# European Diesel Engine Technology: An Overview

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**AVL Powertrain Engineering, Inc.**

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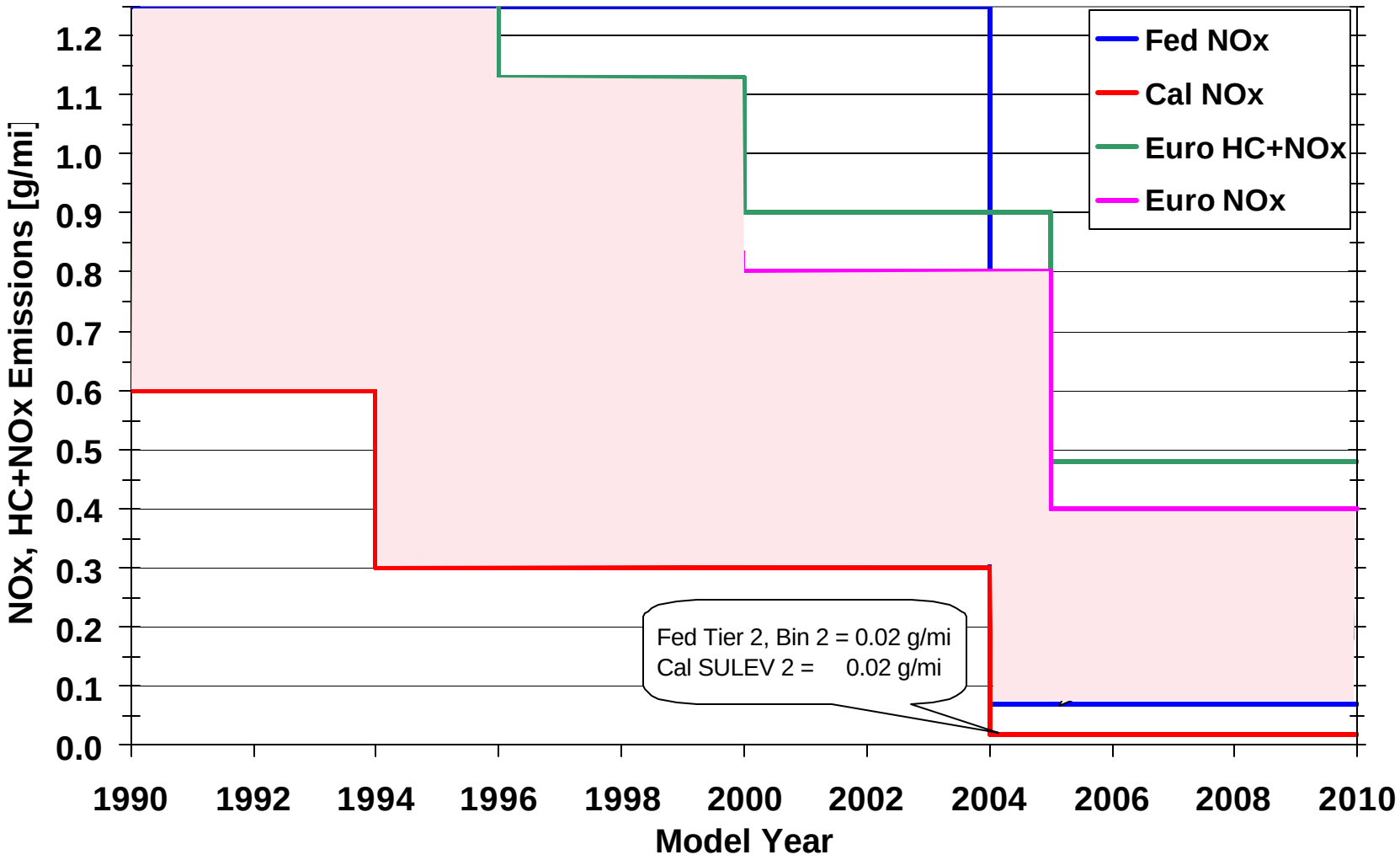
- Market Factors
  - Legislation
  - Customer Requirements
  - Europe vs. US
- Current Trends
- Future Technologies
- Summary

