Ten Years of Development Experience with Advanced Light Truck Diesel Engines

September 2004

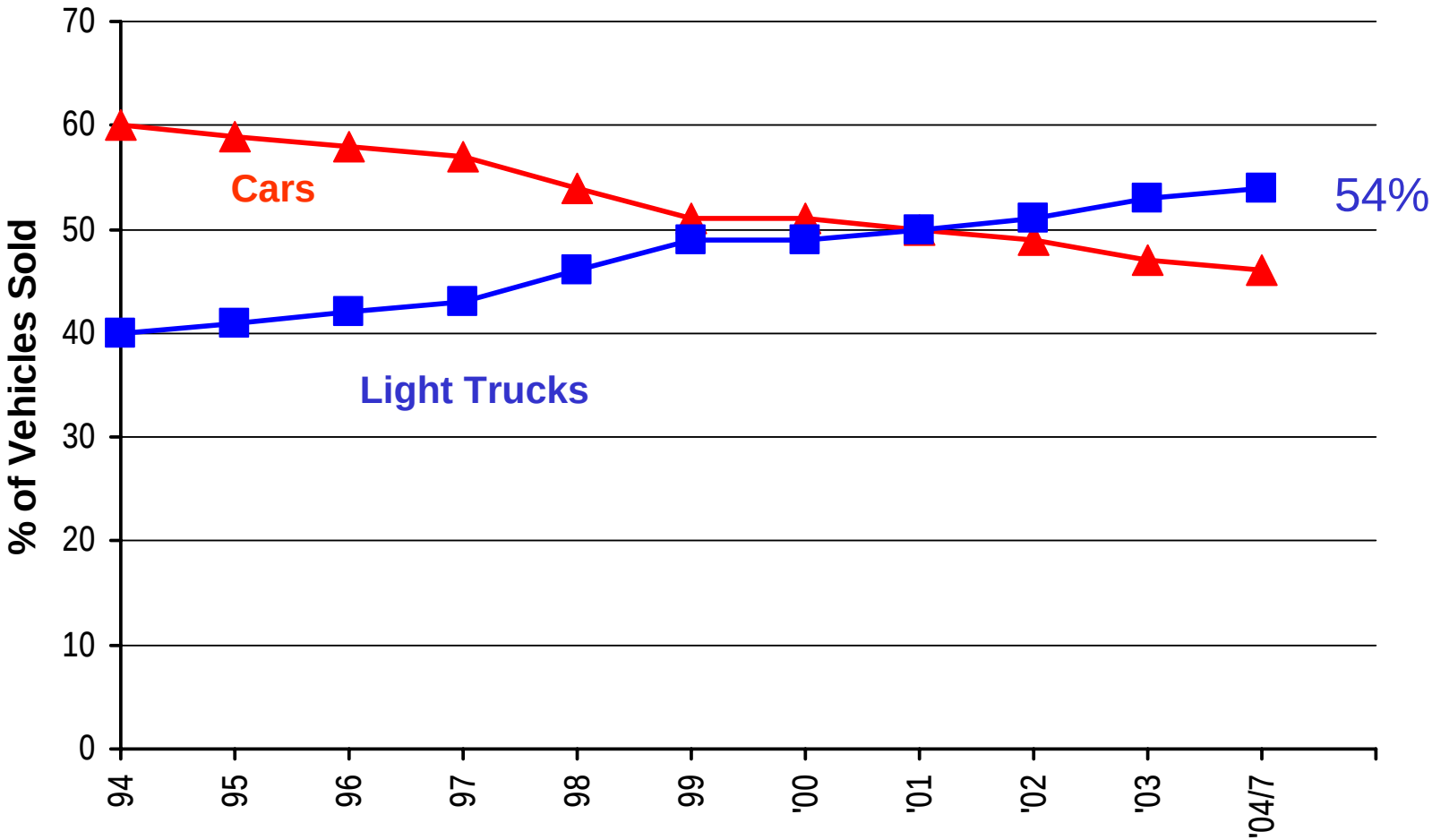
Introduction

Elements to be Considered , Looking Back Over 10 Years of Light Duty Diesel Development

