

Future Powertrain Technologies: 2010 to 2025



Hybrids, Alternative Fuels, Diesels or ? Update Of A CO₂-Driven Outlook to 2025

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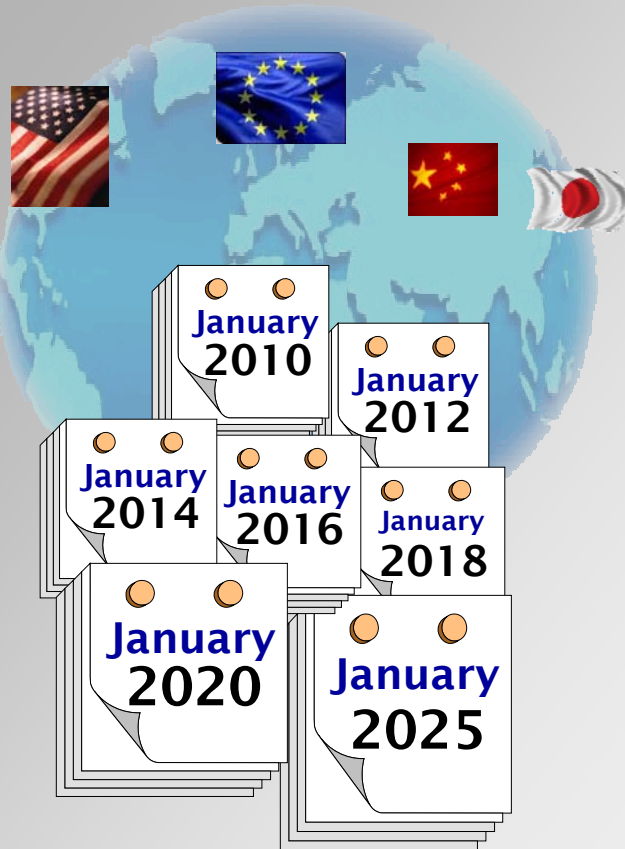


Agenda

- **Introduction**
 - Scope
 - Methodology
- **What's new on the horizon, 2006 vs. 2001?**
 - Major changes in our thinking
 - Oil Price and availability
 - Alternative fuels
 - Consumer playing a role in powertrain choice
 - Vehicle market segments
 - Hybrid market
 - Powertrain technology breakthroughs
 - Regulatory environment driven by energy and CO2 concerns
- **Impact on powertrain forecasts**
 - Powertrains & relative costs
 - Implications for policy makers

