Technical Cost Modeling - Life Cycle Analysis Basis for Program Focus

Sujit Das (PI)

Dave Warren (Presenter)

Oak Ridge National Laboratory

May 16, 2012

Project ID: LM001

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

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

Budget

- Total project funding
  - $450K (FY'08 thru FY'10)
  - $410K (FY'11) [$125K for carbon fiber cost model development]
  - $100K (FY'12) [25% vehicle mass reduction study]

Partners

- Natural Resources Canada
- VEHMA International
- Ford Motor CO.

Barriers

- High cost of lightweight materials solutions supported by Materials Technology Program to meet national objectives for improved fuel economy
- Identify specific technology improvements that affect major cost drivers
- Economic viability determined on the basis of part-by-part substitution
- Focus on vehicle retail price instead of life cycle cost consideration

Study Objective (Technical Cost Modeling – Life Cycle Analysis for Program Focus)

Validate the cost-effectiveness of reducing the weight of passenger vehicle by 25%, with safety, performance, and recyclability comparable to 2002 vehicles (FY12 focus)

Examine a comparative cost-effectiveness analysis of material to material substitution of vehicle components

Evaluation to be based on a systems-analysis methodology recommended by National Academy and developed and validated for a baseline 2002 midsize vehicle during FY11

Milestones

- **Complete the development of a baseline multi-material vehicle cost model (Completed Sept.'11) – Results Presented**

- **Complete the cost-effectiveness analysis of alternative powertrain, body and chassis lightweighting strategies for achieving 25% vehicle weight reduction goal (Sept. '12) – Approach Presented**

- **Complete the lightweighting potential of pick-up trucks (Completed July'11) – Results Presented**

- **Complete the cost model development of alternative carbon fiber manufacturing technologies (Apr. '12) – Initial Results Presented**

- **Complete the cost-effectiveness analysis of MOxST primary magnesium production technology (Completed Oct.'11)**

Cost-Effectiveness Analysis of LM's Multi-Year Vehicle Weight Reduction Goal -- Approach

- **A systematic approach developed using ORNL Automotive System Cost Model facilitates**
  - **Consideration of various lightweight materials and processing technologies at 35+ component level and interactions among various vehicle components within a scenario**
  - **Mass and cost breakdown at a major vehicle component level identify cost-effective LW opportunities**
  - **Comparative analysis of several alternative lightweighting strategies by specific lightweight material component substitution within a scenario**
    - **Lightweight metals, composites, and multi-materials scenarios**
  - **Consideration of multiple lightweighting pathways based on technology status and timeframe for desired vehicle weight reduction goal/target**
  - **Assessment of complete vehicle retail price and life cycle/ownership costs as affected by lightweighting's impact**

Baseline Multi-Material Cost Model Development: 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 ft^3
  - 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 & acceleration (22.4 MPG, 9.8 secs 0-60 time, Top speed 134 mph)

- **Component aggregation based on principle of fair representation of major technologies: 5 major systems comprised of 35+ components (similar to industry's Uniform Parts Grouping (UPG) concept)**

- **Major vehicle component-level data collection**
  - Technology characteristics represent average 2002 midsize sedan technology trends
  - Mass breakdown: Average vehicle teardown data from the 3 predominate OEM vehicles (2002) in A2mac1 database
  - Cost data: Emulation of OEM purchased cost from numerous data sources and estimated where data were unavailable

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**

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

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

Technical Accomplishments & Progress
(multiple project components)

- **Developed a systematic approach to estimate the cost-effectiveness of LM's multi-year vehicle weight reduction goals**
- **Developed a 2002 baseline multi-material vehicle cost model to facilitate cost-effectiveness evaluation of various multi-year LM weight reduction goals**
- **Determined that lightweighting potential of pick-up trucks market is significant, i.e., 29-40% in the near-term**

  (Design, manufacturability, and economics issues remain to be addressed)
- **Determined that alternative precursor materials and carbon fiber manufacturing process pathways have tremendous potential in improving its economic viability in automotive use**
- **FY12 progress extends past FY initiatives**
  - **Development of scenarios, model development, and data collection for the demonstration and validation of FY12 25% vehicle mass reduction goal**