- Market
- Regulations
- Customer Needs
- Major System Requirements
- Development Tools
- System Results

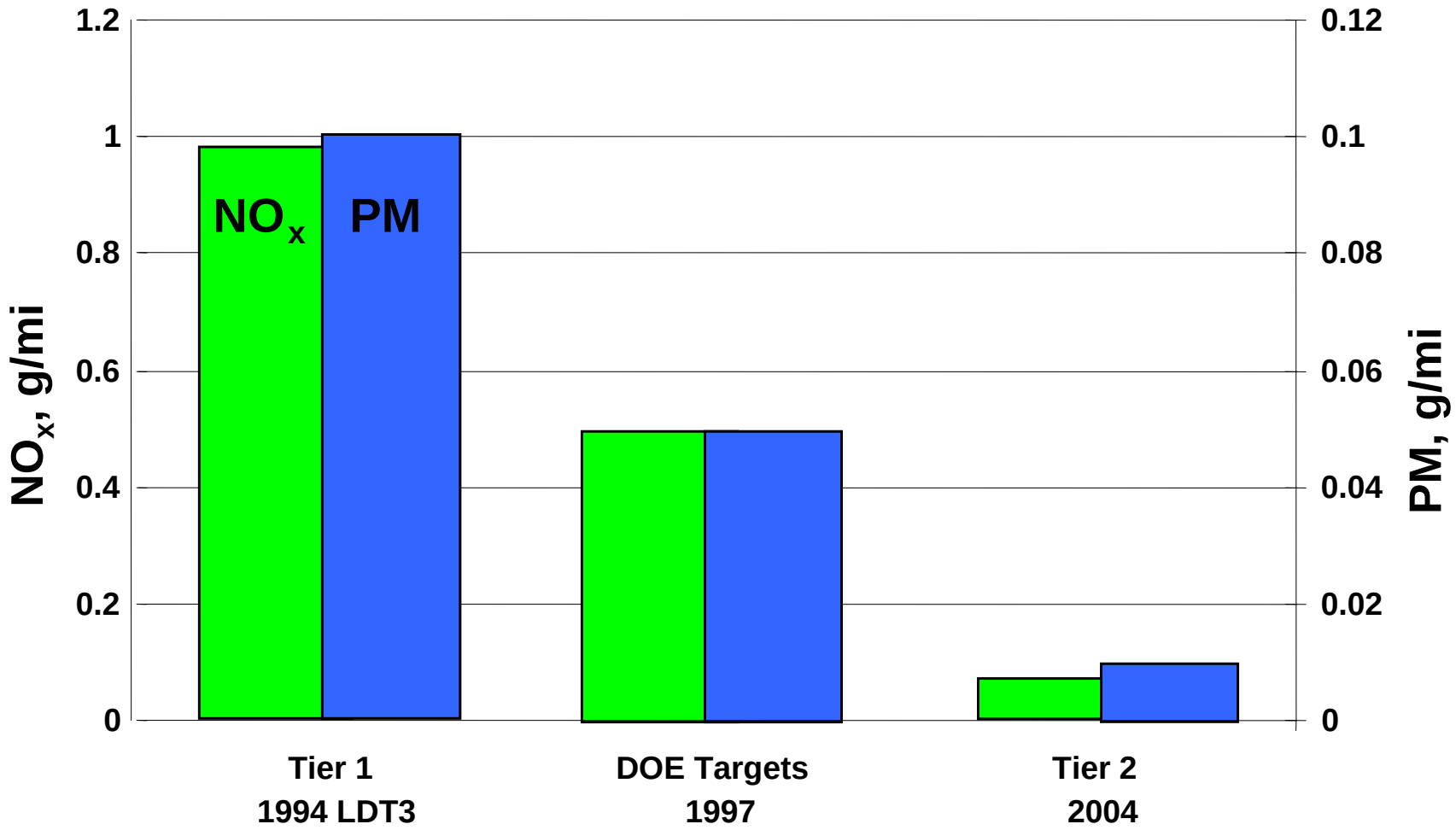
} 1994 Vs 2004

US Passenger-Car & Light-Truck Market

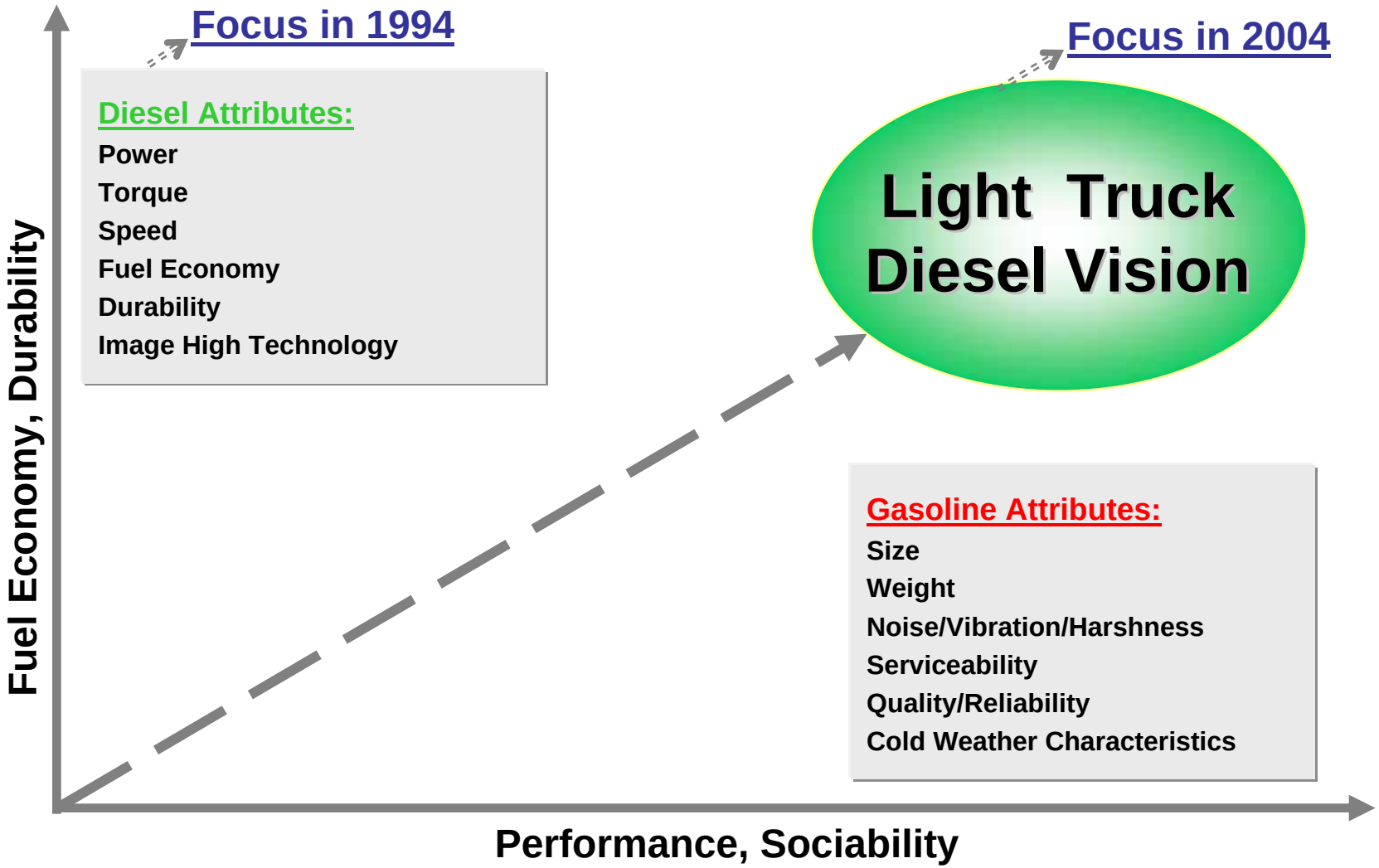


Source - Automotive News

Regulations



Engine Design Focus



Major Systems Requirements

	1994	Vs	2004
•Overall	•GVW > 8500 lb •GVW < 8500 not possible		•GVW < 8500 focus
•Fuel System	•<1400 bar •Mechanical •Torque Curve Focus		•>1800 bar •Electronic •Multipulse •Precision at Normal Drive Cycle
•Air Handling	•Wastegate		•Variable-Nozzle
•EGR	•NA		•EGR prime, >40%
•Aftertreatment	•DOC •Soot Filter in Buses		•DOC •NOx Adsorber •Soot Filter
