Technical Cost Modeling - Life Cycle Analysis Basis for Program Focus

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Project ID: LM001

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Overview

Timeline

- Start – Oct. 2008
- Finish – Task order funded

Budget

- Total project funding
  - $300K (FY'08 & FY'09 Combined)
  - $150K/year (FY'10)
  - $285K (FY'11) [$75K for baseline multi-material vehicle cost model development]
- Funding also supported
  - Lightweighting potential of pickup trucks
  - Cost-effectiveness of Solid Oxide Membrane (SOM) primary magnesium production technology

Partners

- Natural Resources Canada

Barriers

- Examine materials solutions supported by Materials Technology Program addressing industry's desire for reduced cost of lightweight materials while meeting national objectives for improved fuel economy
- 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

Develop a baseline cost model for a multi-material vehicle to facilitate the development and validation of the cost-effectiveness of various multi-year Lightweight Materials body and chassis weight reduction goals from a system perspective ($75K)

- Supports National Academy recommendation to develop a systems-analysis methodology to determine the most cost-effective path for achieving a 50% body and chassis weight reduction for hybrid and fuel cell vehicles by 2015
- Other life cycle modeling studies supported during this FY include
  - Lightweighting potential of pickup trucks ($50K)
  - Cost-effectiveness of Solid Oxide Membrane (SOM) primary magnesium production technology ($60K)

Milestones

- **Complete the cost-effectiveness analysis of 50% body and chassis weight reduction goal (Completed May ’10)**
- **Complete the life cycle energy and CO2 analysis of solid oxide membrane primary magnesium production technology (Completed Oct. ’10) – Results Presented**
- **Complete the development of the cost modeling framework, vehicle system definition, and identification of vehicle mass and cost data for a baseline multi-material vehicle cost model (Completed Mar’11) – Presentation Focus**
- **Complete the development of a baseline multi-material vehicle cost model (Sept.’11)**
- **Complete the lightweighting potential of pickup trucks (Sept.’11) – Approach Presented**
- **Complete the cost-effectiveness analysis of MOxST primary magnesium production technology (Sept.’11)**

Approach

- **Composite 2002 Baseline Vehicle – Midsize sedan based on following EPA-listed average vehicle technology characteristics**
  - **Curb Weight: 3249 lbs (includes 14.5 gallons of fuel); Interior Volume: 114.8 cu-ft**
  - **Engine (177 CID, 185 HP, Port Fuel Injected, V6 Aluminum, 4 Valves per Cylinder, Naturally aspirated (No Turbo))**
  - **Transmission (Front Wheel Drive, Locking Automatic)**
  - **Fuel Economy and Acceleration (22.4 MPG, 9.8 secs. 0-60 time, Top Speed 134 MPH)**
  - **Other major vehicle component technology characteristics based on average 2002 midsize sedan technology trends**
- **Component mass breakdown based on the average vehicle teardown data from the 3 predominate OEM vehicles in model year 2002 available in A2mac1 database**
- **Component aggregation based on the principle of fair representation of major technologies at a level of five major systems comprised of 35+ components (similar to Uniform Parts Grouping (UPG) concept used by the industry today)**

ORNL Automotive System Cost Model (ASCM)

- **ORNL Automotive System Cost Model (ASCM) is a system-level vehicle cost estimation tool capable of considering 13 EPA light-duty vehicle classes of several advanced powertrain types**
  - **Estimates vehicle life cycle cost at a level of *five* major subsystems and 35+ components, each representing a specific manufacturing technology**
  - **A standalone spreadsheet-based model with sizing and cost estimation capability**
    - **Interrelationships among subsystems considered in terms of secondary mass savings/ mass decompounding effect**
  - **Vehicle subsystem technology representation at a macro level but detailed enough to estimate vehicle cost sensitivity**
  - **Financing, insurance, local fees, fuel, battery replacement, maintenance, repair, and disposal costs are explicitly considered for the life cycle cost estimation (fuel economy input to the model)**
  - **Allows *relative* production cost estimation via a uniform estimation methodology--facilitates comparison of major component level alternative technologies considered by the industry**