An objective projection of the future of powertrain technology

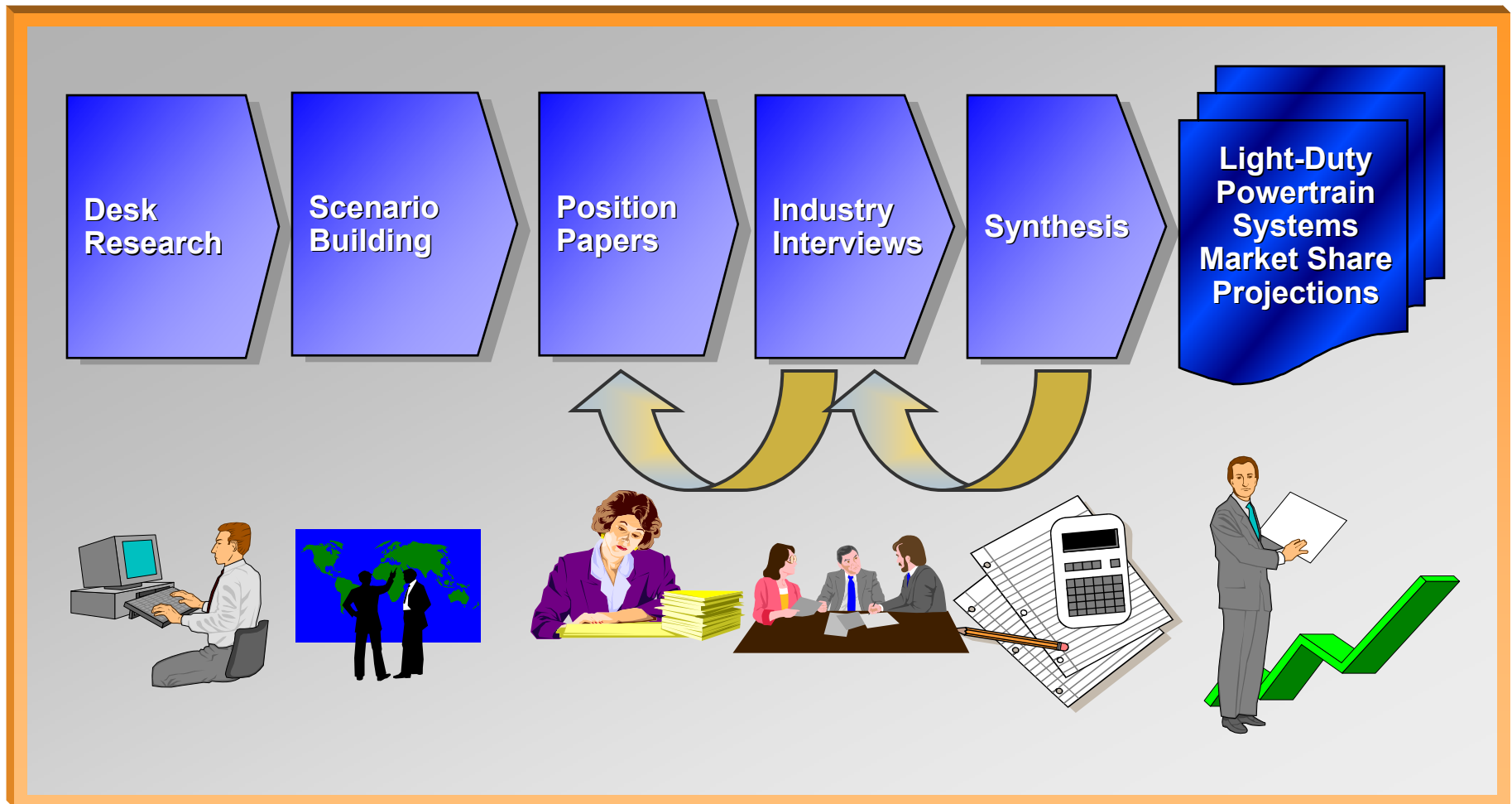
Scope



- Western Europe, North America, and Japan as technology drivers
- China – how will powertrain evolve?
- Years 2010 to 2025
- Primary light duty powertrain system
 - » IC engines
 - » Hybrid electric
 - » Battery electric
 - » Fuel Cell
 - » Transmissions
- Alternative Fuels
- Describe each technology and its enablers
- Assess market share trajectories under each scenario - and why?
- What is the sensitivity of these to each of 3 scenarios?

The market shares future engines and transmissions were developed in six steps.

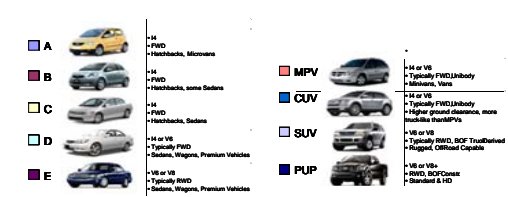
Methodology



Synthesis: The lowest risk, lowest cost technologies needed to meet future scenario requirements in each of 9 vehicle segments for each region were determined based on objective performance modeling

Methodology

- 3 Alternative Scenarios
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- 3 Alternative Scenarios
- CO₂/Fuel Consumption
- Emissions
- Fuel Price and Characteristics
- Market Segmentation



9 Vehicle Segments



3 Regions



Engine

- NASI
- TC/SCSI
- HSDI
- HCCI
- EGT
- Ox Cat
- SCR
- LNT
- NAC
- ST
- DPF

Transmission

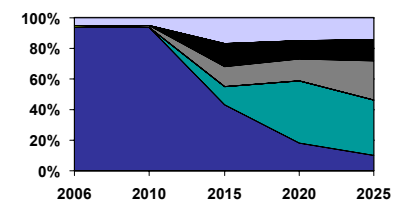
- Manual
- AMT
- Planetary Auto
- Dual Clutch
- CVT

Hybrid

- Parasitic load management
- Micro
- Mild
- Full
- Plug In



GT Drive™ and Proprietary Segment-Level Spreadsheet Market Models



Market Shares Of Powertrain Technologies by Region, Segment and Scenario

	2006	2010	2012	2016	2025
Conventional A1 SI	56%	30%	20%	6%	0%
A1 SI w/Full IVT	0%	0%	0%	0%	10%
Boost DISC	2%	0%	0%	0%	0%
Lean Boost DISC	0%	4%	15%	15%	14%
DNSZ A1 Boost SI	1%	6%	11%	14%	16%
LTE	0%	0%	0%	2%	15%
HSDI	42%	58%	54%	55%	45%

Market Shares Of Powertrain Technologies by Region, Segment and Scenario



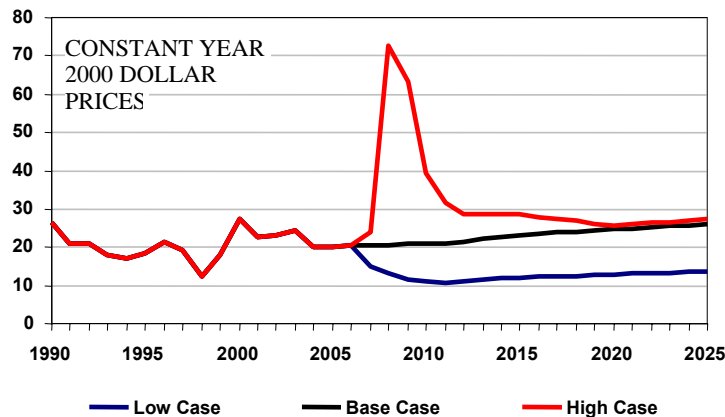
2006 Program Compared to 2001: Oil Up \$10 Per Barrel Long Term

Rationale

2001

- **Petroleum**

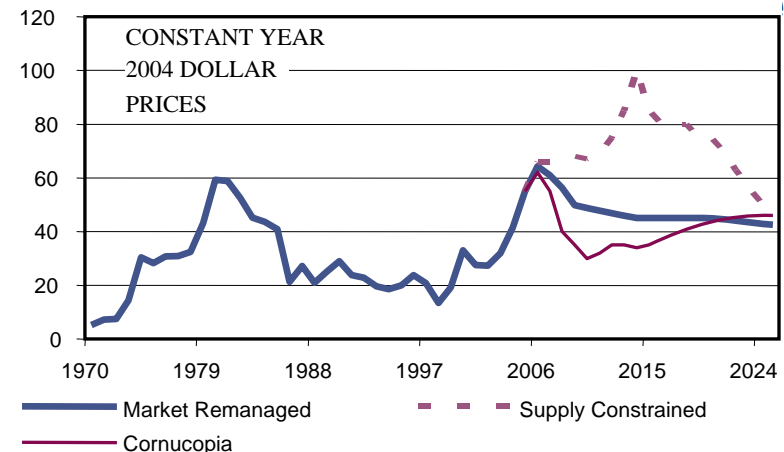
- Primary fuel
- Small amount of biofuel blending
- Subject to short term price fluctuations, but even with disruption will return to <\$30 per barrel



