

# Light-Duty Diesel Market Potential in North America

Diesel Engine Emissions  
Reduction Conference

August 22, 2005

Chicago



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Executive Director, Diesel Engineering  
General Motors Corporation

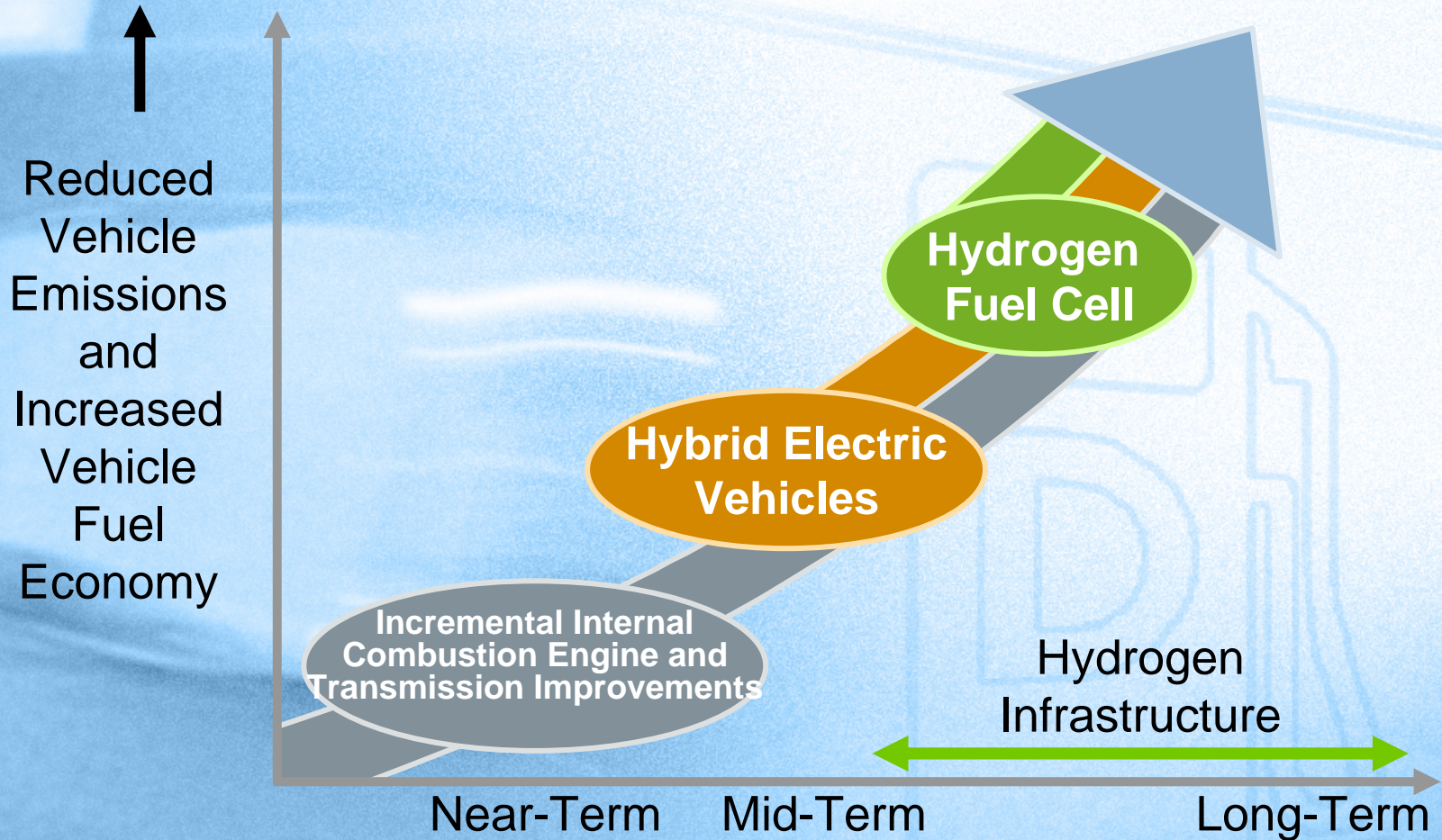


# GM's Long Term Vision

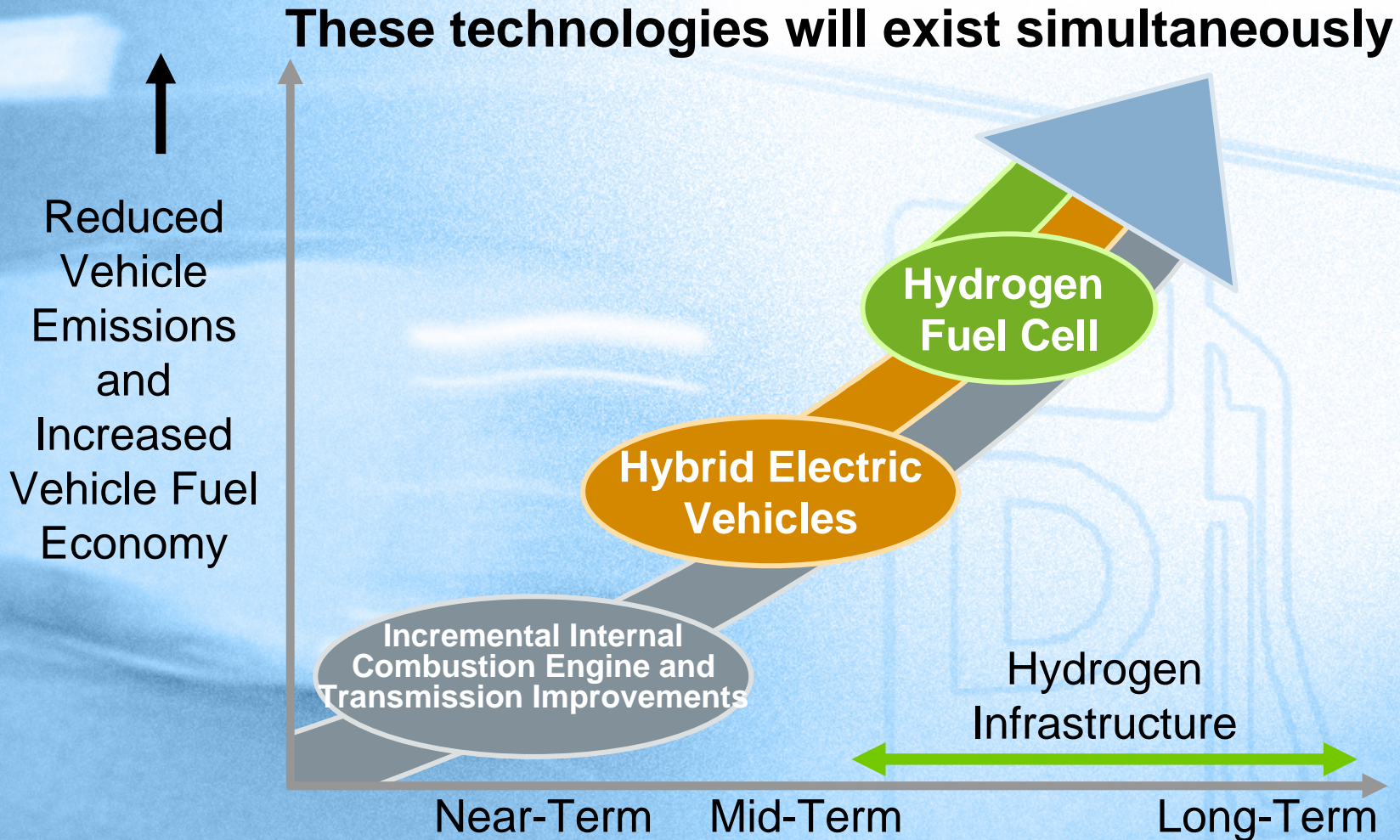
Remove the automobile  
from the energy & environmental equation