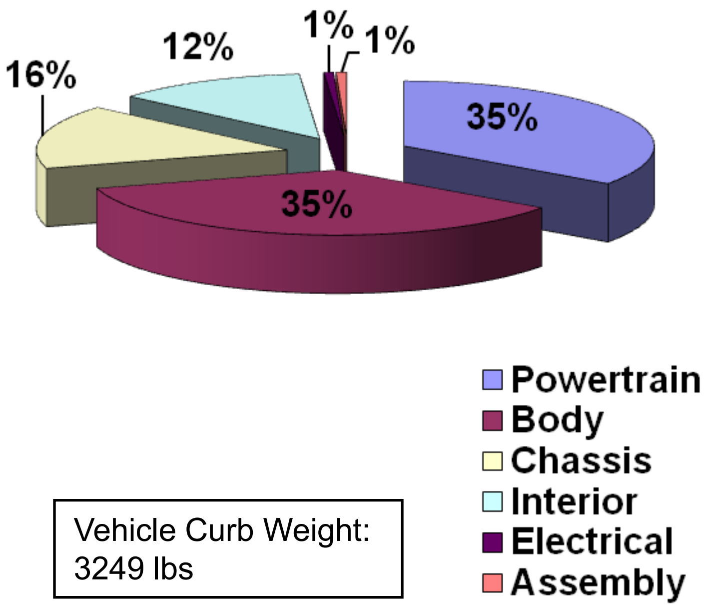
Components Considered for Vehicle Cost Modeling – Baseline 2002 Midsize Vehicle Curb Weight Distribution

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 lbs

III. Body

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

IV. Interior

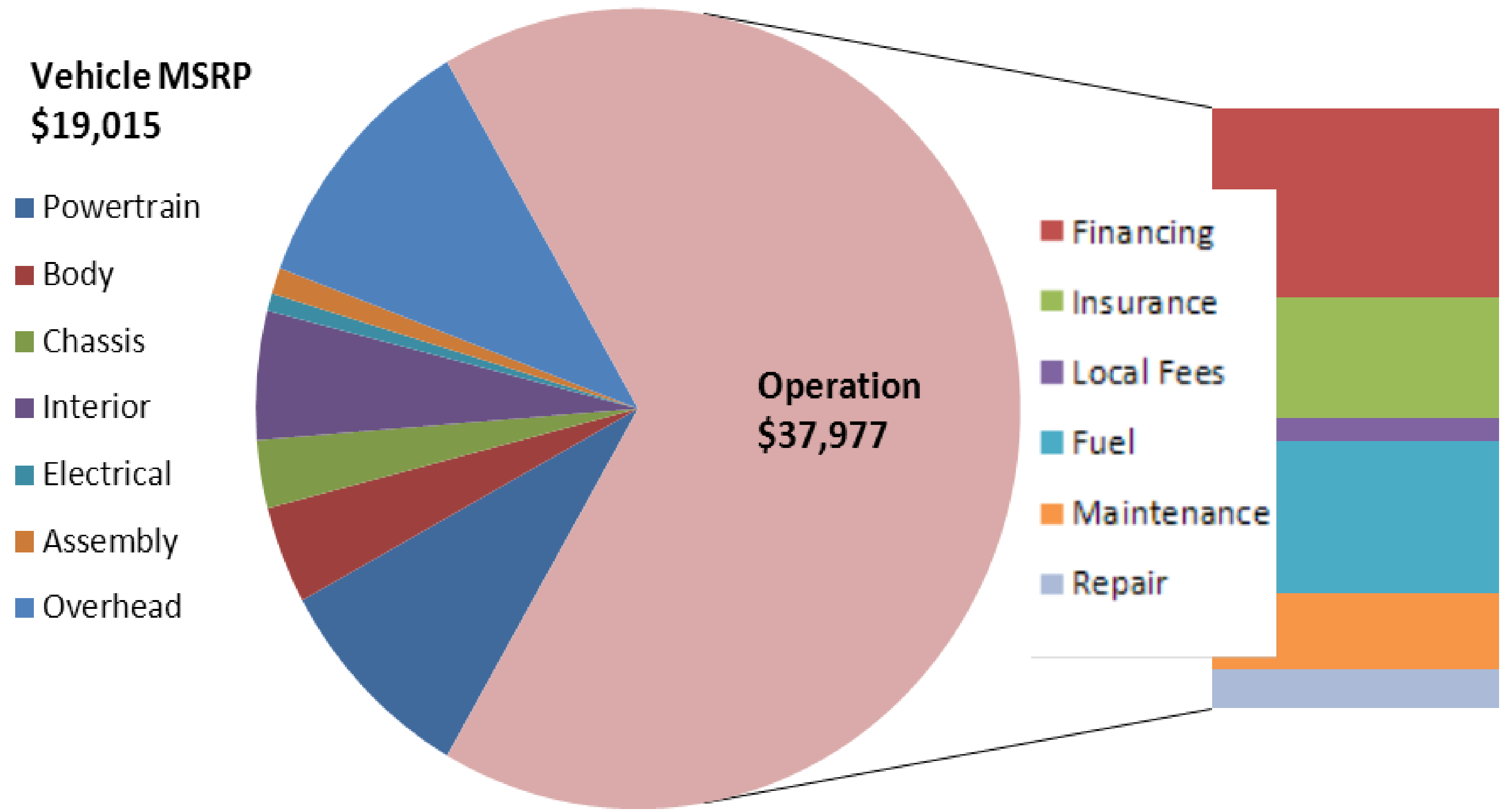
- Instrument Panel
- Trim and Insulation
- Door Modules
- Seating and Restraints

