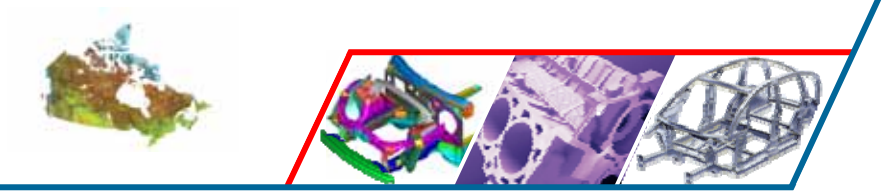


Lightweighting of Automotive Vehicles

Wojciech Kasprzak and Kumar Sadayappan

CANMET MTL; Natural Resources Canada

Presented at MDEC meeting, Toronto, Oct 7, 2010

Canada

CANMET MTL

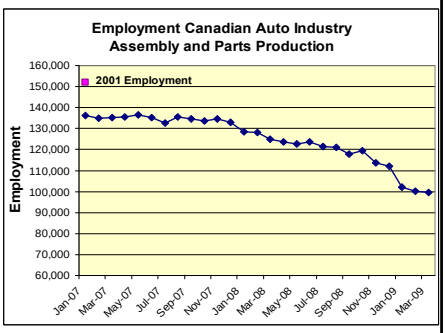
MTL is a federal laboratory reporting to the Minerals and Metals Sector of the department Natural Resources Canada (NRCan)

MTL's Mandate for research in automotive issues within NRCan:

- Energy efficiency
- Greenhouse gas emission reduction
- Value-added use of materials
  - steel, aluminum, magnesium, other metals, polymer-based materials
- Industry Competitiveness and Productivity
  - auto industry strongly linked into the Canadian economy
- Efficient use of natural resources

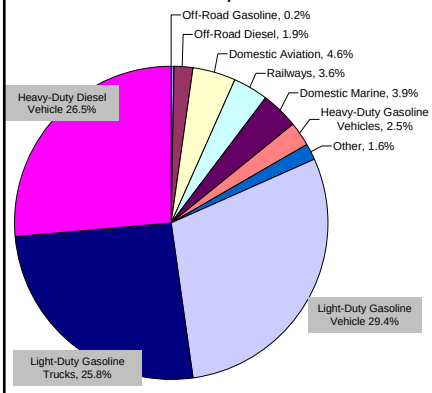
Auto Industry in Canada

- The automotive industry is Canada's largest manufacturing sector (2006 data …)
  - 12 percent of manufacturing GDP
  - 24 percent of manufacturing trade
  - Employed 158,302 people in automotive assembly and component manufacturing, 336,212 in distribution and aftermarket sales and service.
  - One in seven jobs in Canada; and one in six jobs in Ontario, are related to the automotive industry

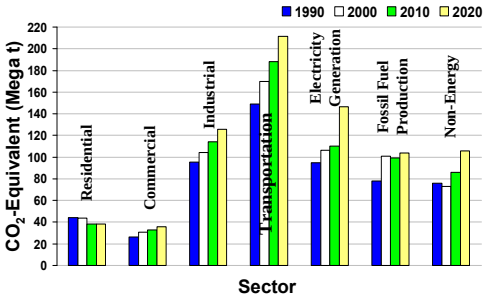


Emissions

😐 Passenger vehicles + light trucks
~55% of transportation emissions



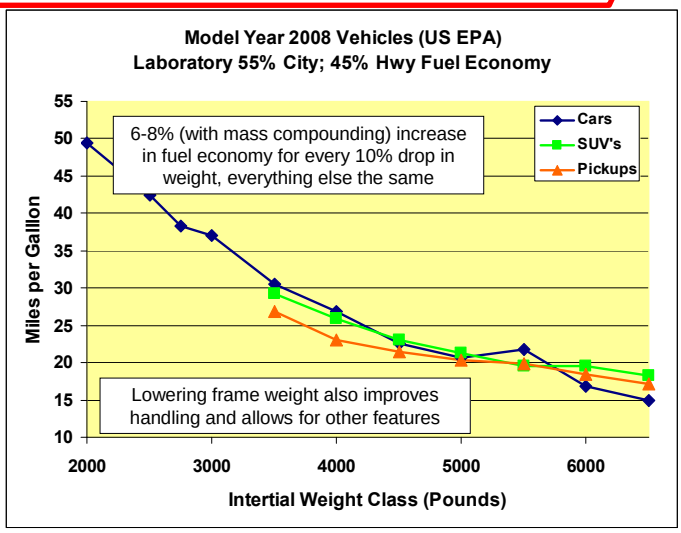
Source: Canada's GHG Emissions from Transportation in 2004