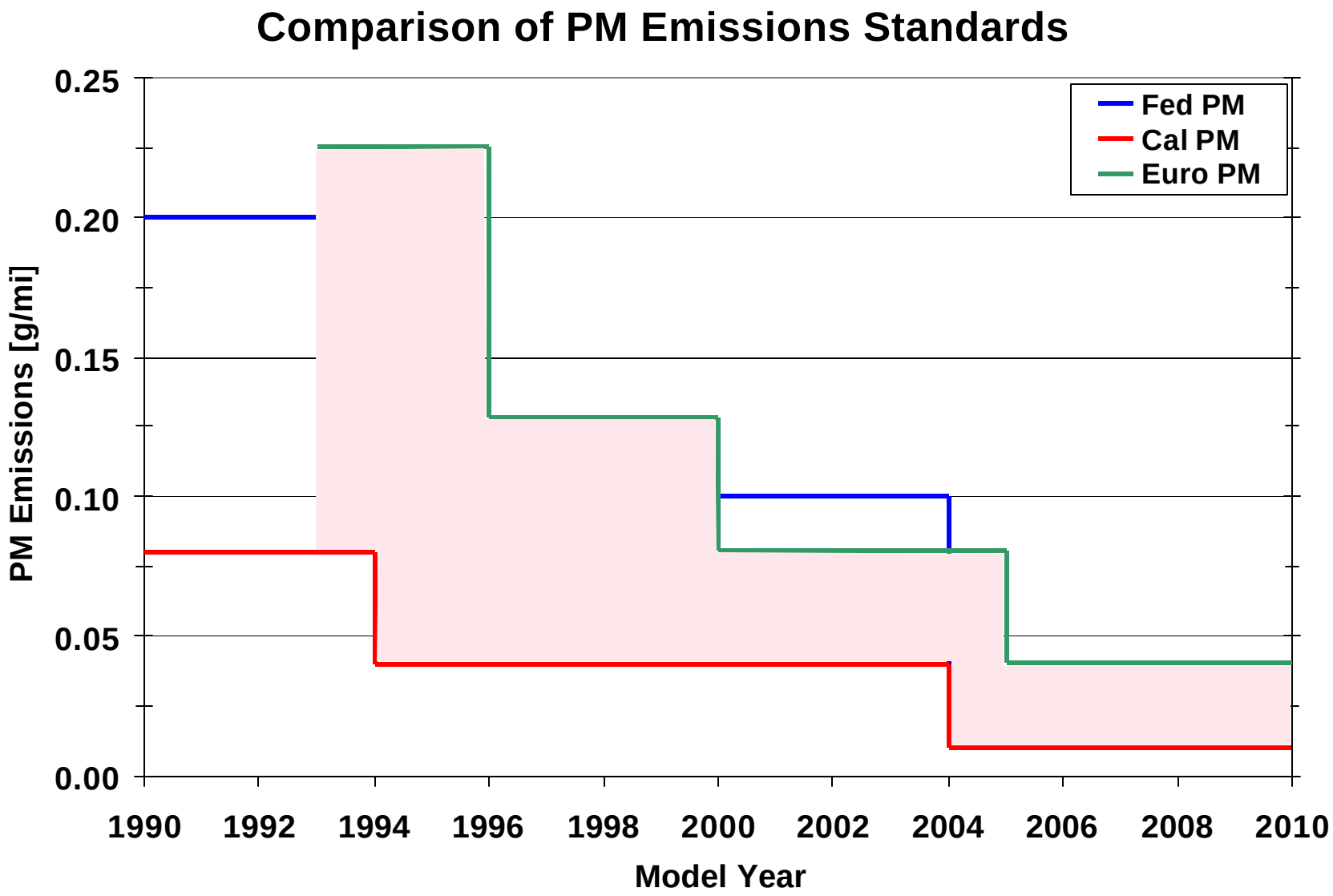
# Legislation

- Emissions
- $CO_2$

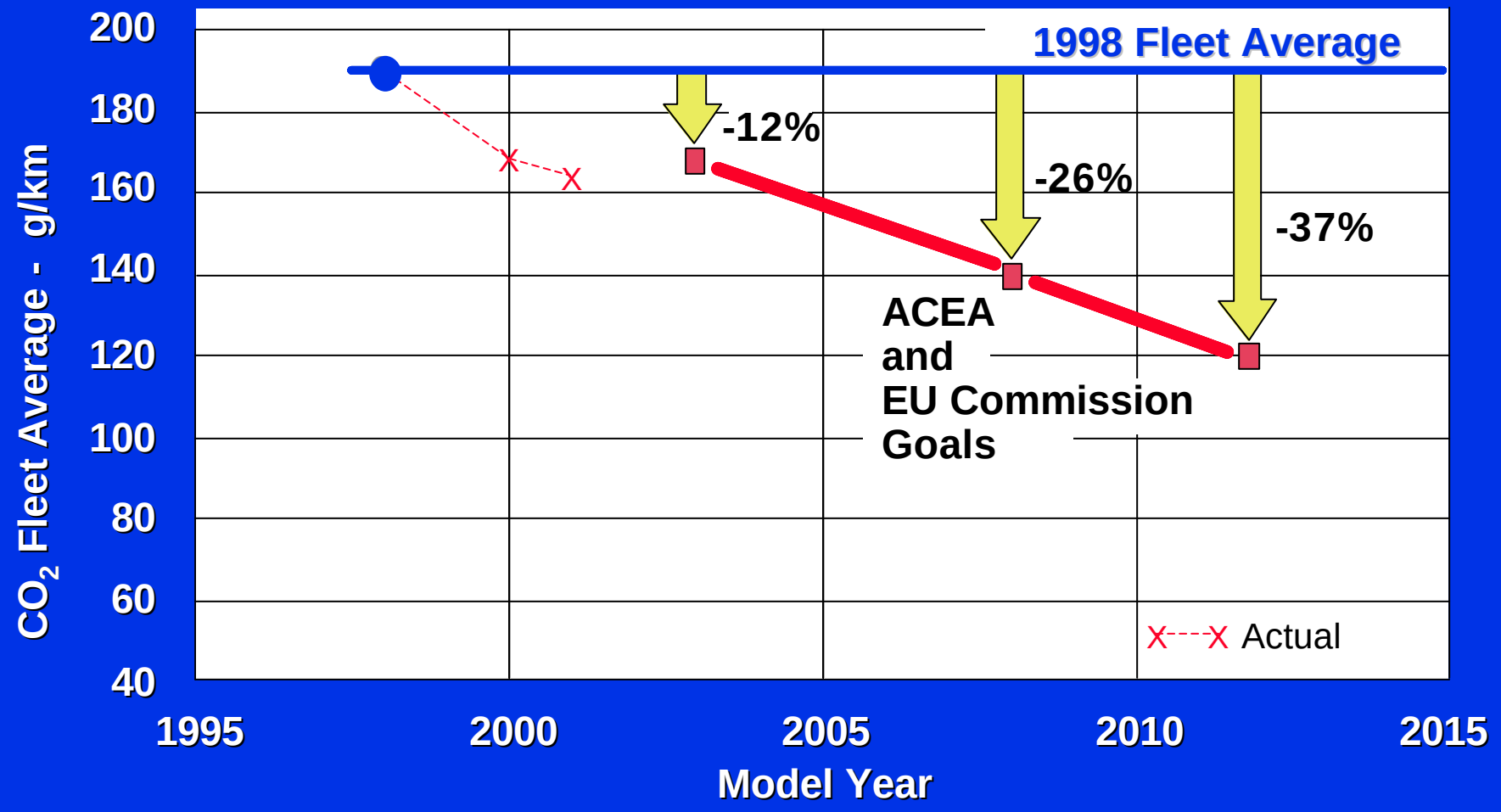
# Emissions - $NO_x$



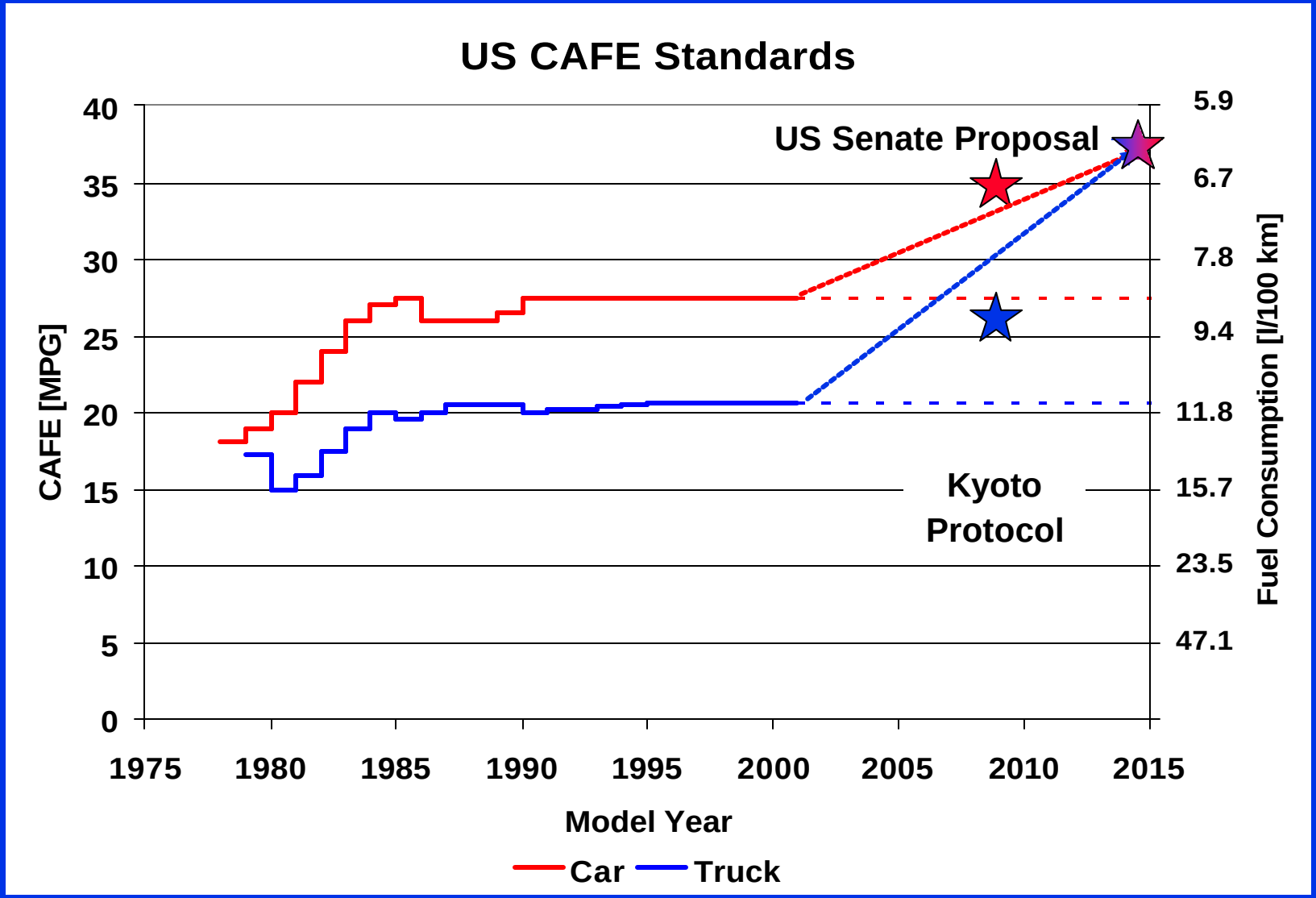
# Emissions - Particulates



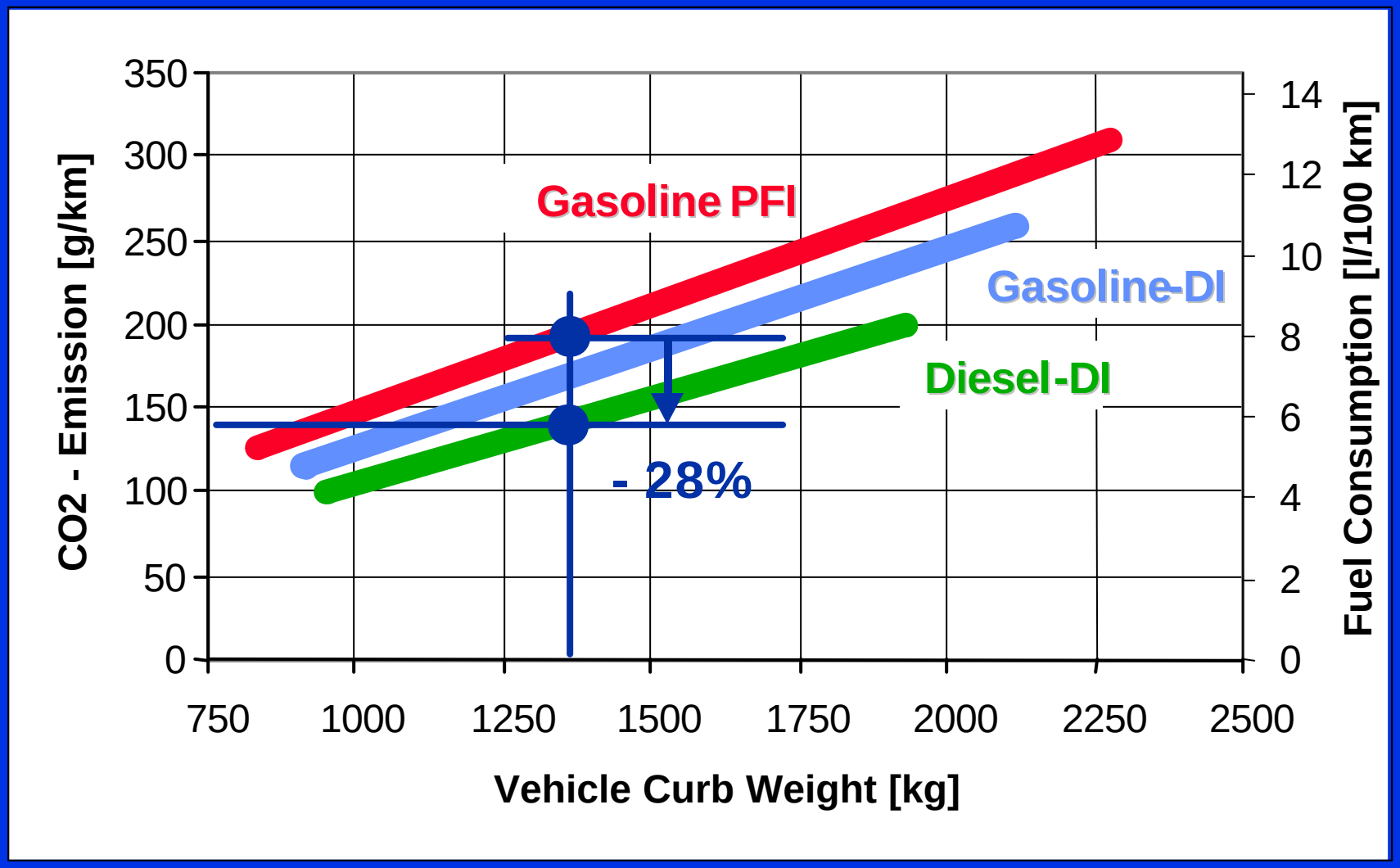
# $CO_2$ Emissions - European Fleet Average and Required Reductions