2006

- **Petroleum**

- Supplemented with biofuel, to 20%, possibly up to 30%
- Credit for benign bio-fuel CO₂
- Subject to short term price



Regulatory policies in all scenarios include biofuel and Fischer-Tropsch fuel blends

Fuel Blends

Region	Ethanol Gasoline				Biodiesel			
	2010	2015	2020	2025	2010	2015	2020	2025
North America	E4	E6	E7.5	E10	B2	B3	B5	B5
Europe	E5	E7	E10	E10	B4	B6	B10	B20
Japan	E5	E5	E5	E5	B2	B2	B2	B2

- The above chart reflects an average distribution across regions
- Point to point deviations from the average will be small for diesel blends
- Point to point deviations for gasoline blends could be large due to distribution issues
 - E85 could be available in the midwest of the U.S. with low blends on the coasts
- Use of vegetable oils as refinery feedstock based on NExBTL, UOP or other processes could negate any impact on powertrain technology
 - More likely in Europe
 - Infrastructure and short-sighted policy in U.S. could limit refinery option

Our social consciousness is being raised about anthropomorphic climate change...

Rationale

True or false, more and more policy-makers ask: is ignoring it worth the risk? ...

Glacier National Park Boulder Glacier



1932



1988

Photos: George Grant, Glacier National Archive; Jerry DeSanto, National Park Service

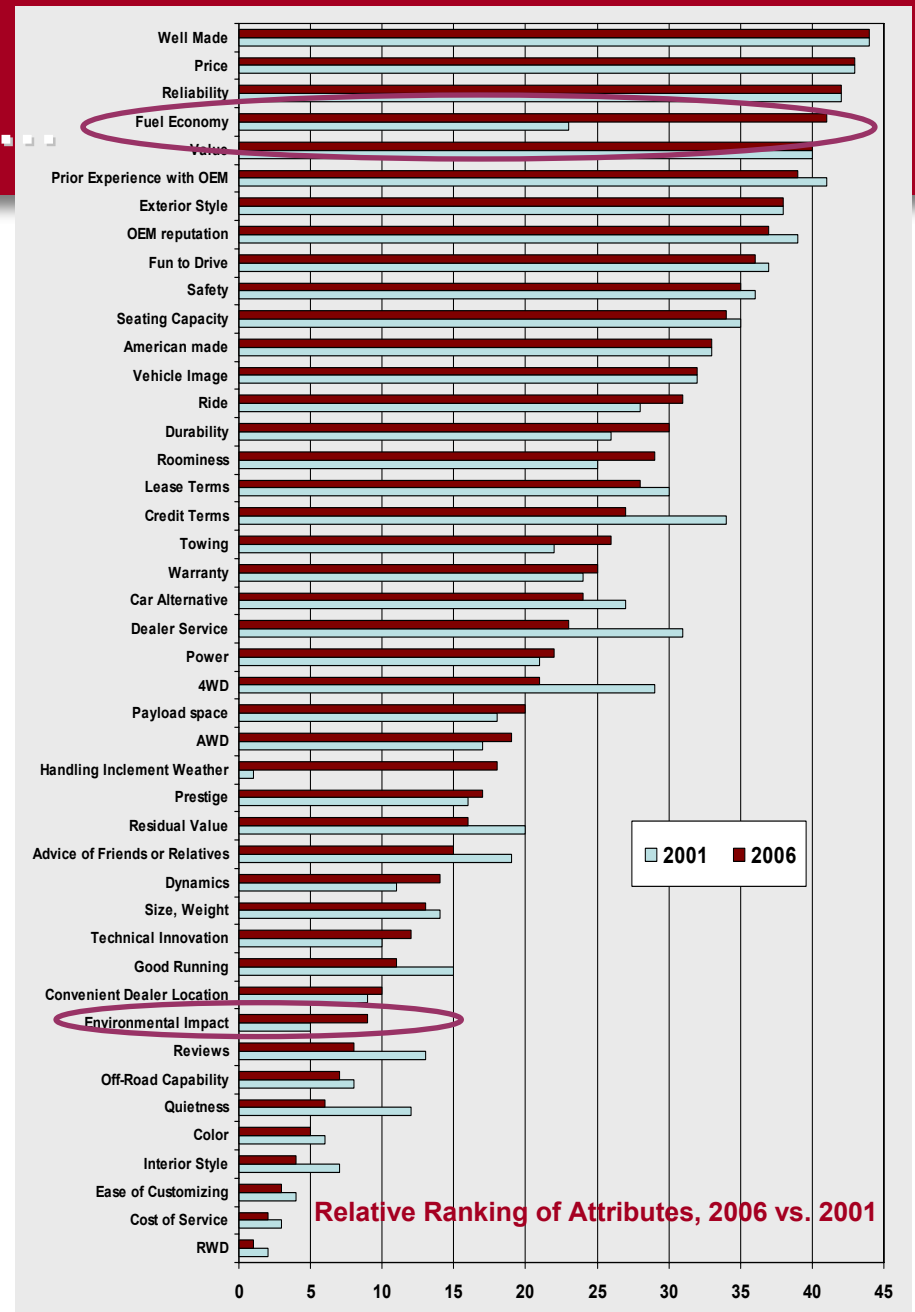
As used by A. Gore in "An Inconvenient Truth"

... and fuel consumption is a higher priority amongst buyers . . .