V. Electrical

- Interior Chassis Exterior

VI. Assembly

Vehicle Ownership Cost Distribution of a 2002 Midsize Car



OEM Vehicle Manufacturing Cost: $14,548
Vehicle Ownership Cost: $43K (Operation + Downpayment ($5K)) or $0.36/mile

Approach: FY12 25% Vehicle Mass Reduction Study

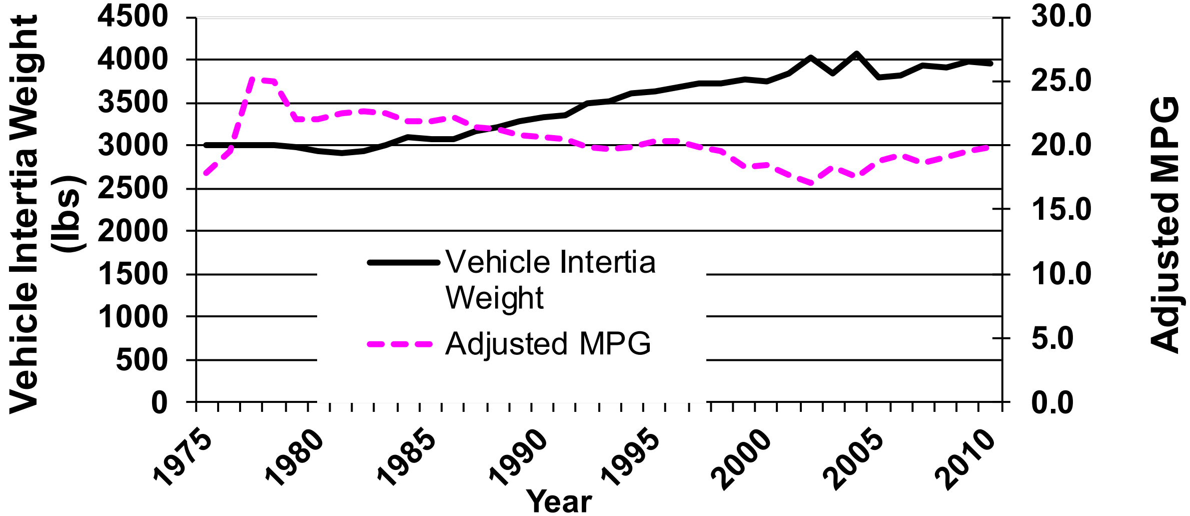
- 25% vehicle mass reduction study based on the systematic approach using the FY11 baseline mid-size vehicle system cost model
- Scenarios to combine lightweighting approaches and advanced powertrain

