Fleet-Based LCA:
Comparative CO_2 Emission Burden of Aluminum and Steel Fleets

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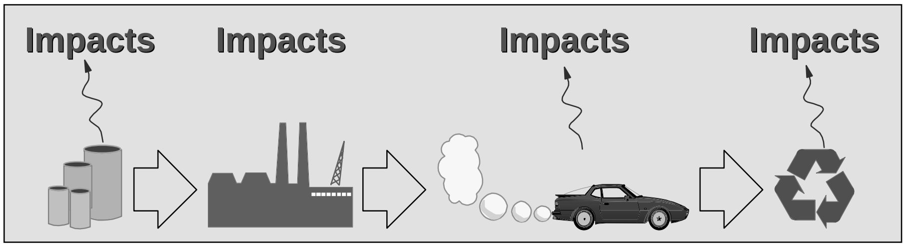
Life Cycle Analysis

- **Conventional Analysis Is Focused On A Single Product**
- **Necessarily "Compresses" All Time-Dependent Emissions Into A Single Value**
- **May Be Appropriate In Some Cases**
- **However, When Significant Emissions Differences Occur Over Long Periods Of Time, May Provide An Incomplete Picture**
- **Pertinent In The Case Of Automobiles, Where Use-Phase Emissions Dominate LCA Inventories**

Study Objectives

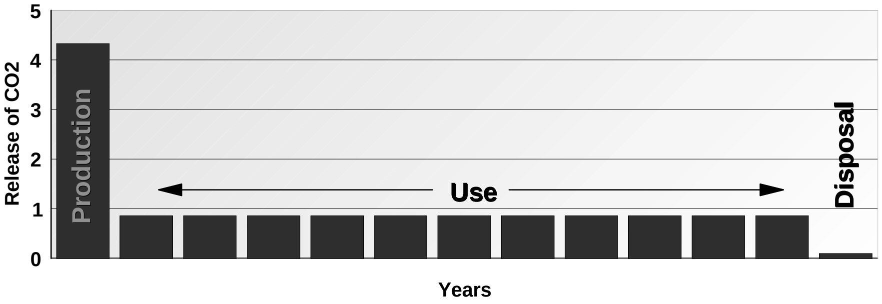
- Detailed treatment of temporal effects in life-cycle assesment
  - When do impacts occur?
  - When is "payback" achieved?
  - What if production is distributed over time?
- Make analytical assumptions explicit
- Reveal implications of analytical assumptions



Temporal Effects on Life-Cycle Assessment

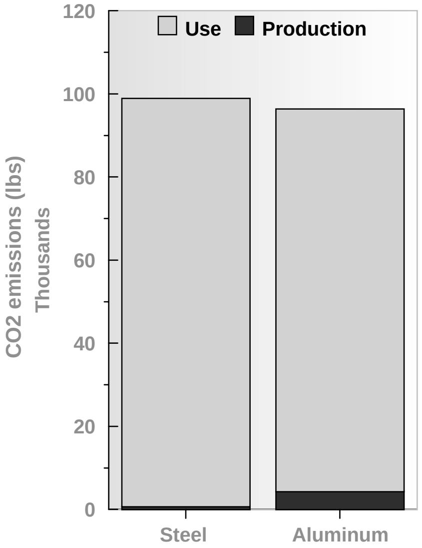
- Conventional LCA studies have looked at impacts of single products
  - Production –> Use –> Disposal
- Even for single products, effects are inherently distributed over time
  - Particulary true for long-lived products like automobiles