# Advanced Propulsion Technology Strategy

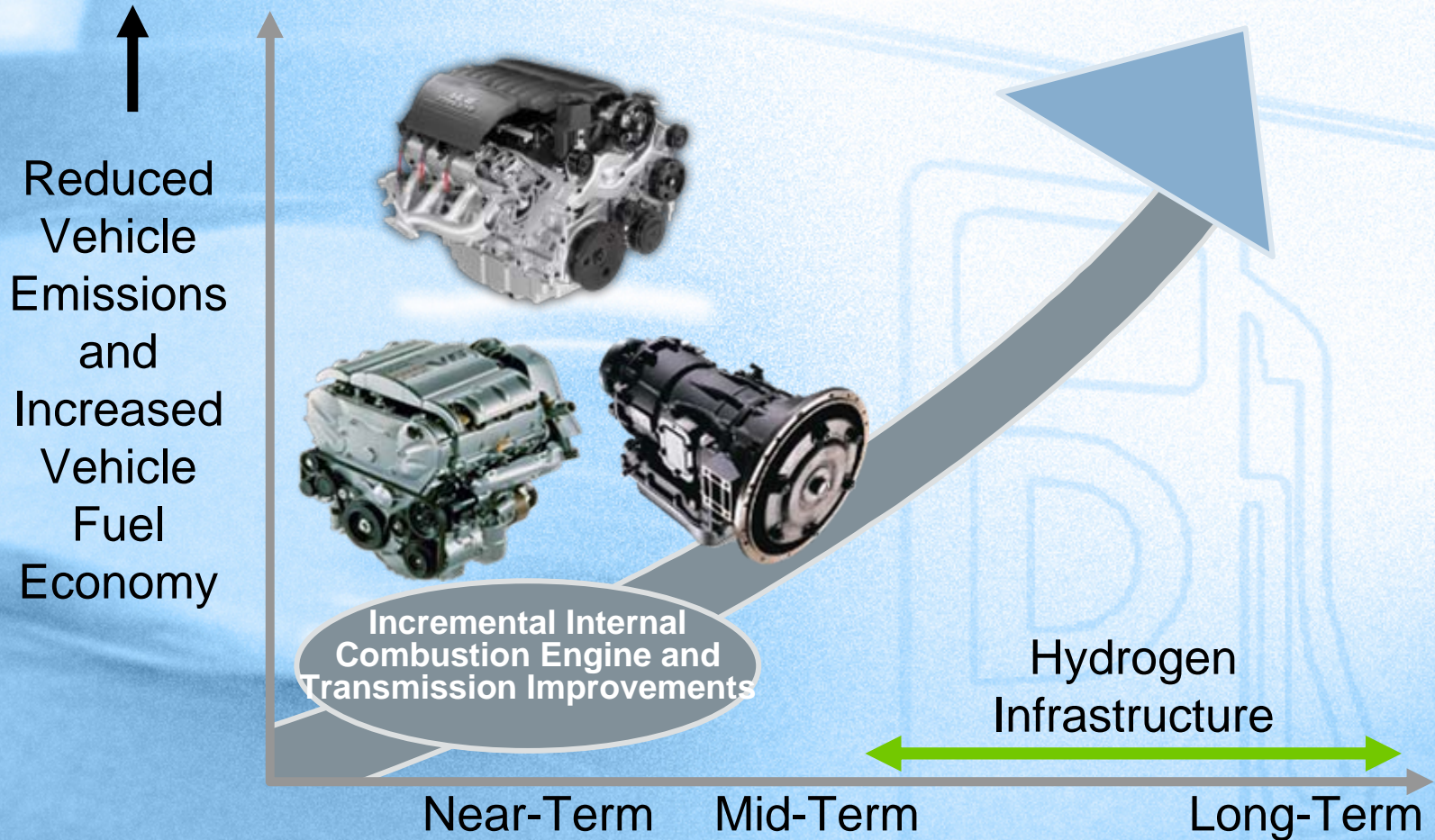


# Advanced Propulsion Technology Strategy



# Advanced Propulsion Technology Strategy

## Near-Term



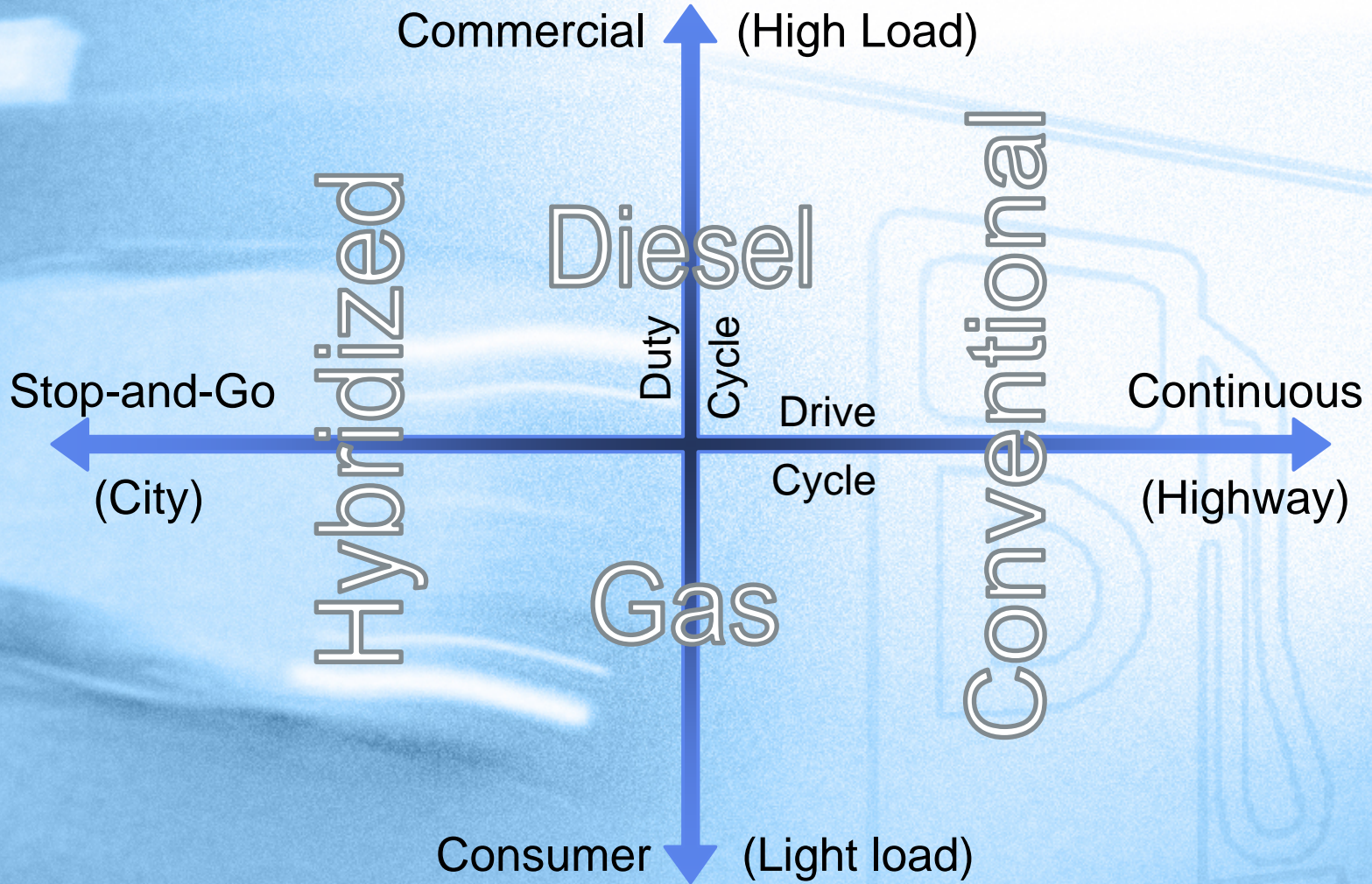
# Diesel Market Overview

## GM's Perspective

- Diesel engines are a key strategic component of GM's advanced propulsion strategy
- GM has capacity for over 1.3 million diesels per year
- Diesel powertrains satisfy unique vehicle requirements
  - Utility & large vehicles
  - Displacement limited passenger cars
- Significant technological challenges exist for long term light duty North American presence
  - NO<sub>x</sub> aftertreatment & fuel limitations
- GM is committed to developing global diesel solutions



# Propulsion Application Map



# Propulsion Application Map

Diesel Hybrid Bus



Commercial (High Load)

Stop-and-Go  
(City)

Duty

Cycle

Drive  
Cycle

Continuous  
(Highway)

Consumer (Light load)





# Propulsion Application Map

Commercial (High Load)

Diesel Hybrid Bus



Stop-and-Go  
(City)

Duty Cycle

Drive Cycle

Continuous  
(Highway)

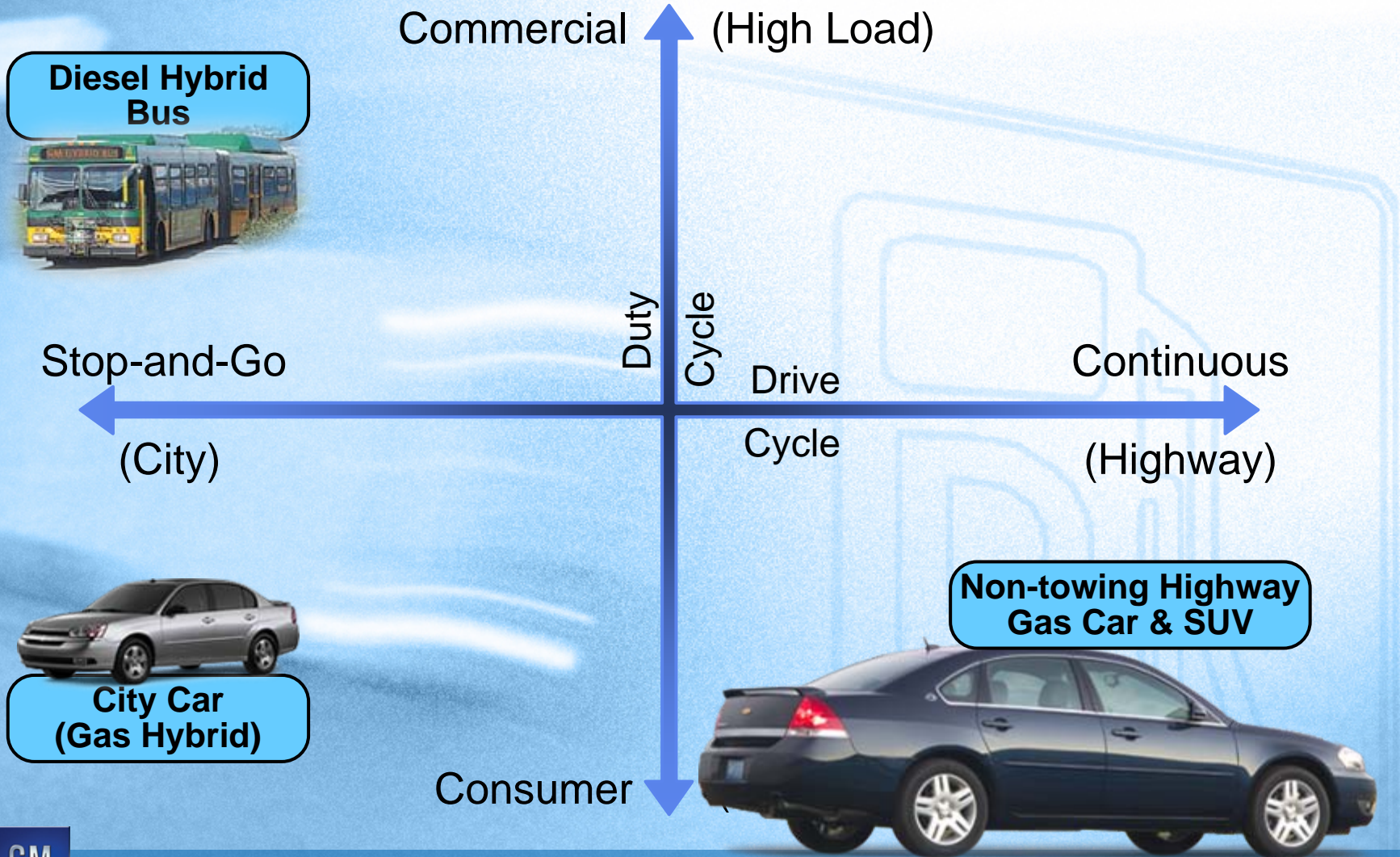
City Car  
(Gas Hybrid)