# US Fleet Fuel Economy



# $CO_2$ Emissions Potential - Diesel vs. Gasoline Engines

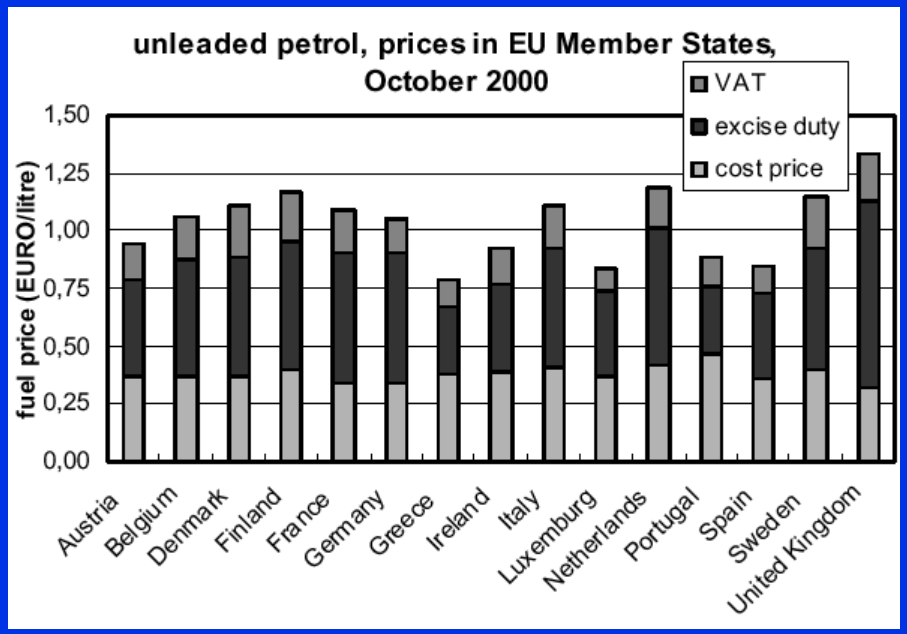


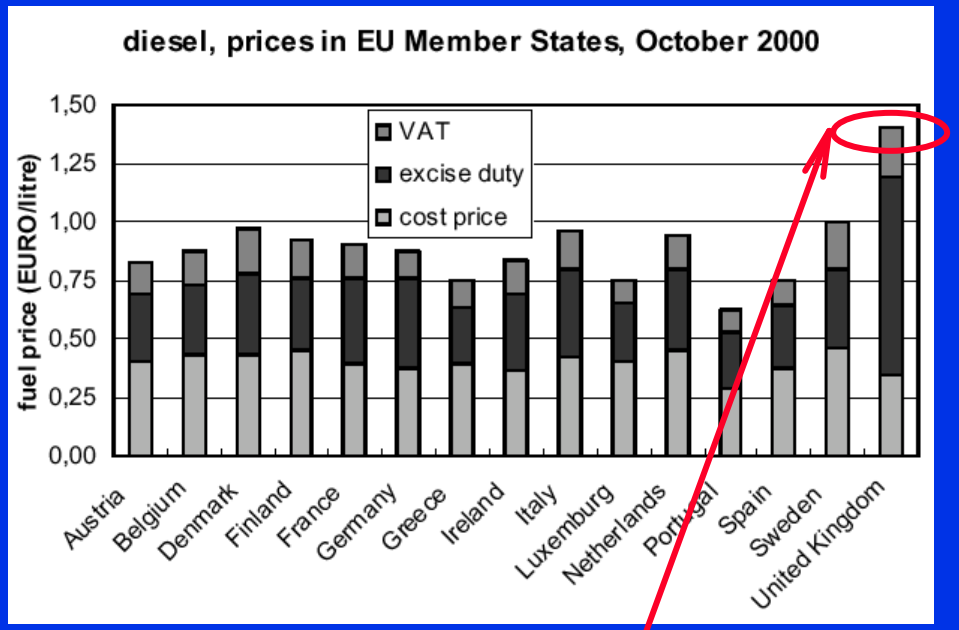

Source: Kraftfahr-Bundesamt (KBA), 7/1999

# Customer Requirements

- Costs
  - Fuel Costs
  - Initial Purchase vs. Operating Costs
- Performance

# European Fuel Prices

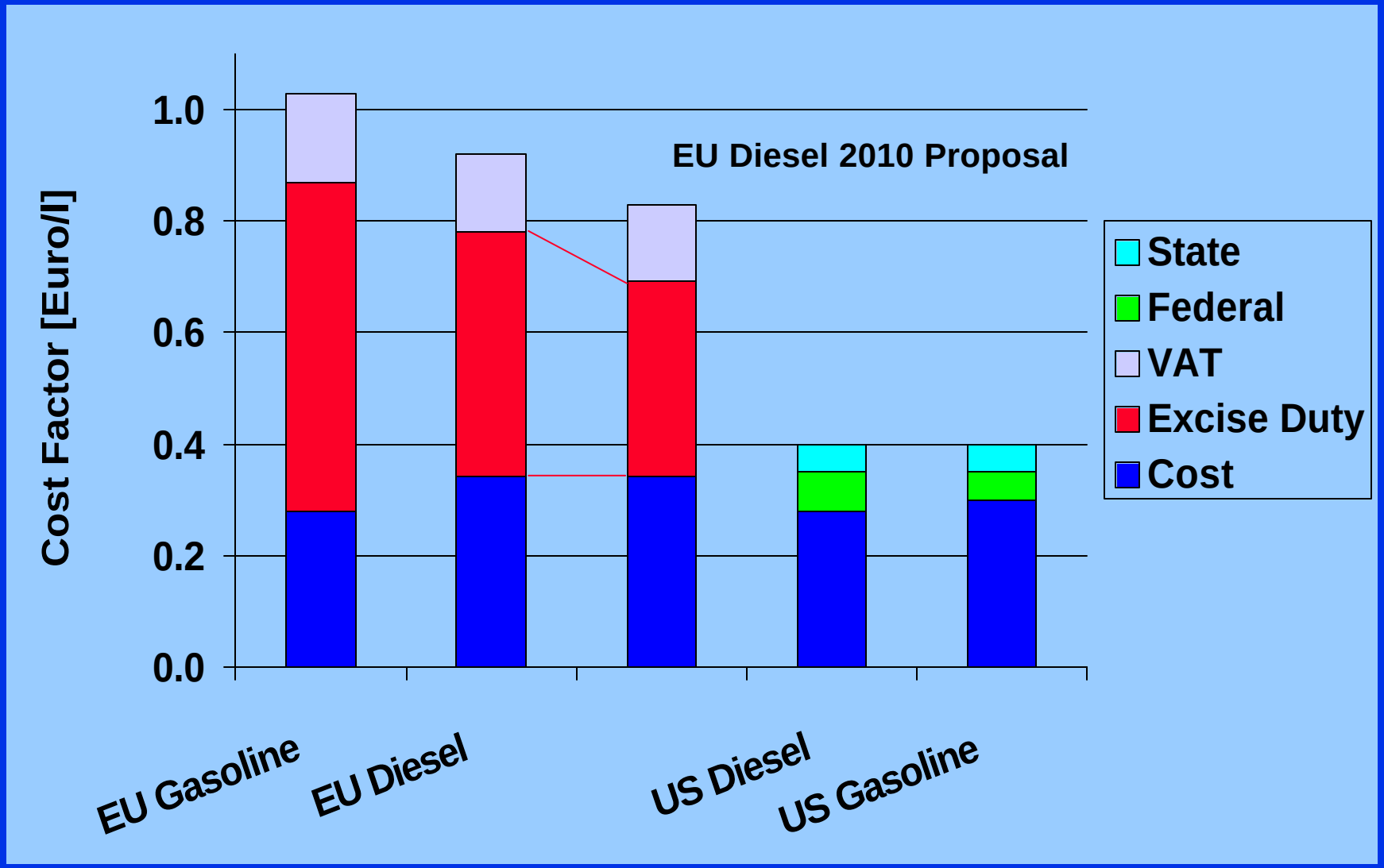



Source: Eurostat, 2001

**Only Country With Lower Gasoline Price**

# Fuel Price Comparison

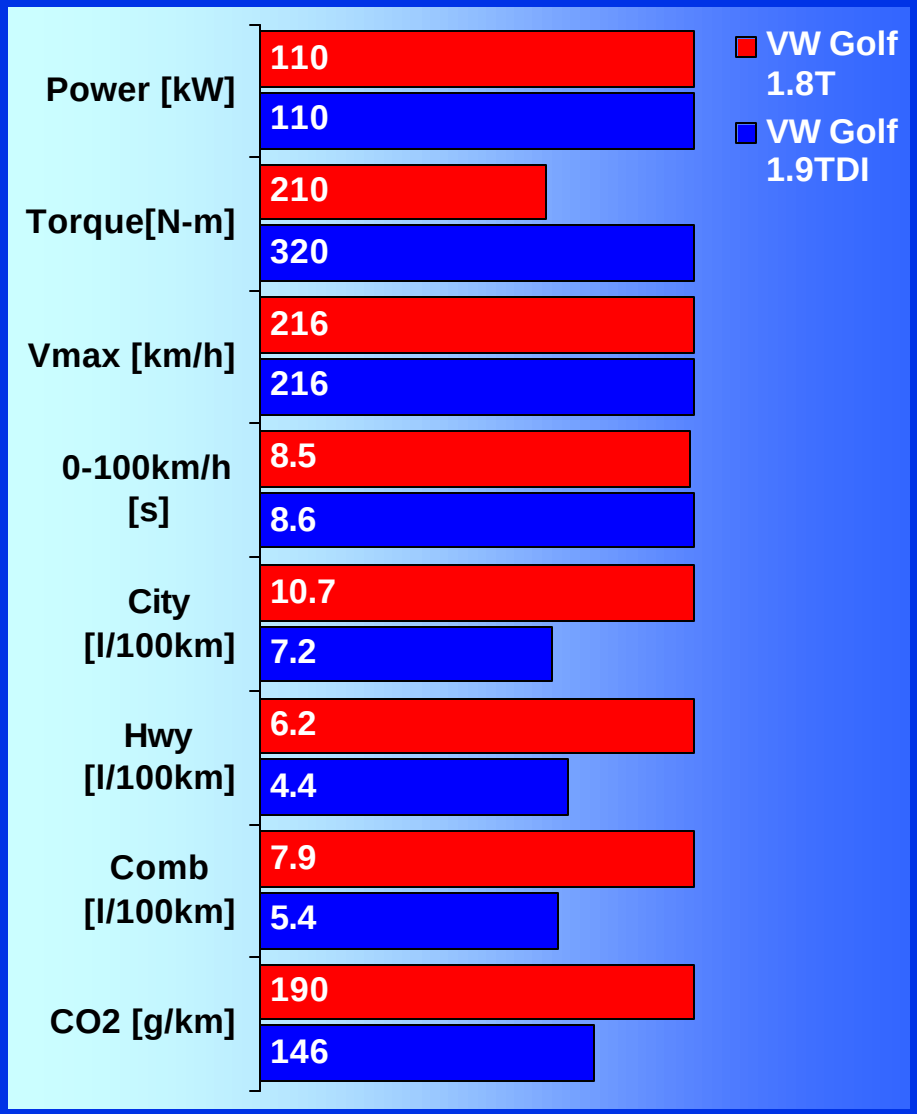


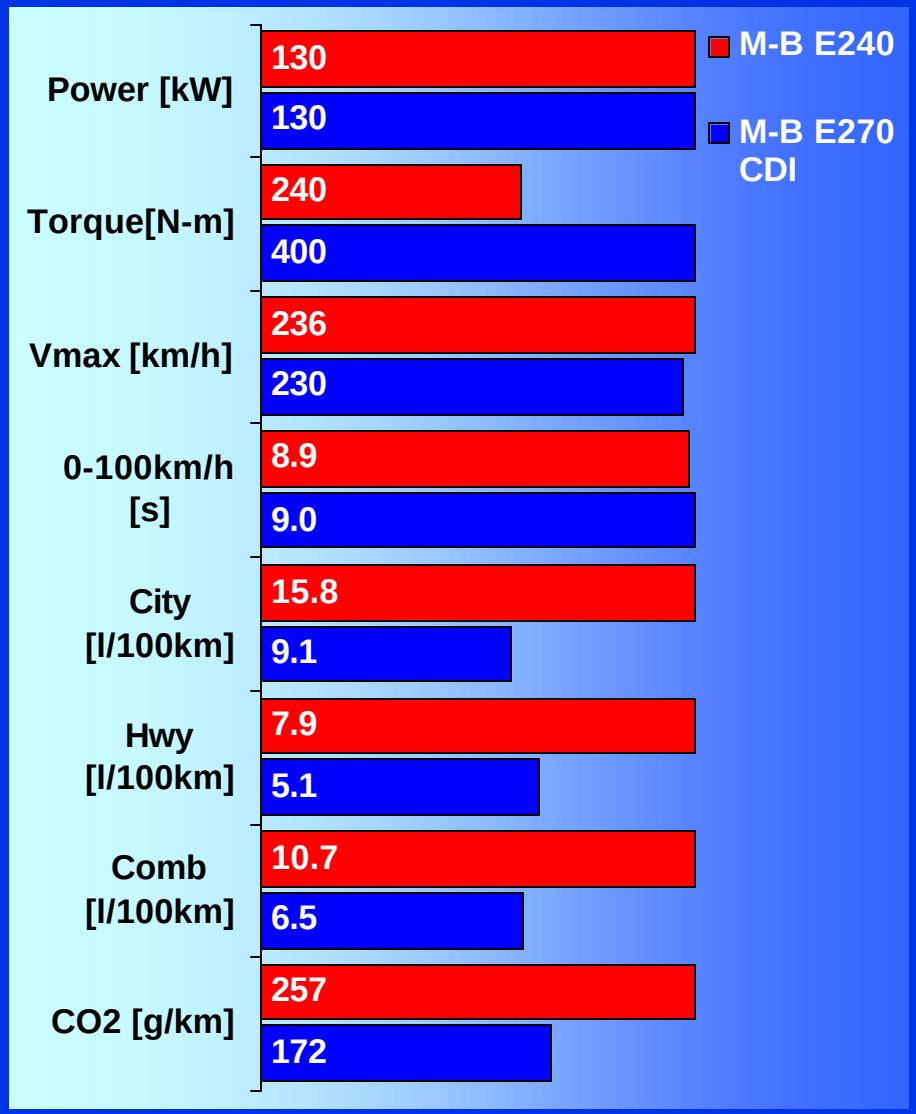

Source: Eurostat, 2001; EIA 2002

# Cost Comparison

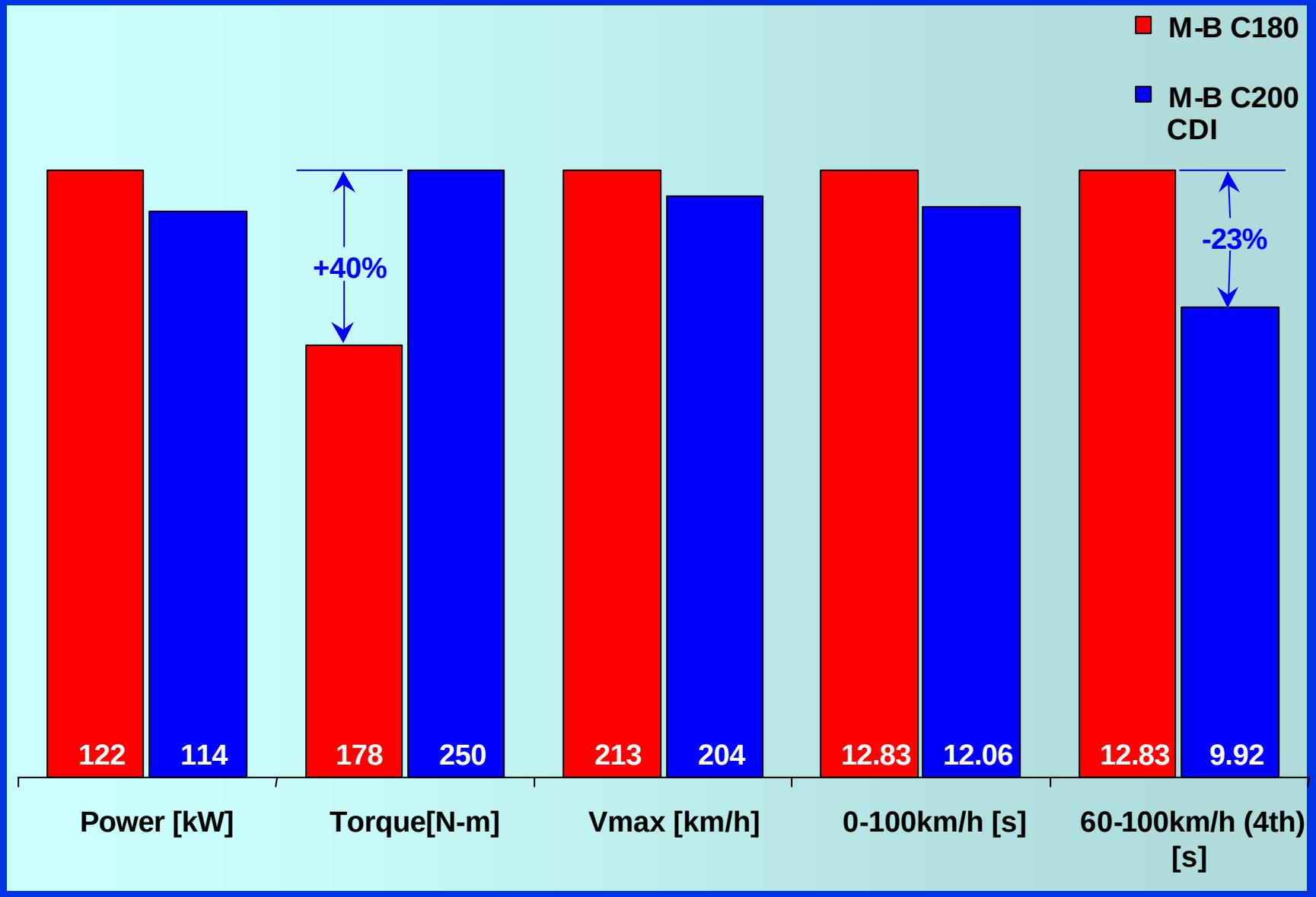