Vehicle Life Cycle Cost Estimation

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

Production

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

Selling

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

Administration and Profit

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

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

Vehicle MSRP

Vehicle operation and maintenance costs include

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

Vehicle Life Cycle Cost per Vehicle and Mile

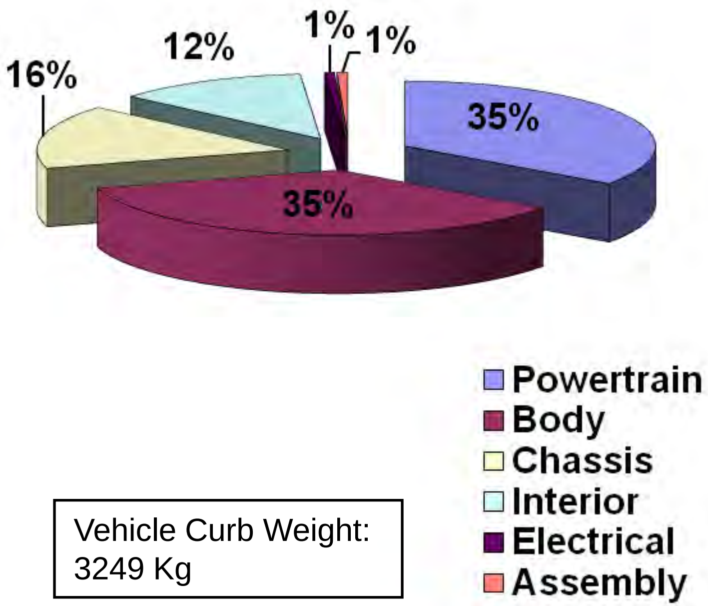
Technical Accomplishments & Progress

- **In FY '10 analyzed cost-effectiveness of LM 50% body and chassis weight-reduction goal and conducted a comparative life cycle assessment of magnesium vs. steel front-end**
- **Vehicle life cycle cost equivalence for achieving 50% body and chassis weight reduction goal can be achieved with**
  - **Secondary mass savings consideration**
  - **Lower material prices (e.g., aluminum ingot $1/lb; carbon fiber $5/lb)**
  - **High fuel price ($3-$4/gallon)**
- **Improvements in primary metal production and end-of-life recycling are necessary to improve magnesium life cycle footprint**
- **FY11 progress extends past FY initiatives**
  - **Development of a new 2002 baseline multi-material vehicle cost model to evaluate cost-effectiveness of various multi-year LM weight reduction goals**
  - **Life cycle analysis of alternative primary magnesium production technology**

Components Considered for Vehicle Cost Modeling – Baseline Vehicle Curb Weight Distribution

I. Powertrain
- Engine
- Fuel Cell System
- Generator
- Motor
- Controller/Inverter
- Energy Storage
- Fuel System
- Transmission
- P/T Thermal
- Driveshaft/Axle
- Differential
- Cradle
- Exhaust System
- Oil and Grease
- Powertrain Electronics
- Emission Control Electronics

II. Chassis
- Corner Suspension
- Braking System
- Wheels and Tires
- Steering System



Vehicle Curb Weight: 3249 Kg

III. Body
- Body-in-White
- Panels
- Front/Rear Bumpers
- Glass
- Paint
- Exterior Trim
- Body Hardware
- Body Sealers and Deadeners