- In Europe and Japan fuel economy has always been very important, while the engine plays a very small role in vehicle purchase decisions**.
- New U.S. car buyers place greater emphasis on fuel consumption, 2006 compared to 2001*.

* Strategic Vision New Car Buyer Surveys, 2001 vs. 2006 – see chart at right

** Prescher K. Alternativen oder Ergaenzungen?, Commentary in MTZ Motortechnische Zeitschrift, 56, (1995) 12, p 711, (1995)



... leading to a consumer that policy makers may attempt to influence ...

Rationale

2001

- **Consumer**
 - Will not give up vehicle attributes to save fuel
 - Will not tolerate coercive fiscal policies
 - “Worst Case” scenario, market shares freeze as of 2006.



Now

- **Consumer**
 - Will not willingly give up vehicle attributes to save fuel
 - Recognizes need for change, giving policy makers the courage to attempt (at some risk) fiscal policies that move consumers in the “right” direction.
 - “Worst Case” scenario, market moves to smaller cars, CUVs and small SUVs. Pickups, other commercial vehicles retain “work-related” volumes

... and a more balanced policy-making environment...

Rationale

2001

- **Regulatory policy focused heavily on emissions**
 - Diesel treated equally to gasoline engines
 - Potential trade-off between particulate and NOx reduction and CO₂ was not appreciated by policy makers
 - Long term Diesel viability put into question
 - Industry expected to carry the entire burden

2006

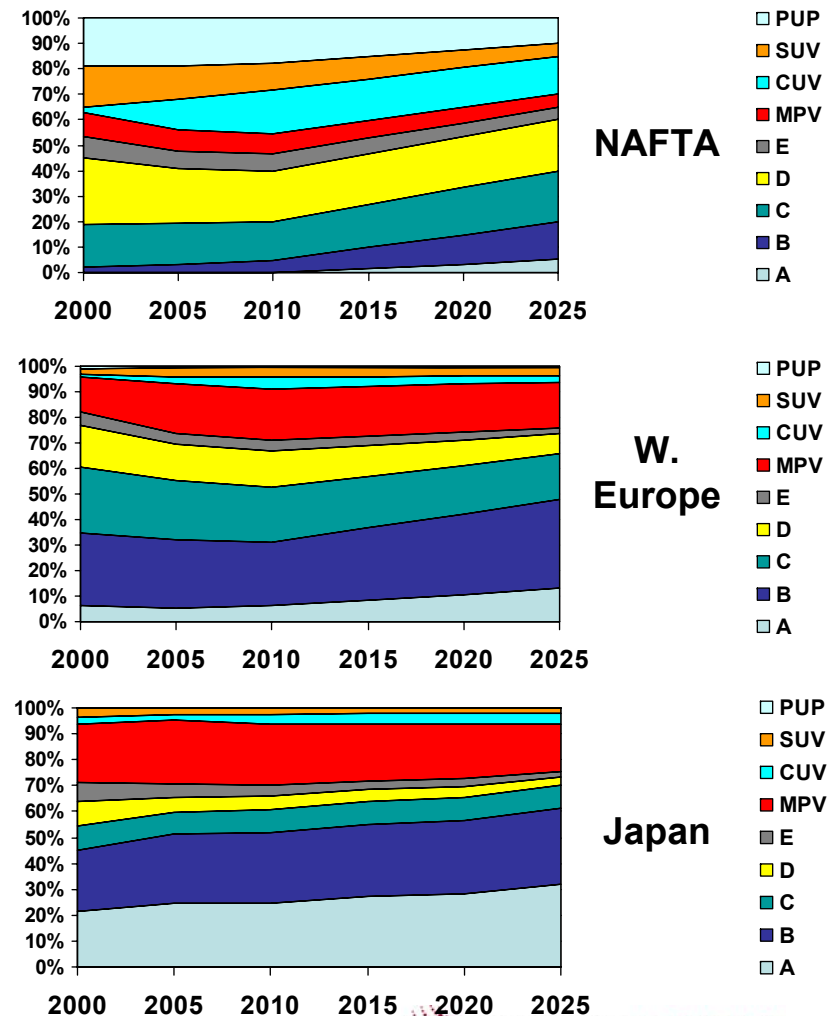
- **Regulatory policies evolving in a more balanced manner**
 - Diesel treated equally to gasoline engines
 - PM and NOx versus CO₂ trade-off not acceptable
 - Long term viability of Diesel still in question
 - Integrated policy approach involving
 - Tailpipe CO₂ reduction
 - CO₂ trading schemes
 - Biofuels credit for CO₂
 - Consumer must do their part in CO₂ reduction

...that can result in a recurring CO₂-based annual tax on vehicles in use to encourage the consumer to buy inherently more efficient vehicles.

