US Heavy Duty Fleets - Fuel Economy

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Anthony Greszler
Vice President
Advanced Engineering

VOLVO POWERTRAIN CORPORATION

Drivers for FE in HD Diesel

- Pending oil shortage
- Rapid oil price increases
- CO_2 impact – Global Warming
  - Less fossil fuel burned = Less CO_2
- Key competitive feature

Fuel economy has always been a critical factor in diesel engine and truck marketing!

US '07 EMISSIONS TECHNOLOGY

- Primary selection criteria
  - ✓ Meet emissions limits
  - ✓ Reliability is most important for customers
  - ✓ Lowest operating cost
    - ➢ **Fuel economy**, maintenance, etc.
  - ✓ Durability
  - ✓ Performance
- Conclusion: stay with the simplest, most proven technology that can meet US'07 requirements.

Slide taken from presentation on US07 engine technology.

Note: fuel economy is a key criterion.

Typical lifetime cost of fuel is 2-4X cost of a new truck.

Fuel Consumption Drivers

Engine

Daily Customer variables

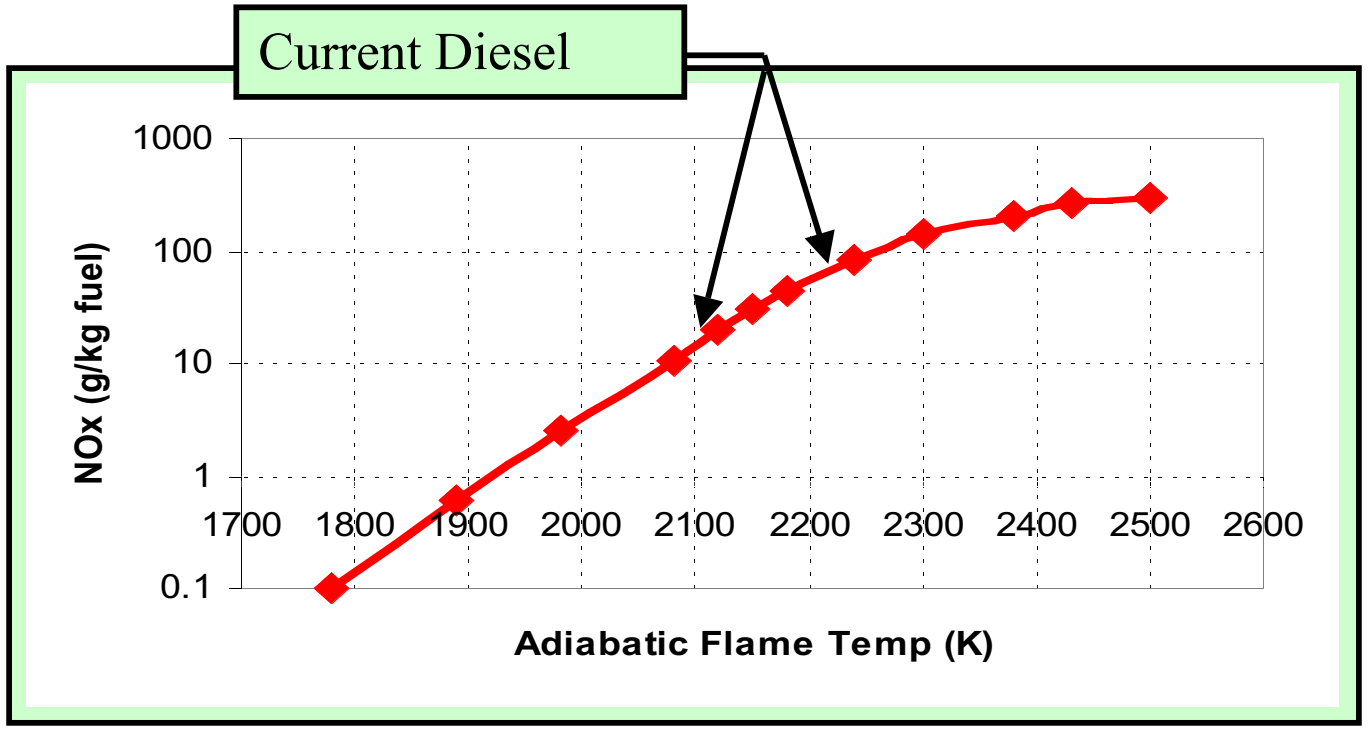
- Fuel quality
- Drive line friction
- Air resistance
- Auxiliaries
- ***Rolling resistance***
- ***Idle time***
- ***Driving habits***
- ***Speed***
- ***GCW***
- ***Road type***
- ***Weather***
- *others*