IV. Interior
- Instrument Panel
- Trim and Insulation
- Door Modules
- Seating and Restraints

V. Electrical
- Interior Chassis Exterior

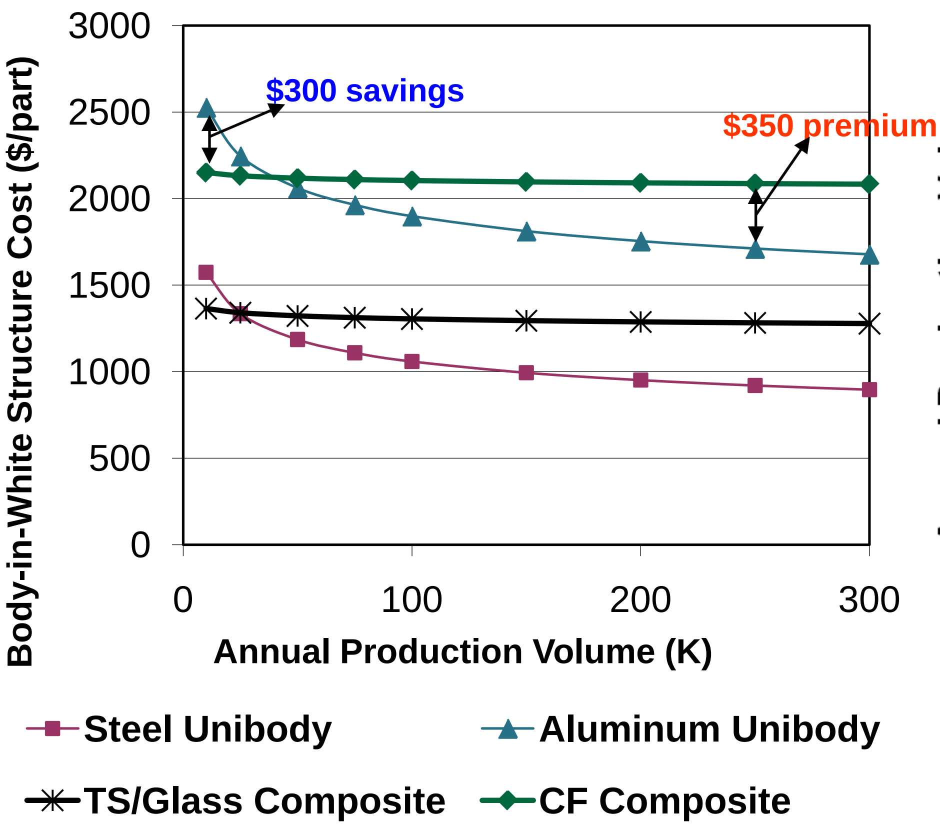
VI. Assembly

Component Cost Data

- Only "first order" subsystem-level costs are addressed in terms of relationships to primary drivers
  - Example: BIW $=f(material price, mass, piece count)
  - Material property and weight-reduction considerations are included in user-input aggregate component-specific technology data
- Data sources
  - Primary benchmarking data from vehicle teardown studies and interviews of technology proponents
  - Published data from open literature
  - Regression of case study data
  - Calculations & estimations based on relevant comparisons
  - Actual cost estimation of technologies under development
- OEM/supplier data sources critical for model validation and data collection activities (less important when focus is on examination of relative impacts of competing manufacturing technologies)
- "Open code" provides for dynamic source for cost-effectiveness data
  - Users see design logic
  - Facilitates future updates and enhancements as manufacturing technology matures and material prices change
  - Includes new component-manufacturing technologies (ongoing VT R&D technology activities' data)