Rationale

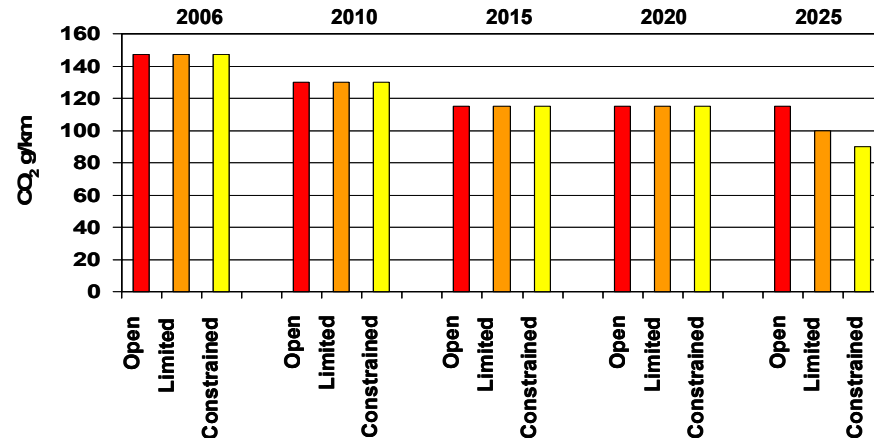
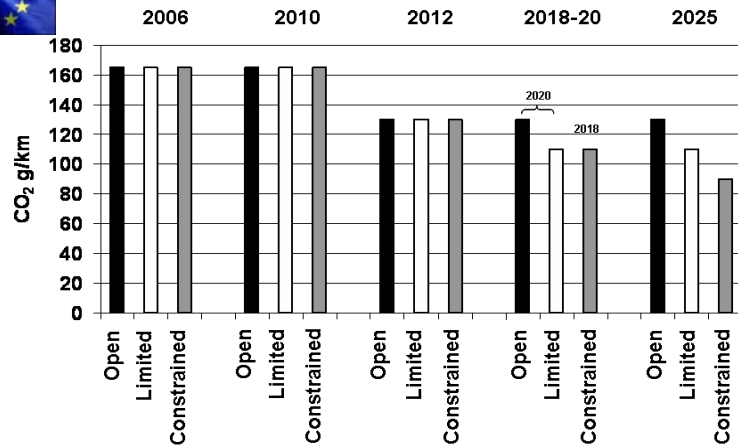
- A dramatic but plausible change in new-vehicle segment mix will result in different reductions in fuel consumption and CO₂, 2005 to 2025, depending on region.
- Results of the segment shift alone are surprisingly limited in W. Europe and Japan because their new vehicle fleets are already quite efficient
 - NAFTA: -12%
 - W. Europe - 4%
 - Japan - 5%

**Vehicle Market Segment Shares:
Accelerated Change**



New vehicles will be subject to sales-weighted average CO₂ performance – after a CO₂ credit is given for biofuel blends: E10 & B20 – by 2020

Rationale



Three tailpipe emissions scenarios

Rationale

- **Full-stop**
 - No further reductions in tailpipe emissions beyond the standards that are currently enforced or planned
- **Normal Pace**
 - Air quality degradation in each country due to increased vehicle miles travelled offset with further reductions in tailpipe emissions
- **Full Sprint**
 - Global perspective taken
 - Developed nations strive to offset increased emissions from developing markets
 - Further aggressive reductions in tailpipe emissions output

Leading to powertrain forecasts based on 3 different, internally consistent scenarios

Rationale

	Open Market	Limited Market	Constrained Market
Oil Price & Availability	Cornucopia	Market Remanaged	Supply Constrained
Regulatory Environments	Full-Stop	Normal Pace	Full-Sprint
Consumer Trends	As Expected	Market Freeze	Accelerated Change
	Low Probability	Most Likely	Moderate Probability

- **Open scenario**
 - Serves as a comparison to today, with only evolutionary powertrain developments
 - Addresses the question “What if environmental concerns abate?”
 - Normal consumer progression to heavier, larger vehicle segments
- **Limited scenario**
 - “Business As Usual”
 - Current level of environmental quality accepted as adequate
 - Emissions reduced only to offset increases in vehicle traffic
- **Constrained scenario**
 - Accelerated efforts to stem further environmental change
 - Consumer forced to buy with a “social conscience.”
 - Further reductions in emissions needed



There Have Also Been Revolutions in Combustion...

Rationale

2001

- Otto cycle and Diesel cycles were the two mainstream systems
- Key issue was exhaust gas treatment to meet toxic emissions standards
- More or less conventional portfolio of efficiency improving options
- Major breakthrough expected was to be stratified (unthrottled) DI gasoline

2006

- Low-temperature combustion “revolution” (PCCI, HCCI) driven by heavy duty developments
 - Will evolve to replace Diesel cycle as we know it
 - Reduces exhaust gas treatment challenge significantly
- Spark ignited engines evolving from the portfolio of expected options as in 2001 study
- DI gasoline, both $\lambda 1$ and lean evolving as expected

... Leading to at least 6 different engine options

Rationale

- **Conventional $\lambda 1$ Spark Ignition (SI): Naturally Aspirated Spark Ignition**
 - Variable and optimized cooling rates at different operating conditions,
 - Variable valve timing (Miller/Atkinson cycles),
 - Reduced mechanical friction losses
 - May be either pre-mixed or DI
- **SI IVT: $\lambda 1$ Spark Ignition with Infinitely Flexible Valve Timing and Boosting (Turbocharged)**
- **DISI: Direct Injection Turbocharged Gasoline Engine**
 - Combustion system development for stratified operation across entire part load range
 - Lean with NOx treatment (20% risk) or Stoichiometric (5% risk)
- **DNSZ SI: Downsized, highly boosted DISI**
 - 30% reduction in displacement
 - Turbocharged
 - Lean with NOx treatment (30% risk) or Stoichiometric (10% risk)
- **HSDI: (High Speed) Direct Injection Diesel (lean)**
 - Turbocharged – perhaps multi stage
 - Lean NOx exhaust gas treatment
 - Diesel particulate filter
- **LTE: Low Temperature Engine (lean)**
 - Also known as HCCI, PCCI or CAI
 - Power boosting – perhaps electrically assisted turbocharger
 - Advanced controls including start of combustion sensing
 - Low-temperature oxidation catalyst