Typical Life Cycle Impacts



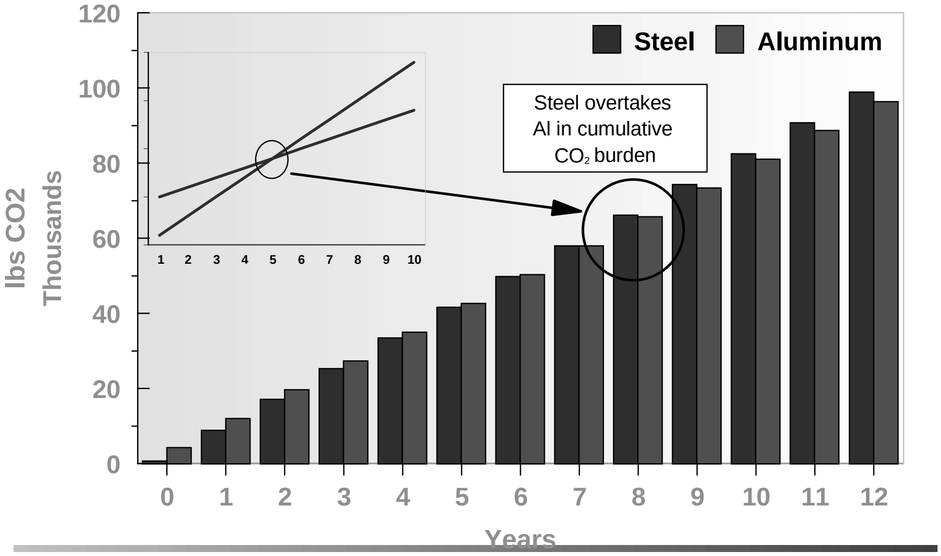
Issues with Conventional Analysis

- Because impacts are distributed, point estimates do not fully describe a life cycle
- Relative timing of impacts may be important
- A question arises:
  - When does the impact of one product drop below that of another?



Production emissions accounts for only BIW material.
Remainder of vehicle assumed to be same for both

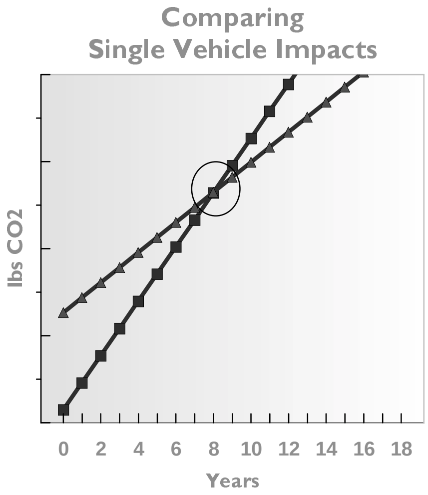
Timing of Life-Cycle Burden Can Be Important



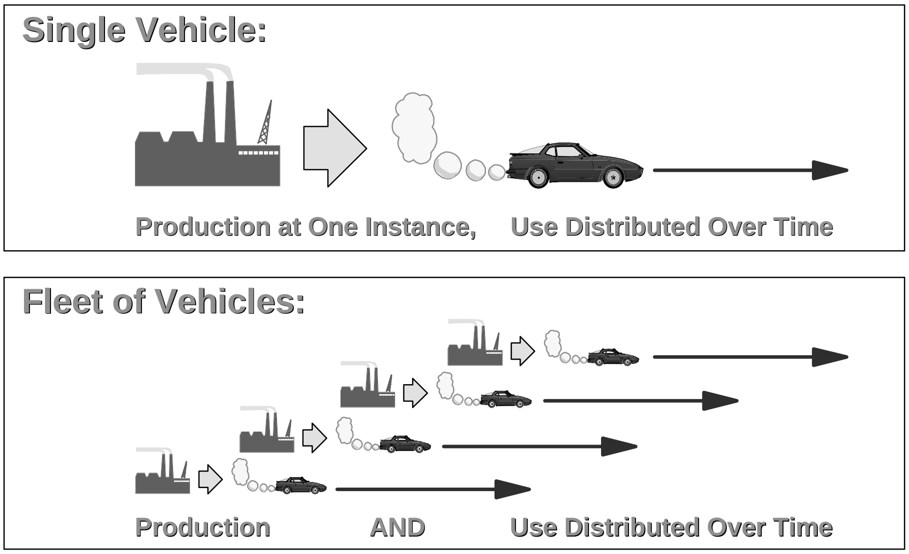
Steel overtakes Al in cumulative CO_2 burden