Lightweight Material	Powertrain
Metals	ICE
Carbon Fiber Polymer Composites	Downsized and Boosted ICE
Multimaterial	Conventional HEV

- Cost-effectiveness will be determined by a comparative life cycle cost analysis of plausible scenarios

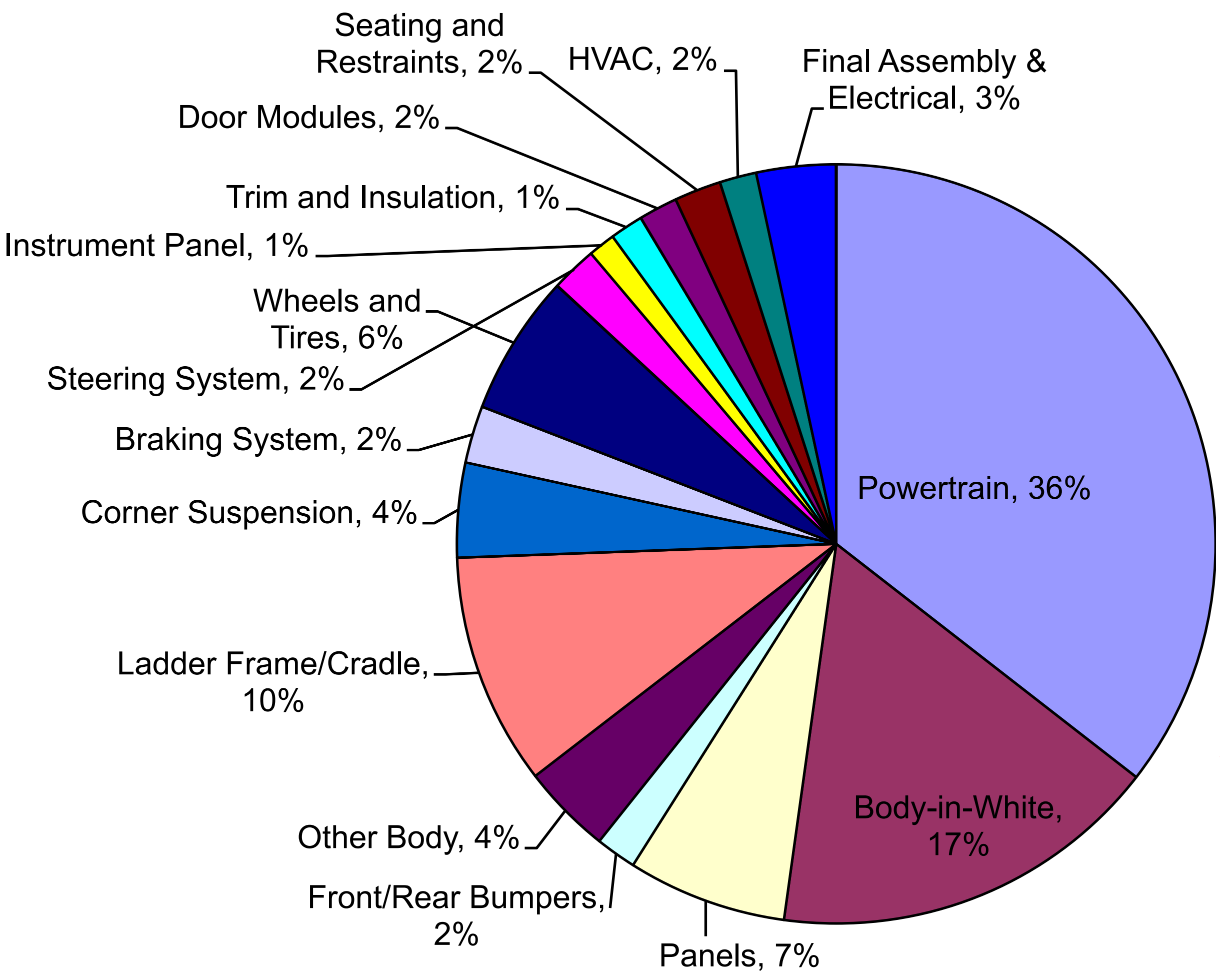
(Collaboration with the multimaterial vehicle industrial partners towards the scenarios' data development and lightweight component cost data collection)