By 2020/2025, battery developments are not expected to enable battery-electric vehicles (BEV) to compete as equals to liquid-fueled vehicles

Rationale

- Will meet ZEV requirements
- Ideal for Closed Communities and City Centers
- Not substitutes for more conventional light vehicles
- Perfect for limited duty cycles



Hybrid's sensitivity to duty cycles depresses expected market acceptance and viability as a solution for fuel consumption reduction

Rationale

Drivers Upset as Hybrids Fall Short on Fuel Economy: USA Today, June 11, 2004

July 31, 2005

"More Thirsty Than You'd Think"
By THE NEW YORK TIMES

All said and done, if you were driving the same route, at the same speeds, in the same conditions, it would take roughly 144,000 miles before the Hybrid paid back its \$1440 premium over the Civic EX:
Popular Mechanics, July 15, 2003

None of the top cars are hybrids. That's because, with their added cost, hybrids aren't really a good value from a purely economic standpoint. But we've provided a hybrid choice in some categories for those who are willing to pay more to burn less fuel.

CNNMoney.com, May 8, 2006

2006 Lexus RX 400h: The Hybrid Emperor's New Clothes - New York Times , 7/31/2005

With help from a hefty tax credit, consumers driving 15,000 miles per year completely recover the premium paid for the Ford Escape, civic Hybrid, Saturn Vue Greenline and Toyota Camry hybrid in three years. for other cars The break-even point takes six years to reach.
Marketwatch by Dow Jones, August 22, 2006

Consumer Interest In Hybrid Vehicles Dropping

CNW Marketing Research says that a year ago about 30% of car shoppers considered buying a hybrid and were willing to pay a premium of nearly \$2,500 US more than for a conventional vehicle. Now, however, hybrid consideration is at 12%, and shoppers are willing to pay only an additional \$1,152 US.
Source: Chicago Tribune, Jan. 04, '07

Hybrid buses' fuel economy promises don't materialize:
Seattle post-Intelligencer, December 13, 2004

Will Plug-in hybrids make a difference?



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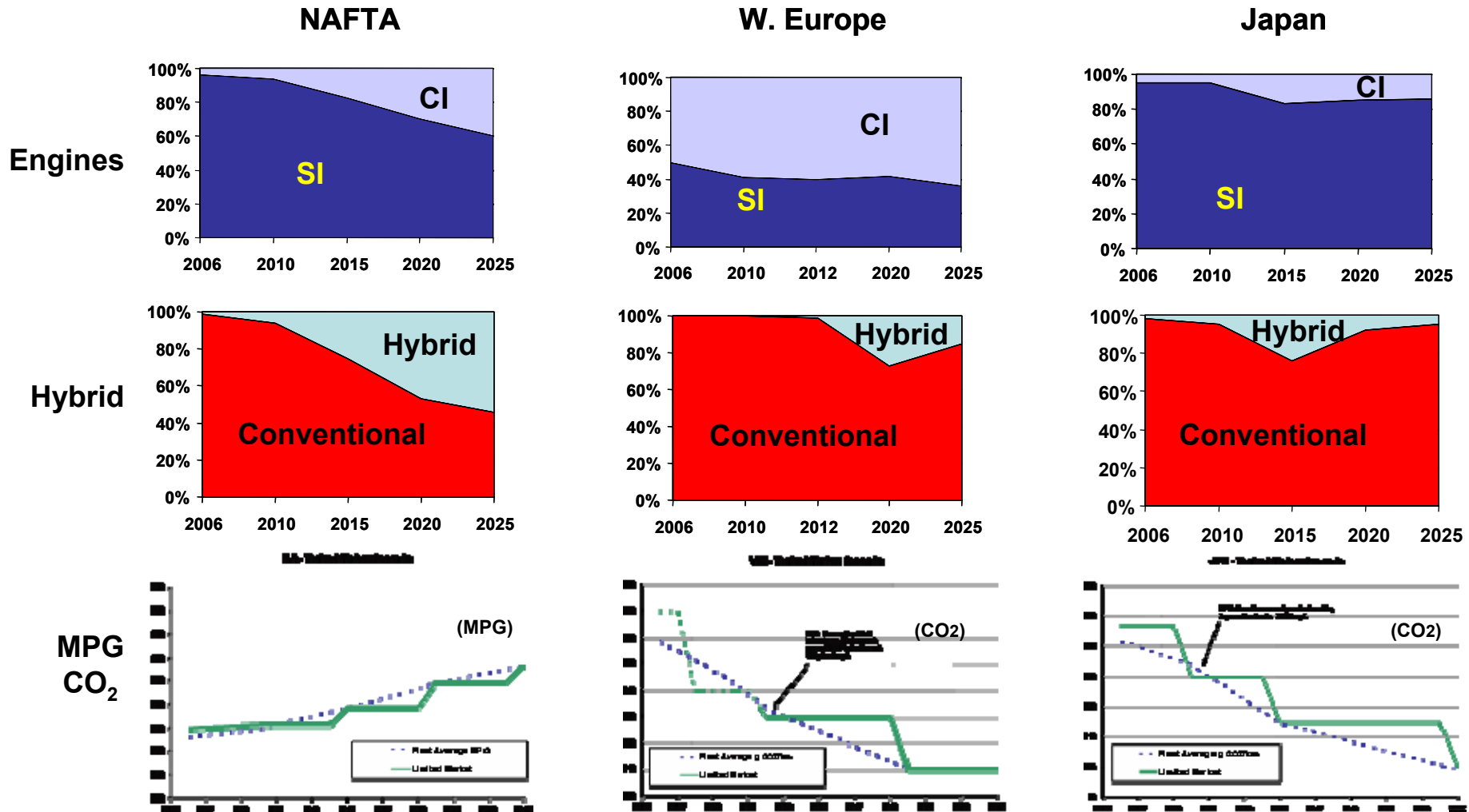