- VW Golf 1.9l TDI vs. 1.8l T
  - » 1500 Euro Difference in Purchase Cost
  - 5.4 vs. 7.9 l/100 km
  - 15000 km /year
  - 0.89 vs 1.03 Euro/l
  - 720 vs. 1220 Euro Annual Operating Costs
  - 3 Year Payback Period
- M-B E 270 CDI vs. E 240
  - » 700 Euro Difference in Purchase Cost
  - 6.5 vs. 10.7 l/100 km
  - 15000 km /year
  - 0.89 vs 1.03 Euro/l
  - 870 vs. 1650 Euro Annual Operating Costs
  - 1 Year Payback Period

# Performance: Diesel vs. Gasoline

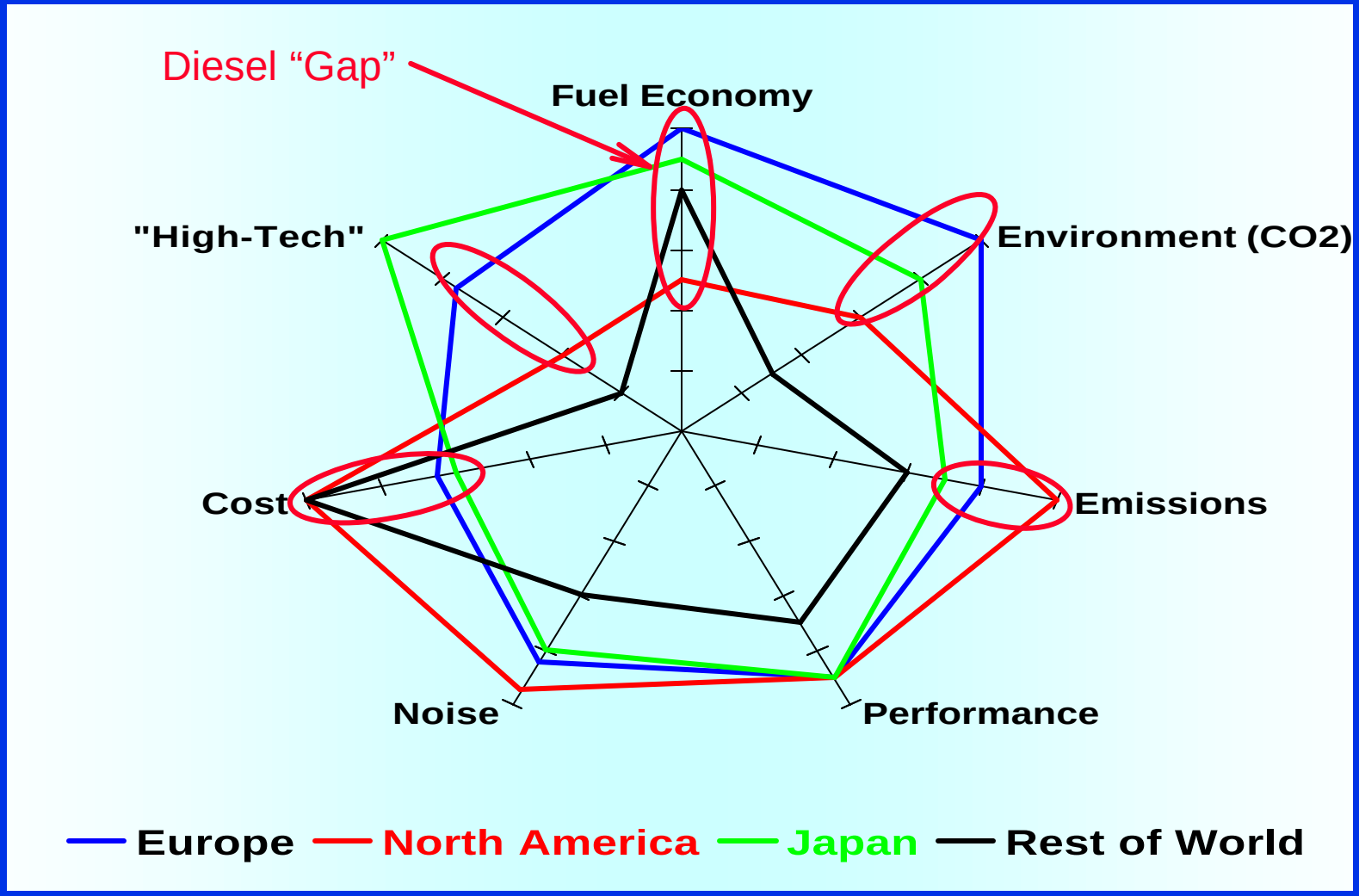


# Elasticity: Diesel vs. Gasoline



# Europe vs. US


Diesel "Gap"
Fuel Economy
Environment (CO2)
Emissions
Performance
Noise
Cost
"High-Tech"
Europe
North America
Japan
Rest of World

