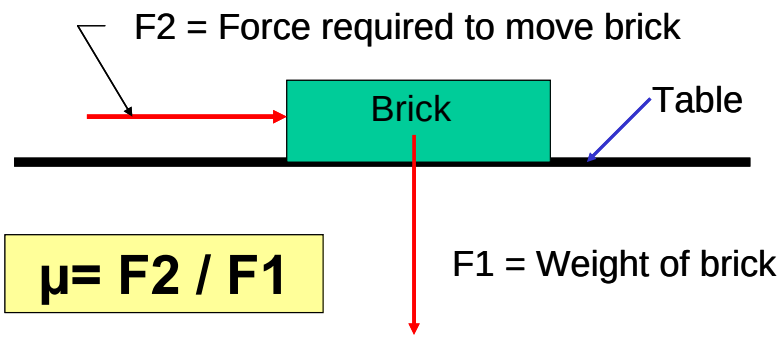
Friction

- Friction force is the relative resistance of objects in contact to motion.
- Tribology is the study of friction.
- The most commonly quoted term related to friction material is Coefficient of Friction, or Mu (μ).
- Friction is still the most effective way of dissipating a vehicle's kinetic energy. Even electric vehicles require friction brakes.



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OE Friction Material Requirements for North America

PERFORMANCE

- Must Meet FMVSS-135
  - Medium output (μ = 0.32 ~ 0.4)
- Stable μ in low decel conditions
- Fading Behaviour secondary
- Low residual drag
- Adequate mechanical strength
- Very long life (pad & rotor) desired

COMFORT

- Squeal-noise free
- Groan-noise free
- High Speed Vibrations free
- Judder / RTV tolerant
- Pedal feel secondary

COST

- Formulation
- Cycle Times
- Power Consumption
- Robust Process

ENVIRONMENT

- Environmentally Friendly
  Raw Materials---> “Green Pad”
  Emphasis is growing

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Federal Motor Vehicle Safety Standard - 135 (FMVSS135)

- ✓ Written and maintained by the National Highway Traffic Safety Administration (NHTSA)
- ✓ All passenger cars manufactured after September 1, 2000 must comply.
- ✓ All multi-purpose vehicles, trucks and buses with a Gross Vehicle Weight less than 3500 kg (7716 lbs) manufactured after September 1, 2002 must comply.
- ✓ FMVSS-135 replaces FMVSS-105 for passenger vehicles, SUVs, and Light trucks
- ✓ FMVSS-135 was developed with the intent to harmonize North American and European brake system requirements (ECE-R13H).
- ✓ Passenger cars have the same pass requirements as multi-purpose vehicles, trucks and buses regardless of classification or size.

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Federal Motor Vehicle Safety Standard - 135 (FMVSS135)

- ✓ The test consists of 200 burnish stops + approximately 120 performance stops of various speeds and decelerations.
- ✓ Each stop is performed with a "best effort" to achieve a minimum stopping distance without exceeding a pedal force of 500 N (112 lbs).
- ✓ Most vehicle manufacturers require a 10% pass margin.
- ✓ FMVSS-135 Failed Boost is more stringent than FMVSS-105 because of pedal effort limitation (SUVs, trucks and buses under 3500 kg; 33% less pedal force is allowed with same stop distance).
- ✓ FMVSS-135 Hot Performance is more difficult than FMVSS-105 because of pedal effort limitation and less stop distance.
- ✓ FMVSS-135 requires higher effectiveness friction material.

