Technical Cost Modeling - Life Cycle Analysis Basis for Program Focus

Sujit Das

Oak Ridge National Laboratory

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Project ID: LM001

Overview

Timeline

- Start – Oct. 2008
- Finish – Sept. 2010 & beyond
- 50% Complete for FY10

Budget

- Total project funding
  - $125K/year (FY'08 and FY'09)
  - $150K (FY'10)
- Funding also supported other technology-specific cost analyses

Partners

- Natural Resources Canada, CSIRO/CAST (Australia)

Barriers

- Lightweight materials are several times more expensive than conventional steel – would they be economically viable when commercialized?
- Specific technology improvements affecting major cost drivers detrimental to the technology viability
- Economic viability in most cases determined on the basis of part by part substitution
- OEMs' focus on vehicle retail price instead of life cycle cost consideration

Study Objective

Estimate the cost-effectiveness on a life cycle basis of the FY2010 50% vehicle body and chassis weight reduction goal compared to 2002 vehicles of the Automotive Lightweight Materials activity

- Previous years examined the cost-effectiveness of intermediate vehicle body and chassis weight reduction goals of 25% and 40%
- Economic, energy, and environmental viability from a life cycle perspective of specific lightweight materials technologies under development and validation are also examined

Milestones

- Complete the cost-effectiveness analysis of 40% body and chassis weight reduction goal (Completed June'09)
- Complete the Phase 1 life cycle analysis of magnesium front end (Completed Sept.'09) – Results Also Presented
- Complete the cost-effectiveness analysis of 50% body and chassis weight reduction goal (Completed May'10) – Presentation Focus
- Complete the initial Phase 2 life cycle analysis of magnesium front end with a focus on MOxST primary magnesium production technology (Sept.'10)