Diesel Cycle Fuel Efficiency

- Contrary to popular belief, almost all fuel is fully combusted-only around .2% exhausted as soot or unburnt HC.
- Optimization goal: inject/burn fuel to release heat and pressure at optimum time- essentially TDC.
- Key limits on efficiency
  - Injection rate and shape
  - Combustion rate
  - Peak cylinder pressure limits
  - Turbocharger efficiency
  - NOx reduction has been most critical since 1991 (estimated impact 17-20% efficiency loss vs. potential)

Low NOx Combustion Strategies

- **In general, combustion strategies that lower the peak combustion temperatures are effective in reducing NOx emissions**
- **Until 2002, this was accomplished primarily by delayed timing, which reduces combustion efficiency.**
- **In 2002, most US engines began using EGR, which also has negative efficiency impact.**



Cooled EGR Impact on FE

US07 Selected Technology

Requires higher pressure in exhaust system than intake to drive exhaust gas. (Gas pumping losses)

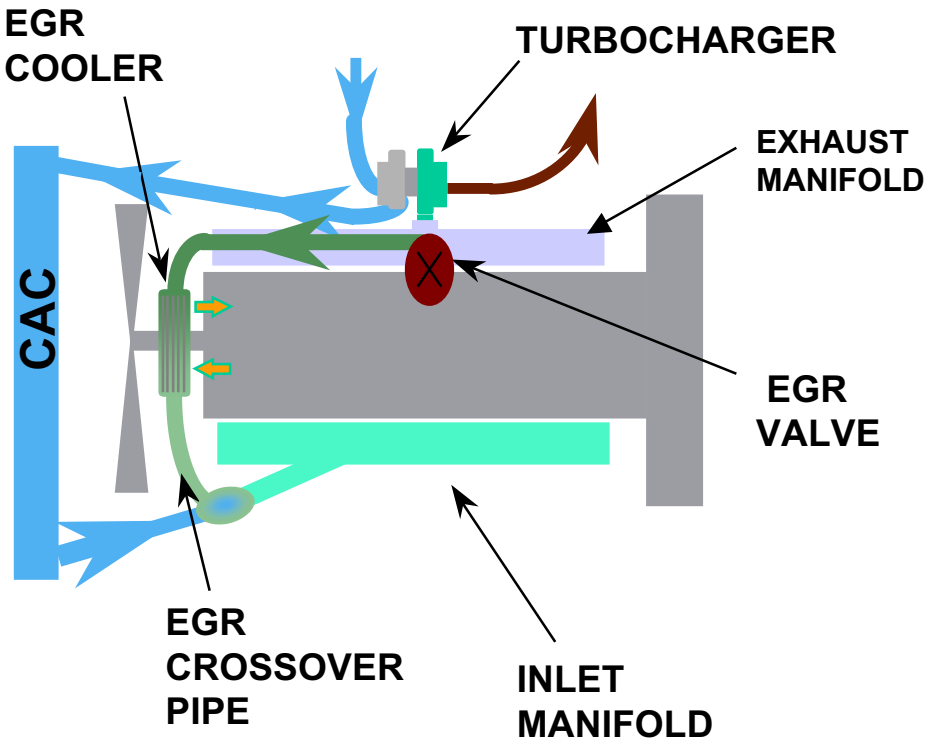
Pumping loss incurred due to EGR flow requirement.

Peak cylinder pressure increases due to EGR.