Lightweighting Potential of Light-Duty Pick-up Trucks



- Midsize pick-up truck weight has steadily increased; fuel economy improving over last five years
- Lightweighting opportunities for a mid-size F-150 pick-up truck examined
  - Major powertrain, body, and chassis components
  - Lightweight material types: AHSS, aluminum, magnesium, and glass- and carbon-fiber polymer composites
- Lightweighting scenarios considered:
  - Metals or composites using near-term technology
  - Maxm. weight savings potential in the longer timeframe using best available technologies from every field
- Mass savings estimates do neither consider any detailed design engineering calculations nor multi-material component technical viability issues

Weight Distribution of a Baseline F-150 Pick-up Truck



Vehicle Curb Weight: 2300 kg

Mass Savings Analysis of Pick-up Trucks

	MASS SAVINGS (kg)		
SYSTEM	A	B	C
Powertrain	171	170	191
Body	184	249	302
Chassis	71	161	242
Interior	23	31	49
Primary Savings	**449 (19.5%)**	**611 (26.6%)**	**783 (34%)**
Total Savings	**674 (29%)**	**917 (39.8%)**	**1175 (51.1%)**

Scenario A: Near-term use of UHSS, Al, & Mg and downsized (V8 to V6) engine

Scenario B: Near-term use of extensive GFRP but limited CFRP with downsized (V8 to V6) engine

Scenario C: Long-term with use of best available technologies in every field, extensive CFRP use and downsized (V8 to V6) engine

Components considered for lightweighting potential →

Heat Exchanger
Transmission
Minor HPDC Components
V6 Block
Transfer Case
Intake Manifold
Differential Carriers
Oil Pan
Drive Shaft and Yokes
Front end module
Front fender
Rear window
Lift gate
Front bumper
Rear bumper
Front doors
Rear doors
Hood
Truck bed
Truck bed outer panels
Ladder frame
Leaf Springs
BIW/Cab
Instrument panel support
Seat structure

Lightweighting Potential of Pickup Trucks – Initial Findings

- **Lightweighting opportunity exists in the highly profitable niche pickup truck segment as demonstrated by recent OEM initiatives**
- **Total vehicle mass savings potential could be in the range of 29-40% using**
  - **Lightweight metals and GFRP (near-term technologies and secondary mass savings)**
- **Mass savings potential of 51% would require extensive use of best available lightweighting technologies from every field and CFRP**
- **Mass savings estimates for pick-up trucks are lower than for passenger cars due to body-on-frame design and requirements for towing and load carrying capability**
- **Multi-year mass reduction goal should account for design and economic factors, since it is relatively more expensive to lightweight a pickup truck than a car**

Carbon Fiber Cost Modeling

- **Estimate the cost-effectiveness of alternative carbon fiber manufacturing technology pathways for automotive use**
- **Technology pathways include several precursor and fiber production process combinations**

Precursors	Fiber Production
PAN MA Comonomer (Solution Spun)*	**Conventional Conversion**
Textile PAN VA Comonomer (Solution Spun)**	**Plasma Oxidation**
Polyolefin (Melt Spun)**	**MAP Carbonization**
Lignin (Melt Spun and Melt Blown)**	**Advanced Surface Treatment and Sizing**