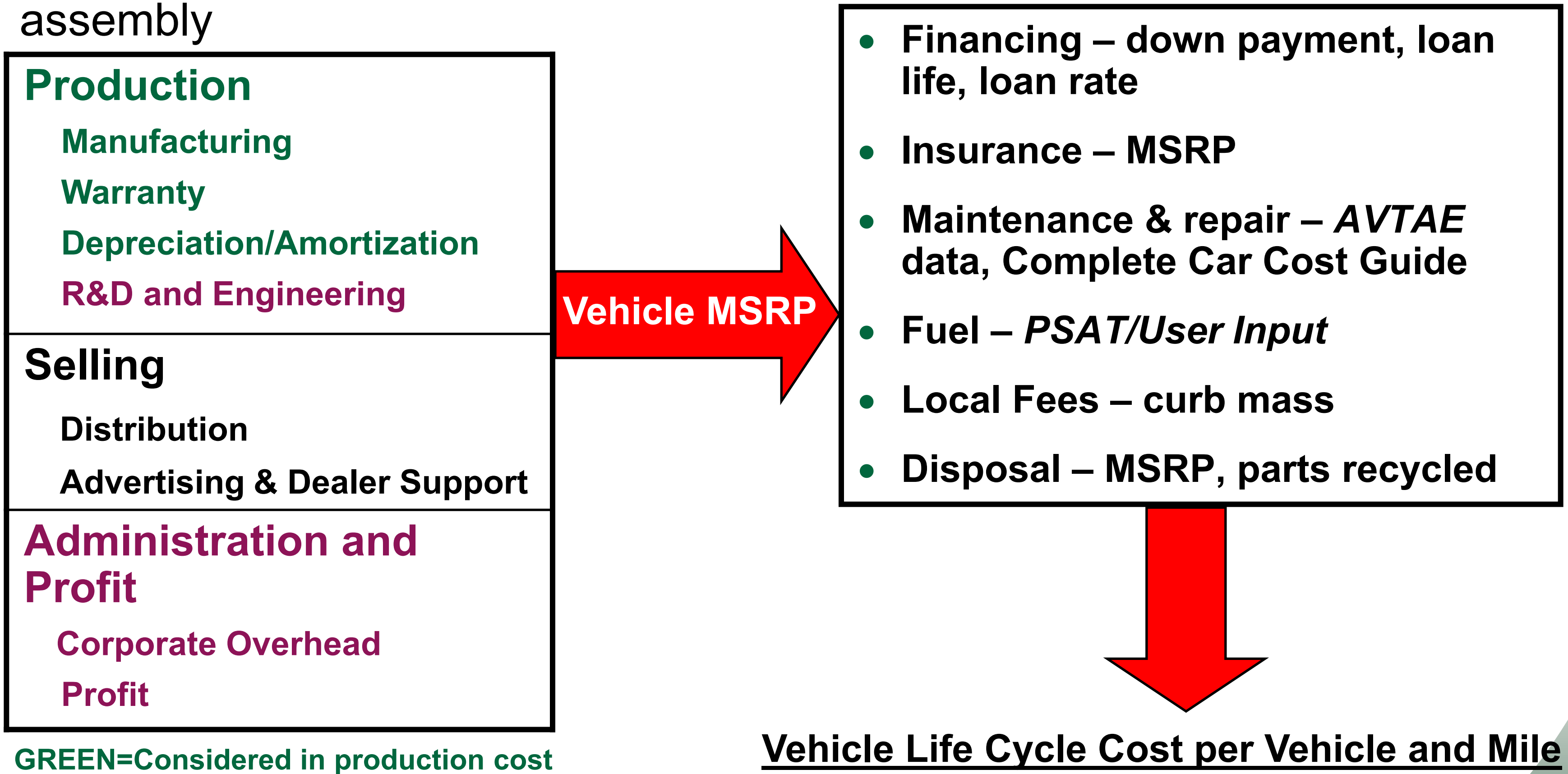
Approach

- 50% body and chassis system weight reduction goal is based on primary weight savings
- Magnesium and carbon fiber composites having weight reduction potentials of 40-60% and 50-60%, respectively, were considered for material substitution in body and chassis components to achieve required weight savings
- ORNL Automotive System Cost Model used for the cost-effectiveness estimation on a life cycle basis
  - Manufacturing cost estimates made at a level of five major subsystems and 35+ components representing a specific manufacturing technology
  - Interrelationships among vehicle components allow estimates of the mass decompounding effect (secondary weight savings)
  - Financing, insurance, local fees, fuel, battery replacement, maintenance, repair, and disposal costs are explicitly considered for the life cycle cost estimation

Vehicle Life Cycle Cost Estimation

Vehicle production cost reflects OEM cost for 35+ parts purchased directly from suppliers and vehicle assembly

Vehicle operation and maintenance costs include



Production

- **Manufacturing**
- **Warranty**
- **Depreciation/Amortization**
- **R&D and Engineering**

