Technology for Fuel Efficiency in Developing Countries

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Developing Country Markets

- North America and EU markets are focused on high cost technology for improving FE.
- In contrast, fuel economy in major developing nations is already very good, and exceeds US 2020 targets now in India and Mexico, and almost equals it in China for example.
- Major factor is the small size and low power of the cars in developing countries, but car retail price is also quite low.
- Technology differences for the same vehicle size are rapidly becoming similar globally due to the dominance of 14 global maufacturers.

Regional Differences

	North America	Europe	India
2007 FE (L/100km)	~9.5	~6.7	~6.5
Engine size	3L to 4L	1.5 to 2.5L	<1.5L
Diesel Penetration	<0.2%	~48%	~20%
Manual Transmission	<5%	~80%	~70%
Average price	$27K	Euro 24K	$8K

Regional Preferences

- Income, taxes, fuel price, geography and infrastructure determine attribute valuations in different regions of the world
- US market has high valuation of comfort, size and convenience, with high income and relatively low vehicle and fuel price.
- European market has high valuation of performance, and diesel engine market is helped by reduced diesel fuel tax.
- Many developing country markets have high valuation of vehicle and fuel cost due to relatively low income, but many also feature a large diesel fuel subsidy.

Improving Vehicle Fuel Economy

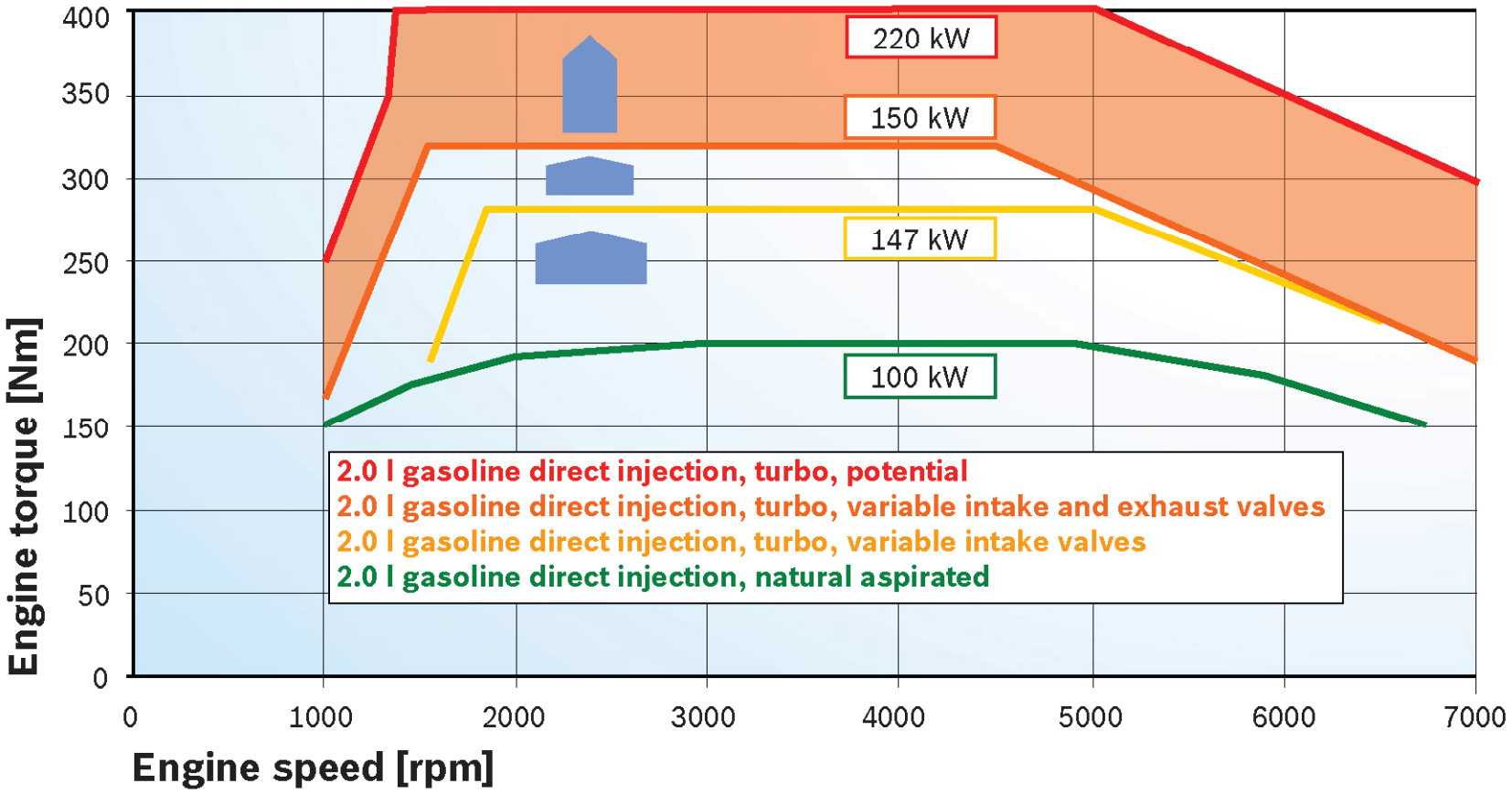
- Methods to improve vehicle fuel economy are well understood from knowledge of energy loss.
- Same methods applicable to all regions
- General methods are
  - improve engine peak efficiency potential
  - reduce losses at light load from throttling
  - reduce weight, drag and rolling resistance
  - reduce accessory load and eliminate idle