Impact On The Forecast



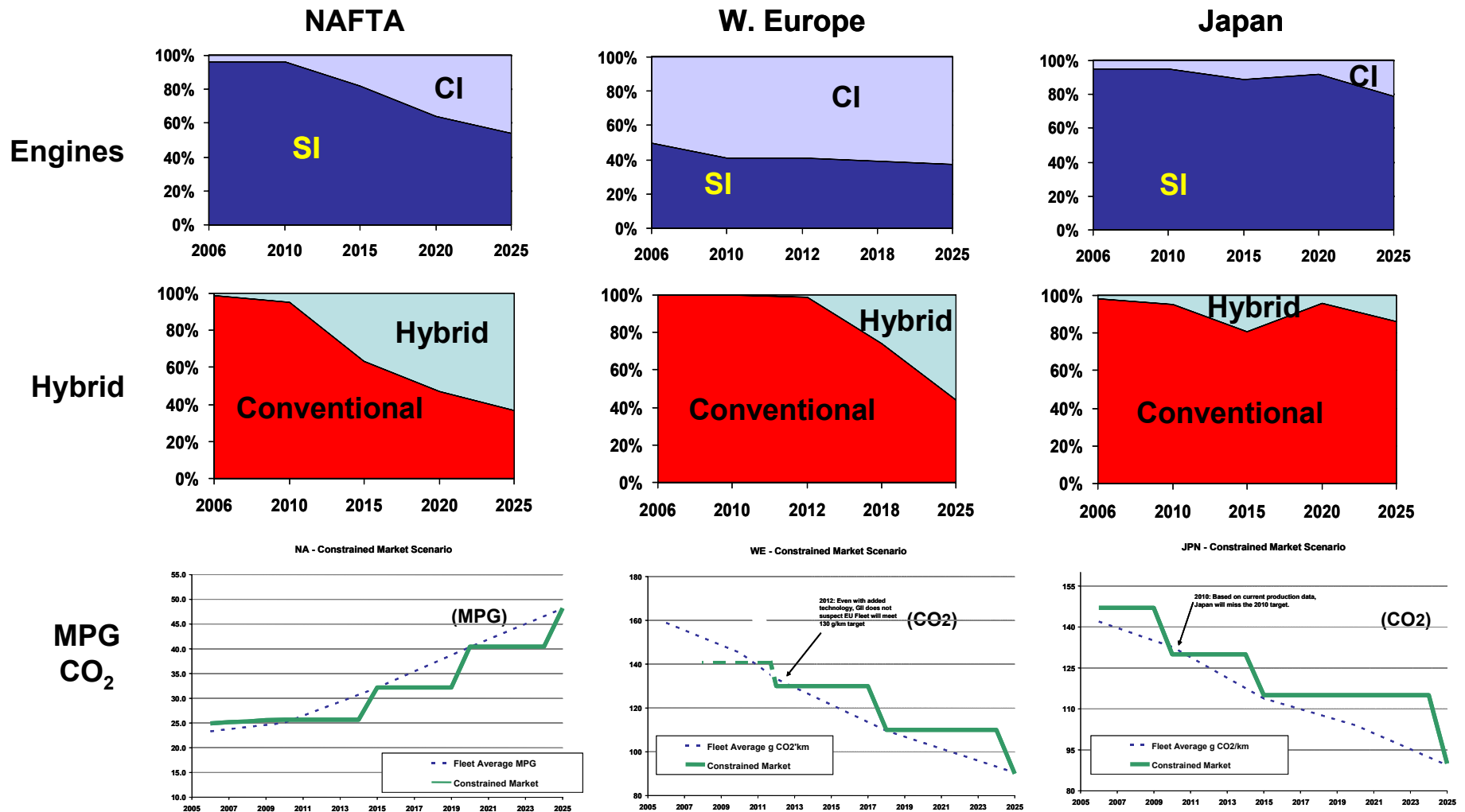
Limited Scenario: Hybrids and CI engines gain globally, SI engines evolve in 4 ways

