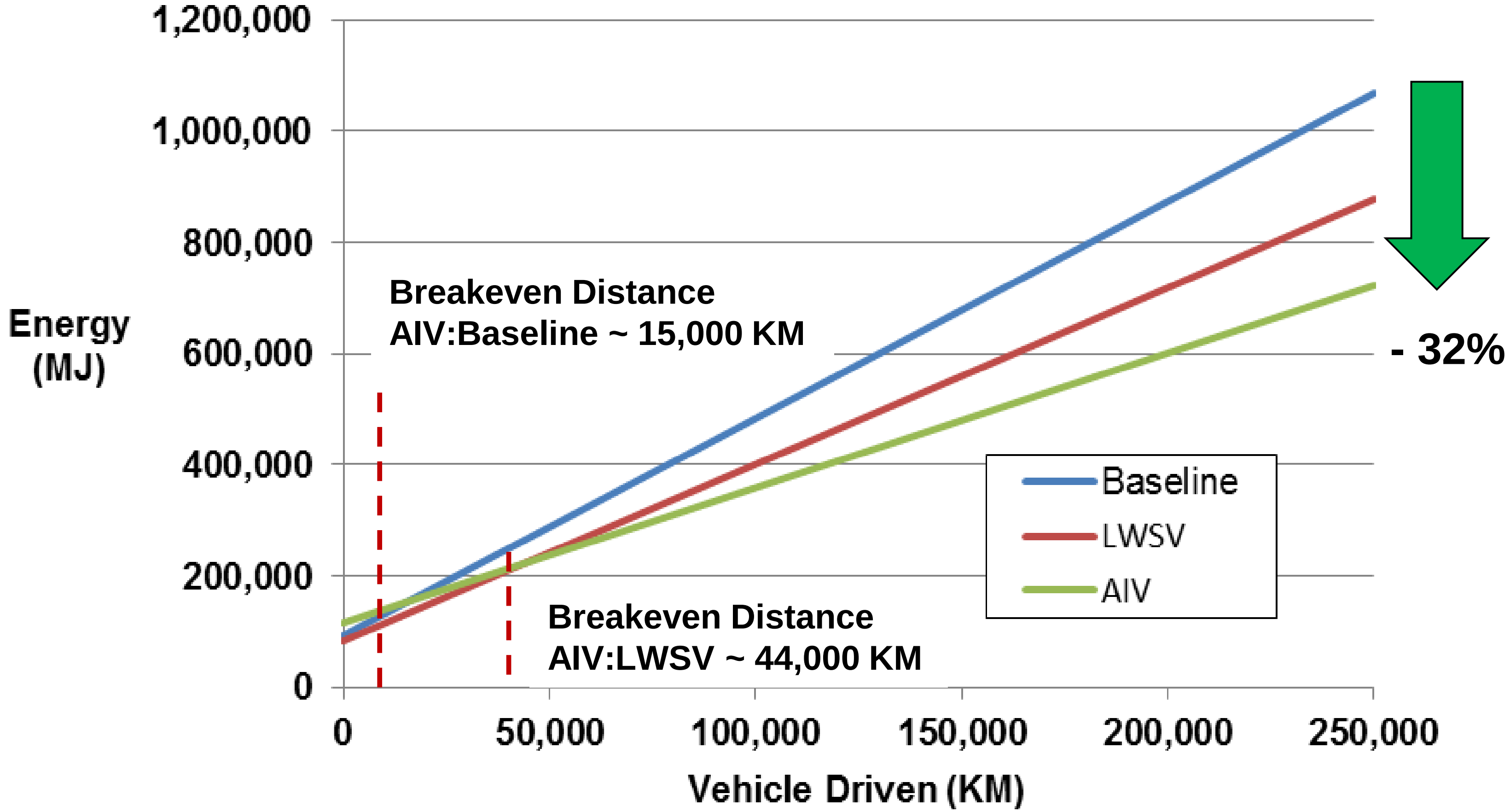
Parameter	**Unit**	**Baseline**	**LWSV**	**AIV**
Global warming	kg CO2 eq	6.93E+04	5.82E+04	4.93E+04
Ozone depletion	kg CFC-11 eq	2.86E-05	4.10E-05	1.27E-04
Smog	kg O3 eq	1.52E+03	1.26E+03	1.09E+03
Acidification	kg SO2 eq	5.32E+01	4.44E+01	4.29E+01
Eutrophication	kg N eq	2.53E+00	2.14E+00	2.11E+00
Carcinogenics	CTUh	7.11E-06	7.67E-06	9.62E-06
Non-carcinogenics	CTUh	2.63E-04	2.93E-04	2.06E-04
Respiratory effects	kg PM2.5 eq	6.56E+00	5.56E+00	5.02E+00
Eco-toxicity	CTUe	4.13E+02	4.96E+02	7.78E+02
Fossil fuel depletion	MJ surplus	2.51E+03	2.29E+03	3.43E+03