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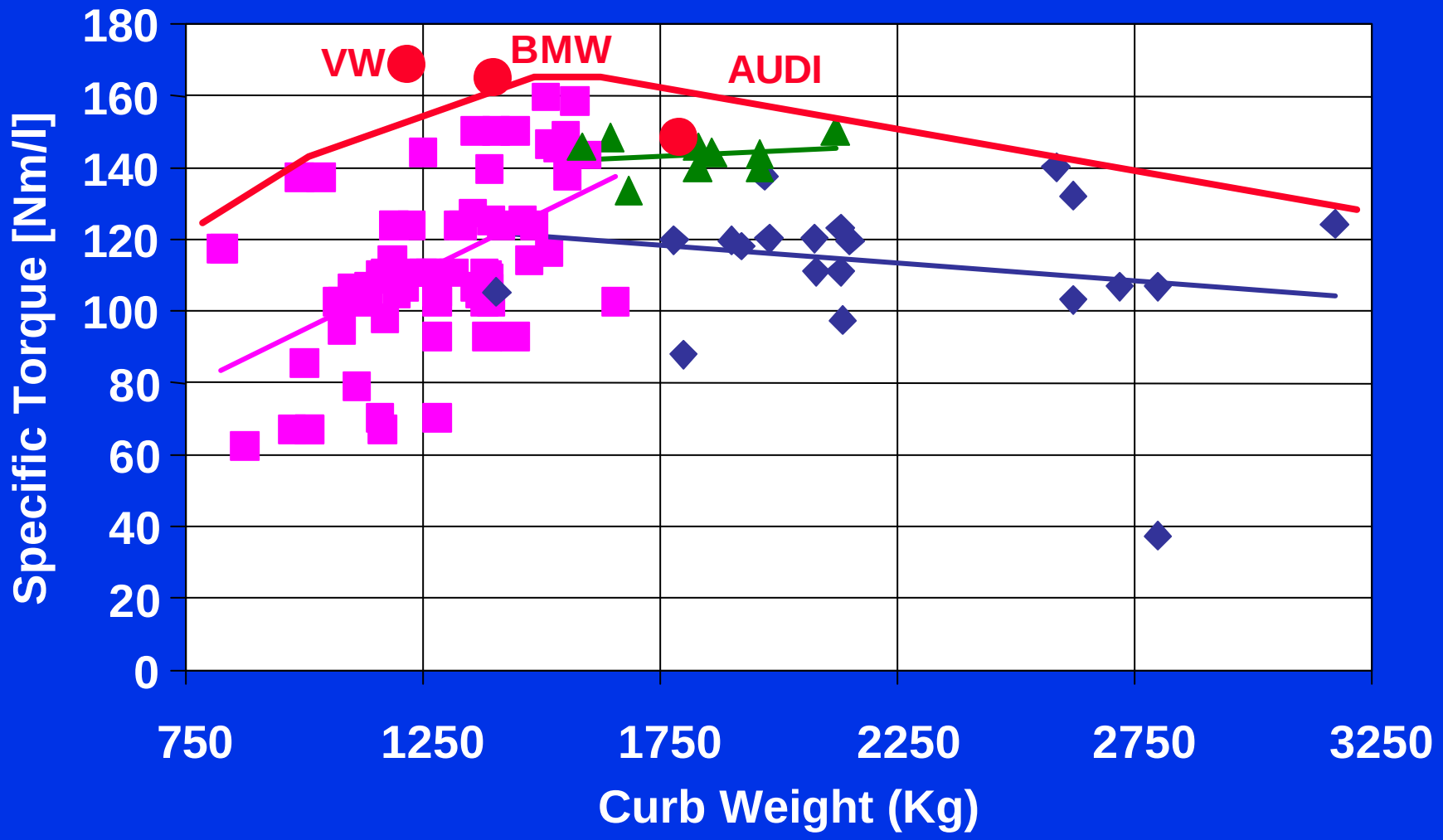
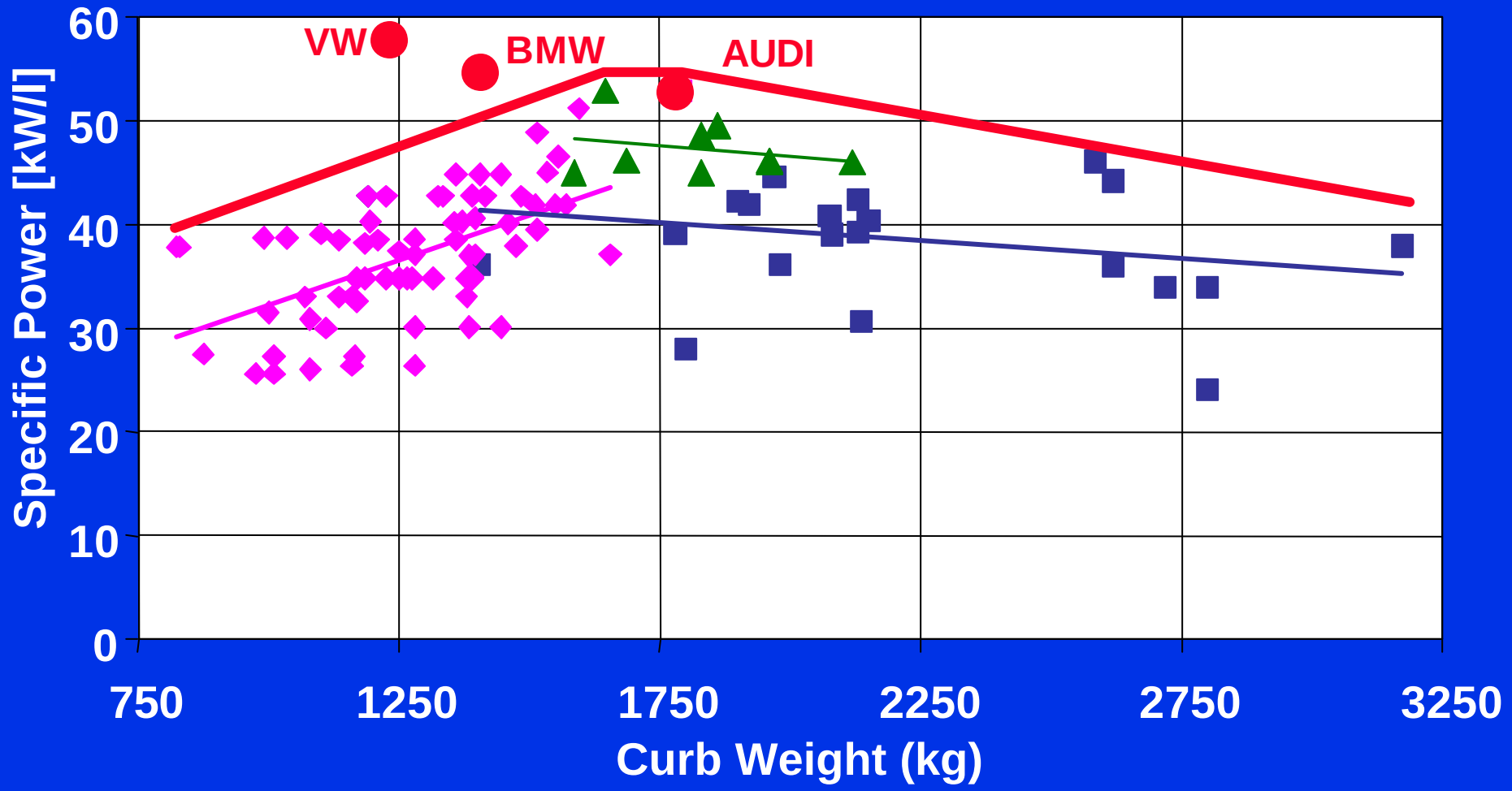
# Specific Torque of HSDI Diesels