Conclusions

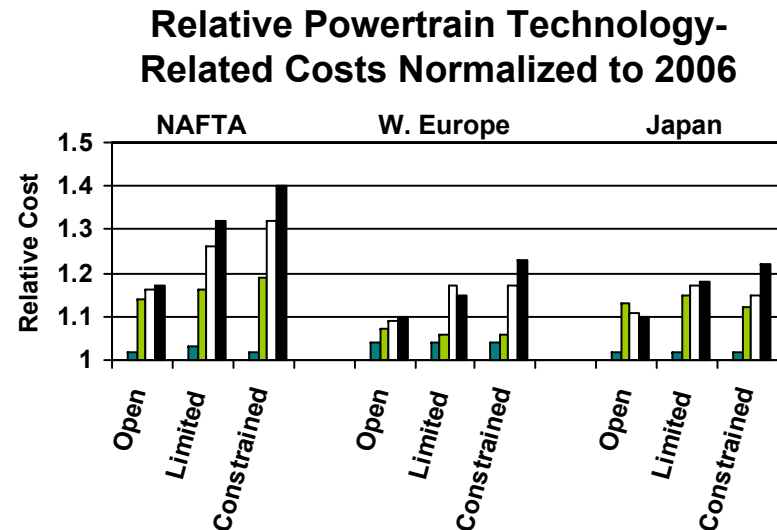
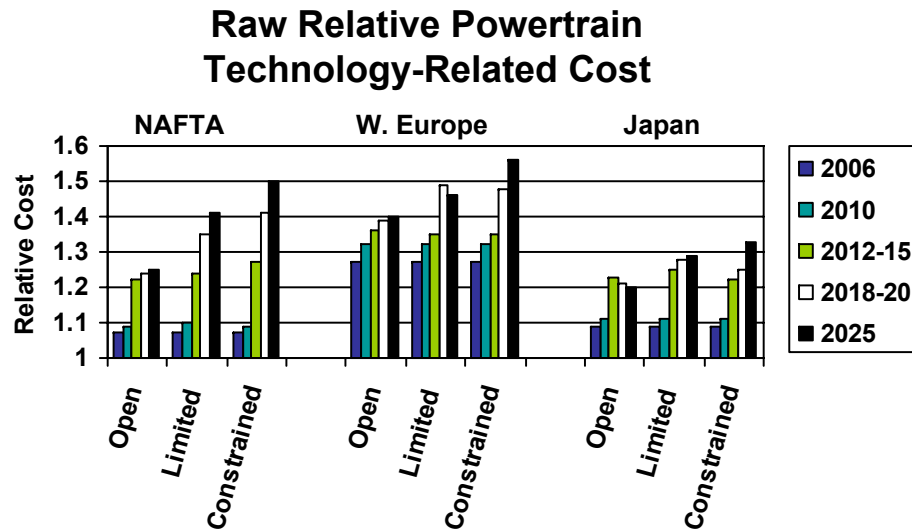


Constrained Scenario: vehicle segment shifts demand new investments in smaller displacement engines, hybrids ease the transition

Conclusions



Limited and Constrained Scenarios can increase relative technology-related* powertrain costs over 40% in NAFTA, 15-20% in Europe and 20-25% in Japan Conclusions



- **NAFTA has the highest cost change of any region in any scenario, but starts from the lowest base**
 - Even the least aggressive scenario presents a 20% increase in powertrain costs
 - But still affordable as fuel economy will likely pay back in first ownership period
- **Japanese home market cost advantage maintained if all regions adopt the same scenario**
- **European powertrain costs remain generally highest due to high percentages of compression ignition engines and hybrids**
 - **Costs decline in W. Europe Limited Scenario as engine improvements and the use of B20 reduce need for hybrids**
 - Profitability of OEMs may not be improved due to the need to invest in new, small diesels engines for the smaller segment vehicles



* Not including new investments needed due to market segment shifts or chassis-body changes such as weight reduction

Hybrids have an important role to play, but present a market and regulatory risk

Conclusions

- **Hybrids –Micro, Mild, Full and Plug-in - have a role to play, but without charging from the grid their perceived benefits are highly sensitive to duty cycle characteristics**
 - Technology developments are not expected to significantly change this
 - Costs will decline by 5 to 10%, but not enough to substantially increase share
 - Plug-in Hybrids may gain greater acceptance for those with access to grid power after 2015 when battery technology can deliver 50+ km autonomous range
 - Cost-neutral trade off, at least in Japan: Diesels versus SI λ 1 VVT with mild-hybrid.
- **Despite the market uncertainties, hybrids are needed as standards continue to challenge the industry and significant market segment changes require investments in new engine displacements.**
- **Hybrids fill the gap between what is needed and what can be achieved with engines, but lose share as engines continue to improve and standards stabilize**
- **Will regulators continue to permit the use of a technology that performs well in tests but only delivers those results to a portion of the buyers?**

Engines move to advanced technologies, enabled by exhaust gas treatment.

Conclusions

- **Spark Ignited Engines**
 - Move to DI
 - Downsized and boosted
 - Some tuned for flex fuel
- **Compression Ignition Engines**
 - Challenged by lifetime NOx and PM requirements
 - Evolve towards low-temperature combustion systems (PCCI, CAI & HCCI)
 - Reduced uncertainty with respect to exhaust gas treatment
- **Exhaust Gas Treatment**
 - Continued uncertainty for conventional combustion systems (Diesel, stratified DI gasoline) for low-temperature NOx reduction and PM control as standards get increasingly tighter
 - Low temperature oxidation catalysts for low temperature systems must evolve
- **Transmissions**
 - CVTs will not gain as much popularity as originally thought
 - Countershaft automatics progressing as expected

Policy makers must look for broader ranging solutions and address the implications

Conclusions

- **Policy makers will need to look beyond powertrain-, fuel- and vehicle-level solutions if minimum CO₂ objectives (90 g/km) are to be achieved cost effectively**
 - **Vehicles**
 - **Market trends towards heavier, larger, faster vehicles must be discouraged (by policy?) in the Constrained Scenario**
 - **Shift to smaller vehicles will require substantial new investments in smaller engines**
 - **Implications on OEM profitability and competitiveness need to be quantified and addressed**
 - **Non-vehicle-related solutions**
 - **Credits for benign CO₂ from renewable fuels**
 - **Lifestyle changes to reduce vehicle distance traveled per year**
- **The cost impact of new regulations is unevenly distributed between regions**
 - **NAFTA gets hit the hardest. Can the domestic OEMs afford it?**
 - **Increased dieselization of smaller cars may increase the challenge of selling them. Can fiscal policy offset negate the higher powertrain costs in these segments?**
 - **How will the shift to smaller vehicles impact the profitability of the OEMs?**

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Thank you for your attention

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