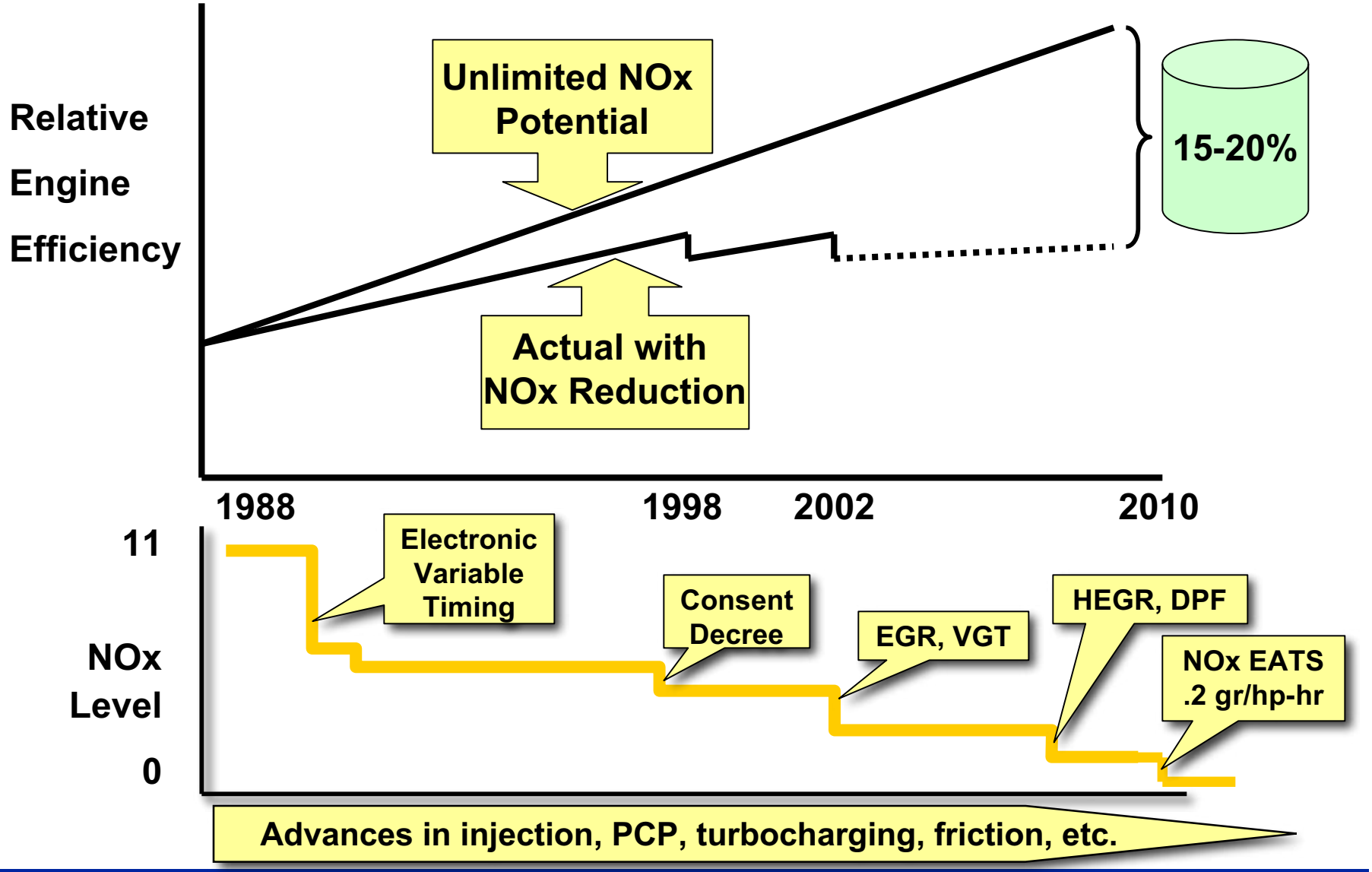
More work required in turbo-machinery (higher boost).

Higher heat rejection means bigger fans with more on time and drives more truck frontal area (negative aerodynamics effect).

EGR routed from Exhaust Manifold to intake manifold.