Selling

- **Distribution**
- **Advertising & Dealer Support**

Administration and Profit

- **Corporate Overhead**
- **Profit**

Vehicle MSRP

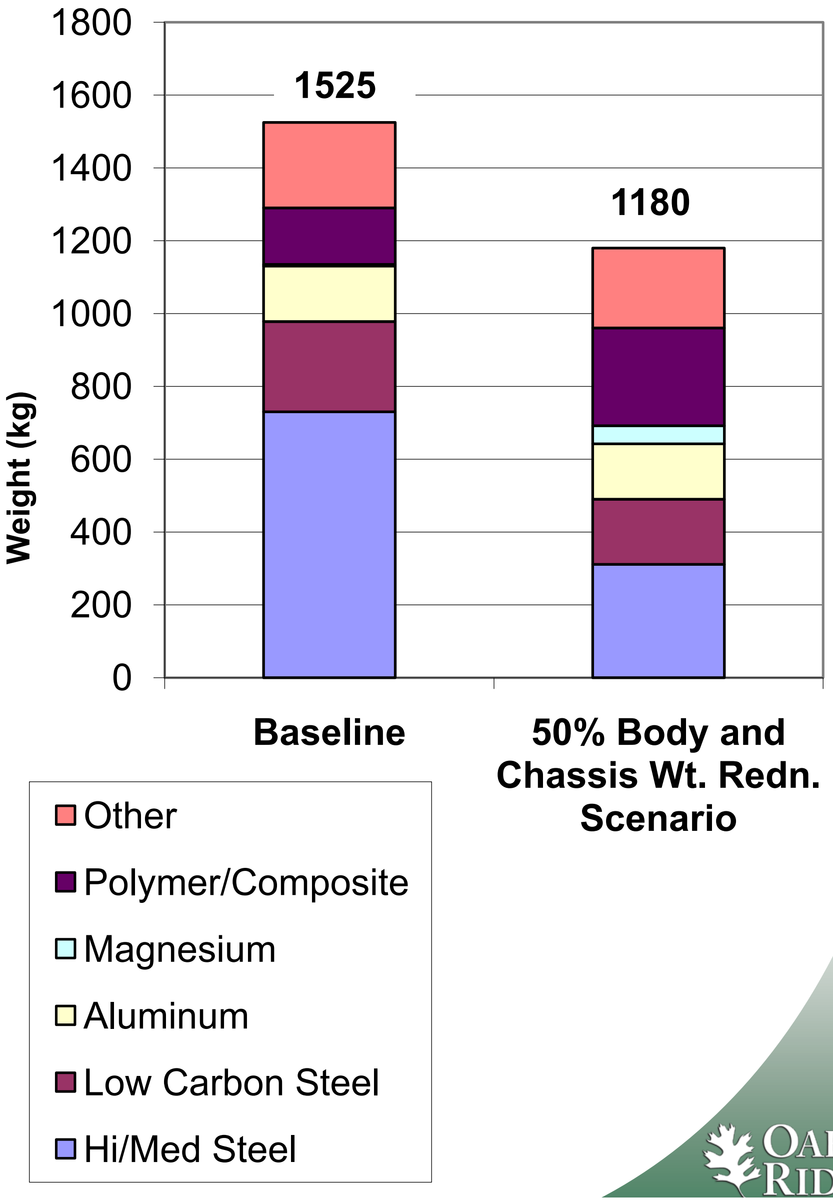
- **Financing – down payment, loan life, loan rate**
- **Insurance – MSRP**
- **Maintenance & repair – *AVTAE* data, Complete Car Cost Guide**
- **Fuel – *PSAT/User Input***
- **Local Fees – curb mass**
- **Disposal – MSRP, parts recycled**

<u>Vehicle Life Cycle Cost per Vehicle and Mile</u>

GREEN=Considered in production cost
PURPLE=OEM indirect costs
BLACK=Selling costs

Scenario Description: Two Alternatives

- A representative mid-size vehicle (i.e., Honda Accord) considered for the cost-effectiveness estimation– allows evaluation at a vehicle level, important for the commercialization of lightweight materials technologies -- Baseline
- 50% body and chassis weight reduction goal scenario considered:
  - Carbon fiber polymer matrix composites – body-in-white, panels, front/rear bumpers
  - Magnesium – cradle, corner suspension (control arms, steering knuckles), braking system (brake actuators), wheels, and steering system (steering wheel column)
  - Other subsystems (body hardware and body sealers and deadners) for a reduction in vehicle mass