Once Recognized, Time Exposes Other Needs

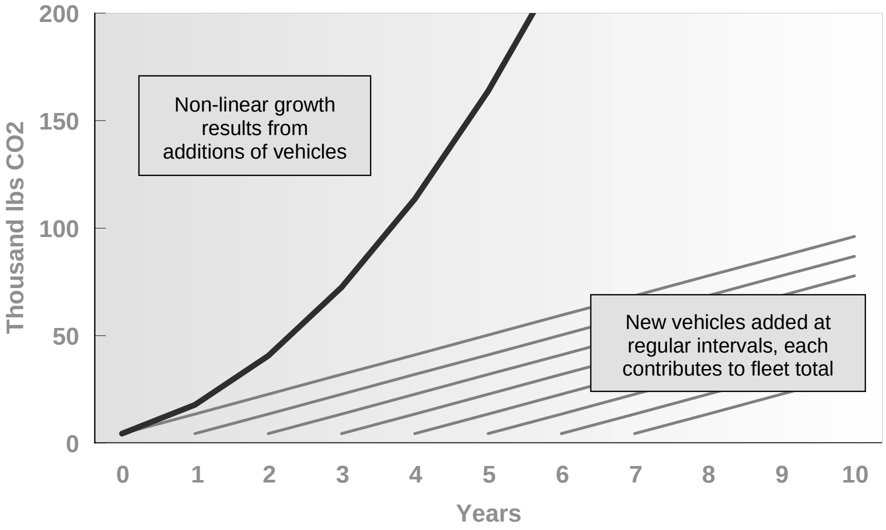
- **Key Issues**
  - **Is a single product the correct unit of comparison?**
    - *Production at one point in time*
    - *Production distributed over time*
  - **Does the performance of production technologies remain constant?**
  - **Do all units operate identically over their life?**
- **Analysis Requirements:**
  - **Detailed treatment of time**
  - **New modeling approach**



Impact of Fleet Perspective



Fleet Introduction Changes Rate of Life-Cycle Emission



Non-linear growth results from additions of vehicles

New vehicles added at regular intervals, each contributes to fleet total

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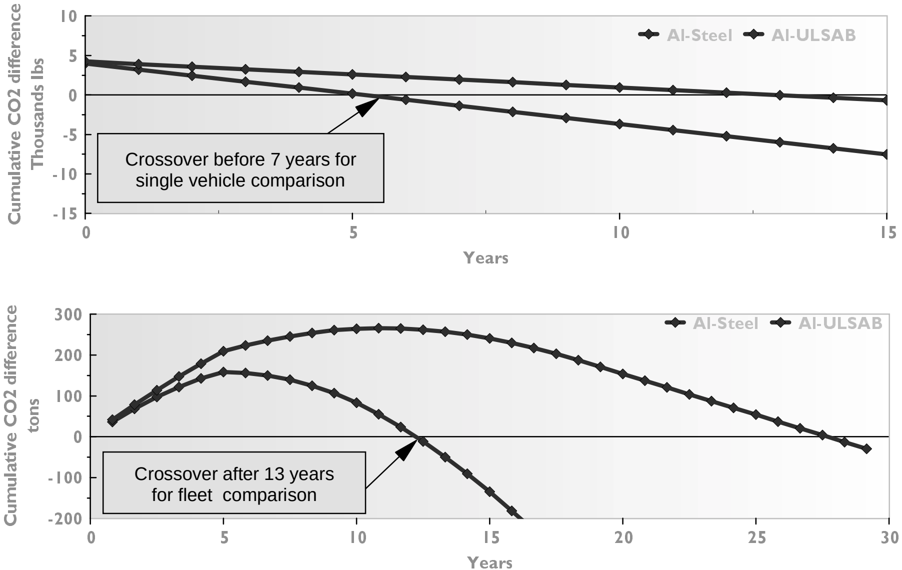
Fleet Changes Shape and Timing of Recovery Curves



Crossover before 7 years for single vehicle comparison

Crossover after 13 years for fleet comparison

Modeling Framework: Systems Dynamics

- Explicit Consideration of Time, Rates of Production and Accumulation

- Unit Of Analysis: Fleets In Production And Use
  - Fixed Production Rates
  - Use Begins Following Production
  - Retirement Follows US Fleet Patterns
  - End-of-Life Vehicle Materials Available For Reuse

- Key Analysis Assumption:

"New" Vehicles Imply Incremental Increases In Production
Of Raw Materials, With Associated Incremental Effects

"Incremental" Production & Effects

- Introduction Of Aluminum Vehicles Will Mean Large Change In Consumption Patterns

- "New" Aluminum Production Will Be Required

- Analysis Examines Incremental Changes In Resource Use
  - Energy Consumption
  - Recycled Material Availability

- Analysis Assumes That All Other Economic Factors and Demands Are Unaffected By New Aluminum Consumption
  - Price Changes & Demand Sensitivity Not Assumed