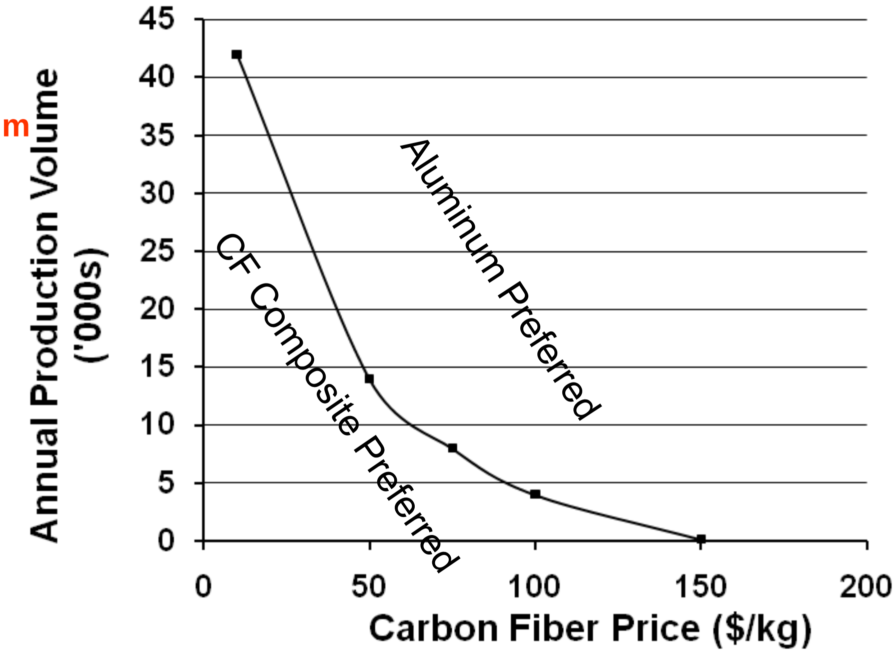
Lightweight Component Cost Estimates

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



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

Aluminum Vs. CF Composite Body-in-White Viability



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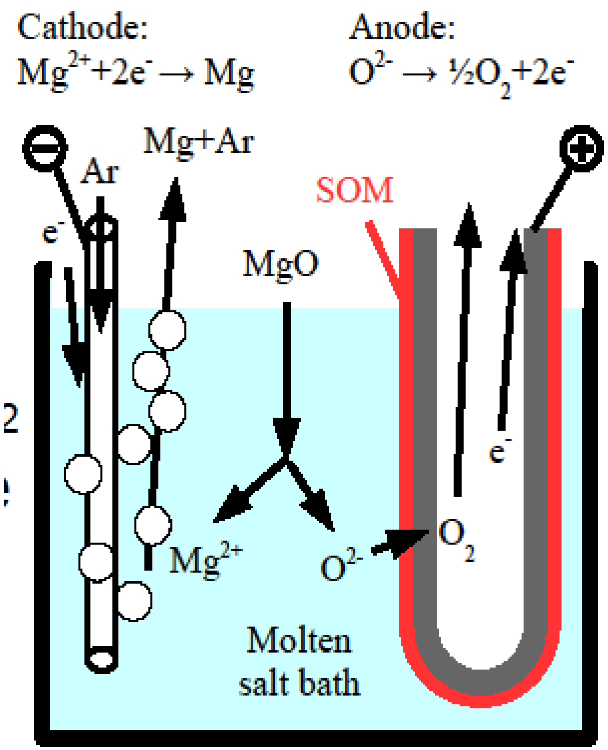
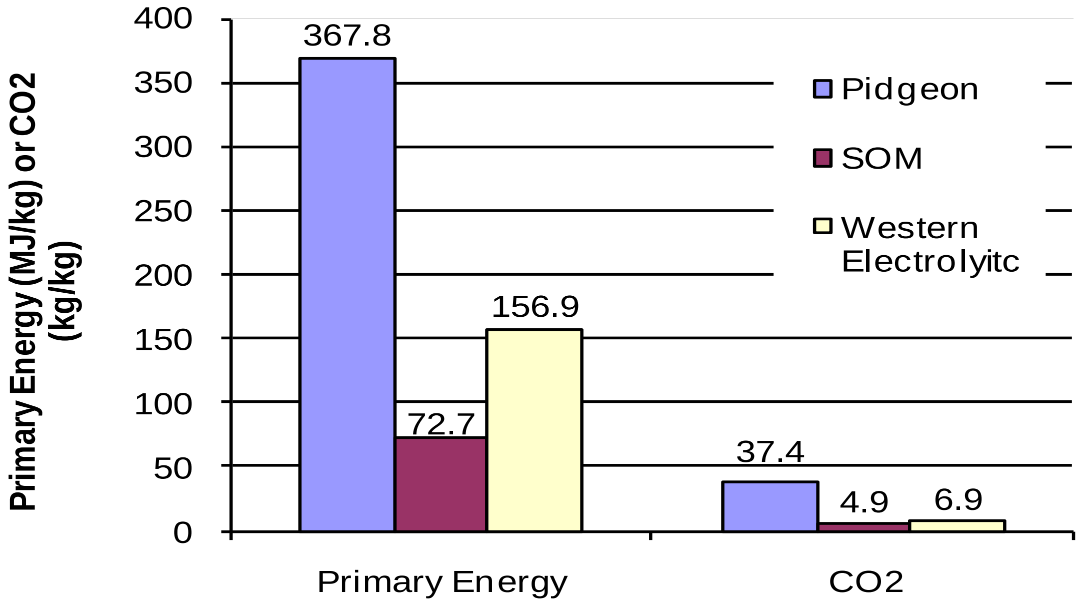
Comparative Life Cycle Assessment of Primary Magnesium Production Technologies

