Automotive Technology for Better Fuel Efficiency

K.G. Duleep
Managing Director, EEA-ICF
2008 Symposium, FIA Foundation

Global or Regional Approach?

- Technology to reach very high levels of fuel economy have been proven in prototypes
- However, prototypes do not account for tradeoff by consumers in cost, size, performance, comfort
- Each global area seems to have different requirements and valuations of attributes
- Technology can be global but application will likely be local and varied.
- Will global markets eventually converge?

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	$7K

Regional Preferences

- Income, taxes, fuel price, geography and infrastructure determine attribute valuations in different regions
- 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.
- Indian market has high valuation of vehicle and fuel cost due to relatively low income, and also features a large diesel fuel subsidy.

Improving Vehicle Fuel Economy

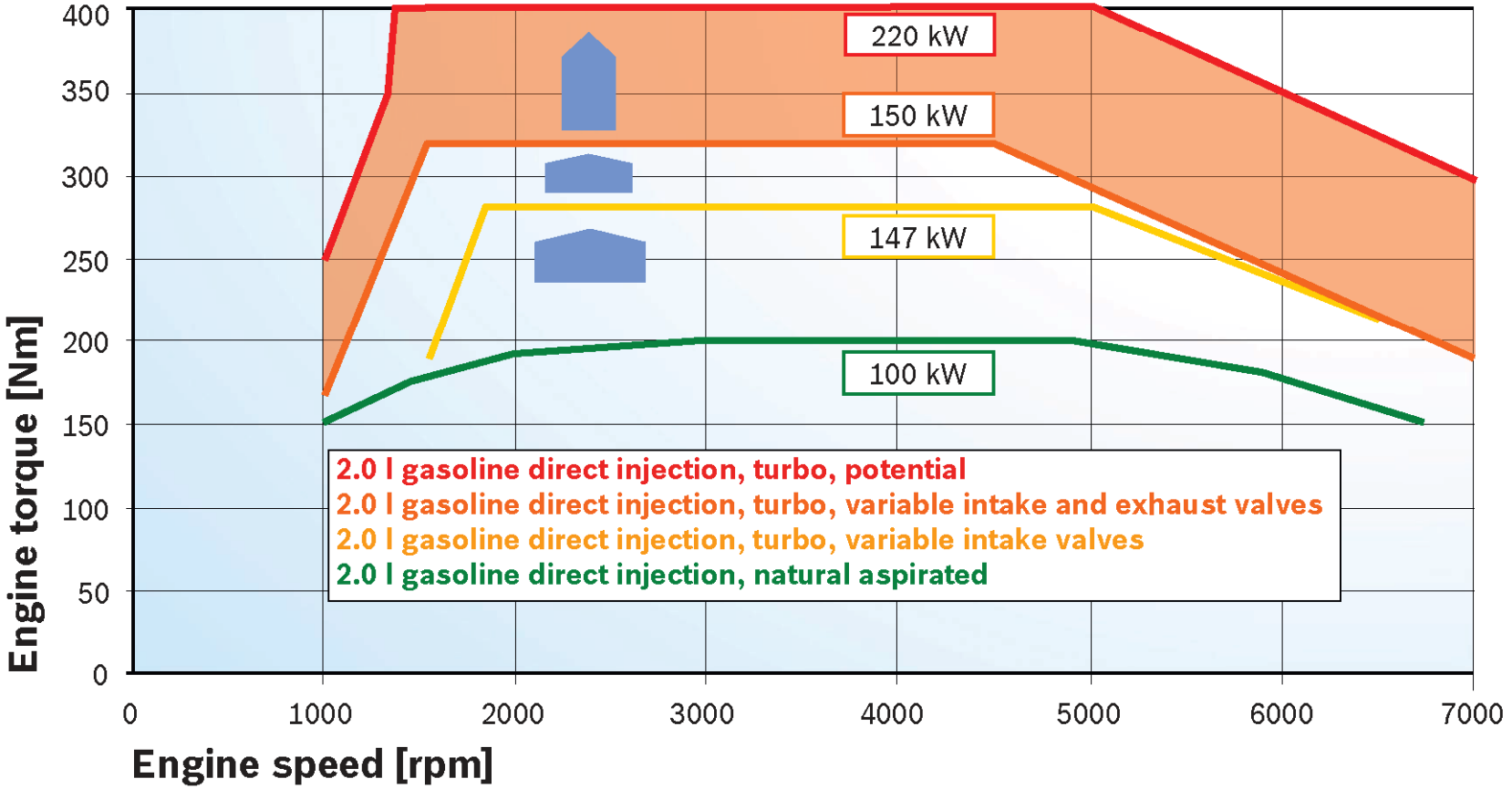
- Methods to improve vehicle fuel economy are well understood from knowledge of energy loss.
- Same methods applicable to all regions
- General methods are
  - improve engine peak efficiency potential
  - reduce losses at light load from throttling
  - reduce weight, drag and rolling resistance
  - reduce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