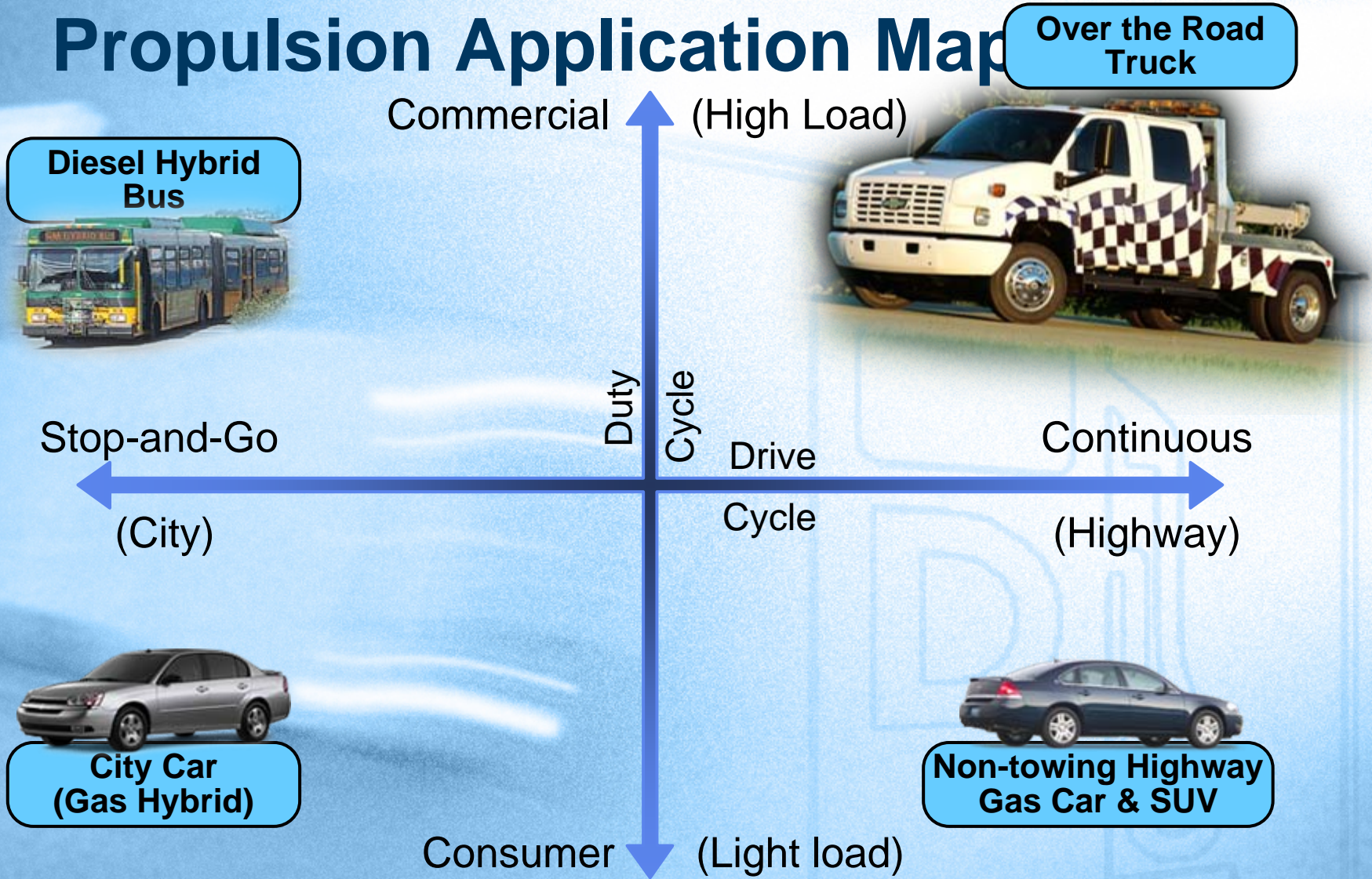
(Light load)



# Propulsion Application Map

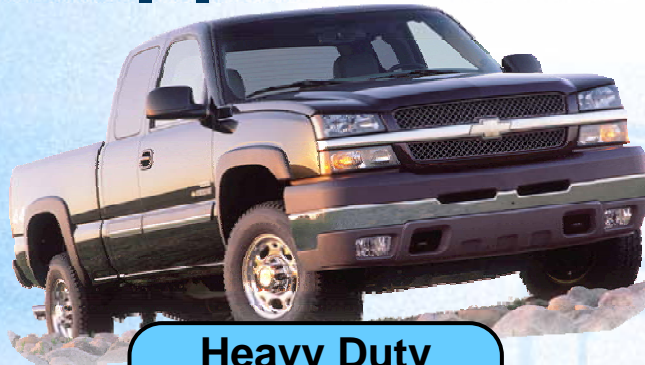


# Propulsion Application Map



# Propulsion Application Map

**Diesel Hybrid Bus**



**Over the Road Truck**



**Heavy Duty Pickup Truck**

Stop-and-Go  
(City)

Drive  
Cycle

Continuous  
(Highway)



**City Car  
(Gas Hybrid)**

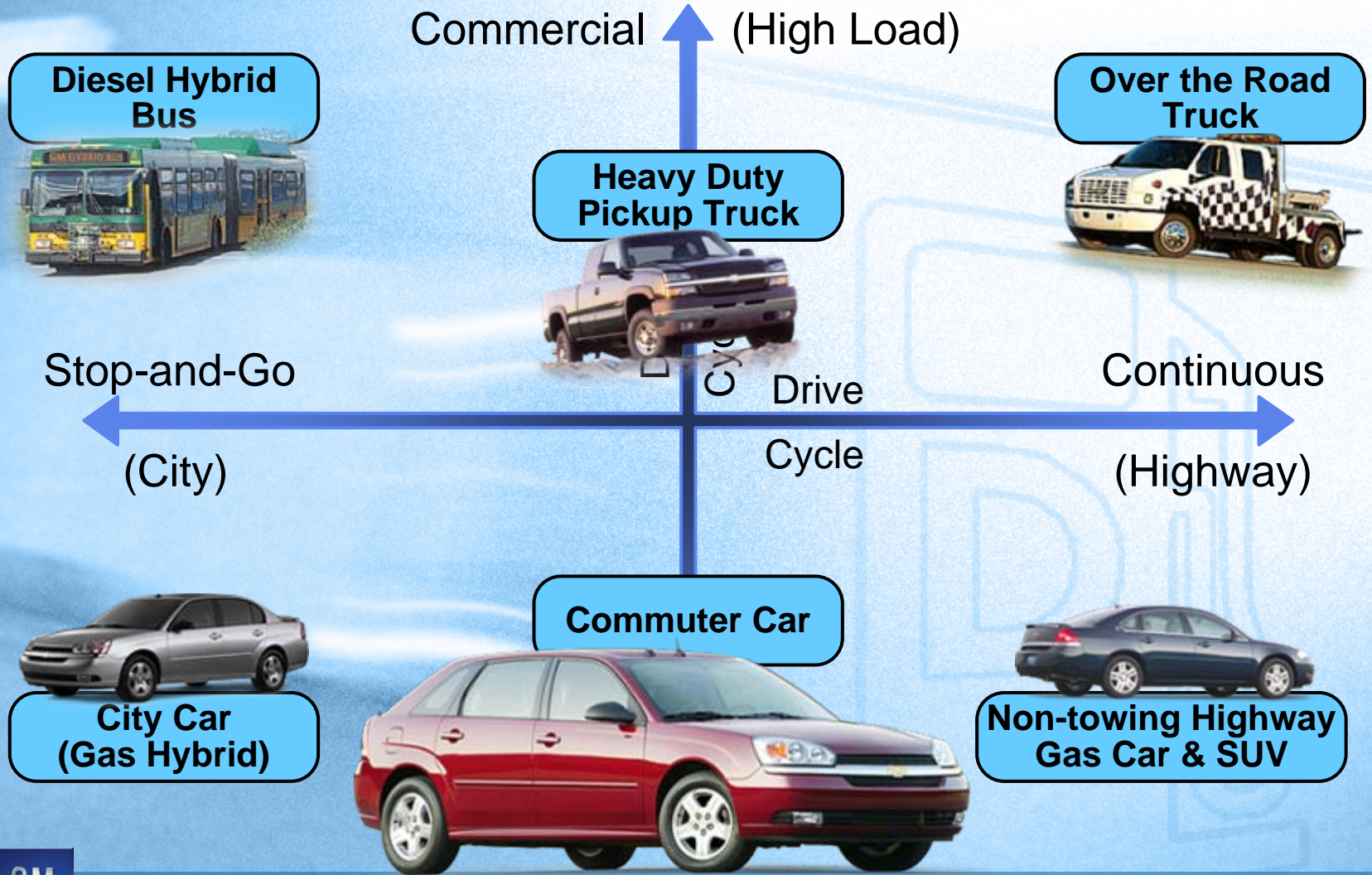


**Non-towing Highway  
Gas Car & SUV**

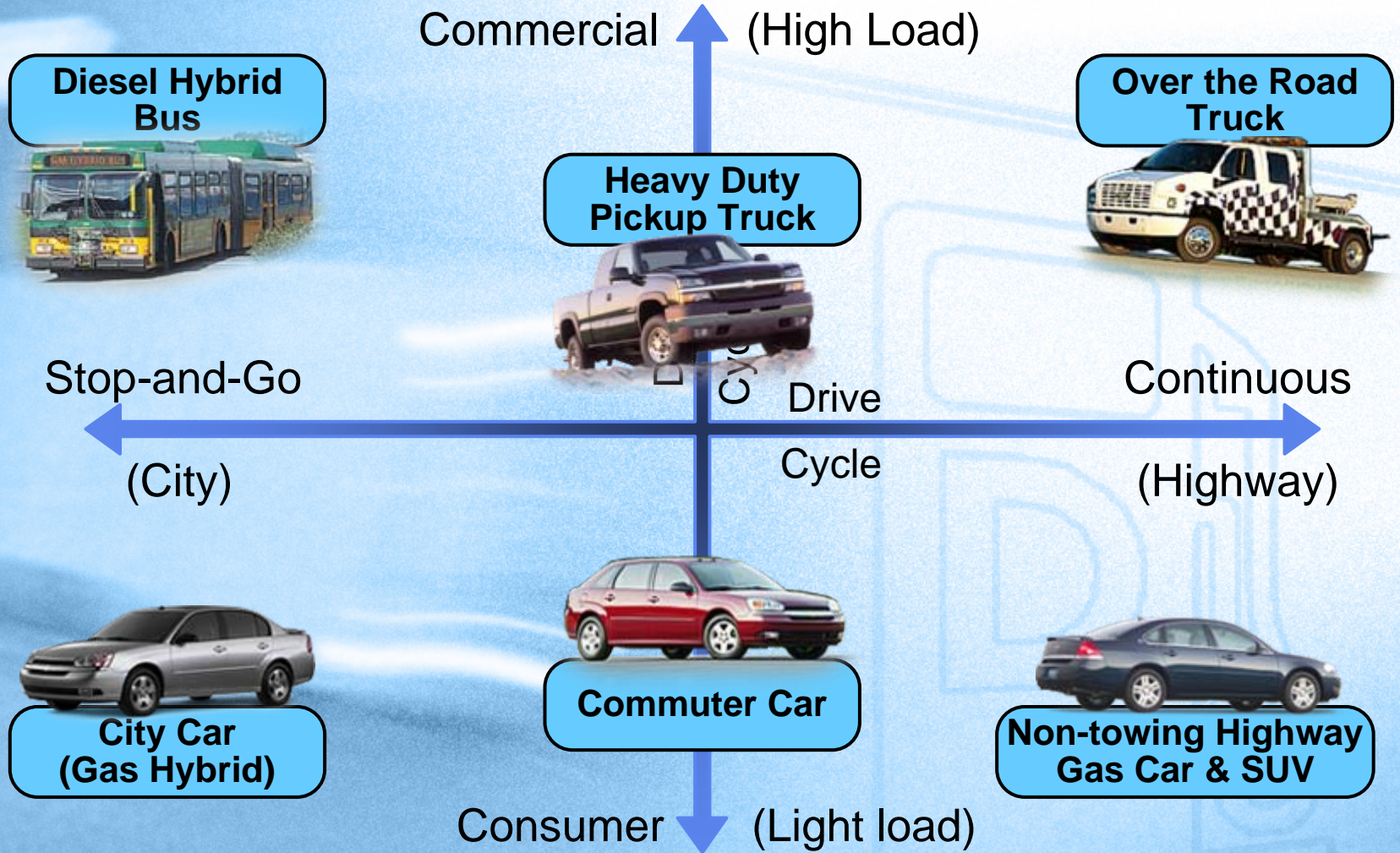
Consumer (Light load)