- **Relatively less-environmentally-friendly Chinese Pidgeon process provides 80% of world magnesium.**
- **A simple, electrochemical magnesium production process—solid oxygen-ion conducting membrane (SOM)—developed by Uday Pal of Boston Univ.**
  - **Uses electricity to split magnesium oxide in a molten salt bath into magnesium vapor and oxygen gas**
  - **Replaces intensive magnesium chloride dehydration necessary for the conventional electrolyte process with a simple $Mg(OH)_2$ or $MgCO_3$ calcining operation**
  - **High-purity valuable by-product oxygen collected at yttria-stabilized zirconia membrane and a contact material (serving as an anode)**
  - **Metal Oxygen Separation Technologies (MOxST) LLC is currently involved in the scale-up production operation**
- **A comparative life cycle assessment of SOM with conventional electrolytic and Pidgeon processes includes both primary energy and CO2 emissions**
  - **SOM processing technology data based on actual experimental data**
  - **SimaPro – a commercial LCA software package used for life cycle analysis**



Source: Powell et. al (2010)

Comparative Life Cycle Impacts of Primary Magnesium Production Technologies



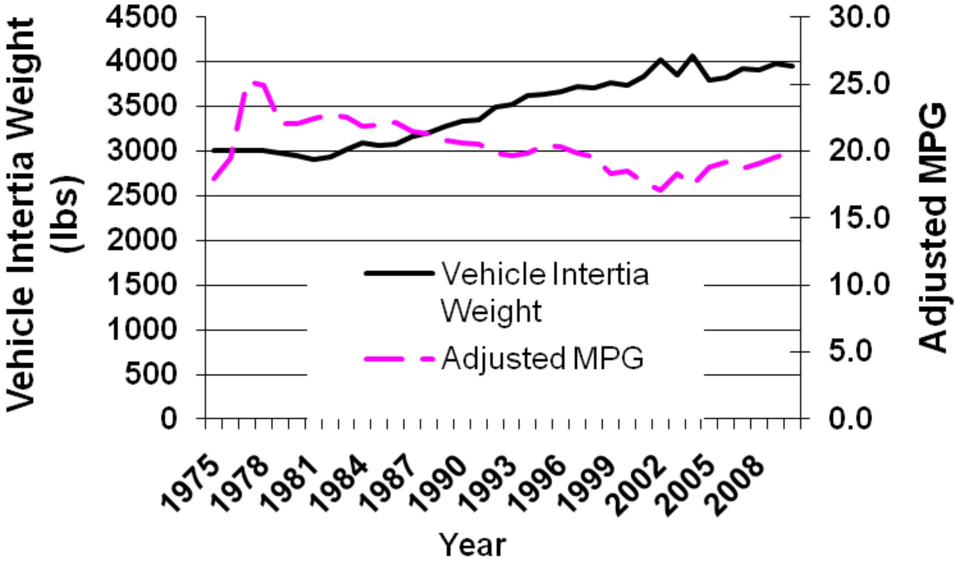
- **SOM is the least energy-intensive primary magnesium production technology, 54% lower than western electrolytic process (mainly due to 42% lower energy reqt. during electrolysis)**
- **GHG emissions for SOM are 29% lower than western electrolytic process and are equally distributed between magnesite calcination and MgO electrolysis processing steps**
- **Change in source of electricity assumption from hydroelectric to U.S. grid mix electricity doesn't affect the overall environmental-friendliness of SOM technology**