Short Term Engine Technologies

- Technologies in the pipeline in the USA and Europe now
  - Variable Valve Lift (2-step/continuous)
  - Gasoline Direct Injection with CR increased by ~2 points (lean burn longer term for US, used in Europe)
  - Cylinder cutout (V6/8 only)
  - Turbo- GDI- VVT combination
  - Reduced Engine Friction

More Torque

by Means of Direct Injection, Cam Phasing and Turbo Charging



BOSCH

Turbo-GDI in Developing Country Context

- In the US and EU, significant engine downsizing is possible and base engine cost reduction can pay for turbo and GDI add on.
- Small engine sizes in developing countries make downsizing difficult without significant turbo and engine efficiency loss.
- Low driving speeds makes turbo benefit very small, and fuel quality issues may limit compression ratio
- Hence, most significant solution for US/EU is not useful for a majority of vehicles in developing countries.

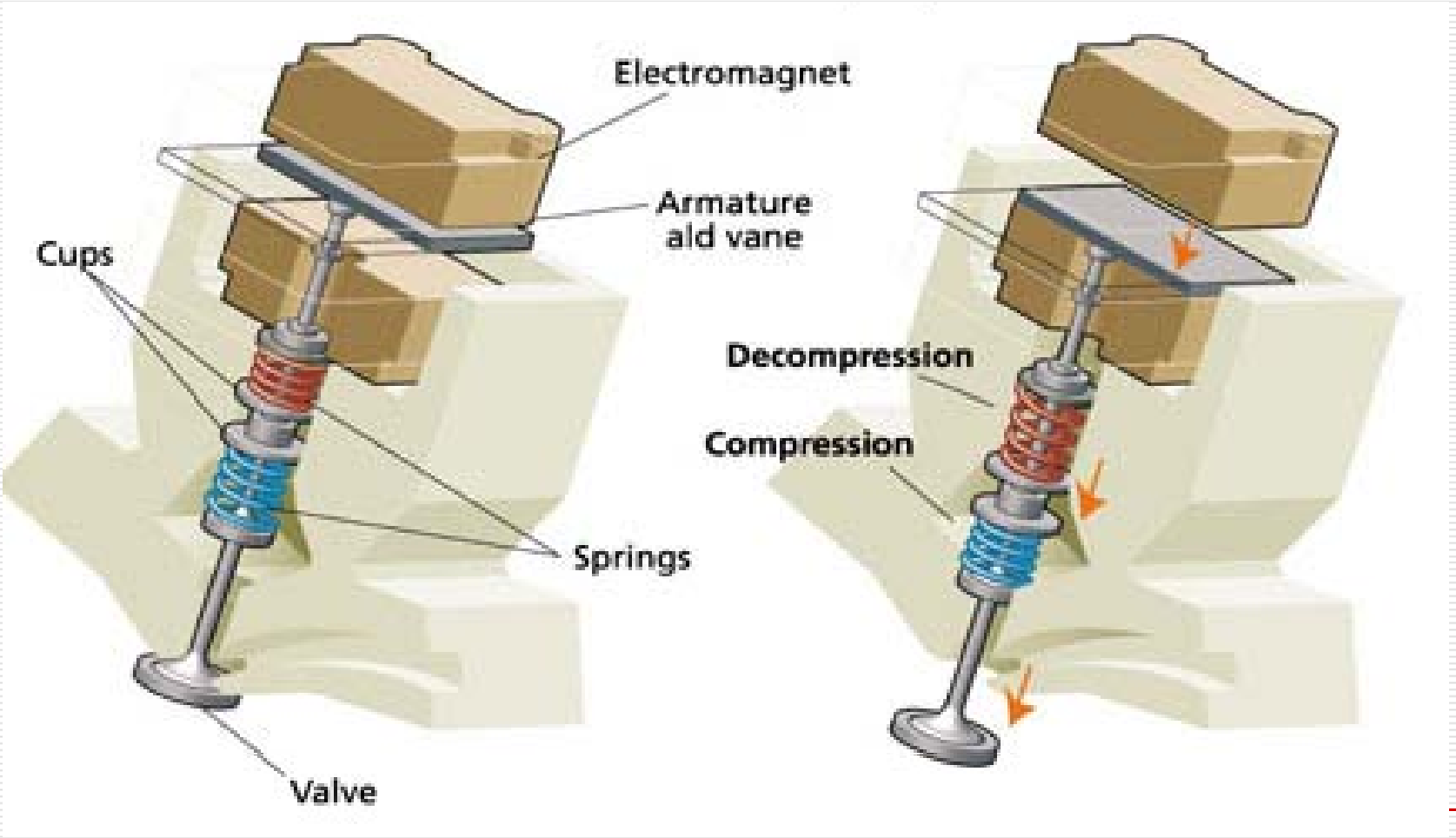
Mid-term Engine Technology

- Most promising development is cam-less valve actuation which offers potential to reduce throttling loss to near zero, and make Atkinson cycle possible at light load.
- Cam-less engine can be key enabler for gasoline HCCI in longer term
- “Half cam-less” engine may enter production by 2015 in luxury cars with about 15%+ FE improvement at a cost of $500 to 800.

2025 Engine Technology Potential

“Half cam-less” engine	15 – 16%	$400 to 600
Full cam-less HCCI with GDI	19 – 22%	$1000 to 1500
Advanced friction reduction	4 to 6 %	~$100
GDI lean burn	17 to 19 %	$1000 to 1500
Combination with turbo	~ 25% ?	~ $1500

Valeo Electromagnetic Camless Valve Actuation Schematic



Next Generation Technology in Developing Country Context

- Significant portion of benefit from Camless and HCCI technology is pumping loss reduction.
- Due to low power-to-weight ratio in developing countries, pumping loss is low and technology benefits are smaller.
- Next generation technology is also more expensive, but price increase is only 3 to 4% in US and EU context.
- In contrast, price increase from next generation technology in developing countries is 10 to 15% which is risky in a very price sensitive market.

Transmission Technology

- Automatic Transmissions are growing even in Europe and Developing countries
- Most future transmission improvements are aimed at automatics as manual transmissions are quite efficient already.
- Double clutch automated manual (AMT) with 6 to 8 speeds can be a very efficient solution for automatics, but is not better than manual.
- Hence transmission improvements like AMT can prevent ‘backsliding’ as consumers prefer automatics but is NOT an improvement over current manual transmission technology.