Baseline Simulation Framework

- Start With A Zero-Car Fleet
  - Growing To Constant Fleet Size of ~150
- Produce One "Car" Per Month
  - Steel Conventional
  - Aluminum Intensive (AIV)
  - ULSAB
- Start Driving The Car Immediately Following Production
- Retire Cars According To US Fleet Statistics
- Collect ELV Materials For Reuse
  - Use Primary Material To Make Up Difference In Current Production
- Calculate And Sum CO_2 Production
- Compare Totals For Each Fleet Alternative

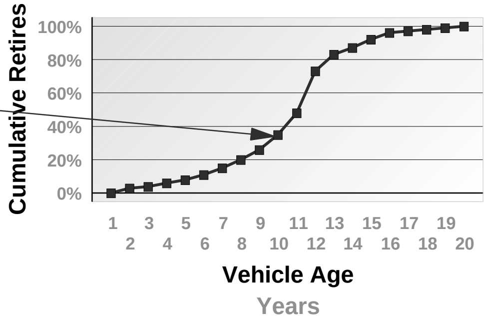
Base Case Assumptions

– Distance driven per year:	11,400 miles (18,240 km)
– Life of vehicle:	average 12.2 years using fate model
– CO_2/gal gasoline:	22.9 lb CO2/gal
– Fleet introduction:	1 "vehicle unit"/month
– Aluminum electricity source:	5 years Coal, then marginal DOE grid
– Secondary weight savings:	50%
– Fuel economy improvement:	5% per 10% weight reduction
– Stamping Yeild:	50%

	Steel	ULSAB	Aluminum
BIW weight - lb(kg)	816 (371)	612 (278)	444 (202)
Curb weight	3180 (1445)	2874 (1306)	2622 (1192)
Fuel economy	27.5 / 23.0 MPG	28.8 / 24.1 MPG	29.9 / 25.0 MPG
CO_2/lb material	1.24	1.24	19.4-12.6(primary) 1.0 (recycled)

Modeling Vehicle Fate

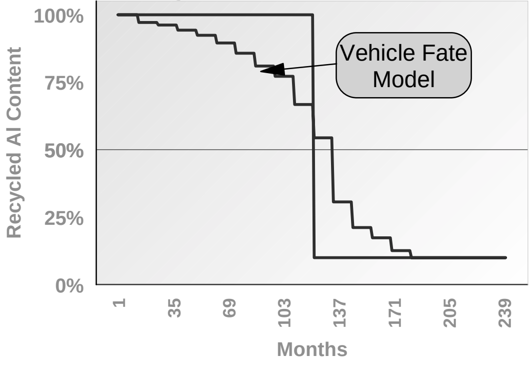
- Single vehicle models assume all vehicles retire at same time
  - All vehicles lasted 10-12 years
- Dynamic model can use real data about vehicle retirement
  - Some vehicles crash and retire quickly
  - Others last a long time
- Base case scenario generates average vehicle life of 12.2 years



Schematic Vehicle Retirement

Implications Of Vehicle Fate

- Early Vehicle Retirement Has Two Effects
  - Scrap aluminum becomes available more quickly
    - *This reduces total primary aluminum usage*
  - In early years, less vehicles on the road
    - *This means less miles driven*



Recycled Content of AIVs

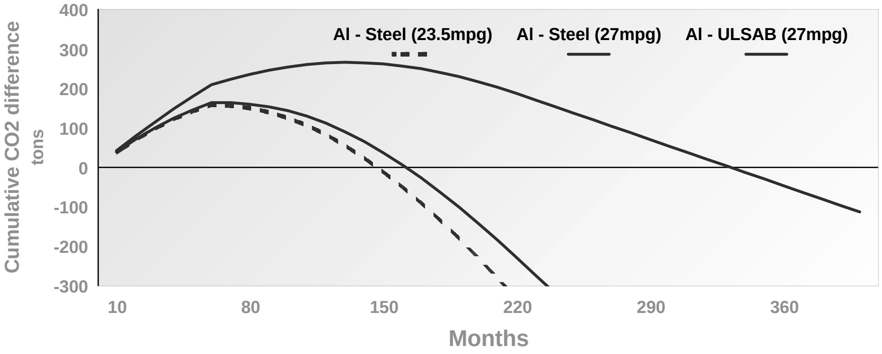
Electrical Power Source Assumption

"5 years Coal, then marginal DOE grid"

1. **Current non-fossil production part of base load generation**
2. **"New" aluminum production will require non-base loads**
   Less efficient, more polluting - currently coal-fired facilities
3. **Eventually, utilities will build new base load capacity to satisfy increases in demand**
   Forecasts predict combined cycle natural gas generation