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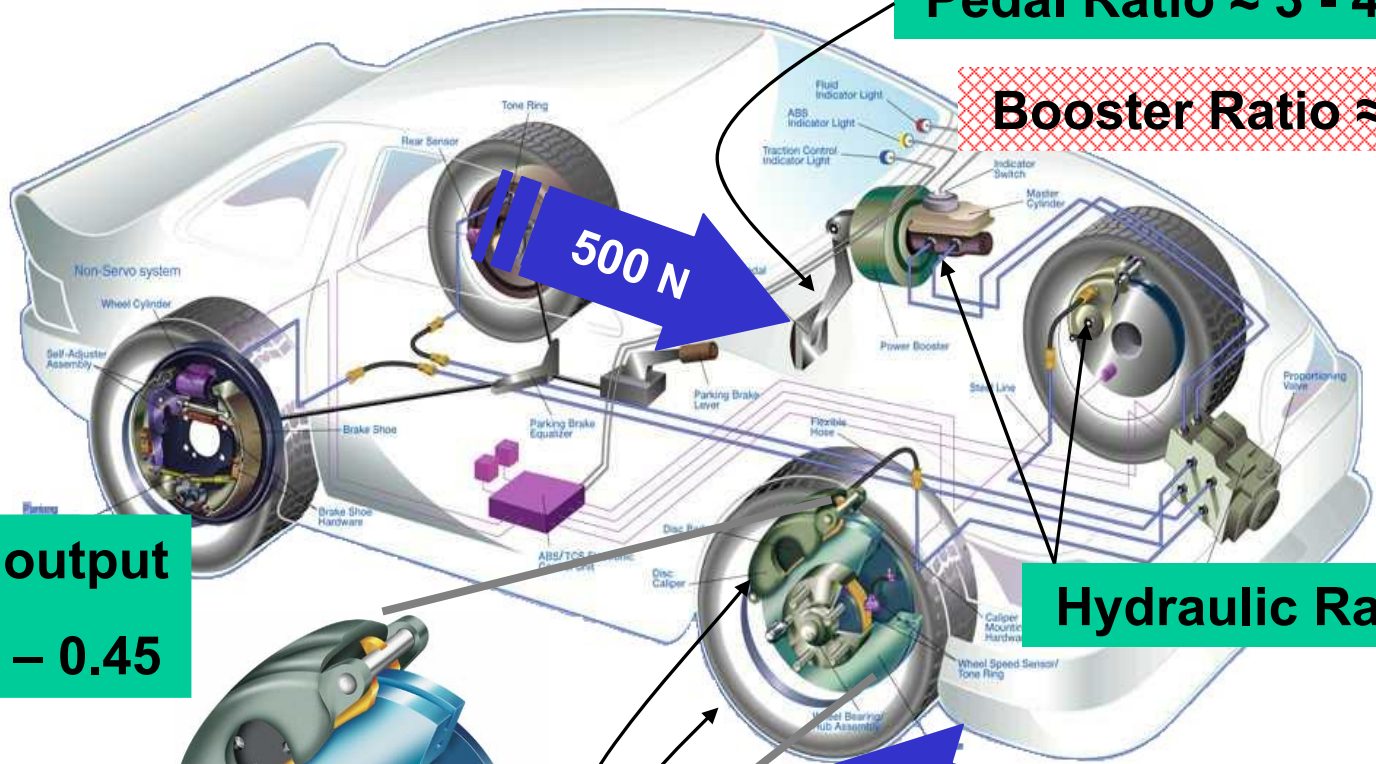
Brake System Design
Inoperative boost



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Classes of Disc Friction Materials

- Semi-metallic formulas – primarily contain steel fiber, porous iron powder, abrasives and graphite/coke lubricants.
- Non-asbestos organics (NAOs) – like typical Akebono formulas contain no ferrous metals, contain nonferrous metals, various abrasives and lubricants, mineral fibers and other reinforcements. In the aftermarket, NAO's are often referred to as "ceramic" formulations.
- Low-metallics – contain some steel fiber and/or iron powder, various abrasives and lubricants, some non-ferrous metals – typically European style materials.