Impact Assessment Method: TRACI 2.1 Version 1.00

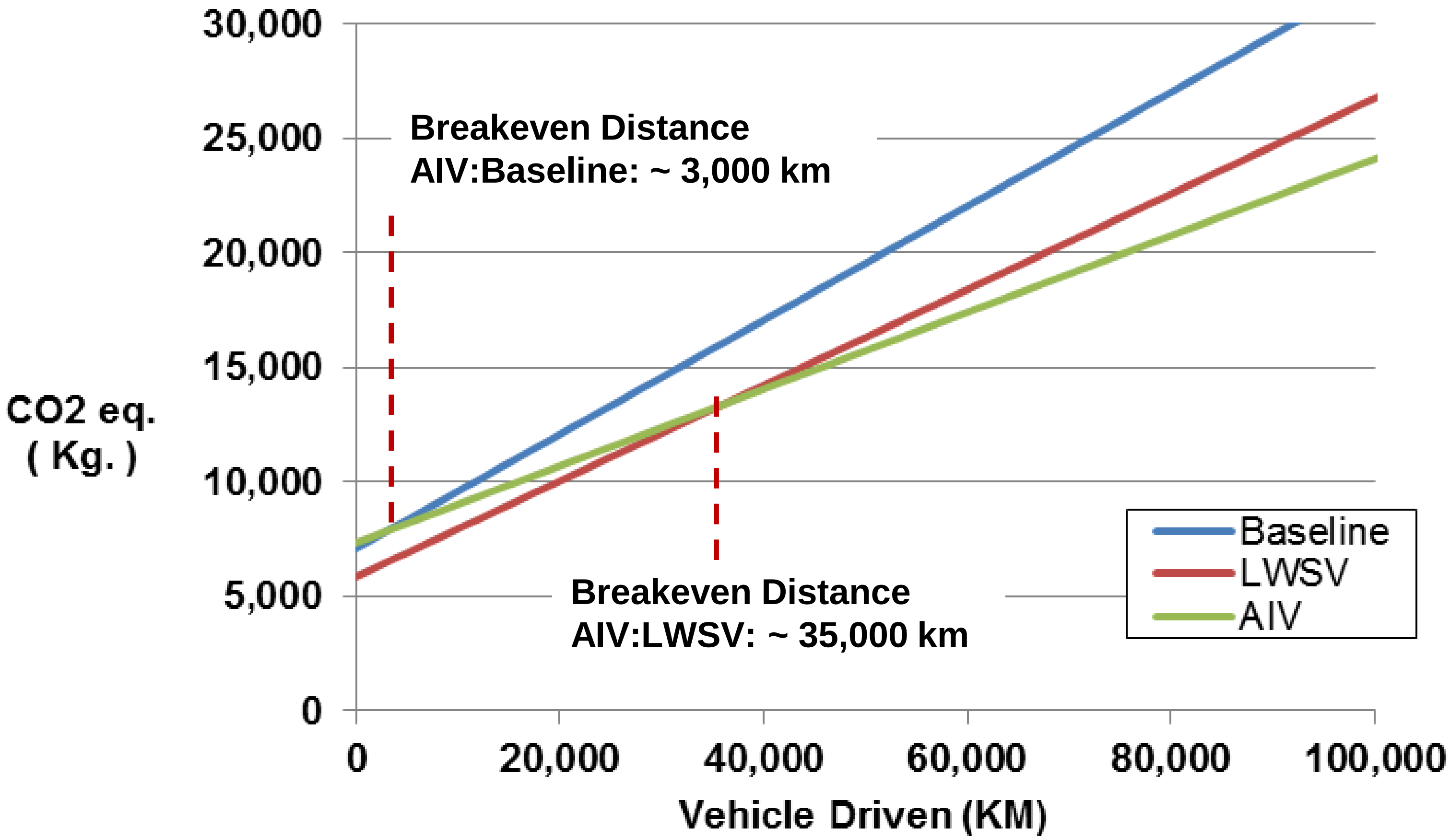
Energy Breakeven Analysis



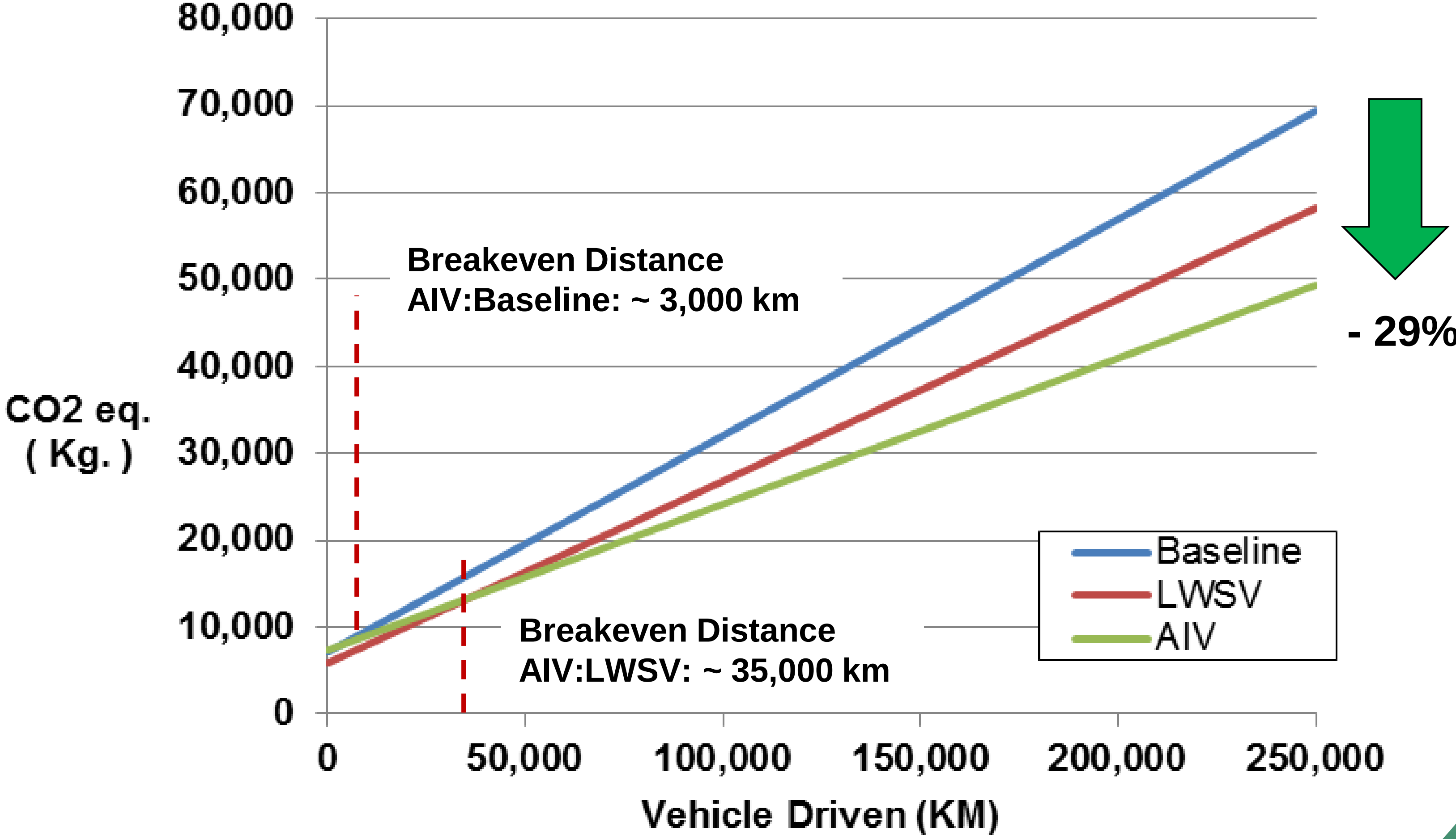
Energy Breakeven Analysis



CO2 eq. Breakeven Analysis



CO2 eq. Breakeven Analysis



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 by 28% (vs. baseline) significantly reducing vehicle use phase energy consumption (32%) and CO_2 emissions (29%)**
- **Use phase (250,000 KM, 155,000 M) contributes over 90% of life cycle impacts for all vehicle configurations studied**

	VEHICLE USE	OVERALL LIFE CYCLE	%USE
Baseline	1002819	1068111	94%
LWSV	848275	877938	97%
AIV	708327	724518	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 15,000 km (9,300 miles)**
  - **AIV:LWSV 44,000 km (30,000 miles)**