# Propulsion Application Map



# Propulsion Application Map



# Where to Use Diesels?

- European light duty vehicles (near 50%)
- Heavy duty Class 7 & 8 trucks for cargo hauling
- Heavy duty diesel hybrid buses
- Asia-Pacific
  - Korea, India, & potentially China are growing markets)
  - Strong diesel bias in Korean SUV market (over 90% diesel)
- North America
  - First introduced diesel engines in larger vehicles
  - Consumer recovery of additional financial investment
  - Utility applications
  - Towing & hauling



# European Diesel Passenger Car Market



Originally  
displacement driven



Now fun to drive &  
gasoline-like

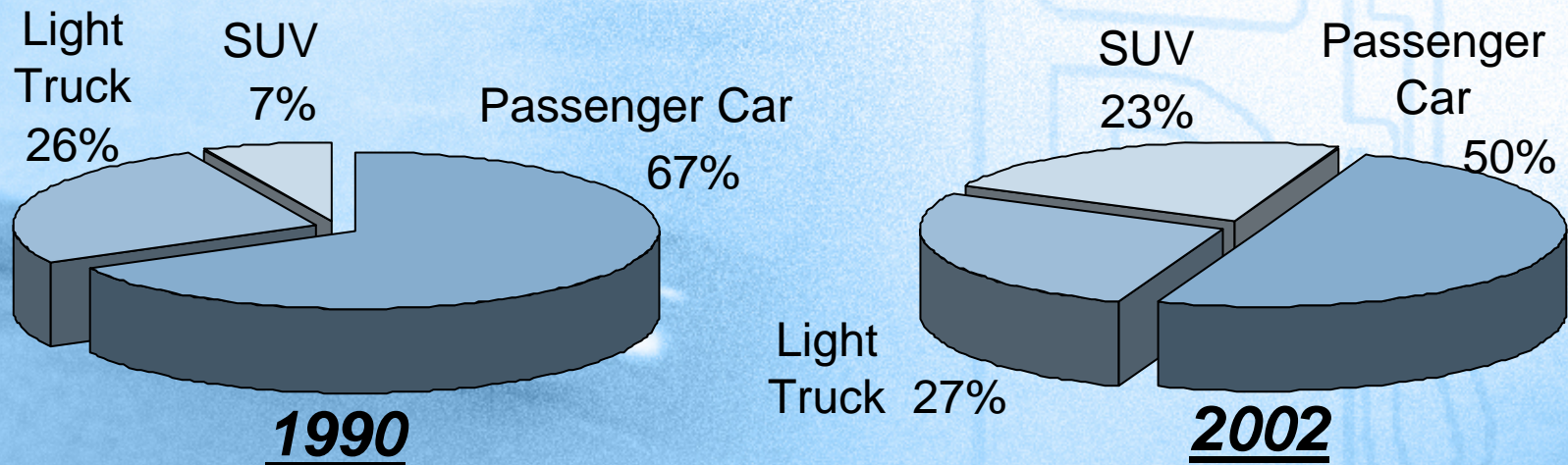




# North American Vehicle Sales Mix

## Light Duty Truck & Sport Utility Vehicles (SUV) Gain Share

- U.S. vehicle market share:
  - Passenger car volumes have declined
  - Light duty trucks & SUVs gained relative market share
- Light truck share will remain high for foreseeable future