2015 Engine Technology Potential

2 –step valve lift		4 to 5%	$125 -175
Continuous valve lift		7 to 8%	$300 -400
Gasoline Direct Injection (GDI)		3 to 4%	$160 – 250
Turbo – GDI		13 to 15%	$ 0 to 650
Friction Reduction		2 to 4%	$30 to 70

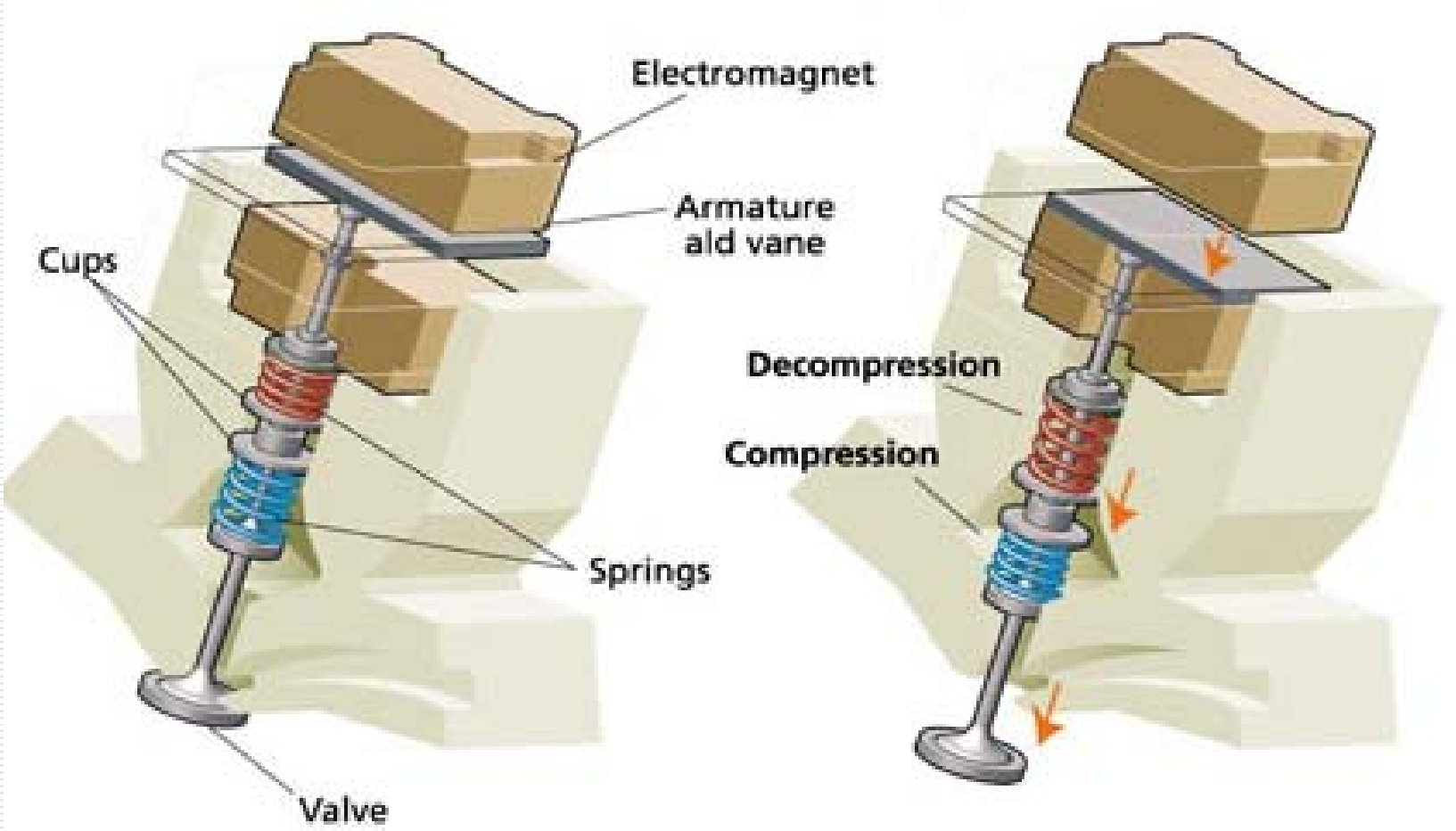
Mid-term Engine Technology

- 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 will be key enabler for gasoline HCCI in longer term
- “Half cam-less” engine will enter production in 2010/2011 in luxury cars with about 15%+ FE improvement at a cost of $400 to 600.

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



Transmission Technology

- Automatic Transmissions are growing even in Europe and India
- Future transmission options seem to be shaping up as follows:

  - Six/Seven speed automatics for RWD and larger FWD cars

  - CVT for smaller FWD cars and small uni-body trucks

  - AMT (6-/ 7-speed) for sporty cars.

Transmission Technology Benefits

Six speed automatic	4 to 5 %	$100 to 150
CVT (small cars)	6 to 8 %	$150 to 200
AMT (sports cars)	7 to 8 %	$150 to 200
Torque converter elimination	3 to 4 %	~ 0