■ 3, 4 and 5 cyl. PC engines ▲ 6, 8 and 10 cyl. PC engines ◆ All SUVs

All SUVs = USA, Japan and Europe

# Specific Power of HSDI Diesels

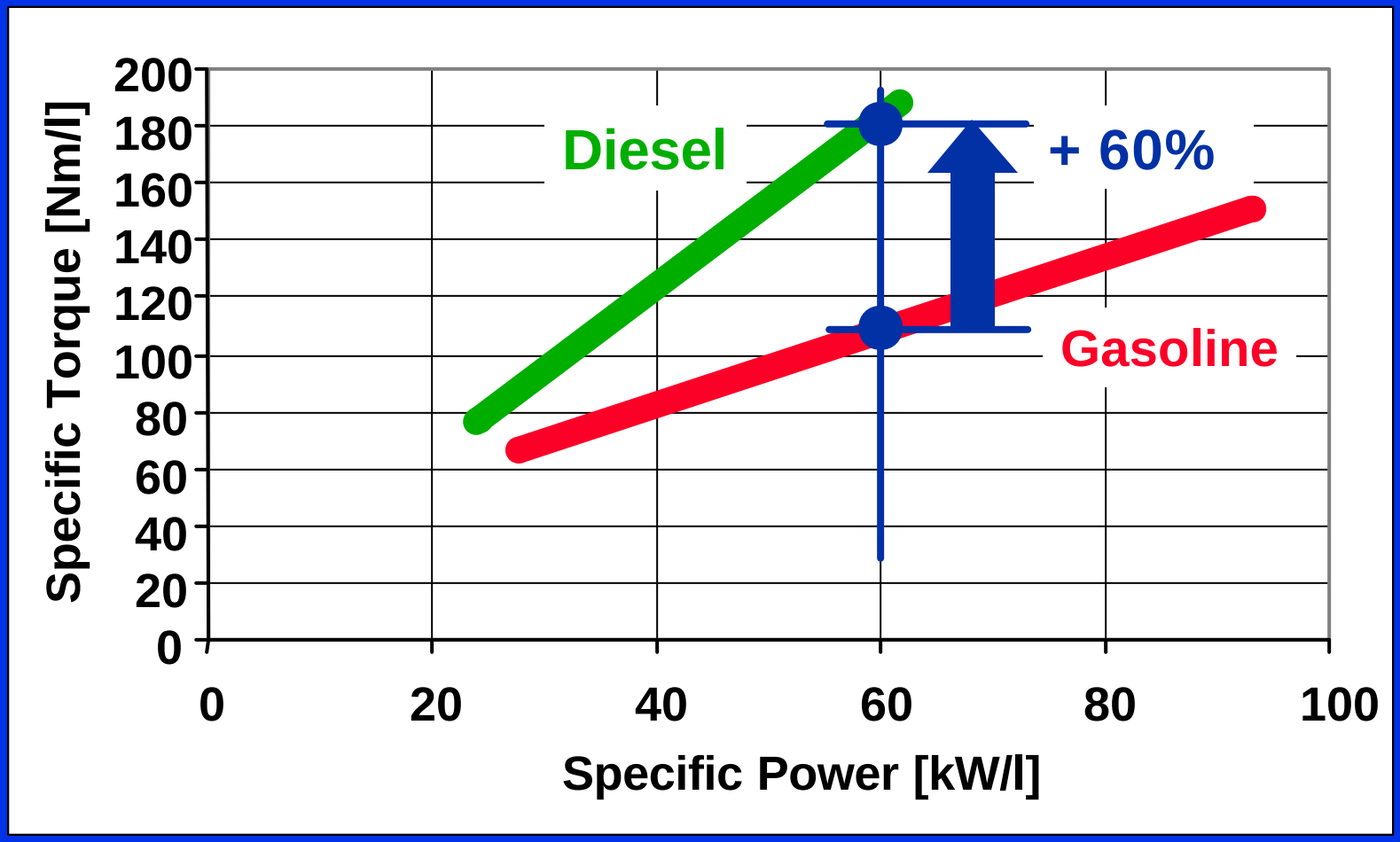



◆ 3, 4 and 5 cyl. PC engines ▲ 6, 8 and 10 cyl. PC engines ■ All SUVs

All SUVs = USA, Japan and Europe

# Specific Torque vs. Specific Power

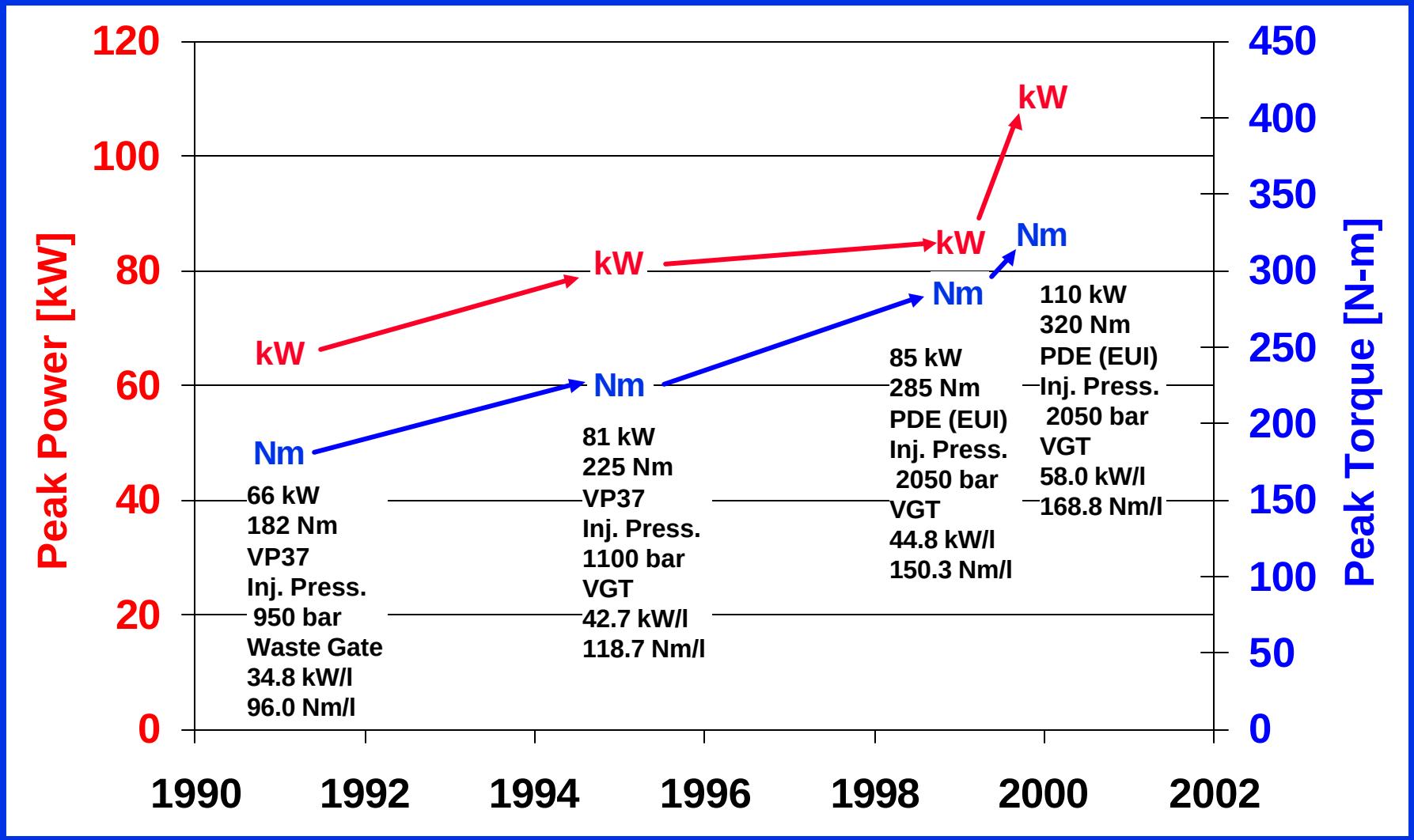
## Passenger Car Engines Certified to EURO III or Better




Source: Kraftfahr-Bundesamt (KBA), 03/2000; mot 11/2000; Automobil Revue 2000

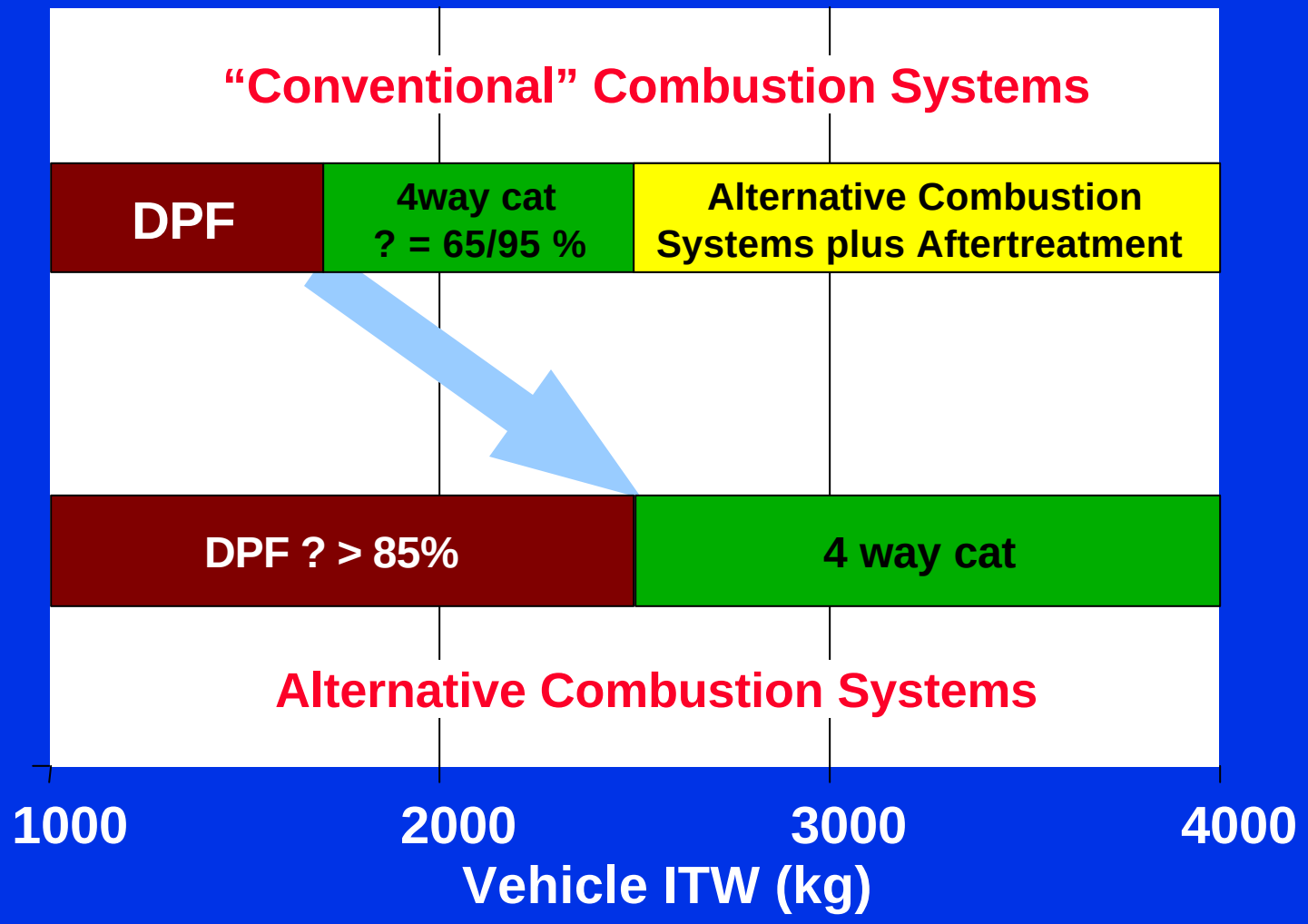
# Evolution in Specific Output

## VW 1.9l TDI 2 Valve/Cyl



# Assessment of Technologies to Meet Future Emissions Standards

## EURO V, US Tier 2, CARB LEV II Standards



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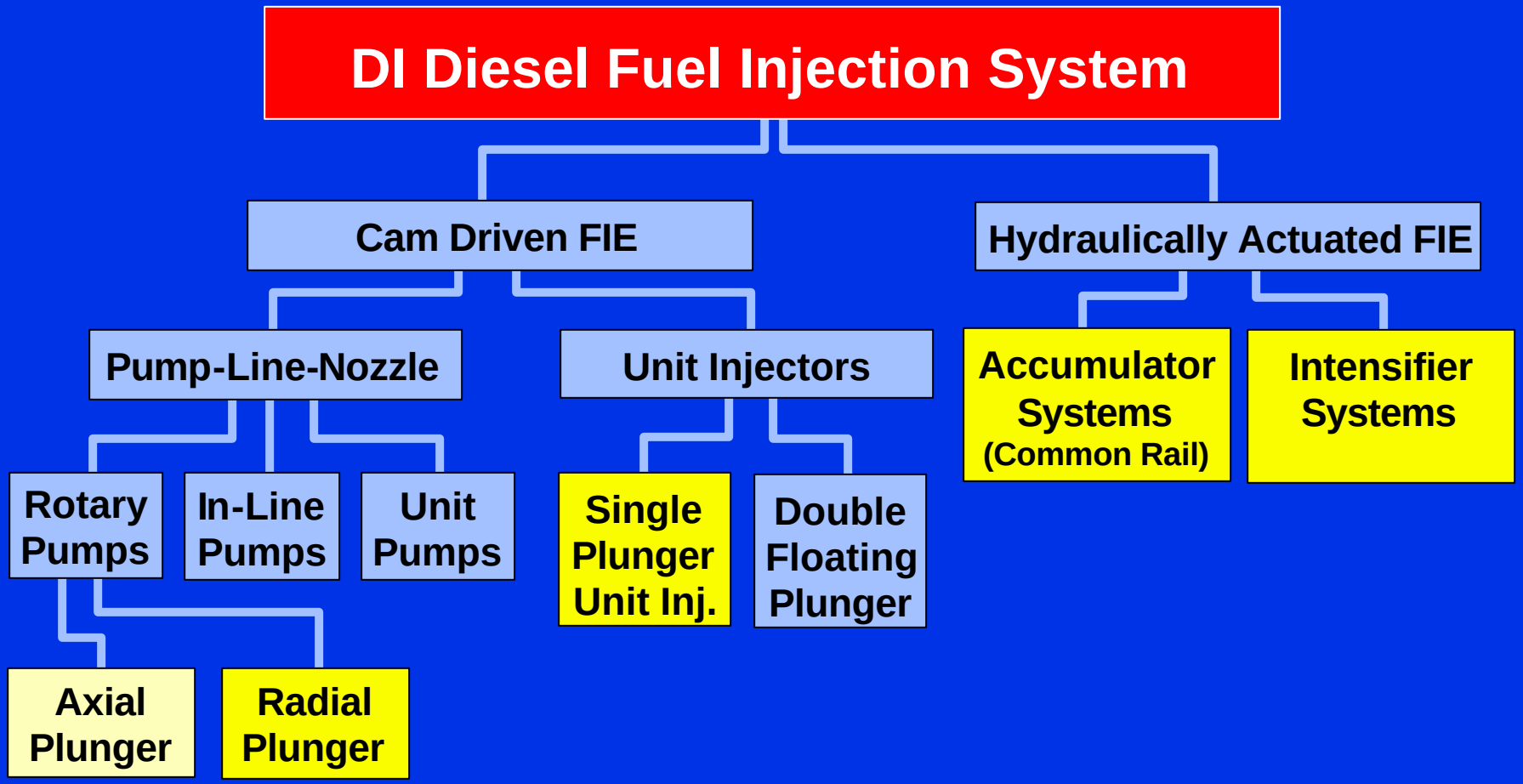
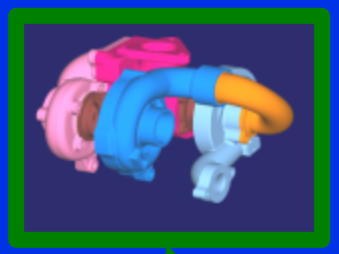
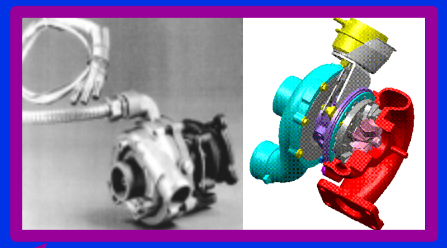
# Diesel Fuel Injection Systems to Meet Future Emission Standards