😐 Transportation sector
Heaviest contributor to GHG emissions

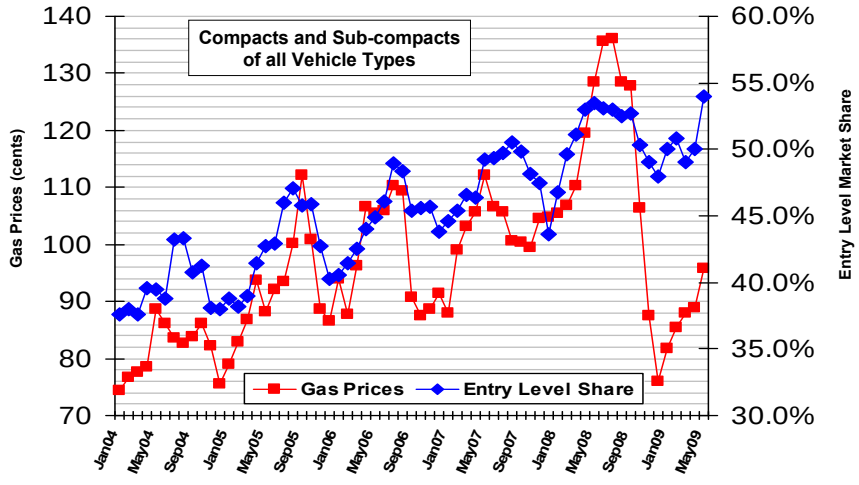
Source: NRCAN, Canada's Energy Outlook: 1996 - 2020

Weight Vs Fuel Efficiency



Canadian Consumer Preferences

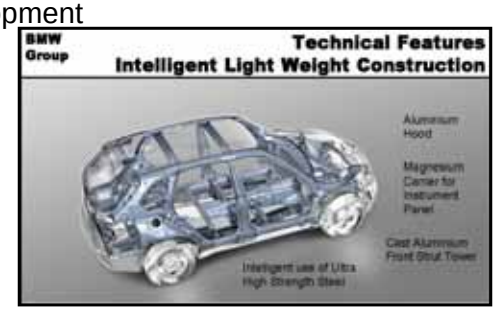
Entry Level Market Share vs. Gas Prices
Jan. 2004 – May 2009



Source: MJ Ervin & Associates, DesRosiers Automotive Consultants Inc.

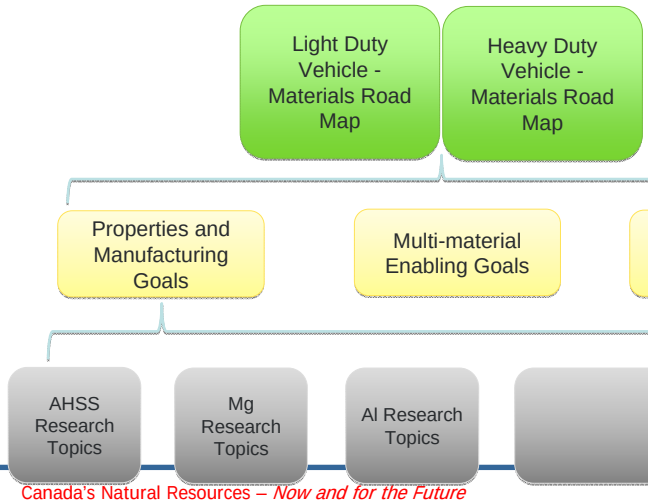
Light weight options

- Light weight structures
- Powertrain
- Innovations in manufacturing process
  - Heat treatment development
- Component design



Structure

Lightweight Materials Goal: *By 2015, validate the cost-effective 50% reduction of the weight of passenger vehicle body and chassis systems with safety, performance, and recyclability comparable to 2002 vehicles*