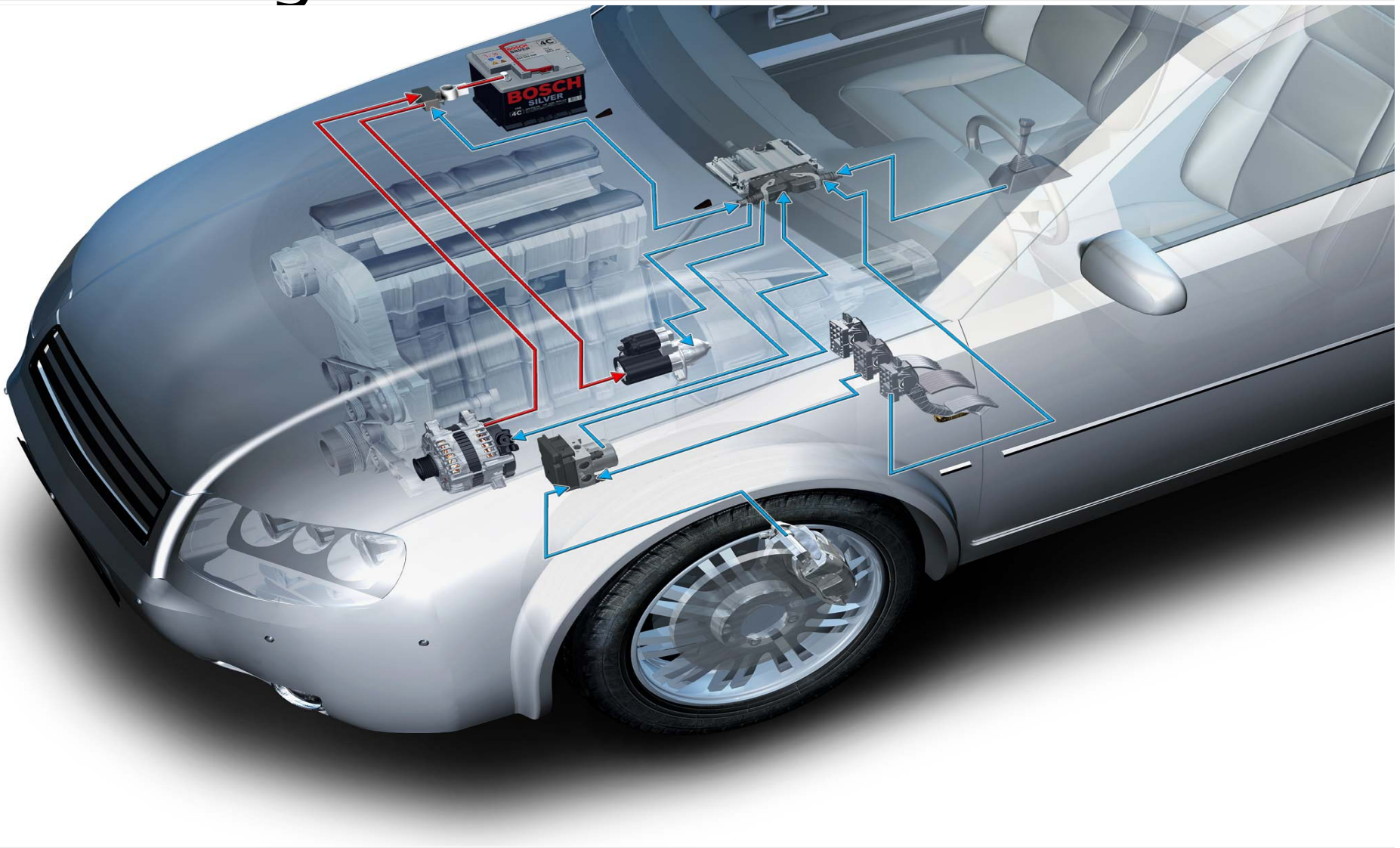
Reducing Vehicle Energy Demand

- Weight reduction is possible but quite expensive. While up to 20% 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.
- 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.
- System will also require electrical AC drive and transmission pump + “hill holder” for automatic transmissions.
- Electrical upgrades will facilitate electric accessories such as power steering and water pump, with additional FE benefit.

Intelligent Starter



Maximum Potential of Conventional Technology (FE Increase)

	2006 – 2015	2016 – 2025
Engine & Transmission	15 – 19 %	22 – 28 %
Weight, drag and tire loss reduction	7– 11 %	11 – 16 %
Accessories	2 – 3 %	3 – 5 %
Idle Stop	3 – 4 %	2 - 3 %

Summary of Gasoline Technology Potential

- 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 for gasoline engines.
- Potential is much less in Europe and India due to 1) smaller engines 2) high dieselization and 3) high manual trans penetration.
- Of course, consumer preference changes to 2020/30 can help or 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.

Common Attributes of Hybrids

- Hybrids must fully exploit all synergies with drive train and accessories to provide large improvements in fuel economy.
- Hybrids provide large fuel economy gains only in stop-and go driving.
- Benefits deteriorate in very hot/cold weather due to space conditioning needs.
- Hybrids not suited for cargo hauling or high continuous load operation.
- Different geographies and densities provide different opportunities for different designs.

Typical Operating Modes

	BAS	ISAD/IMA	FULL
Start-stop at idle	Yes	Yes	Yes
Launch Assist	Some	Yes	Yes
Regen. Braking	Some or none	Limited	Yes
Electric Operation	Creep	Yes	Yes

Hybrid System Benefits

- BAS systems using existing 14V electrical system can be cheap but it will provide limited FC reduction, ~ 15%
- 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%
- Suitability of hybrid and type for specific regions needs understanding of driving conditions.

Plug-in Hybrids

- Definition of PHEV varies on vehicle capability in all-electric mode.