US NOx Reduction Impact on FE



Engine Design Improvements

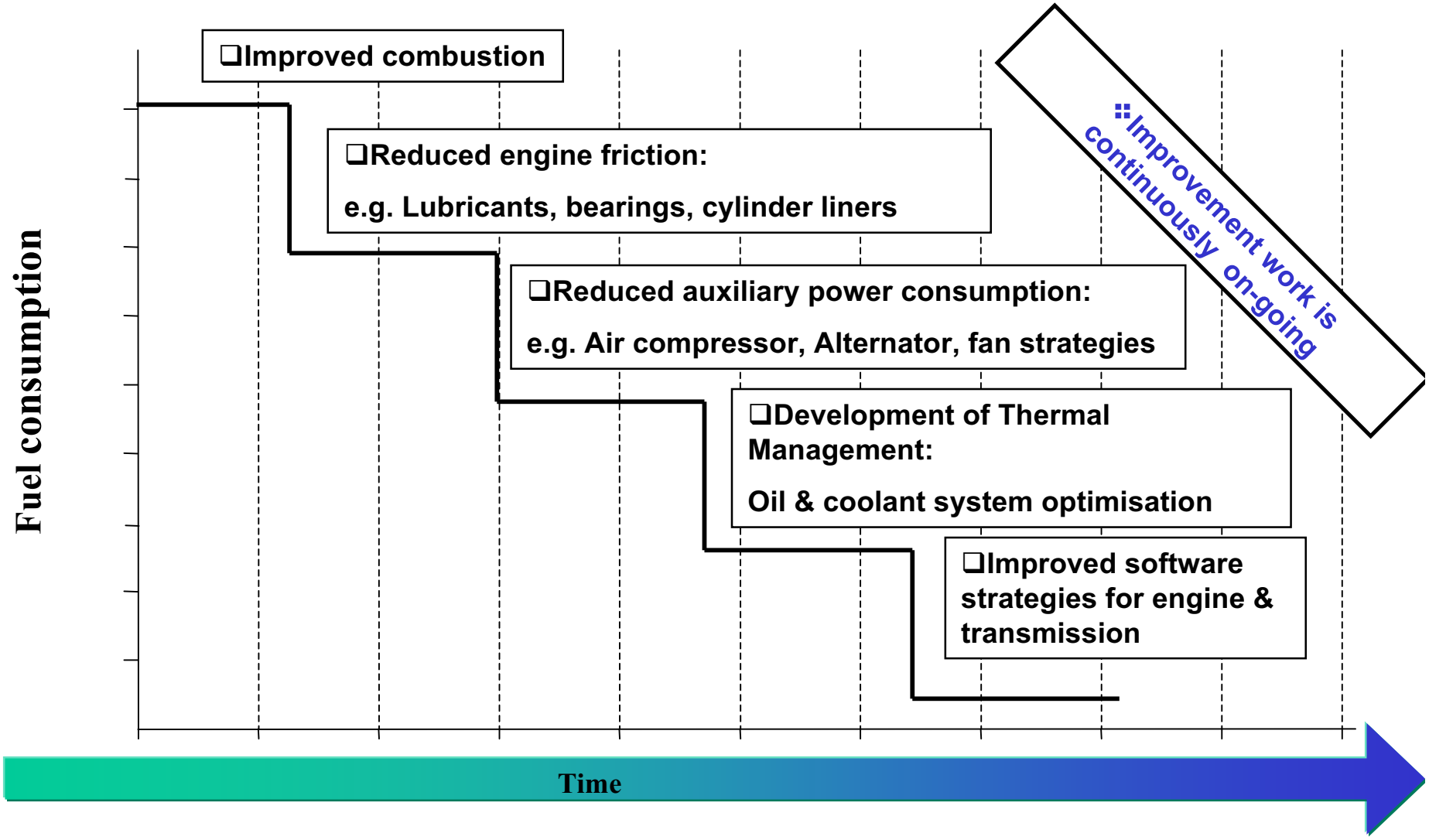
- Diesel cycle efficiency can be improved with high compression ratio and higher cylinder pressure.
  - Requires stronger major components to survive higher loads
  - Internal temperatures also increase
  - Very high boost pressure requires complex and expensive turbos
  - Needed improvements in turbo efficiency are beyond current manufacturing capability.
- Variable Valve Actuation
  - Emissions control
  - Cylinder cut-out for light load
- Continued improvement in fuel injection

Recent improvement in these areas have been used to improve emissions and offset related efficiency losses.