**Examined with all Fiber Processes for solution spun precursor*

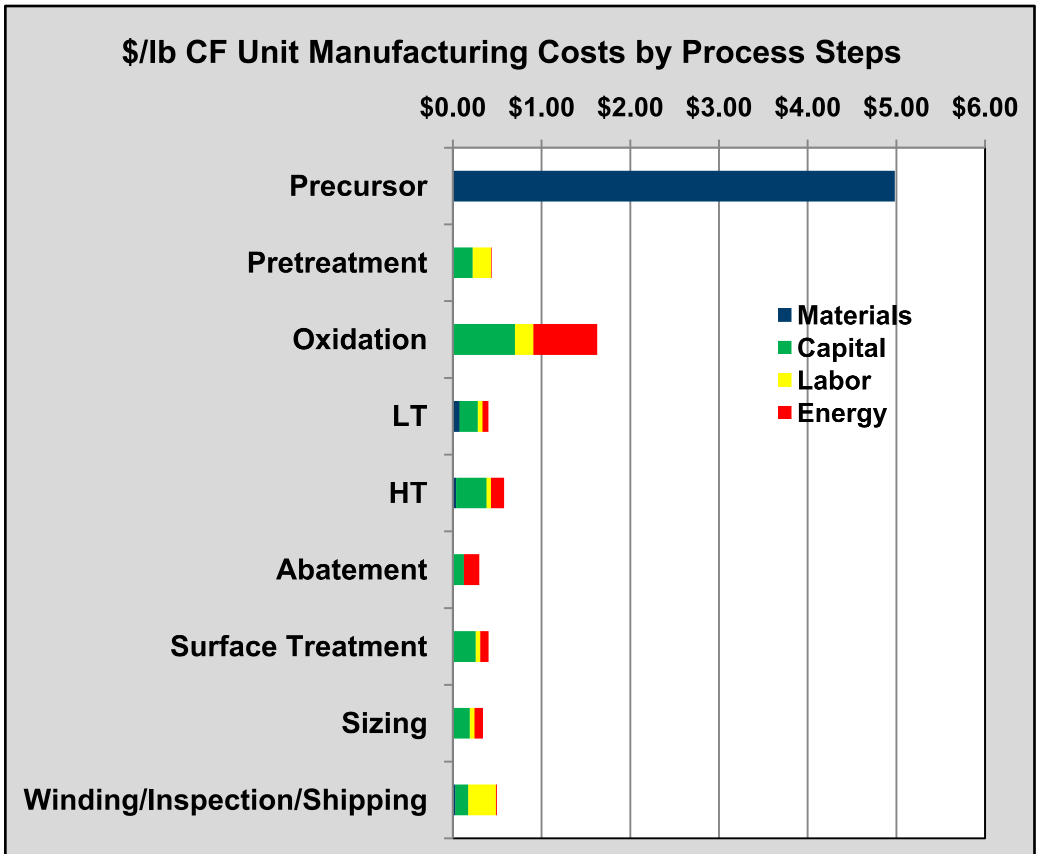
*** Examined with Conventional Conversion Fiber Process only*

- **Examine precursor and conversion costs at a level of major processing steps to identify cost reduction opportunities**
- **Costs disaggregated by materials, capital, energy, and labor**
- **Monte Carlo Simulation and sensitivity analysis test the sensitivity of major input parameters**