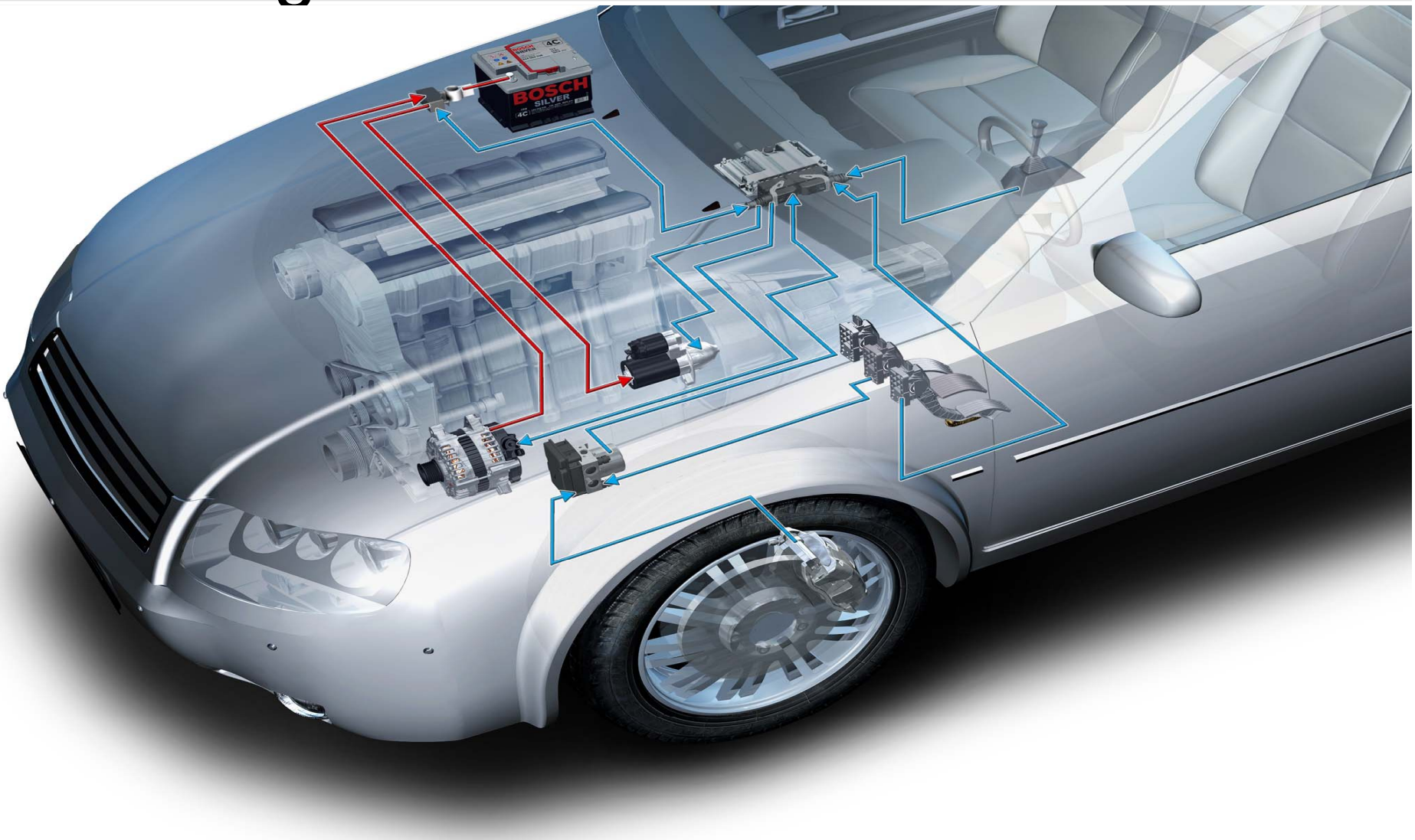
Reducing Vehicle Energy Demand

- While up to 20 to 25% weight reduction is technically possible, only 5 to 10% may be practical at reasonable cost ~ $60 per percent
- Drag and rolling resistance reductions of 10 to 20% can be achieved by 2020. However, drag reduction has limited benefits at developing country speeds.
- Driving the accessories electrically on demand is more efficient than continuous belt drive. Electric Power Steering and Water Pump are the most effective.