- **"New" hydropower currently infeasible, although sites exist**
  - **Regulatory hurdles**
  - **Environmental concerns**
  - **Competing uses (recreation, etc.)**

Base Case Results: Years to Recover CO_2 Burden

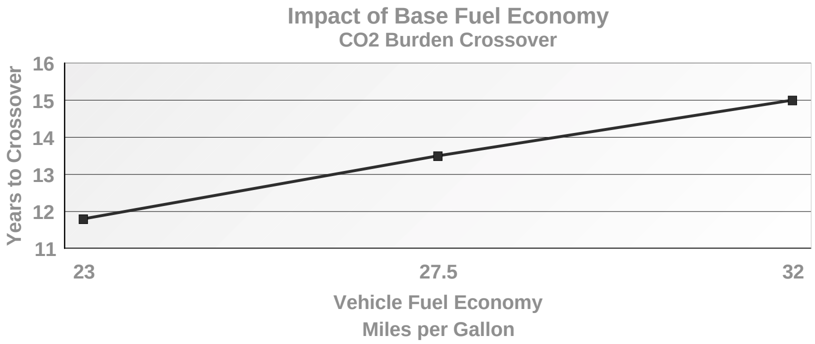


- **Base Case Crossover Points**

  Time Until Aluminum Fleets to Produce Less CO_2 than
  - **Conventional Steel:** **11.8 - 13.5 years** (23.5 - 27 mpg)
  - **ULSAB:** **23.7 - 27.7 years**

Robustness of Result

- Crossover points are sensitive to some initial assumptions
  - Base fuel economy
  - Source of electricity
  - Vehicle weight savings



Role of Aluminum Electricity Source

- Results are sensitive to assumptions about Al electricity source
- Conventional LCA relies on currently used resources
  - Current electrical grid
  - Industry reported electrical sources
- Because manufacturing aluminum autos represents a significant increase in aluminum production, we looked at marginal effects
  - Expansion in electrical demand
  - Current Al electricity sources are fully utilized
  - DOE forecast for expansion
    - *Short term: Use of current facilities*
    - *Mid term: Largely new natural gas facilities (12% coal, 3% renewables)*

Sensitivity To Aluminum Electricity Source

- Nevertheless, other assumptions may be credible
  - Evaluating on marginal burden discourages investment in clean energy sources
  - Other groups may choose most favorable scenario

Impact of Source of Aluminum Electricity
CO_2 Burden Crossovers - (23.0 mpg / 27.5 mpg basis)

Source of Electricity	Al vs. Conventional Steel	Al vs. ULSAB
Coal - 5 years, then Marginal Grid	11.8 / 13.5	23.7 / 27.6
Coal - 10 years, then Marginal Grid	13.6 / 15.3	36.9 / 31.7
Current Grid	9.8 / 11.4	20.9 / 24.3
IPAI Mix	5.3 / 6.2	13.3 / 15.4

* Crossovers in years

Robustness of Result

- Potential fuel economy improvement can effect result
  - Aggressive secondary weight savings
  - Strong response of fuel economy to weight
- Some scenarios push crossover to approximately average vehicle life

Fuel Economy Improvement per Mass Reduction

		5% : 10%	5% : 8%
Secondary Weight Savings	50%	13.5	11.6
	100%	11.1	9.6

* Crossovers in years

Conclusions

- **Base case analysis shows a substantial recovery period before CO_2 benefits of aluminum vehicles are realized**
  - **Al vs. Conventional Steel: 11.8 - 13.5 years** (23.5 - 27 mpg)
  - **Al vs. ULSAB: 23.7 - 27.7 years**
- **Results are sensitive to analytical assumptions**
  - **Fuel economy improvement**
  - **Electricity source**
- **Credible set of assumptions can result in simulated recovery periods less than or equal to current average vehicle lifetime**
- **Results may differ for emissions other than CO_2**

Future Work

- **Continuing Validation and Testing of Simulation Assumptions**
  - **Electrical Power Source Scenarios**
  - **Energy In Post-Smelter/Furnace Processes (i.e., Rolling)**
- **Influences of Changes in Key Rates**
  - **Vehicle Production/Introduction**
  - **Size of Steady-State Fleet**
  - **Rate of Vehicle Use**
- **Displacement of an Existing Fleet**
- **Alternative Recycling Accounting Methods**
- **Emissions in Addition to CO_2**