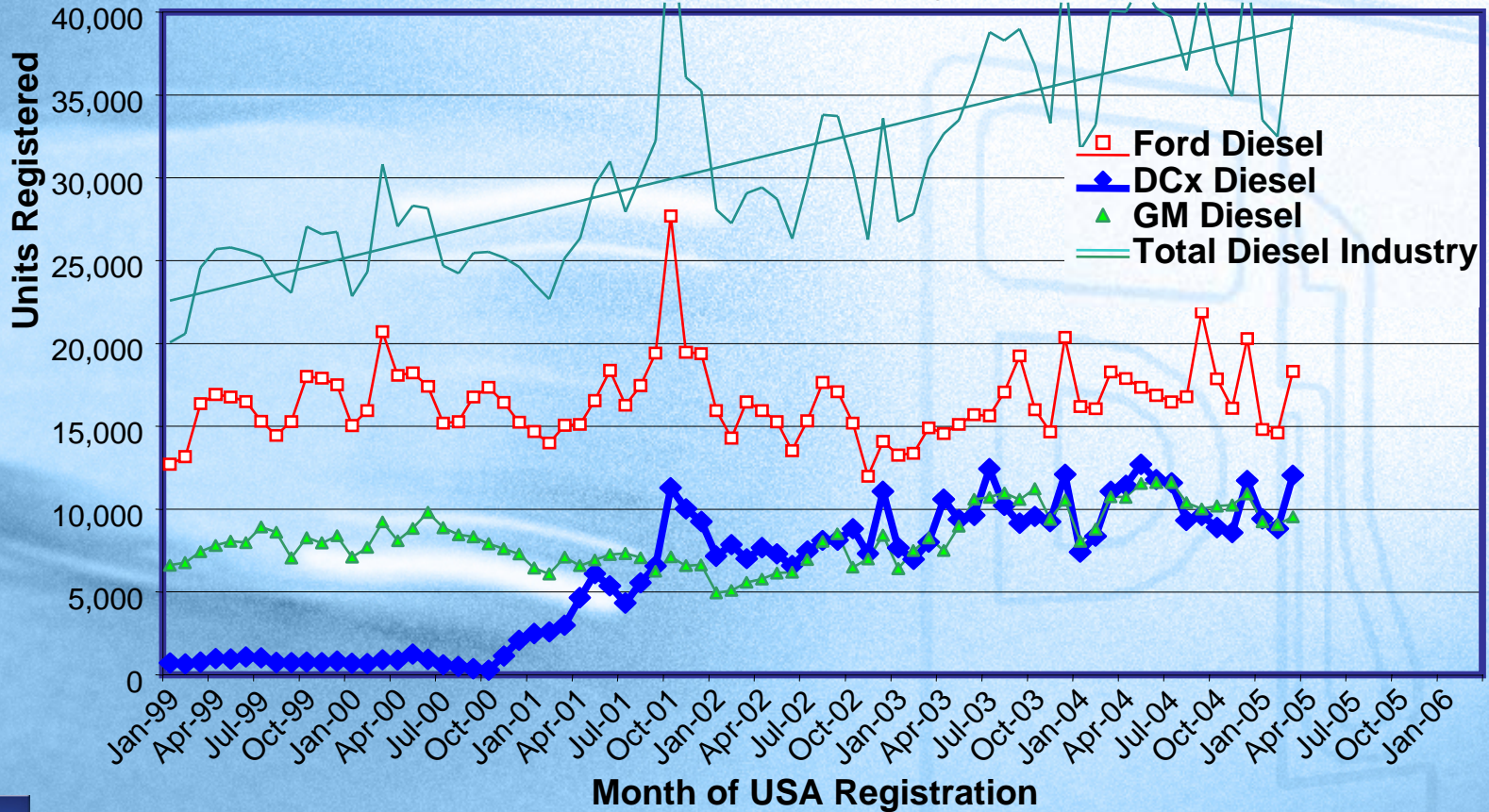
# Heavy Duty Duramax Applications



# North American Growth

## North American Heavy Duty Pickup Truck Market (3/4 & 1 Ton)

3/4 and 1-ton Full Size Truck Volume by Manufacturer – Diesel Only

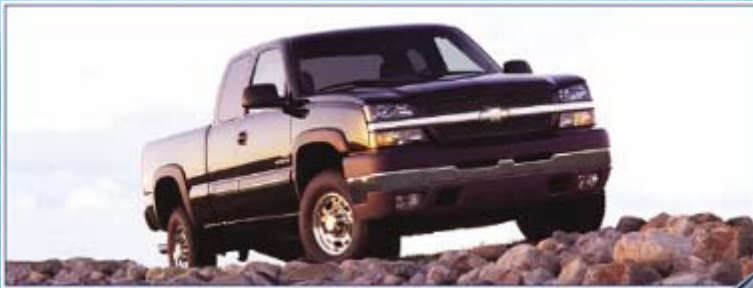


# Heavy Duty Duramax Applications



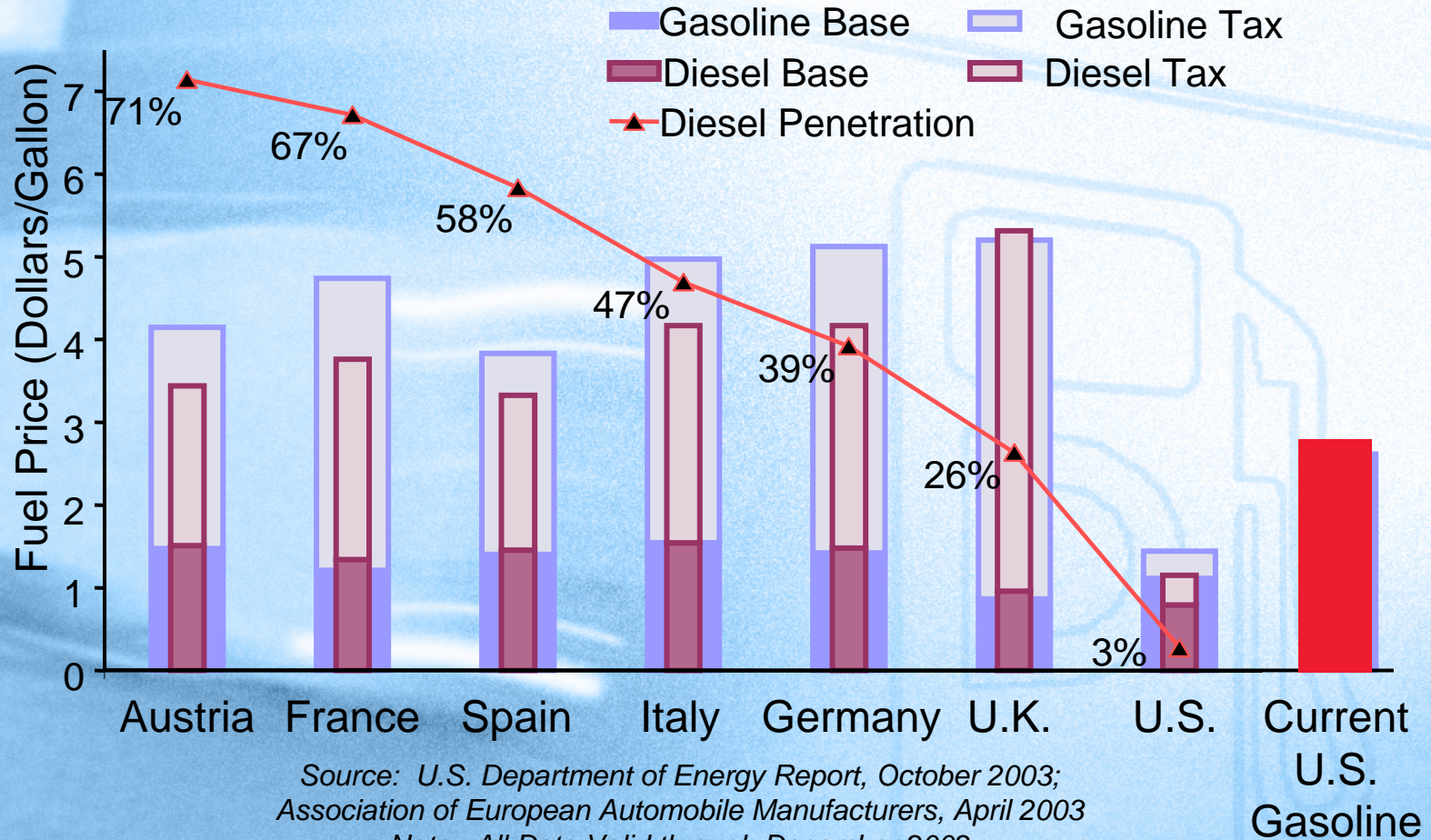
# Why Use Diesels?

- Heavy duty towing & hauling (high load advantage is greater)
- Satisfy fuel economy improvement objectives
  - Positive influence on CO<sub>2</sub> & CAFE
  - Real world fuel economy improvement – a robust solution
- Improve vehicle performance with lower displacement engine
  - Fun to drive
- Achieve benefit of tax incentives in European markets



# Economic Model – Fuel Price as an Influence

## Comparison between U.S. & Europe

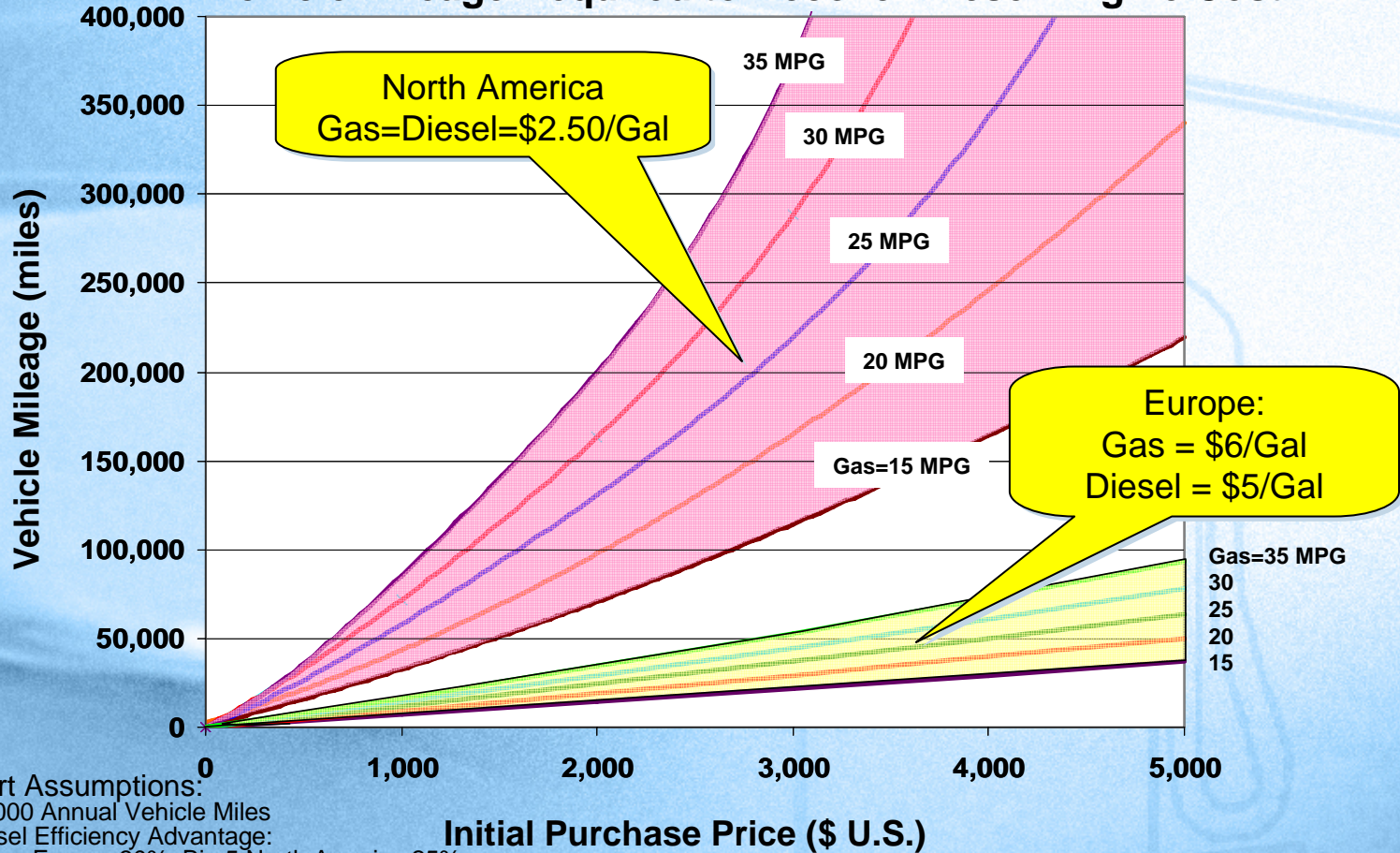


Source: U.S. Department of Energy Report, October 2003;  
Association of European Automobile Manufacturers, April 2003  
Note: All Data Valid through December 2002  
Correlation with fuel price:  $R^2=0.61$



# Economic Model

## Comparison between U.S. and Europe – Diesel Break-Even Point



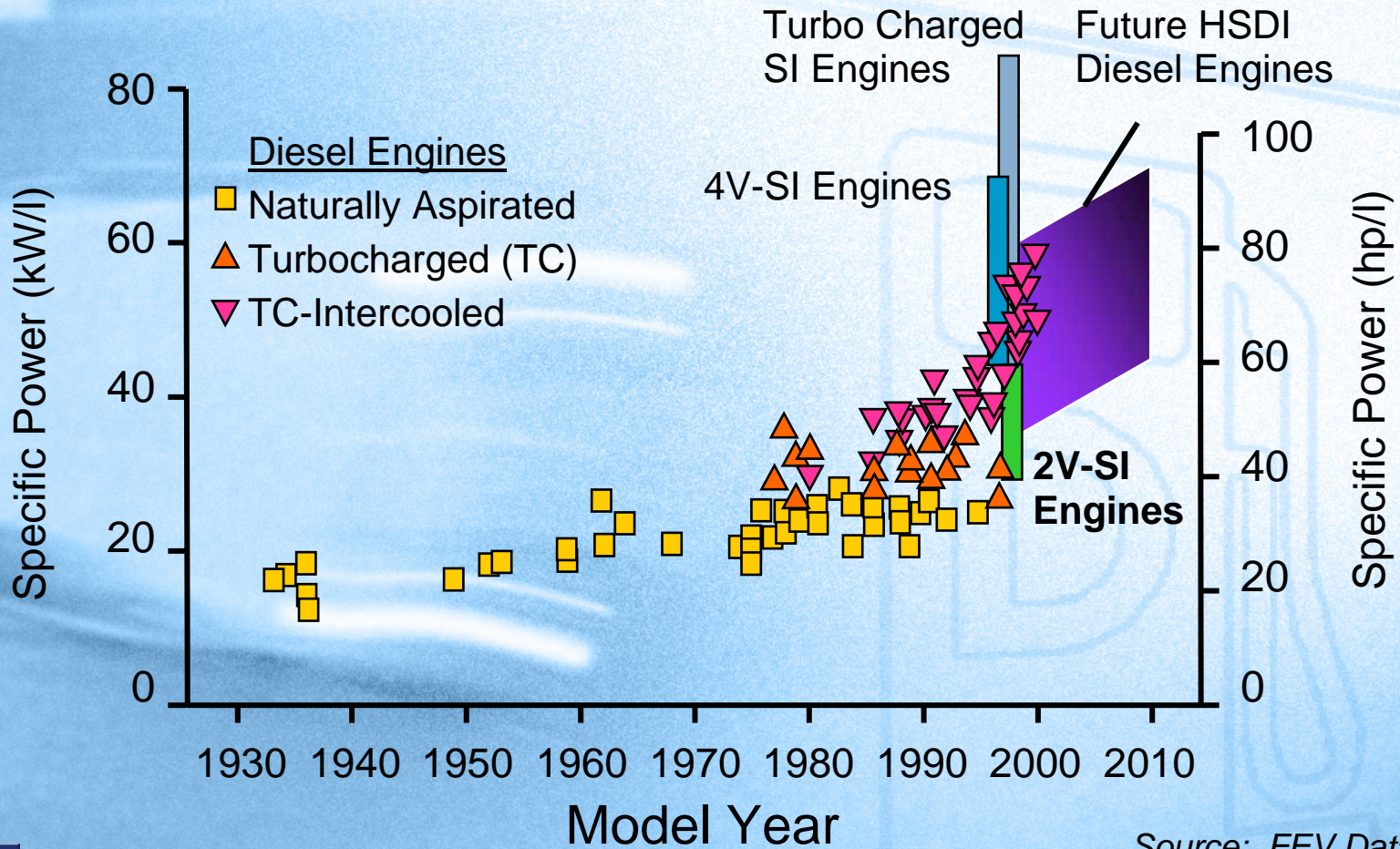
### Chart Assumptions:

- 20,000 Annual Vehicle Miles
- Diesel Efficiency Advantage:  
Europe 30%, Bin 5 North America 25%
- 6% Annual Finance Rate Available