- Type, range in (semi) EV mode and battery cost issues dominate technical debate.
- 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.
- GHG emissions benefits largely a function of electric generation GHG, but benefit is currently small in the US.

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 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 inexpensive and very efficient, and can serve urban commuters or be a rental vehicle.
- However, ideal applications mirror those situations well served by mass transit. Hence, City EVs may have unintended consequences in developed countries!

Diesel Issues

- Unlike a hybrid, the diesel's fuel efficiency benefit is more robust across all driving conditions and under load.
- Cost and benefit on cycle comparable to IMA hybrid, but GHG benefit is lower 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!

Diesel Costs and Benefits

- Current diesel engines add $1500 (4 cyl.) to 3000 (V-8) for the engine alone and another $700 to $1200 for emissions after-treatment at US Bin 5 and EU6 levels.
- FE can be increased by 40 to 45% in combination with other changes relative to today's gasoline vehicle.
- Significant additional improvement is possible with a diesel- hybrid combination, with cost reduction in emission control.
- However, FE gap between diesel and gasoline for light vehicles will be reduced by 2020.

Summary

- Conventional technology improvements for gasoline vehicles continue to be far more cost-effective than alternatives.
- Improvements of up to 50% in FE (33% in FC) can be achieved by 2030 in the US but much less improvement is available in EU or developing countries.
- Hybrids are one element of a strategy but are NOT suitable for everybody.
- Different levels of hybridization are suitable for different vehicle sizes and markets.

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.
- Diesels can be a good answer for certain vehicle types, and provide good fuel economy but may have very small GHG benefit in the future (>2020).
- While technology development is global, technology solutions will be greatly influenced by local conditions.