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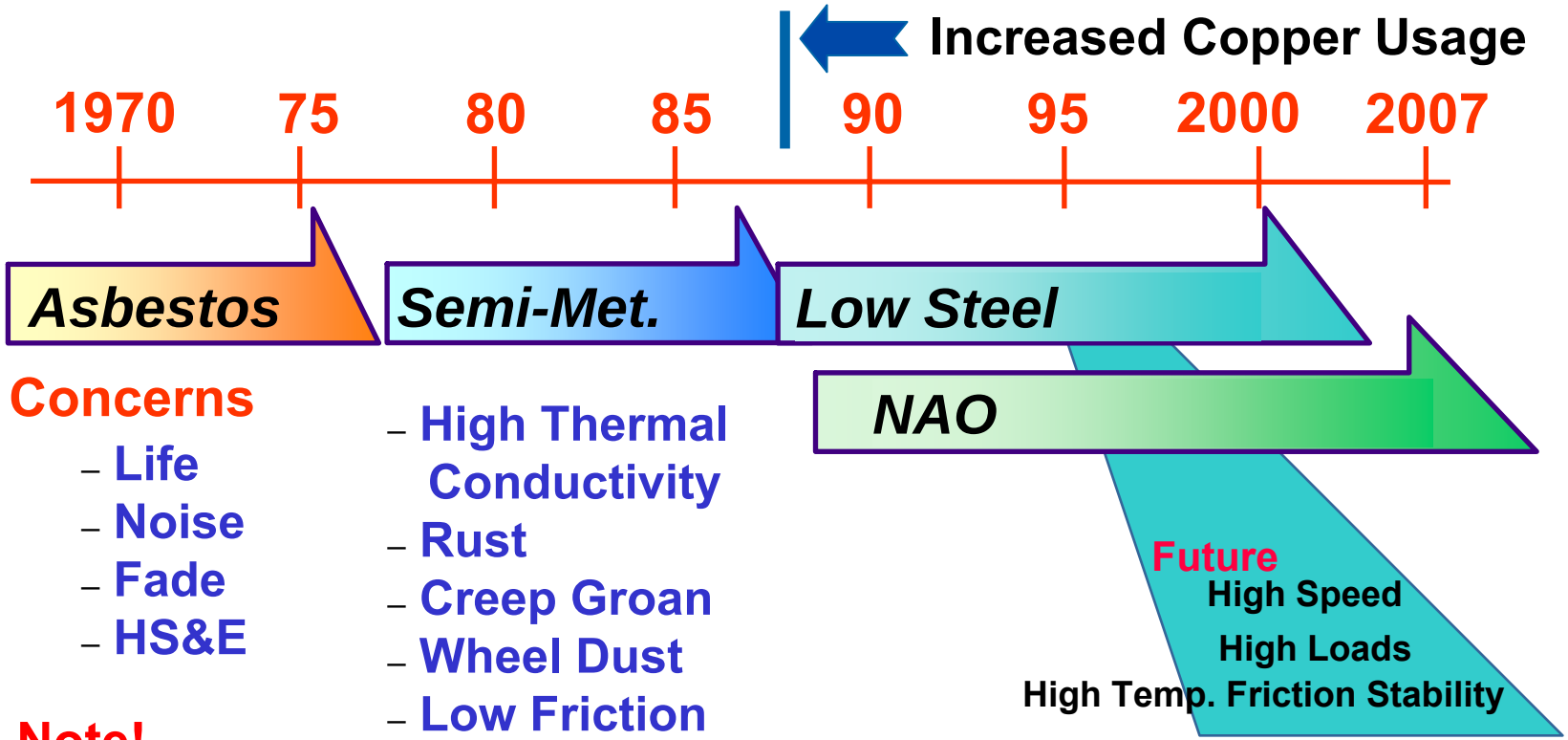
Disc Brake Pad Formulation Trend



Note!

The increase in total copper usage in brakes is primarily the result of increased market penetration of NAO formulations rather than an increase in the percentage of copper per pad.

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Semi-metallics

- Originated with German efforts during WWII to find replacements for asbestos. Lathe turnings replaced asbestos.
- Commercially used in passenger cars starting in the late 1960s.
- Typically contain > 40 wt% ferrous content (steel fiber, porous iron powder).

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Characteristics of Semi-mets

- Low to medium mu - 0.28 – 0.38
- Relatively high mu variation (temperature, duty cycle)
- Good fade characteristics.
- Poor wear at low temps., <100C.
- Excellent wear at temps. over 200C.
- Good wear under heavy loads.
- Poor wear at high speeds.
- Generally inferior Noise, Vibration & Harshness compared to NAOs
- Contains no copper
- Low initial cost
- High fluid temperatures can be an issue.

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Low-metallics

- Developed in the 1970s – mainly for European applications
- Higher mu levels 0.38 – 0.50
- Typically contain ferrous and nonferrous metals, inorganic and organic fibers, aggressive abrasives, lots of carbonaceous and sulfide lubricants.

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Characteristics of Low-mets

- Good pedal feel and braking confidence.
- Good fade and high speed performance.
- High pad/rotor wear.
- Good for high speed wear.
- Lots of wheel dust.
- Can have “corrective” wearing action.
  - Can possibly “true-up” the rotor over time
- Inferior noise and life.