**Most Promising Options for SUV / LDT**

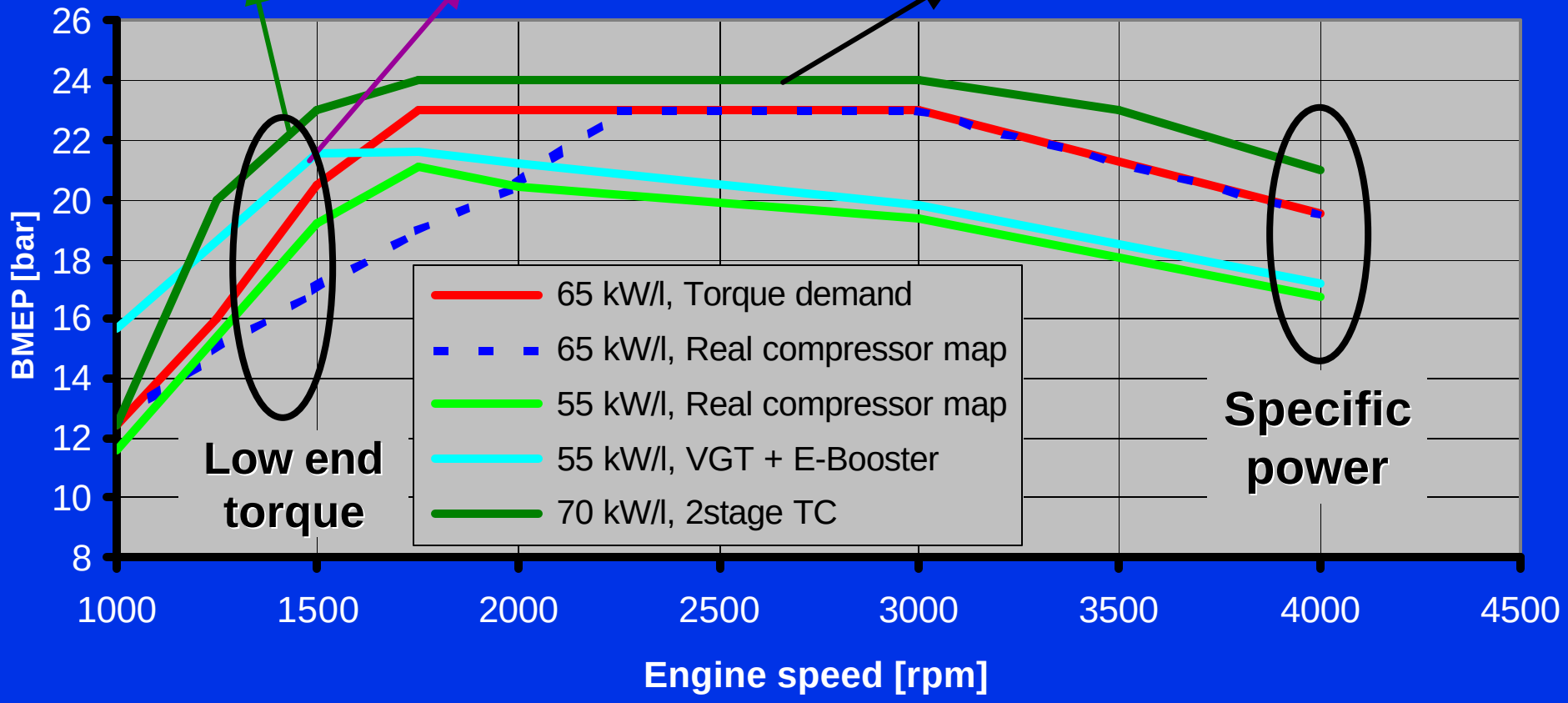
# Effect of Charging Systems on Full Load Characteristics