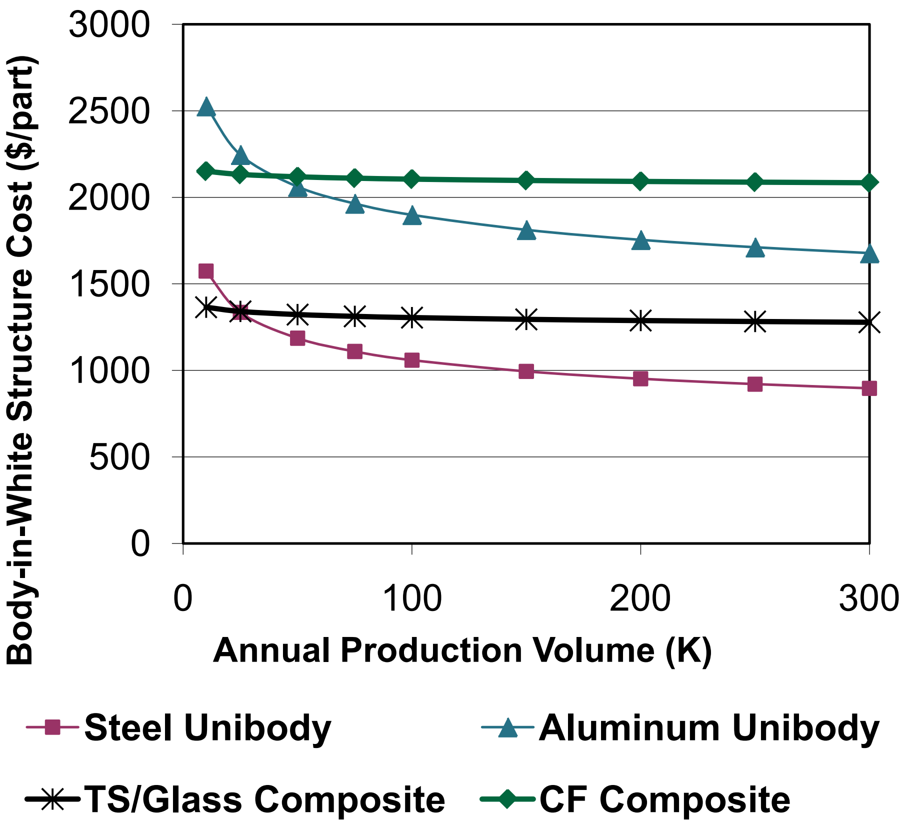
Secondary Weight Savings Impacts

- Total secondary weight savings are estimated to be 54% primary savings (most occur in powertrain and for body and chassis only 14.5% of primary savings)
- Consideration of secondary weight savings result in
  - 57% total body and chassis weight savings
  - 35% vehicle weight savings
- Combined fuel economy improves from 23 mpg to 28.3 mpg

Parameter	**Baseline**	**50% Body and Chassis Wt. Redn. Scenario**
Primary Body & Chassis Wt. Savings	NA	345 kg (50%)
Secondary Wt. Savings (Total)	NA	187 kg
Body & Chassis	NA	50 kg (14.5%)
Powertrain	NA	137 kg
Body & Chassis Wt.	NA	297 kg (57%)
Powertrain Wt.	594 kg	457 kg (23%)
Engine Power	122 kW	85 kW
Final Vehicle Wt.	1524 kg	993 kg (35%)
Combined Fuel Economy	23 mpg	28.3 mpg
Fuel Price	$3/gallon	
Vehicle Lifetime Operation	120,000 miles	