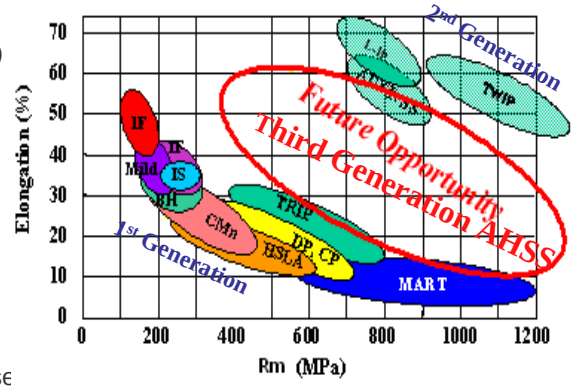
Source: USDOE

Structural Materials

- New Generation Steels
  - Development of UHSS (TWIP and TRIP)
  - Dynamic properties and welding of AHSS
- Light metals
  - Advanced Magnesium Technologies
  - Aluminum alloys
- Composites

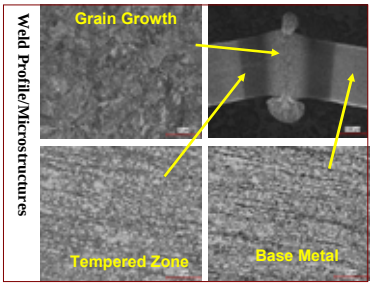
Advanced High Strength Steels Development

- Conventional High Strength Steel (Ferrite based)
- 1st Generation (Ferrite Based)
  - TRIP, DP, CP,
  - Martensitic , Bainitic
- 2nd Generation (Austenite Based)
  - TWIP
  - L-IP (High Al)
  - Austenitic Stainless steel
- 3rd Generation (Multiphase)
  - Potential constituant phase
    - Martensite, Ultrafine grained ferrite
    - Austenite



New Generation Steels

- Design and process lean steel to avoid additional costly alloying elements
- Avoid additional heat treatments such as soft annealing or tempering
- Optimize strength and ductility by microstructure control
- Advanced thermomechanical processing to exploit phase transformation, recrystallization and controlled cooling to tailor microstructure and properties
- Maintain compatibility with enabling technologies: weldability, coatability and formability (hydroforming), etc



USAMP Mg Front End Design - Summary

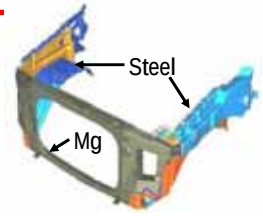
Unibody (BFI, Cadillac)

Steel baseline design
79 Parts & 84.3 kg

Magnesium design
35 Parts & 46.1 kg

38.2 kg mass reduction (45%)
44 part reduction (55%)

Body on Frame (F-150)



Steel baseline design
16 Parts & 70.7 kg

Magnesium design
3 Castings & ~37.5 kg

33.2 kg mass reduction (47%)
13 part reduction (81%)

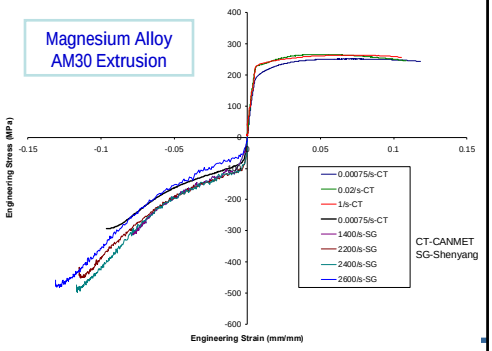
Crashworthiness

- Despite the initial buckling deformation, all three Mg alloys showed pervasive fracture in crash loading, which is less desirable for automotive applications compared to Al or steel