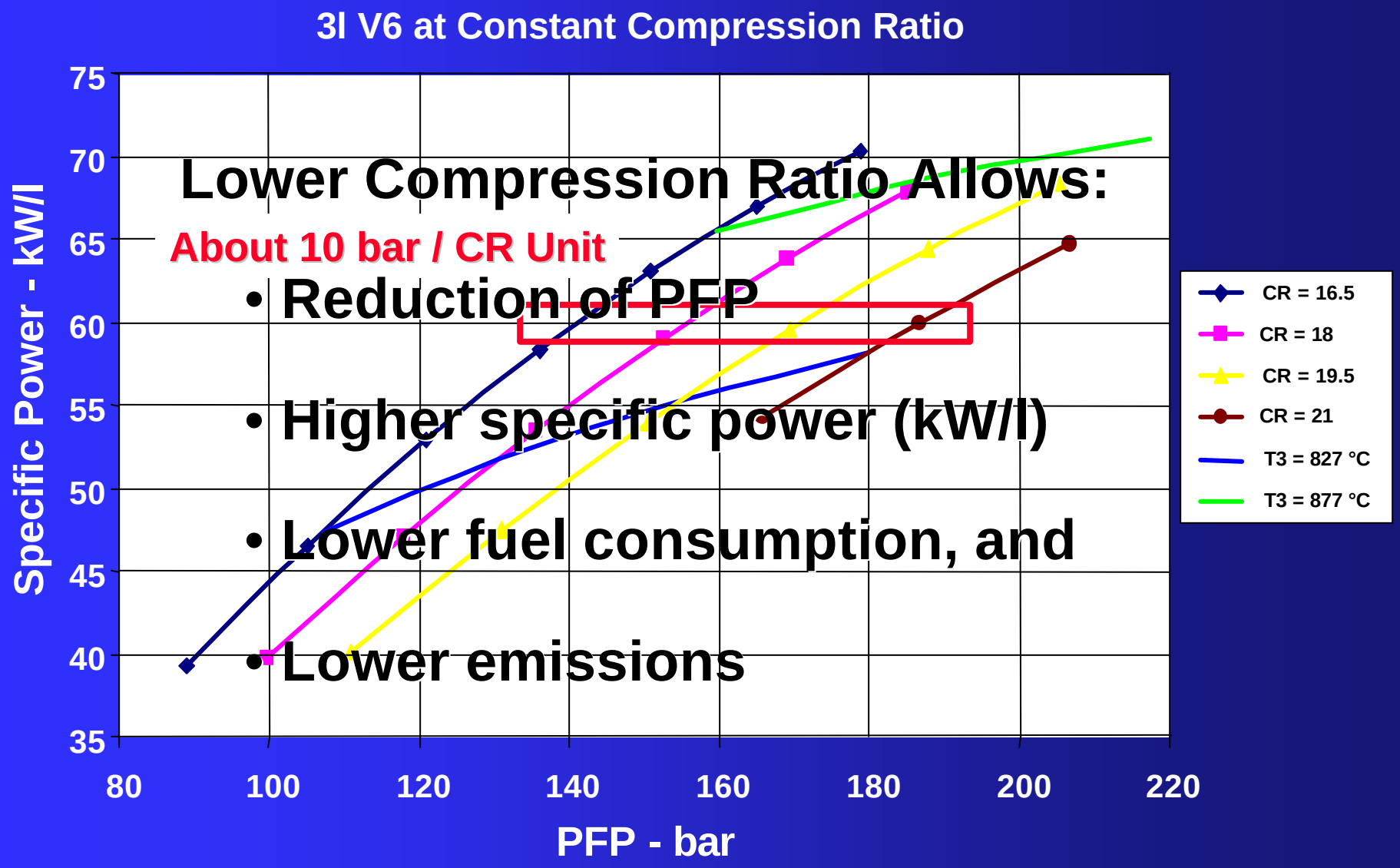


6 Cylinder HSDI, 0.5 l/cylinder Class

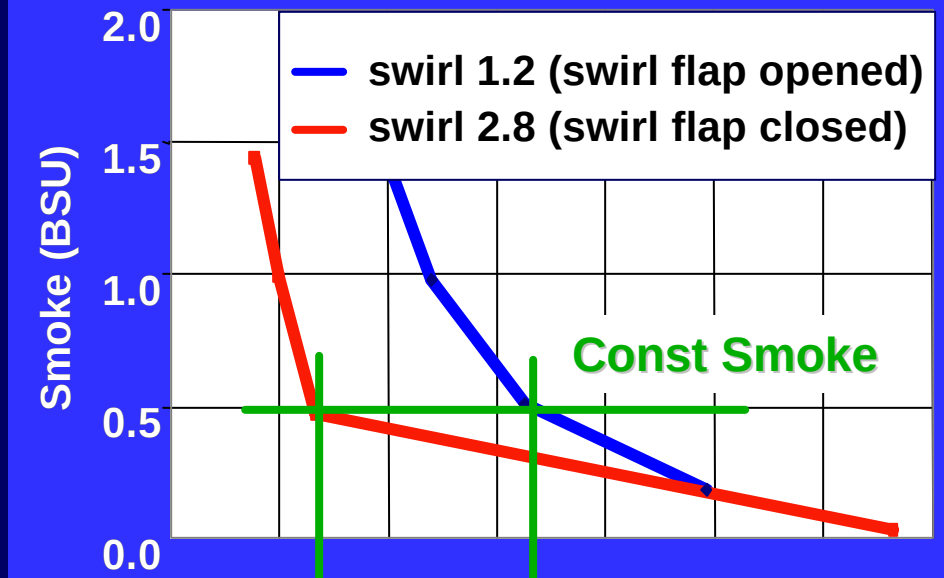
Transmission Torque Limitation

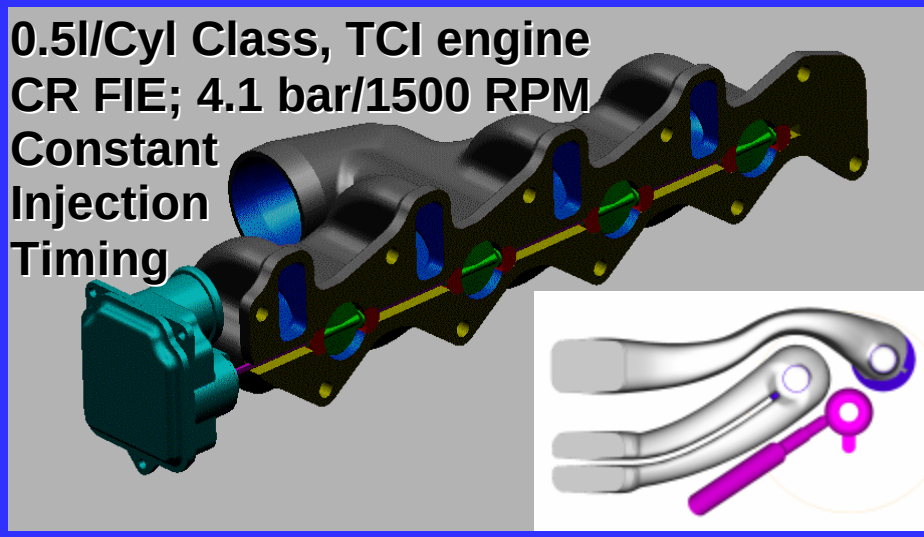


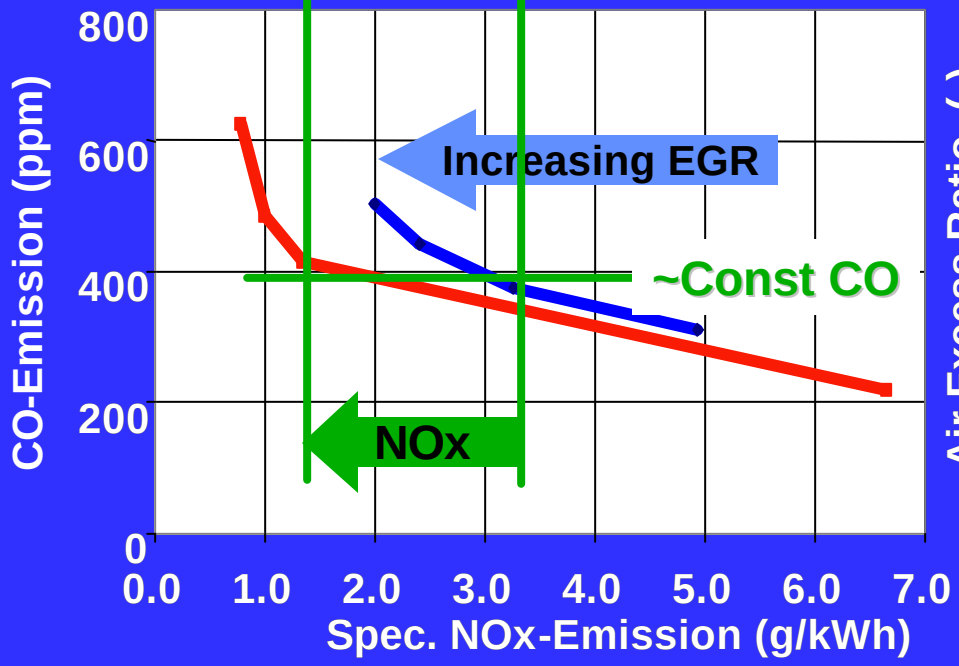
# Specific Power vs. Peak Firing Pressure and Compression Ratio

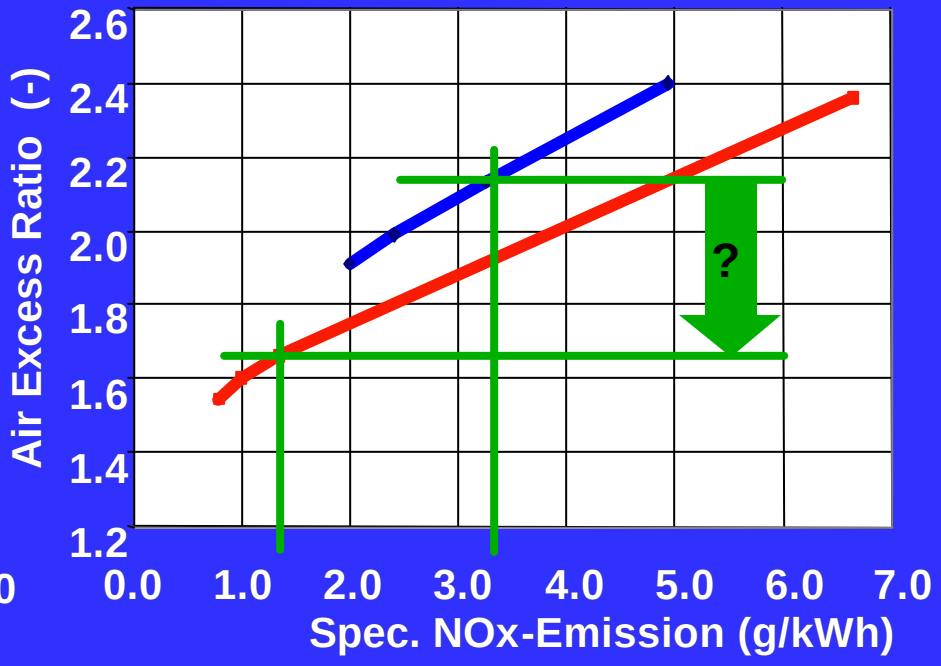


# Variable Swirl: Effect on Exhaust Emissions



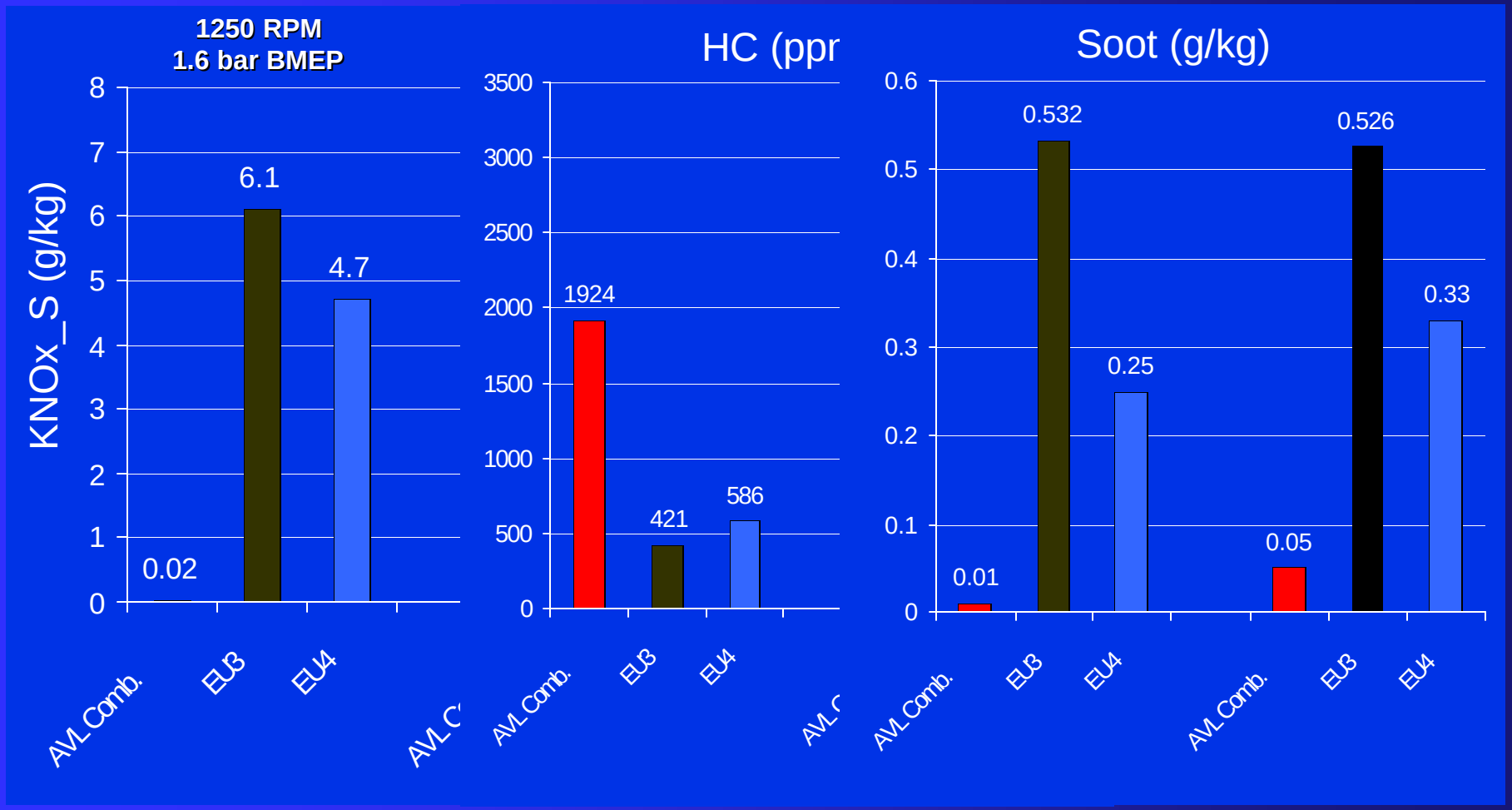



# Alternative Combustion Systems

**AVL Combustion:** Single Cylinder Engine - 0.5 l/cyl.
**EU III & EU IV Data:** Multicylinder Engine - 0.40 l/cyl.



# Summary and Conclusion

- Specific Performance Will Reach
  - 60-65 kW/l
  - 180 Nm/l
- Engine Fuel Consumption Will be Reduced by:
  - Friction Reduction
  - Faster Engine Warm Up
  - Reduced Compression Ratio
  - Cylinder Deactivation, and
  - Start-Stop Operation

# Summary and Conclusion (2)

- Emissions Reductions to Very Low Levels by:
  - Increased Sophistication
  - Exhaust Aftertreatment
  - Improved Fuels
  - Alternative Combustion Systems
- Most Solutions Too Expensive or Not Ready for Mass Production

# Summary and Conclusion (3)

- "Mainstream" HSDI Diesel Technology Will be Cost Competitive With Gasoline Engines
- High-Tech Diesels Most Appropriate for Markets With Strong Emphasis on Fuel Consumption, i.e.
  - Europe
  - North America (Pick-Ups, SUVs, etc.)