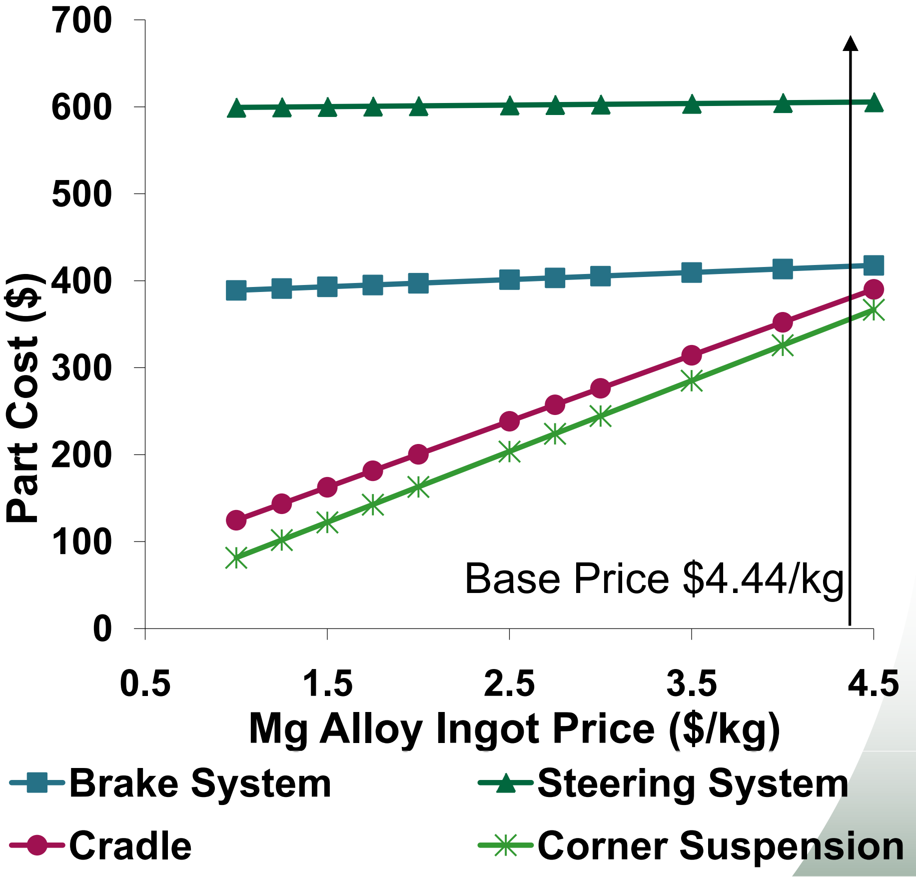
Lightweight Component Cost Estimates

Lightweight Material Body-in-White Cost Sensitivity to Annual Production Volume



(steel: $0.25/lb; aluminum: $1.50/lb; carbon fiber: $8/lb)

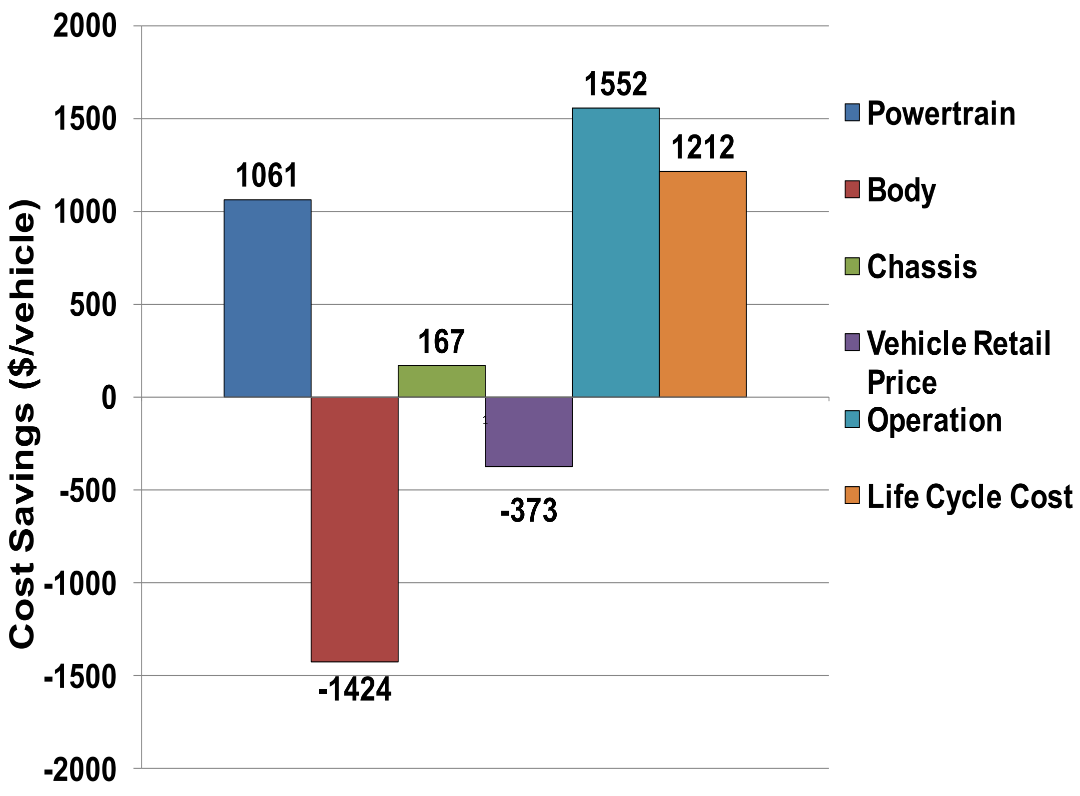
Magnesium Chassis Component Cost Sensitivity to Mg Ingot Price