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NAOs (Non-Asbestos Organics)

- First developed in the late 1960s.
- Commercially available on NA OE applications in the late 1980s.
- Typically contain nonferrous metals, inorganic and organic fibers, abrasives, lubricants and property modifiers.

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Characteristics of NAOs

- Low to medium-high mu 0.33 – 0.40.
- Excellent wear at lower temps. < 200C.
- Good for wheel dust.
- Relatively poor wear under heavy duty conditions and at higher friction levels.
- Good noise & roughness characteristics
- Can have morning effectiveness noise.
  - Low temp / high humidity – squeal noise on first couple of brake applies in the morning
- More expensive.

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Copper's role in NAO friction materials

- **Copper is instrumental in developing and maintaining the transfer layers that govern performance, wear and noise characteristics.**

- **Copper helps in-stop mu build-up.**
  - ⇨ Copper's fairly low melting temperature helps in developing frictional output early in the stop and at lower operating temperatures

- **Helps wear performance and participates in "adhesive wear" mechanisms.**
  - ⇨ Copper's very high thermal conductivity acts as a thermal wick reducing friction surface temperatures and increasing the lining wear.

- **To a smaller degree copper provides mechanical reinforcement and improves heat dissipation.**

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Copper Cost Trend

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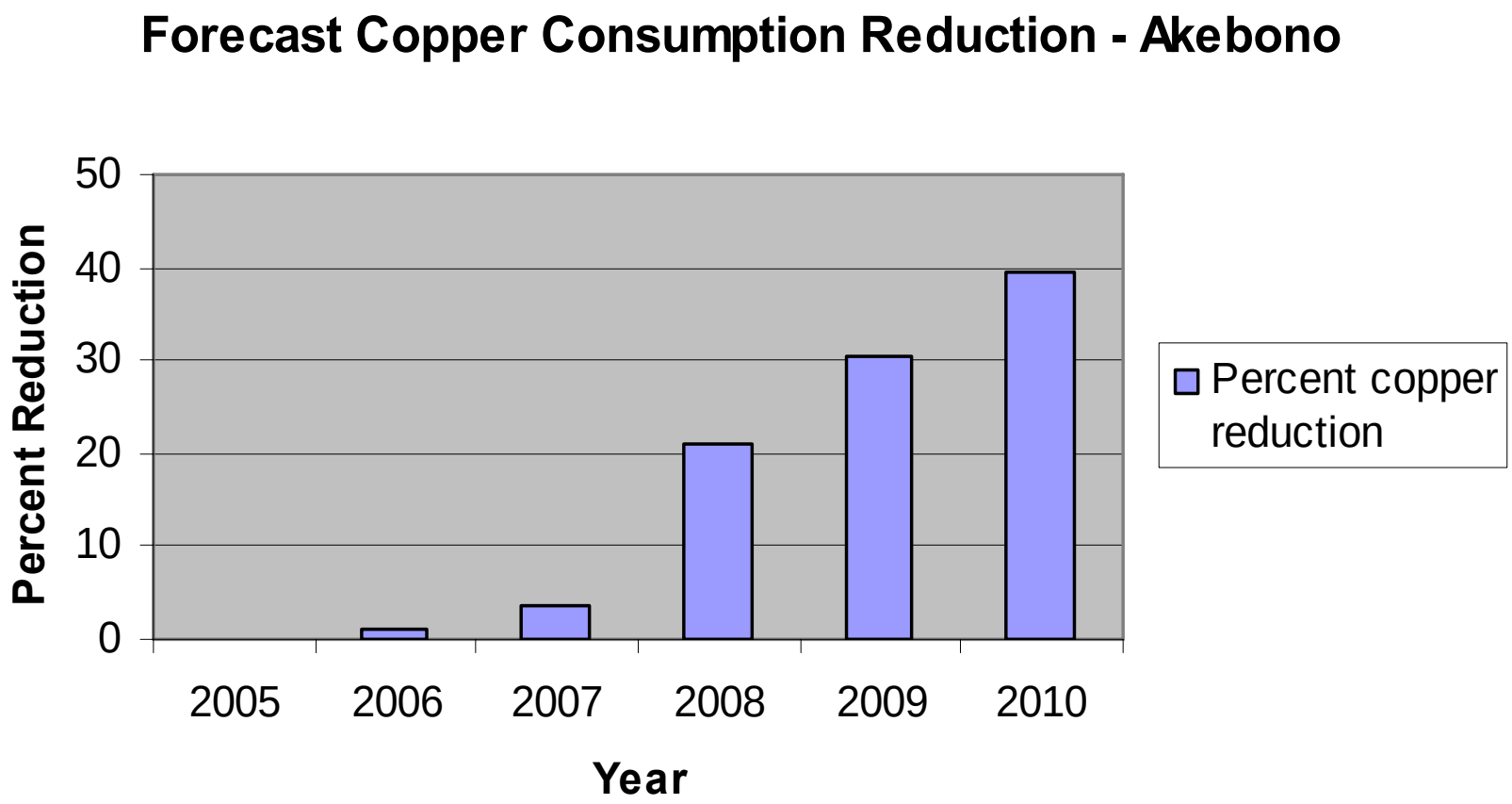
Copper Reduction Forecast