Magnesium Alloy AM30 Extrusion

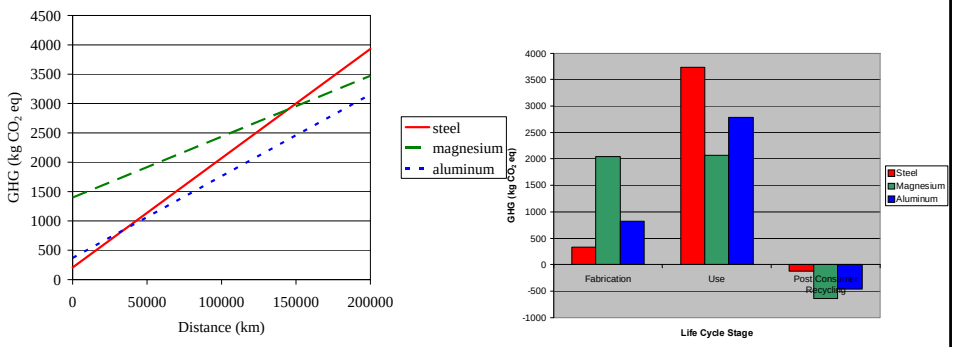
Aluminum Alloy 5754 Extrusion

Magnesium Alloy AM30 Extrusion



LCA - Global Warming Potential

- Alain Dubreuil, CANMET MMSL, NRCAN
- Sujit Das, Oak Ridge National Laboratory



Diesel engines

- 45 million cars were produced in 2002
- 60% gasoline engines in aluminum (weight savings 50%)
- Europe was switching to diesels
  - 39% all cars (14 million) sold in 2003 were diesels
  - France 67%, Austria 71%
  - Daimler-Chrysler was 80% diesel in 2003
  - Turbo-charged common rail diesel
- Significant growth in diesel engines is expected for NA
- If North American SUVs and light trucks were switched to diesel, the energy and emissions would be reduced by 15%. In 1996, a cast iron V8 and transmission weighed 700 lbs.

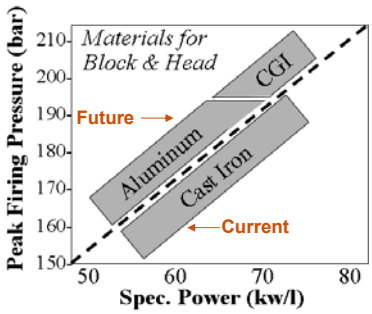
Materials for powertrain (passenger vehicles)

Aluminum alloys

- Al-Si-Mg alloys (ex: A356, A357)
  - good ductility, lack of strength >250ºC
- Al-Si-Mg-Cu alloys (ex: A356 + 0.5% Cu)
  - good ductility, retaining strength between 200-250ºC
- Al-Si-Mg-Cu alloys with Mn, Zr, V, Ti and Cr
  - (ex: A356+1%Cu+0.15%Zr+0.15%Cr and A319+0.15%Mn+0.25%V+0.15%Zr)
  - lower ductility, higher YS and creep at 250ºC

Cast Irons

- Gray iron
- Compacted graphite iron
- Ductile iron



R.Fuoco, M.F.Moreira, Fatigue Cracks in Aluminum Cylinder Heads for Diesel Engines, AFS 2009, 09-117

Advantages of Al-made Components for Gasoline Engines

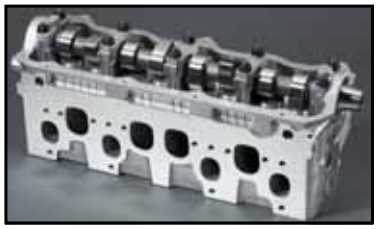
1. Application of light weight alloys

Powertrain

Liner-less Cylinder

Cast-in Iron Cylinder Liners

3.0l V6 Engine Block (Al-Si-Cu alloy)



Heat resistant Al Cylinder Head (Al-6%Si-3%Cu alloy)

Forged Al Piston (Al-11%Si-3%Cu-0.5%Mg alloy)

☹ 30% Engine downsizing

☹ 10-15% less engine weight

☹ 10-20 % less CO_2 emissions

Al Castings for Engine Applications in Passenger Vehicles

Components	Engine Block	Cylinder Head	Piston
Alloy System	Al-Si-Mg-(?) Al-Si-Cu-(?)	Al-Si-Mg-(?) Al-Si-Cu-(?)	Al-Si-Cu-Ni-(?)
Operating Temperature (°C)	135	250	400
Operating Pressure (bar)	-	>180	-
HCF (MPa)	180	140	>200
Creep $\sigma_{0.1/100}$	-	44	-
SDAS (μm)	20	20	-
Process	LPSP, HPDC	SPM	SPM, Forging

LPSP - Low Pressure Sand Package

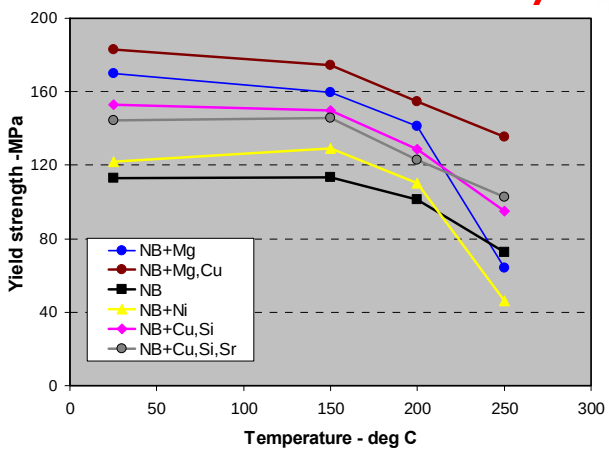
SPM - Semi-Permanent Mold

HPDC - High Pressure Die Casting

Limitations:

Elevated operating temperature and internal pressure disqualify existing Al alloys for small, turbocharged, energy efficient automotive engines

Limitations of the Existing Cast Al Alloys used for Engine Applications



Loss of mechanical properties at elevated service temperatures of above 150 °C

Examples of Aluminium Cast Components for Automotive Powertrain Applications

Alloy	390 (Al-18%Si)
Casting process	LPPM
Heat treatment	T5

LPPM – Low Pressure Permanent Mold

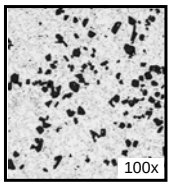
V6 3.2l cylinder block V8 4.2l cylinder block

Alloy	DiASil (Al-20%Si)
Casting process	Vacuum HPDC
Heat treatment	T6

HPDC – High Pressure Die Casting

Yamaha Majesty

The 250cm³ cylinder block

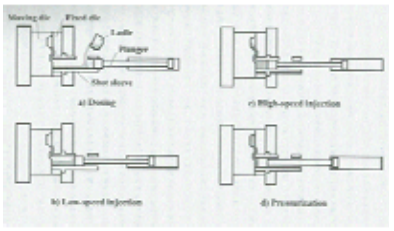


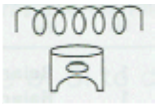
J. L. Jorstad, The Progress of 390 Alloy: From Inception until Now, AFS Transaction 2009, 09-152SA

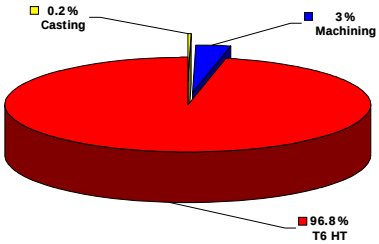
Courtesy of: Essen Motor Show 2007: MTM Audi A5 V6 and WorldCarFans.com: Audi V8

Innovations in Manufacturing Process: Reduction of Engine Block Production Time

HPDC Casting process → Heat treatment → Machining → Honing







Process	Duration, min	Relative, %
Vacuum HPDC	1	0.2
Heat treatment (T6)	480	96.8
Machining Engine block Cylinder bore (honing)	15.5 13.5 2	3

Alloy Chemistry Survey for Diesel Cylinder Heads (Passenger Vehicles)

VW TDI 1998 Model

A

VW TDI 2003 Model

B

Nissan 2005 Model

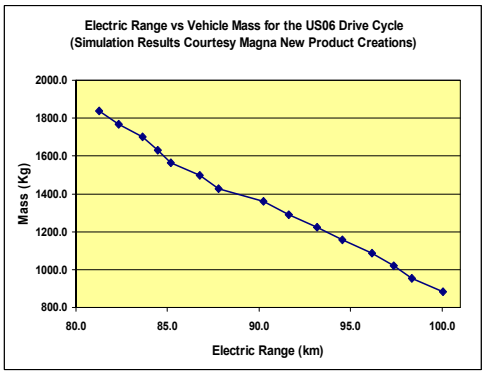
C

Product	Alloying Elements, %													
	Si	Cu	Mg	Zn	Fe	Ti	Mn	Ni	Cr	Sn	Pb	Sr	V	Zr
A	6.4	3.2	0.22	0.52	0.52	0.15	0.40	0.032	0.028	0.007	0.074	0.01	-	-
B	5.5	3.2	0.19	0.035	0.29	0.12	0.34	0.017	0.010	0.005	0.01	0.01	-	-
C	5.3	3.4	0.14	0.27	0.56	-	0.56	0.023	0.03	0.02	0.02	-	-	-

Strong popularity of conventional alloys (Al-Si-Cu-Mg)

Summary

- Light weighting is seen as important for reducing emissions and improve fuel efficiency
- Developments in materials are enabling the light weighting possible
- Safety and durability are the major issues to be resolved before large scale implementations are possible



Weight reduction will be critically important to the large-scale introduction of vehicles with alternative energy powertrains