Technical Accomplishments & Progress

- In FY ’08 and ’09 analyzed cost-effectiveness using the same approach for the intermediate body and chassis weight reduction goals of 25% and 40%.
- Material substitution requirements
  - Either glass fiber-reinforced polymer composites or aluminum (25% weight reduction goal)
  - Carbon fiber-reinforced polymer composites and aluminum (40% weight reduction goal)
- Life cycle cost equivalence would require
  - 25% goal: Secondary mass savings consideration. Retail price equivalence is feasible at aluminum sheet price of less than $3.00/lb)
  - 40% goal: Either aluminum ingot @ $1.00/lb and carbon fiber price at $3.00/lb, or fuel price of $4.25/gallon

Life Cycle Cost-Effectiveness of 50% Body and Chassis Weight Reduction Goal



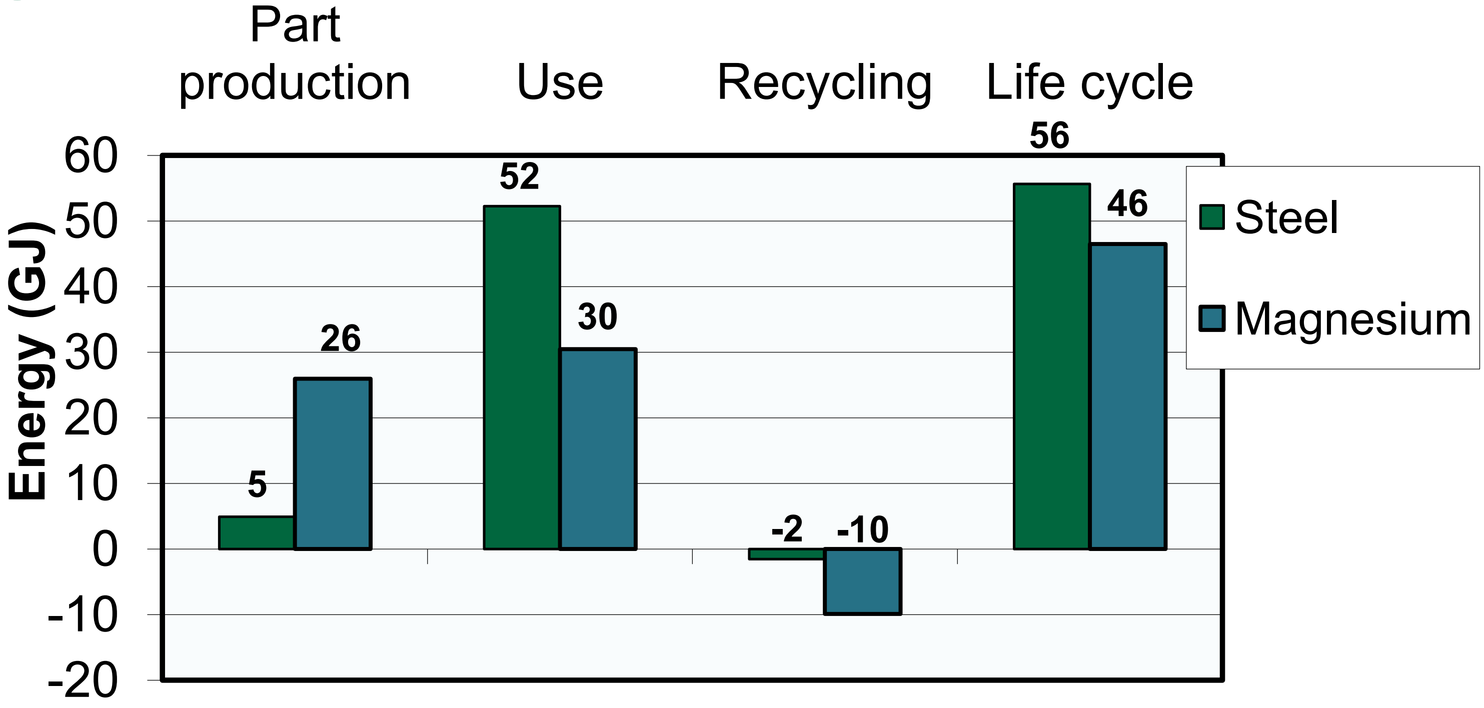
- Life cycle cost equivalence with a small retail price increase is attainable
  - Powertrain cost decrease offsets the body cost increase (significant, despite use of lower commercial grade carbon fiber @ $8/lb)
  - Overall life cycle cost savings from significant fuel economy improvement due to lower weight (especially body-in-white) and secondary mass savings