Engine Design Improvements

- Further reduction in parasitic losses can yield 2-3%.
  - Electronic thermostat (coolant and oil)
  - Modulating coolant pump
  - Modulating oil pump
  - Better fan control
  - Air compressor (electric or clutch)
  - Electric Fuel Pump

Improve fuel efficiency on current products



Engine Design Improvements

- Turbo-compounding
  - Use secondary power turbine in exhaust to extract energy and feed back power
  - Could also generate electricity using power turbine
  - Can allow lower speed engine operation (low speed torque)
  - Complex and expensive hardware and control required

Emissions Control

- Urea SCR (Selective Catalytic Reduction)
  - Effectiveness of over 90% possible within some operation zones
  - Allows engine to run at higher cycle efficiency with higher NOx, which is reacted in the catalyst. Probably allow break even on fuel efficiency for 2010.
  - However, requires use of urea (urea tank, urea injection system, controls, catalyst, etc.)
  - Future improvement in catalytic NOx conversion may free up diesel engineers to improve fuel efficiency

Heavy Truck Improvements

- Aerodynamics (largely available)
- Reduced trailer gap (largely applied)
- Tires -low resistance, super singles (available but not in high use)
- Transmission technologies – forcing use of top gear, managing poor driver habits
- Driver Features
  - Sweet spot indicator
  - Soft cruise
- Idling Reduction
  - APU
  - Truck stop electrification/climate systems
  - Fuel cell

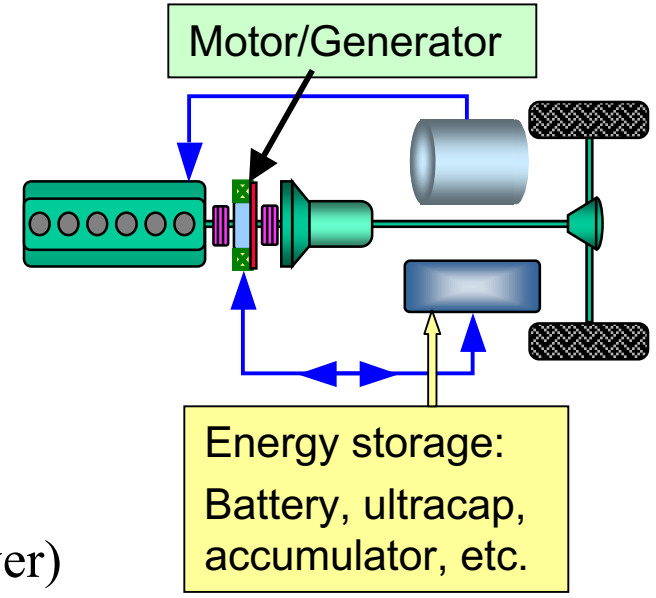
Potential Government Activity

- Higher loads
  - Trailer size
  - Multiple trailers
  - Load limits (GCW)
- Reduce traffic congestion
- Road Speeds

Vehicle Electrification/Hybrid

Hybrid for Stop/Go Duty Cycle:

- Improved Fuel Economy (up to 50%)
- Improved Performance
  - Launch assist
- Reduced Emissions (per Ton-mile)
- Reduced transients and Idle operations
- Recovery/recycling of braking energy
- Quieter Operation
- Eliminates need for APU (uses battery power)



Electric Auxiliaries for Long Haul

- Modulate pumping, fans, air compressor, air conditioning, power steering to match requirements
- Improved fuel economy
- Improved cooling
- Facilitate reduced idling
- 3-5% Fuel Economy improvement potential

Conclusions

- Customer focus on fuel economy is extremely high, forcing FE as key competitive feature.
- Improvements are possible by better application of existing technologies.
  - Customer acceptance?
- Steady improvement in engines has been largely offset by NOx emissions requirements.
- Big gains possible by use of hybrid technology on urban vehicles (highly cyclical duty cycle).
- Biggest potential for highway application would be a breakthrough in NOx exhaust after-treatment.