•Combustion	•Experimentally Optimized		•Analytically Optimized •Experimentally Verified

Making Designs and Drawings

1994	Vs	2004
•CAD Systems –Pro/Engineer 3D AutoCad/Raster 2D –SUN UNIX Workstations		•CAD Systems –Pro/Engineer 3D Advanced Techniques –Ultra-Fast NT Workstations
•Networking –Local Limited Access to eStandards		•Networking –Worldwide Access
•CAD Properties –Limited Producibility »Draft, Parting, Etc.		•CAD Properties –Extensive Producibility »Fully Featured
•Data Transfer –4 & 8 mm Tape –Limited FTP Capability		•Data Transfer –Email, FTP, Internet –CD
•Prototype Parts –Castings from Drawings –Machining from Drawings		•Prototype Parts –Castings from “Master” CAD Data –Machining from CAD Capability
•Virtual Build –None Existent		•Virtual Build –Engine CAD Assembly –Rapid Prototype – SLS, SLA

Engine Analysis Tools

1994	Vs	2004
•FEA –ANSYS – Defeatured Models		•FEA –ANSYS – Complete Models –Mechanica – Designer Level
•Fluid Analysis –1D Analysis		•Fluid Analysis –CFD – 3D Analysis –Flowmaster – 1D Analysis
•Combustion System –Cycle analysis		•Combustion System –CFD –Extensive Kinetic Analysis
•Dynamic Analysis –DARE – Input Fortran Codet		•Dynamic Analysis –ADAMS – Pre-programmed Elements
•Tolerances –Worst Case		•Tolerances –DVA –Statistical
•Statistical Tools –Loosely Defined Set of Tools		•Statistical Tools –DFSS - Organized Set of Tools –Widely Available