# Diesel Engine Technology Trends – Europe

Benchmark trends to help predict requirements



Source: FEV Data



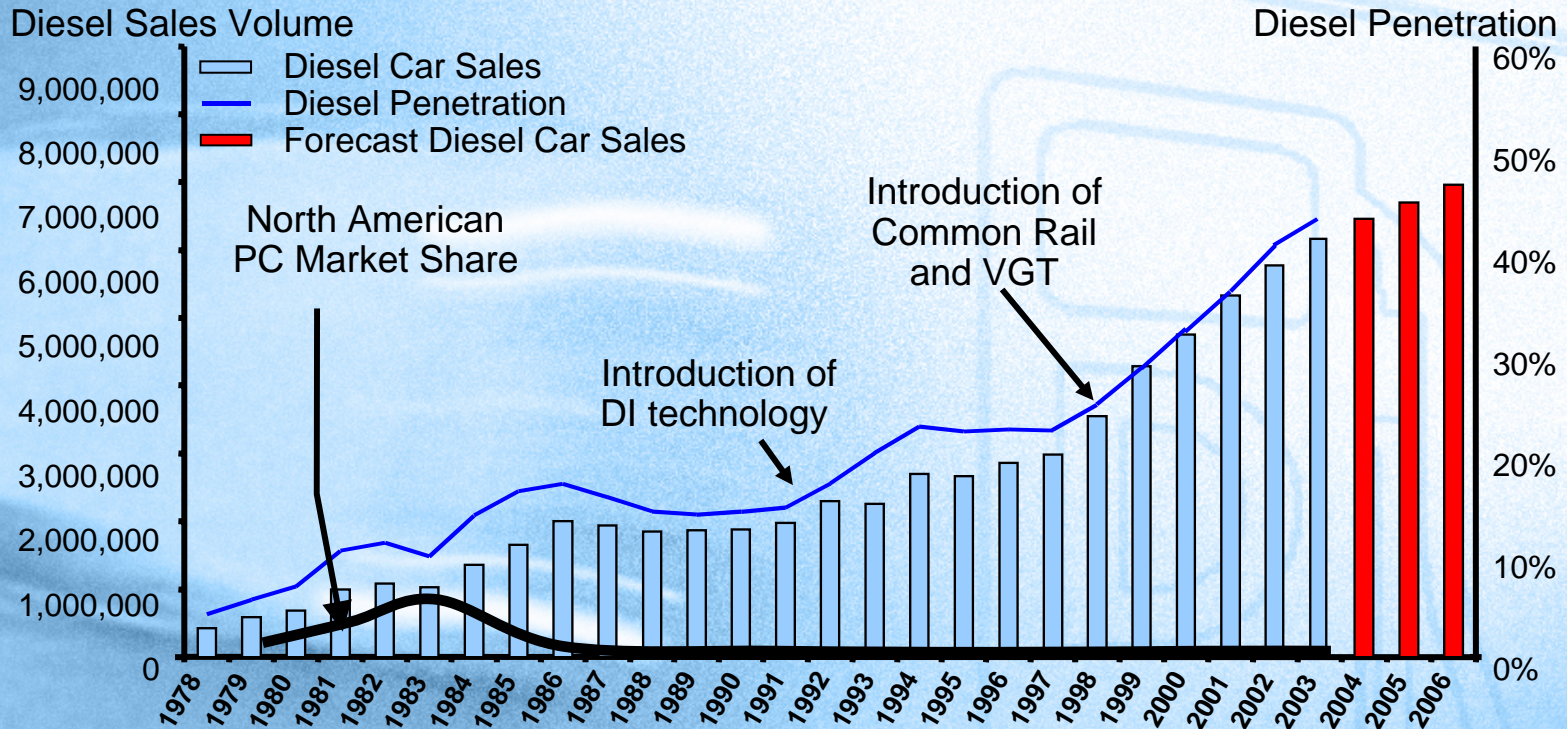


# Diesel Growth

## Western Europe & North America

### Western Europe

Ricardo Forecast Diesel Passenger Car Sales & Market Penetration to 2006

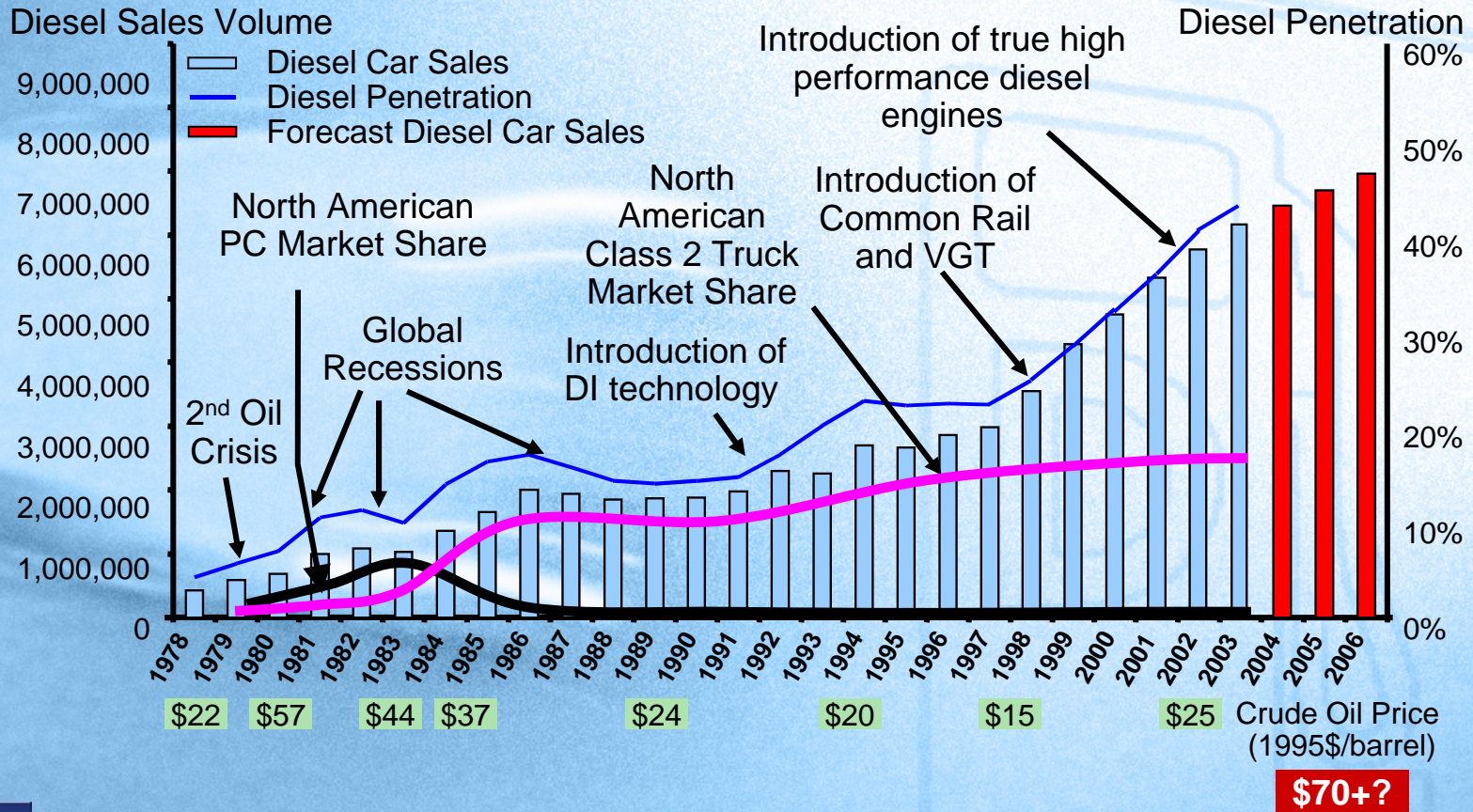


# Diesel Growth

## Western Europe & North America

### Western Europe

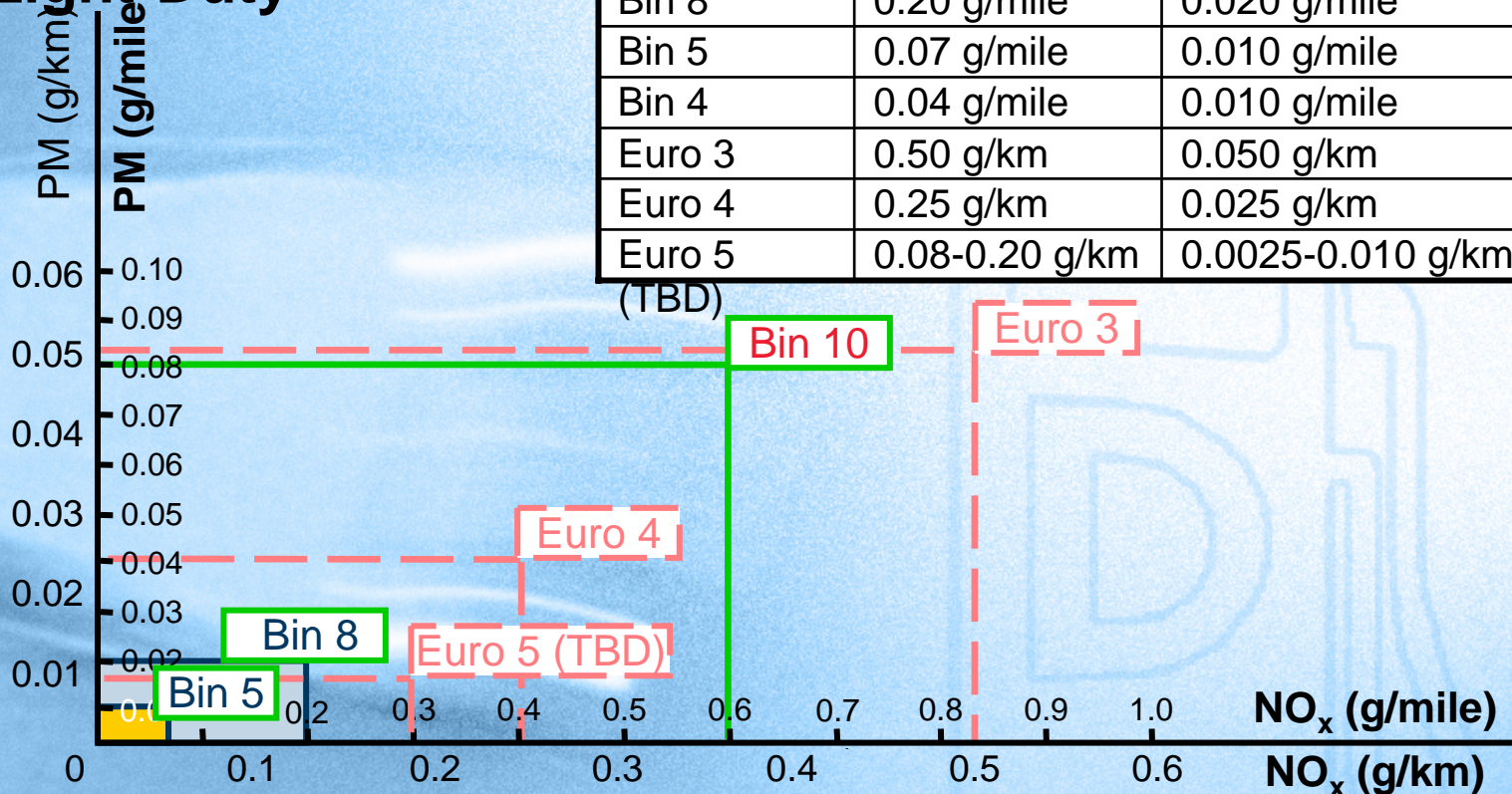
Ricardo Forecast Diesel Passenger Car Sales & Market Penetration to 2006