Life Cycle Impacts of Magnesium Automotive Front End Application

Impact Category	All Steel	100% Pidgeon	80% Pidgeon + 20% Western Electrolytic	100% SOM
Primary Energy(MJ)	48,679	43,512	41,533	32,284
GHG (kg CO_2 eq)	3,931	3,740	3,473	2,506

- **Magnesium front end weighs 45.2 kg, compared to 82.2 kg for steel baseline for a GM-Cadillac CTS application**
- **Primary energy and GHG emissions are 22% and 28% lower, respectively, with SOM process than with 80:20 Pidgeon:Western electrolytic production mix used today**
- **Environmental friendliness of SOM will significantly improve the viability of magnesium as a potential substitution material for aluminum in automotive applications**

Lightweighting Potential of Light-Duty Pickup Trucks



- **Midsize pickup truck weight has steadily increased whereas fuel economy has shown upward trend during the last five years**
- **Lighweighting opportunities will be examined at the level of major body and chassis components and by four lightweight material types, i.e., AHSS, aluminum, magnesium, and glass- and carbon-fiber polymer composites**
- **Total intermediate and final multi-year body and chassis weight reduction targets will be developed on the basis of demonstrated technical feasibility of multi-material substitution of major pickup truck components**

Collaborations

- **Natural Resources Canada – a collaborative research effort on the life cycle analysis of multi-materials vehicle using advanced powertrains**
- **Metal Oxygen Separation Technologies (MOxST) LLC – cost-effectiveness of alternative Solid Oxygen Ion Membrane (SOM) primary magnesium production technology**
- **Purdue University and Pacific Northwest National Laboratory – cost-effectiveness of alternative Large Strain Extrusion Machining (LSEM) primary magnesium production technology**
- **Numerous tiered automotive suppliers for vehicle component cost verification necessary for baseline vehicle cost model development**

Proposed Future Work

- **Development and validation of cost-effectiveness of various weight reduction goals (25%, 40%, and 50%) of a multi-material midsize vehicle**
- **Viability of lightweight materials in advanced powertrains such as hybrids and fuel cell vehicles**
- **Cost-effectiveness of multi-year weight reduction goals of lightweihgitng of Class 1-2 pickup trucks**
- **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**
- **Carbon fiber production cost as a function of processing throughput and/or speed for different precursors and processing technologies**

Summary

- Development of a baseline cost model for a multi-material vehicle with a representation of alternative technologies at the major component level is critical for the evaluation of cost-effective weight reduction strategy
- Life cycle cost consideration from a systems-level analysis perspective is essential in the evaluation of cost-effectiveness of vehicle lightweighting opportunities. Component cost representation should reflect the sensitivity of major parameters rather than absolute cost/price.
- Body and chassis component masses comprise 51% of total vehicle curb mass – significant multi-material lightweighting opportunities exist on the basis of primary component mass savings alone
- Lightweighting opportunity for improving fuel economy of light-duty pickup trucks could be substantial since unlike other vehicle types options are limited (reduction in size is not a viable option)
- Alternative solid oxygen–ion conducting membrane primary magnesium production technology is favorable in terms of both life cycle energy and emissions