Emissions Support Equipment

1994

Benches

Few, Very Low Utilization

Manual Operation Only

Gaseous Analyzers

Large, Manual, and Analog Signals

Filter Room

± 3 ° C Temperature and Humidity Control

Filter Scale

1.0 Microgram Accuracy

2001

Benches

Additional Emission Benches

Multiplexer to Meet Engine Needs

Partial Integration of with Test Cells

Gaseous Analyzers

Digital Signal

Shoe Box Size

Virtual Zero and Span Cap

Internal Quality Checks

2004

Benches

Full Integration with Test Cells

24 Hour Unattended Testing

Older Benches Upgraded for Less than 1% Drift per 24 Hour Period

CVS Tunnel

Integrated with Test Cells

Unattended CVS Testing Capabilities

2007

Benches

Every Performance Test Cell

Gaseous Analyzers

Noise Level at Zero Critical for 1st Time

Full Scale for NOx – 10 ppm

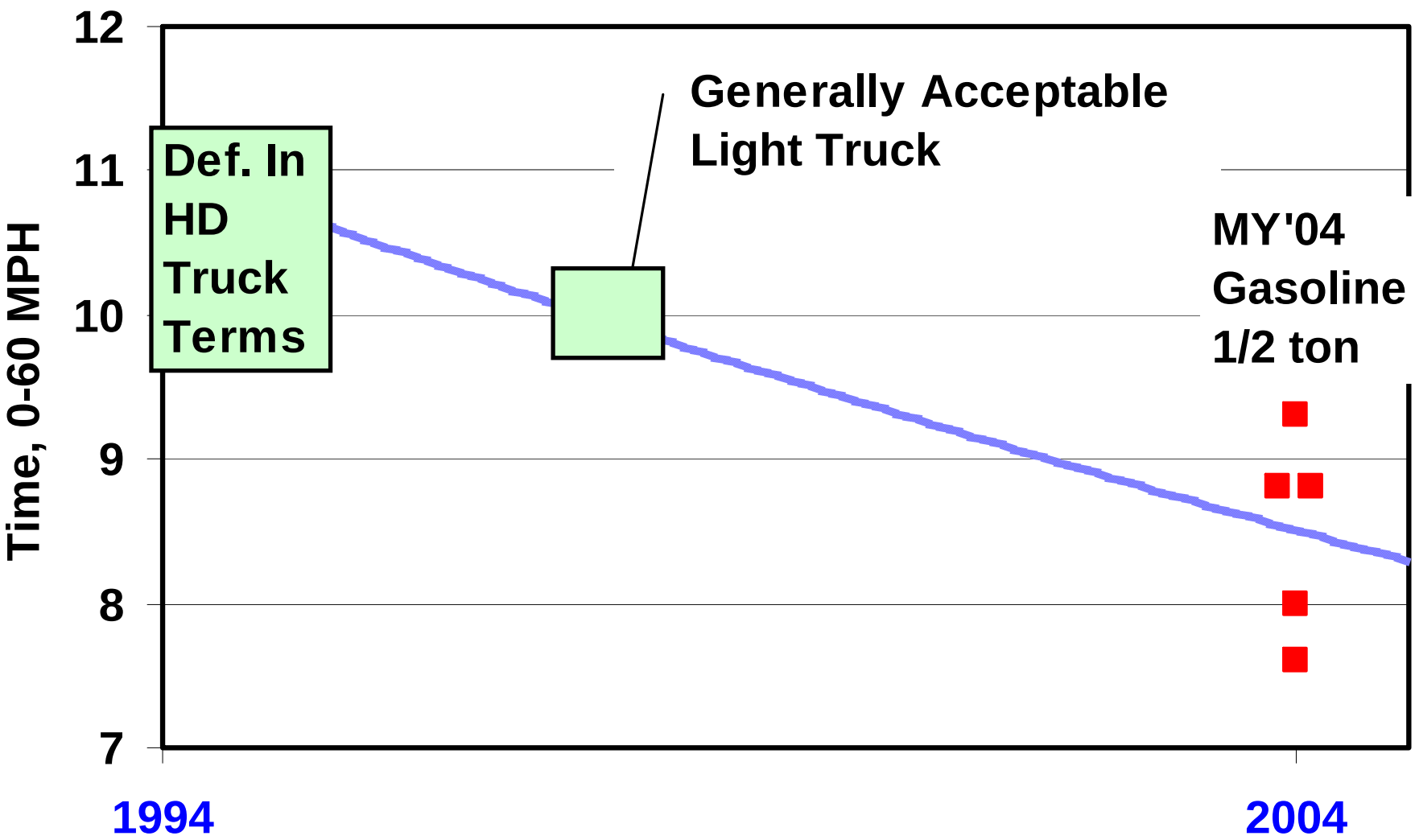
Filter Room

± 1 ° C Temperature and Humidity Control

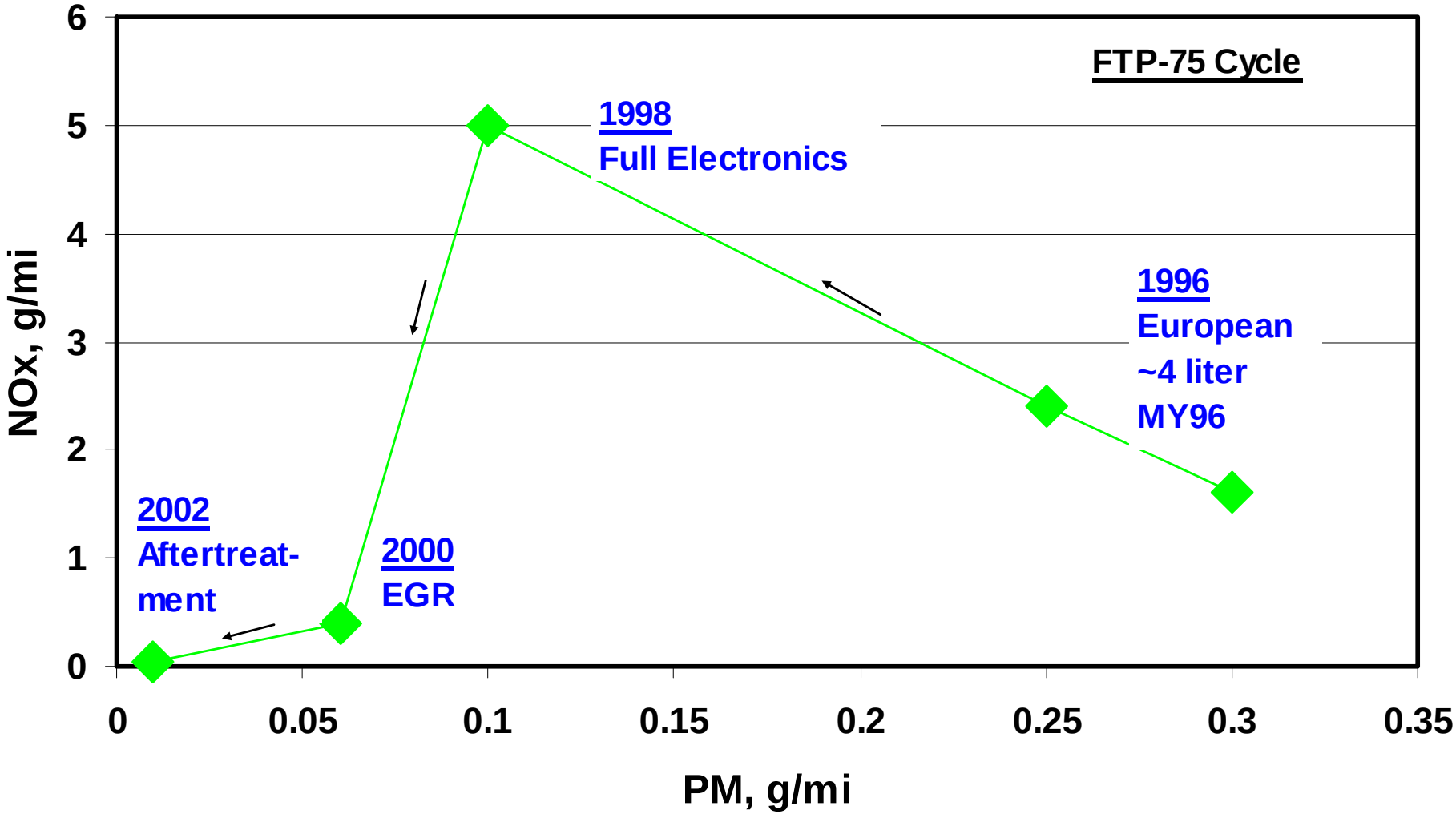
Filter Scale

0.1 Microgram Accuracy

Performance Challenge - Acceleration



Emissions Improvements



Summary

- **10 Years have seen much change**
- **In 1994 didn’t envision today’s diesel technical status in the U.S.**
- **What’s next?**