# Europe vs. U.S. Tier 2 FTP-75 Emissions

## Light Duty

Standard	NO <sub>x</sub>	PM
Bin 10	0.60 g/mile	0.080 g/mile
Bin 8	0.20 g/mile	0.020 g/mile
Bin 5	0.07 g/mile	0.010 g/mile
Bin 4	0.04 g/mile	0.010 g/mile
Euro 3	0.50 g/km	0.050 g/km
Euro 4	0.25 g/km	0.025 g/km
Euro 5	0.08-0.20 g/km	0.0025-0.010 g/km



$$\text{Emission (g/mile)} = \text{Emission Index (g/kg fuel)} \times \text{Fuel Consumption (kg fuel/mile)}$$



# Global Emissions (Europe vs. U.S. Applications)

## Light-Duty



1.7L I-4



Opel Astra



6.6L V-8



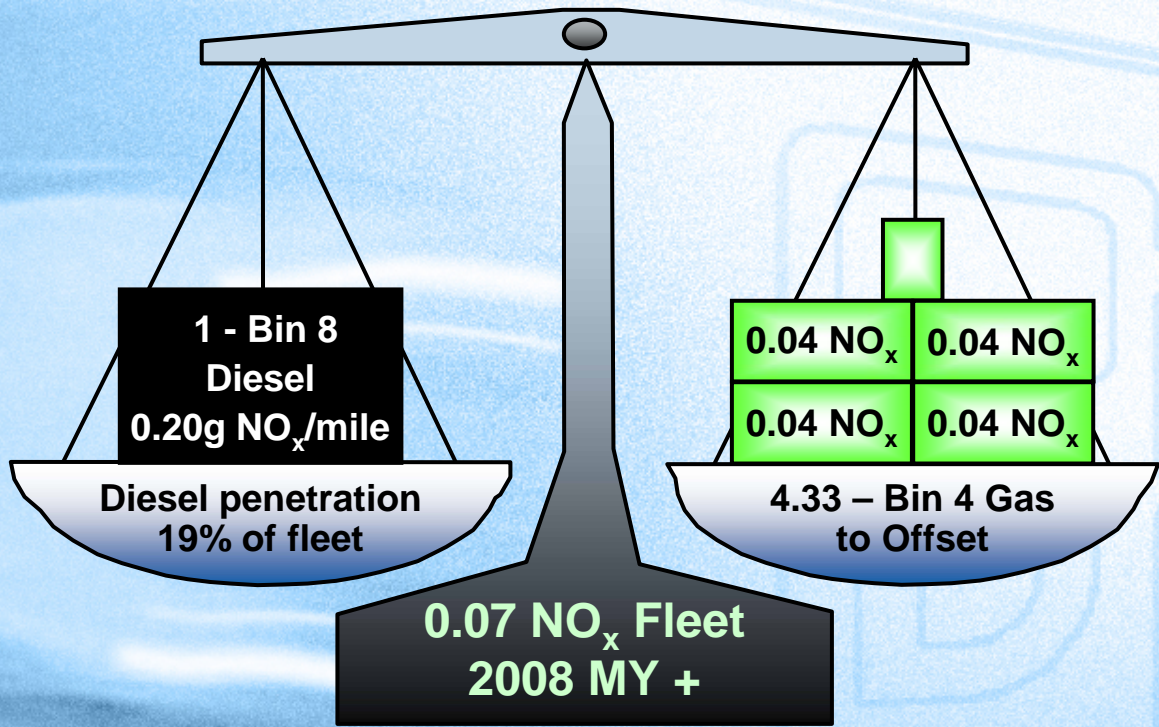
Chevrolet Silverado



# Offsetting Diesel NO<sub>x</sub> Emissions – Tier

## 2

### Option 1 – Bin 4 offset



Moving to a lower bin adds incremental cost to gasoline off-set vehicles



# FTP-75 versus US-06 Drive Cycles

FTP-75 & NEDC are similar

- Produce similar emissions

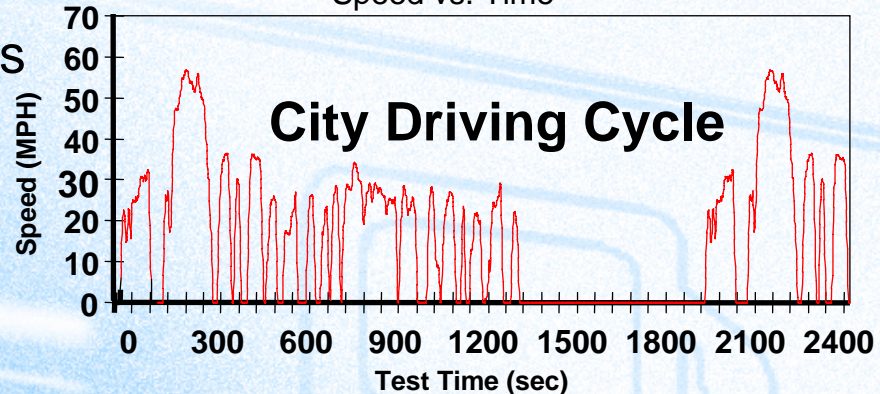
Supplemental FTP (SFTP) includes:

- US-06
- SC-03 (accessory load)

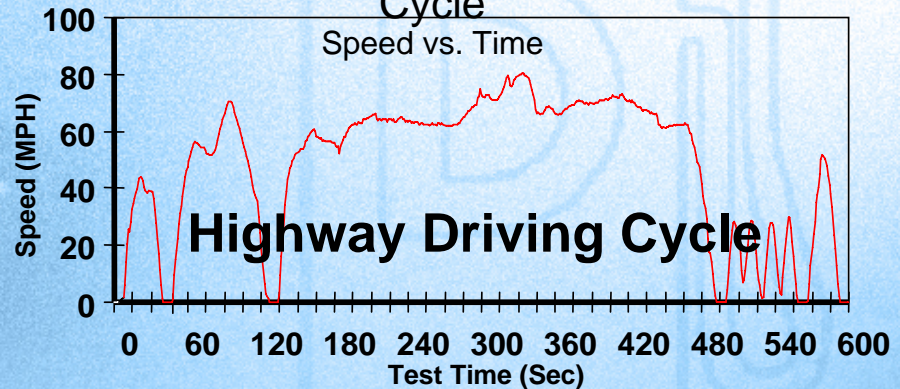
US06 is more challenging

- US-only
- Higher load
- Higher speed
- Higher  $\text{NO}_x$
- 50% to 150% more  $\text{NO}_x$  than FTP-75

FTP Emissions Test Driving Cycle  
Speed vs. Time



US06 Aggressive Driving Emissions Test Cycle  
Speed vs. Time




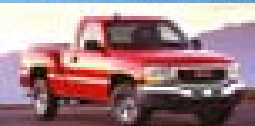


NEDC = New European Drive Cycle



# Light Duty Supplemental Emissions Test Cycles

## US-06 Emissions Limits versus FTP-75

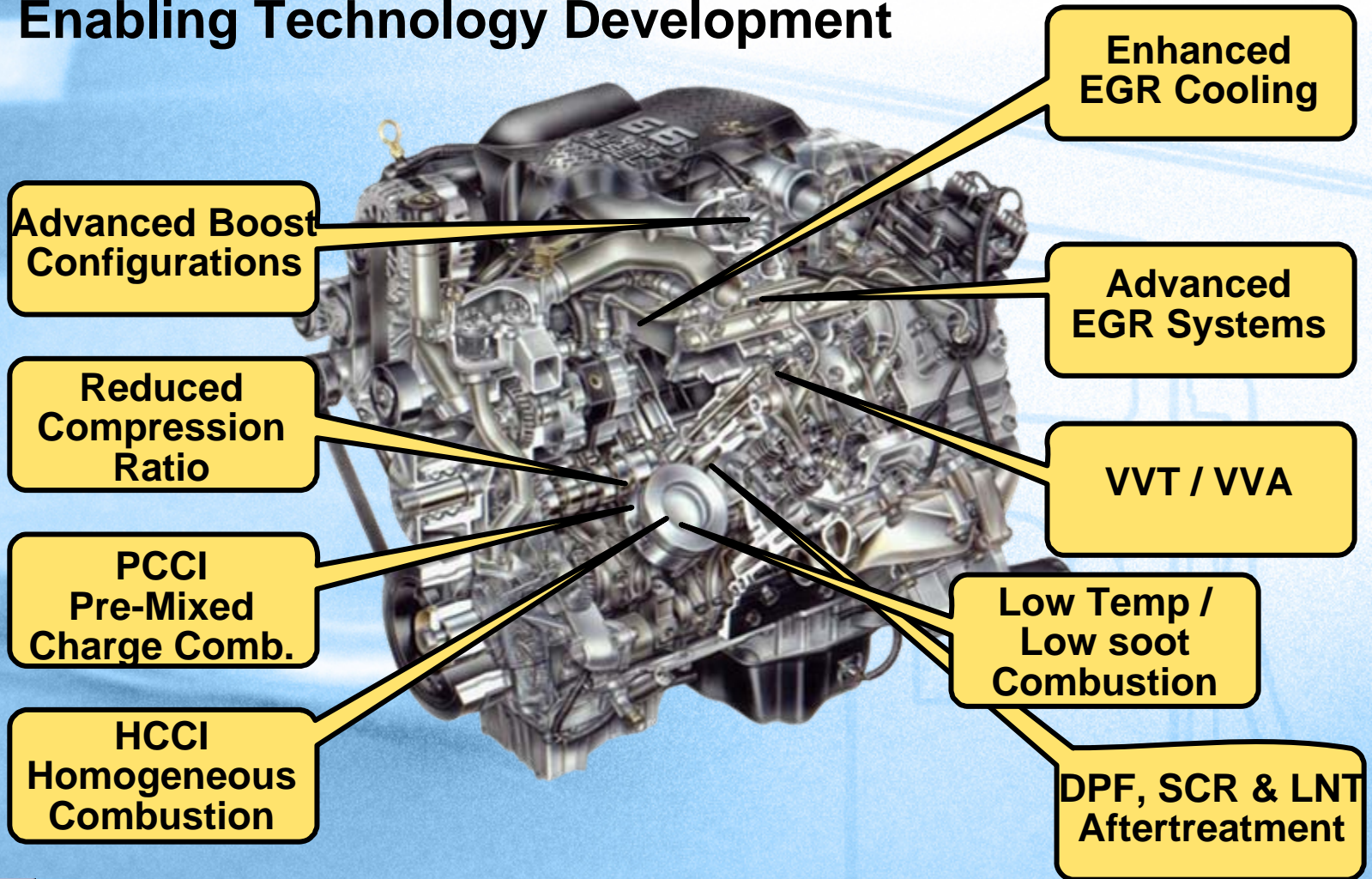
	US-06 NMHC+NO <sub>x</sub>	FTP Bin 8 (@120K) NMHC+NO <sub>x</sub>	FTP Bin 5 (@120K) NMHC+NO <sub>x</sub>
PC/LDT1 	0.140 g/mile	0.325	0.160
LDT2 	0.250	0.325	0.160
LDT3 	0.400	0.325	0.160
LDT4 	0.600	0.325	0.160