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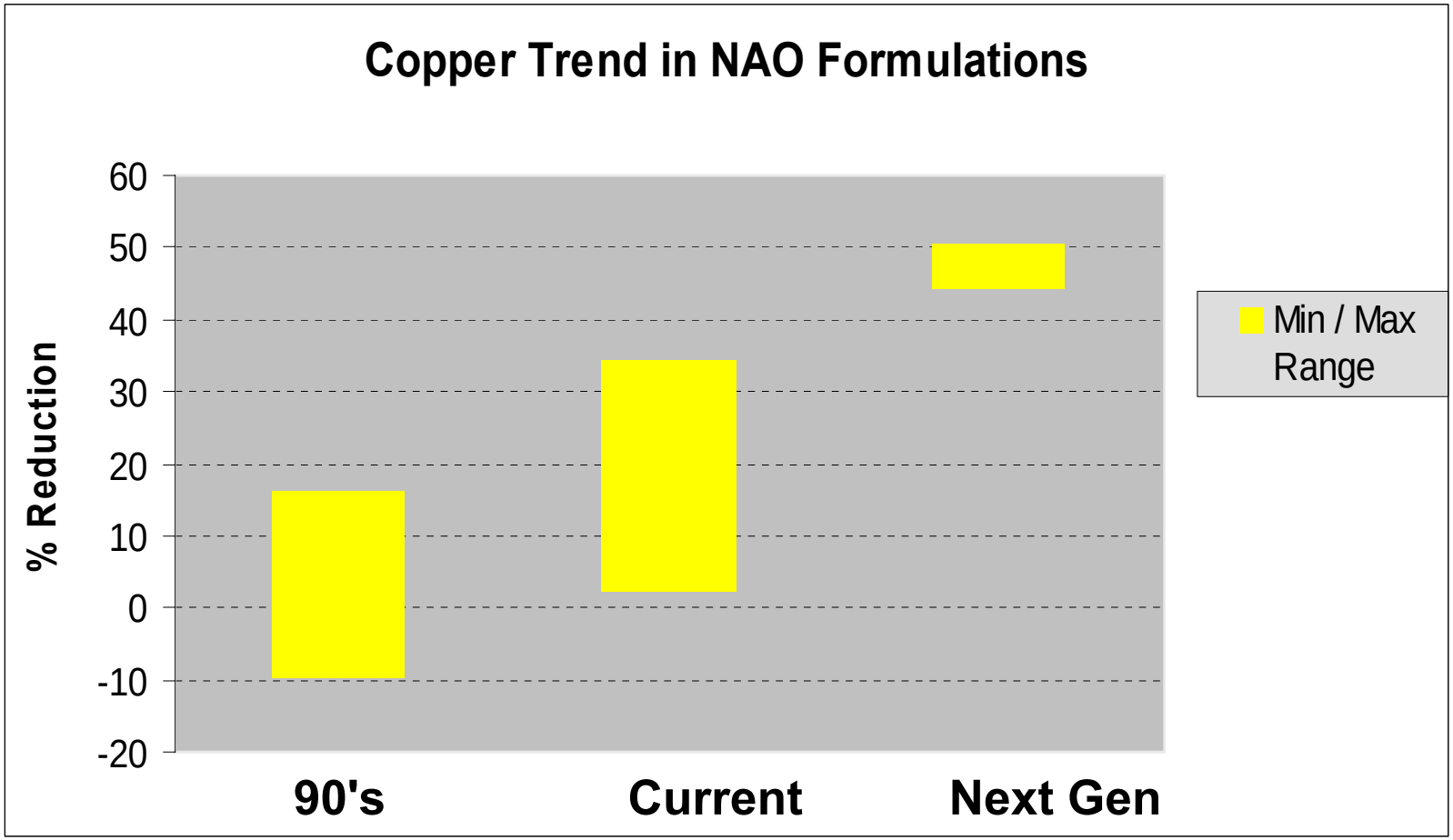
Copper Reduction in Lining Formulations