- Retail price equivalence can be achieved with these material prices: carbon fiber @ $5.00/lb; Mg ingot @ $1.75/lb; and fuel @ $3.00/gallon

Comparative Life Cycle Assessment of Magnesium vs. Steel Front-End

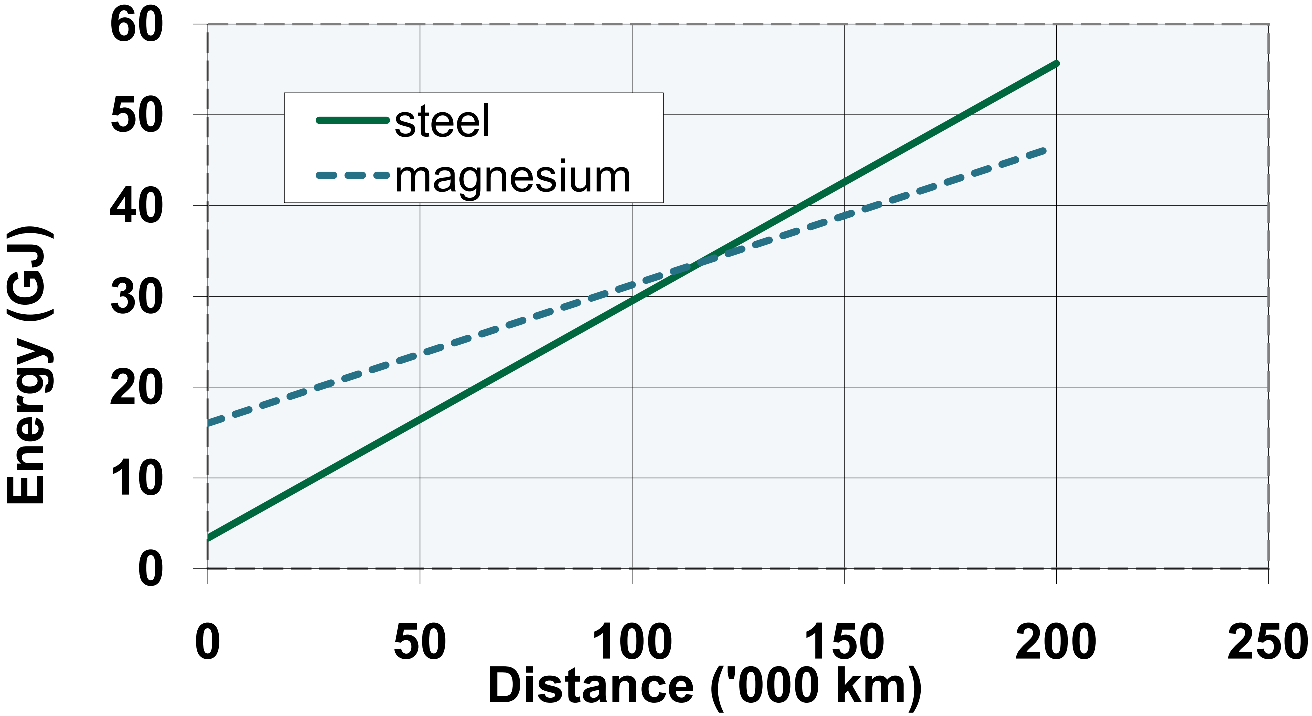
- Collaborative effort between Natural Resources Canada and ORNL in partnership with CSIRO/CAST (Australia)
- Compare potential life cycle energy and environmental impacts based on front-end design of Cadillac CTS
  - Estimate effects of technology and material changes
  - Identify energy improvements and potential reductions in GHG, criteria pollutants and acidification gases and
- Development of LCA framework based on ISO standards and LCA technical reports such as 14040, 14044, and 14049 completed
- Most LCI data collection based on using a variety of sources
  - Western and Chinese primary magnesium alloy production
  - Magnesium part manufacturing (casting, sheet, and extrusion)
  - Well-to-Wheel use phase energy and emissions using ANL GREET