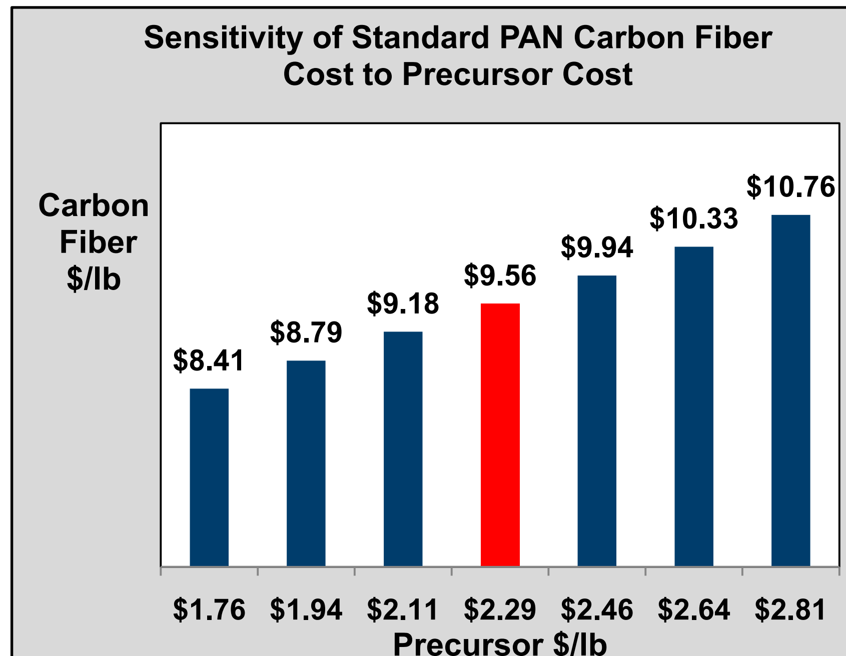
Solution Spun Standard PAN Carbon Fiber Manufacturing Cost

Precursor → Pre-treatment → Oxidation → LT → HT → Abatement →

Surface Treatment → Sizing → Winding, Inspection, Shipping



Acrylonitrile: $2200/tonne
Standard 50K Precursor: $2.29/lb
Annual Prodn. Volume: 1500t
Carbon Fiber = $9.56/lb



Baseline Standard PAN Carbon Fiber Cost Indicates

- Conventional Standard PAN carbon fiber cost is well above target $5-$7/lb for automotive use
  - High petroleum-based raw material costs (95% precursor mass based on acrylonitrile $2200/tonne)
  - Low precursor conversion yield in the 45-50% range
  - Slow solution spinning with high capital costs
  - Lengthy fiber conversion oxidation processing step, i.e., 2 hrs
  - Energy intensive fiber conversion processing steps (oxidation, carbonization)
- Cost models developed to consider potential cost reduction opportunities include:
  - Alternative precursors (Textile PAN, PE, lignin) with lower raw material costs and higher conversion yields
  - Productivity enhancing alternatives (melt spinning, plasma oxidation) to increase line speeds and throughput
  - Low energy requirement fiber processing alternatives (plasma oxidation, MAP carbonization)
  - Advanced post treatments leading to stronger fiber/resin bonding and concomitant reduced CFRP part material requirements

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**
- **VEHMA International & Ford Motor Co. – development of lightweight material scenarios and component cost data collection for the FY12 25% vehicle mass reduction study**
- **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 (40% and 50%) of a multi-material midsize vehicle using the systematic approach developed in FY11
- Viability of lightweighting in advanced powertrains such as hybrids and fuel cell vehicles
- Cost-effectiveness of multi-year weight reduction goals of lightweighting of Class 1-2 pick-up 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
- Lightweighting potential in heavy-duty vehicles

Summary

- **Systematic approach developed** to evaluate and validate the cost-effectiveness of LM's multi-year vehicle weight reduction goals
- **Development of a baseline cost model for a multi-material vehicle** with a representation of alternative technologies at the major component level (Critical for the evaluation of cost-effective weight reduction strategy)
- **Life cycle cost consideration from a systems-level analysis perspective** (Essential in the evaluation of cost-effectiveness of vehicle lightweighting opportunities)
- **Body and chassis component masses comprise 51% of total mid-size vehicle curb mass**
  - Significant multi-material lightweighting opportunities exist on the basis of primary component mass savings alone.
- **Near-term lightweighting opportunity for light-duty pickup trucks could be substantial (e.g., 29-40%)** with secondary mass savings benefits (Unlike other vehicle types, options are limited -- reduction in size is not a viable option)
- **Alternative precursors have significantly higher potential than carbon fiber production technologies** to improve the viability of carbon fiber in automotive use.