Idle Stop- Start

- New “intelligent” starter motor design pre engages engine when stopped, resulting in faster, quieter start, even with 14V system.
- Electrical system must be upgraded with additional battery to withstand start cycles.
- Air conditioning is a major issue and solutions such as coolant storage or electric compressors are available but still expensive.
- System is more complex with automatic trans.
- Electrical upgrades will facilitate electric accessories such as power steering and water pump, with additional FE benefit.

Intelligent Starter



Summary of Gasoline Technology Potential for Developing Countries

- Overall, the sum of all conventional technologies can lead to a 32 $\pm$ 3% FE increase by 2020 and possibly, up to 50 $\pm$ 5 % FE increase by 2030 in the US .
- Potential is much less developing countries and only about half the benefits can be realized in a cost effective manner.
- Idle stop can be very effective in developing countries but needs a lot of auxiliary changes.
- Of course, consumer preference changes for larger vehicles in developing countries to 2020/30 will further hurt these values.

Hybrids

- Larger gains in FE will require ICE combination with electric drive (or other types?).
- A large number of “hybrid” designs have been unveiled, each with unique attributes.
- Four types that will be in the US market and span the range of designs
  - Belt drive Alternator Starter (BAS)
  - Crankshaft mounted single motor (IMA)
  - Dual Motor “full” hybrids (Prius/Escape)
  - Plug-in hybrid vehicles.

Hybrids in Developing Countries?

- 14Volt BAS systems can be cheap but it will provide limited FC reduction, ~ 10%, not much better than a stop-start system
- The Toyota system can be very efficient with FC reduction approaching 45% but has the disadvantages of high price, ~US$5000-7000
- One- motor systems of the Honda IMA type could be more cost effective than other types while offering significant FC reduction, ~30%
- One motor type hybrids may be possible in developing countries but further cost reduction is required

Plug-in Hybrids

- Definition of PHEV varies on vehicle capability in all-electric mode. Type, range in (semi) EV mode and battery cost issues define PHEV.
- However, consumer acceptance and likely level of electricity use issues are probably more important than technical issues.
- At present, difficult to make any economic case for purchase even with off-peak electricity. Many developing countries have serious electricity shortages.
- GHG emissions benefits largely a function of electric generation GHG, but benefit is currently small in many developing countries.

Electric Vehicles

- Li-Ion Battery technology has now advanced to the point where 200+km range is possible, but cost is still high.
- EV costs in US and EU are being driven by idea that they should replace rather complement typical cars and offer all their attributes.
- City car type EV designs can be cheap and very efficient, and can serve urban commuters or be a rental vehicle in developing countries.
- EV may be a more optimal solution for some developing countries than PHEV, but not if coal fired plants generate electricity.

Diesel Issues

- Unlike a hybrid, the diesel's fuel efficiency benefit is more robust across all driving conditions and under load.
- Fuel efficiency benefit relative to gasoline will narrow, but GHG benefit will disappear due to higher carbon content of fuel.
- Terrific low-end torque makes it well suited to cargo hauling and towing .
- Diesel fuel subsidy in EU and some developing countries creates incorrect incentives for light vehicle dieselization. Some studies show diesels in EU have double the VMT of gasoline!

Summary

- Vehicles in developing countries are already quite fuel efficient due to the small average vehicle size and low power engines.
- Due to the high FE baseline and market price sensitivity, FE improvements to conventional gasoline vehicles are limited to 12-15% by 2018 and 20 – 24% by 2030
- Stop-start can be a very good solution but requires development of auxiliary systems.
- Diesel may not be a good solution long term, if fuel is subsidized for commercial use.

Summary (continued)

- There is still much uncertainty about the cost effectiveness and GHG benefit from a plug-in hybrid or an EV that has all the functionality of current gasoline/ diesel vehicles.
- Limited range and function ‘city EV’ may be good solutions if electricity is available and derived from low carbon sources
- While technology development is global, technology solutions should be greatly influenced by local conditions.