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Material Design

- Friction formulations are closely guarded and considered highly proprietary.
- No single set of material requirements or environmental restrictions exist
- The brake industry uses Vehicle Manufacturers specific component materials requirements documents (ie. GMW3059, CS9003, Delphi 10949001, Ford RSMS)
- The global nature of the automotive and friction material business tends to incorporate requirements and drive design based on most stringent requirement.
- Databases such as Global Automotive Declarable Substance List are beginning to integrate the many individual automotive materials requirements.

Manufacturing Process

- Volatiles and other by-products comply with OSHA requirements and local EPA.

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North American - Brake System and Friction Suppliers

OE Friction Suppliers

- Advics (Sumitomo)
- Akebono
- Delphi
- Federal Mogul
- Fras Le
- Galfer
- Haldex
- Hitachi
- Honeywell
- JBI
- Korea Beral
- Nisshinbo
- Saeron
- TMD
- Others

Flow of Requirements

Brake System Suppliers (Tier1)

- Advics
- Bosch
- Continental Teves
- Delphi
- Mobis
- TRW

Flow of Requirements

Vehicle Manufacturers (Partial List)

- Daimler Chrysler
- Ford
- GM
- Honda
- Hyundai
- Nissan
- Toyota
- Etc.

Red indicates supplier is in financial trouble (ie., Chapter 11)

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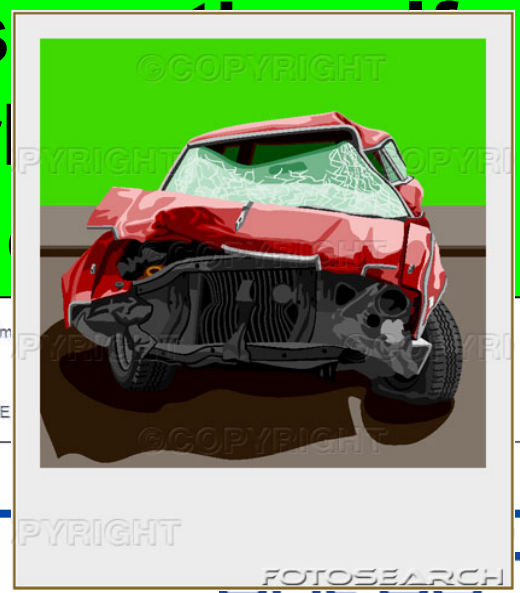
Tier 1 - Lining Implementation Timing

Overall Timing

Tier 1's and VM's will not accept the risk of developing a friction mate… vehi… marl…

The friction material selection process is very cons… the brakes don't worl… stop – rebooting is n…



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Recap of Design Criteria

- Safety is foremost in the brake industry. Material integrity and frictional output are the primary drivers in Friction Material. A conservative approach is taken toward changes by the Friction manufacturers, Tier1's and VM's.
- Friction material formulation is a trade-off – everyone is looking for high output, long life, no noise, no dust, no roughness, good corrosion removal, environmentally sound, very inexpensive material.
- Restrictions on material usage vary by manufacturer and location, and are difficult to anticipate.
- **Market pressure and environmental pressure to reduce copper in friction materials are aligned. Copper in new Akebono formulations is down by an average of 20%**

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Summary

- BMC's involvement in the BPP has been as a consistent, dedicated, reliable partner since its inception.
- Results of involvement in the BPP:
  - Focused attention of major US market players to dedicate resources to the issue (PEC formed).
  - Joint development of a methodology that allowed usually competitive independent companies to work together.
  - Generation of a published SAE wear debris standard.
  - Participation in modeling work plan and data evaluation.
  - Initiation and ongoing support of the copper use reporting program.
- We want to continue engagement with the BPP on next steps

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