Comparative Energy Use by Life Cycle Stage



- **Magnesium has 18% lower life cycle energy (46 GJ/assembly for magnesium vs. 56 GJ/assembly for steel)**
- **Use phase dominates the life cycle energy use – 42% lower than steel for a 200K Km driving**
- **Net energy savings obtained for magnesium is close to savings at the recycling stage**

Life Cycle Energy Equivalence of Magnesium and Steel Front Ends



- **Primary energy equivalence can be achieved at around 116,000 km of driving distance – significantly lower, i.e., less than 50,000 km in case of aluminum front end**

- **Improvements in primary metal production and end-of-life recycling are necessary to improve magnesium life cycle footprint**

Proposed Future Work

- Development of a baseline cost model for multi-material vehicle
- Development and validation of various weight reduction goals (25%, 40%, and 50%) of a multi-material vehicle
- Viability of lightweight materials in advanced powertrains such as hybrids and fuel cell vehicles
- Economic, energy, and environmental impact analyses from a life cycle perspective of lightweight material manufacturing technologies with an emphasis on magnesium and carbon-fiber polymer composites
- Recycling of lightweight materials from an economic, energy, and environmental life cycle perspective
- Lightweight material potential in heavy-duty vehicles

Summary

- Development of advanced lightweight materials technologies (particularly aluminum, magnesium, and carbon fiber-reinforced polymer composites) is essential to achieve the multi-year body and chassis weight reduction goals
  - Lightweight materials such as carbon fiber-reinforced polymer composites will be essential to achieve higher weight reduction goal

- Important to evaluate cost-effectiveness of weight reduction goals at the vehicle level, allowing the consideration of a plausible commercialization scenario in a system perspective

- Cost of lightweight materials remains a barrier, weight reduction goals will be difficult to achieve at the vehicle retail price equivalence level favored by the industry without a higher part weight reduction caused by secondary weight savings and lower material prices

- Life cycle vehicle cost equivalence can be achieved with
  - Secondary weight savings considerations
  - Lower material prices (e.g., aluminum ingot $1/lb; carbon fiber $5/lb)
  - High fuel price ($3-$4/gallon)