More difficult US-06 test has lower standard than FTP



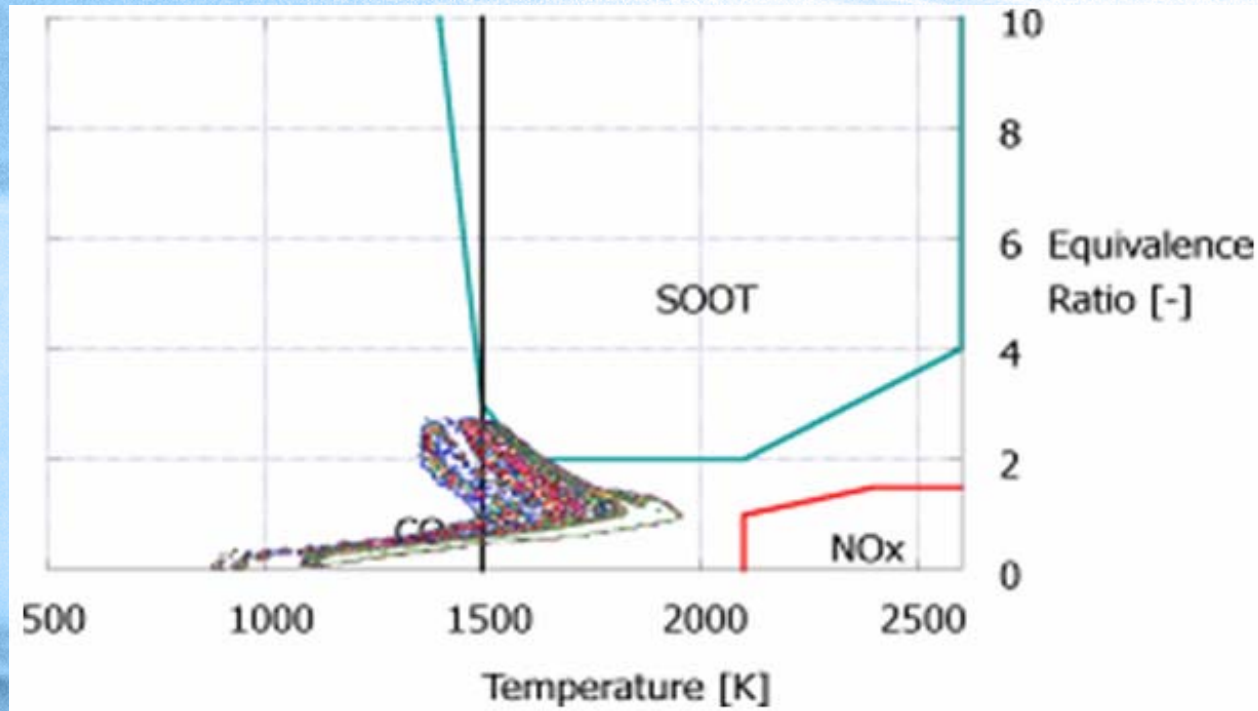
# Diesel Engine

## Enabling Technology Development



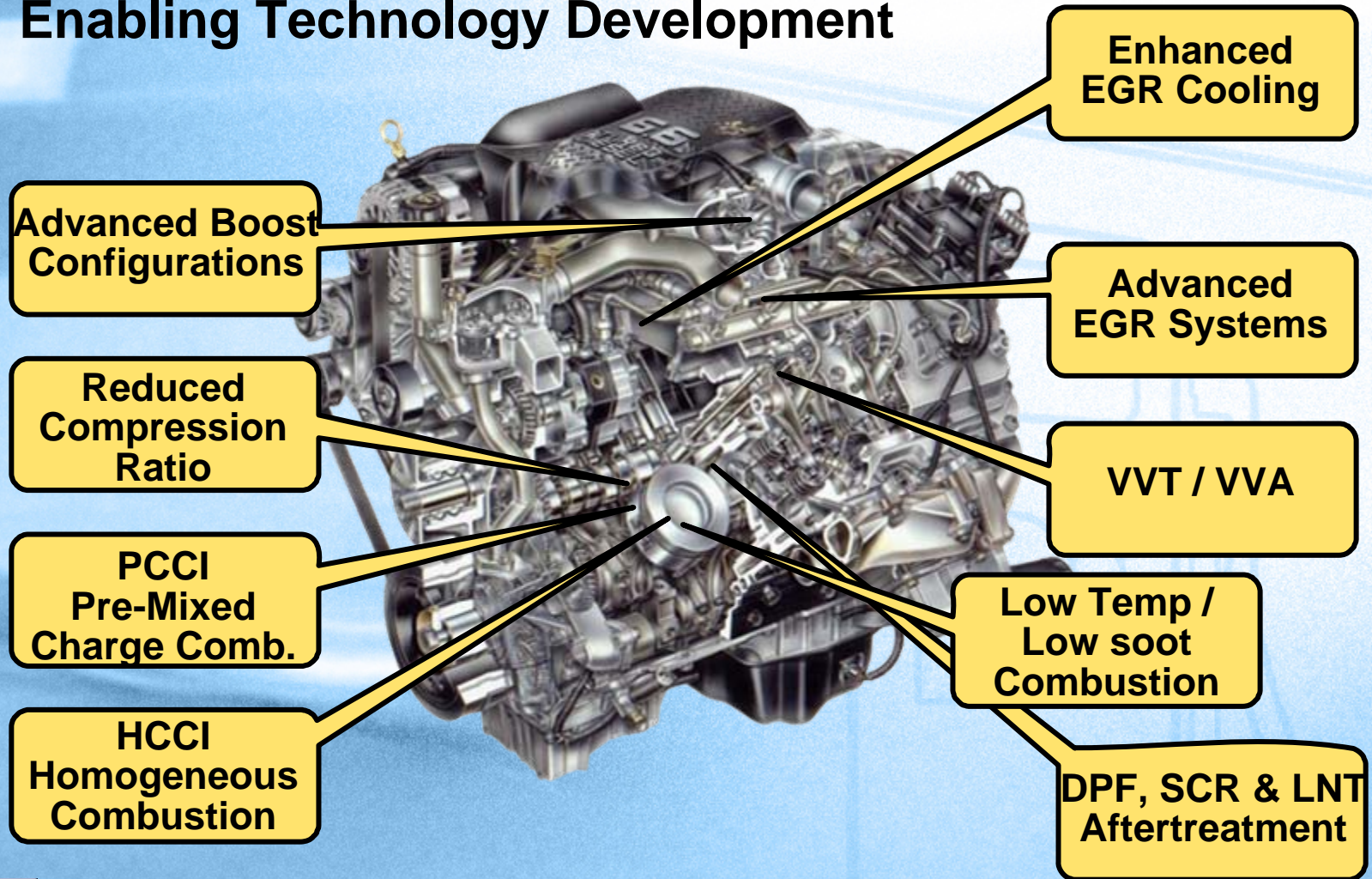


# PCCI Combustion

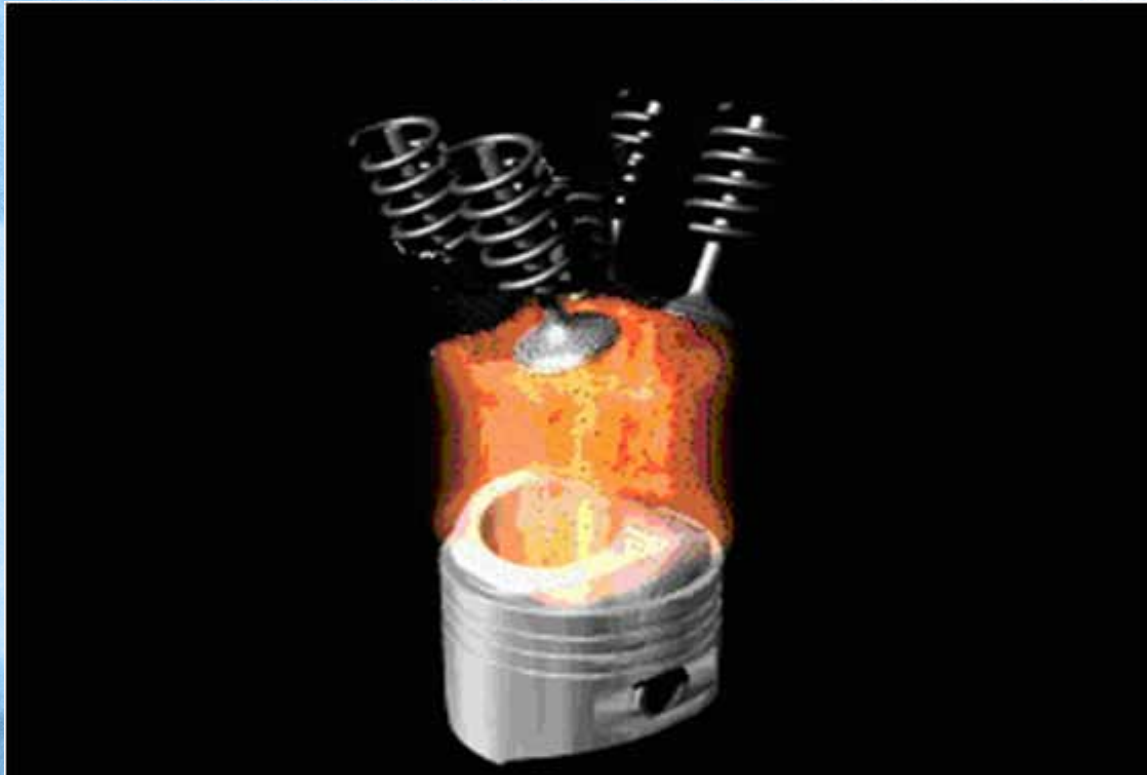


# Diesel Engine

## Enabling Technology Development

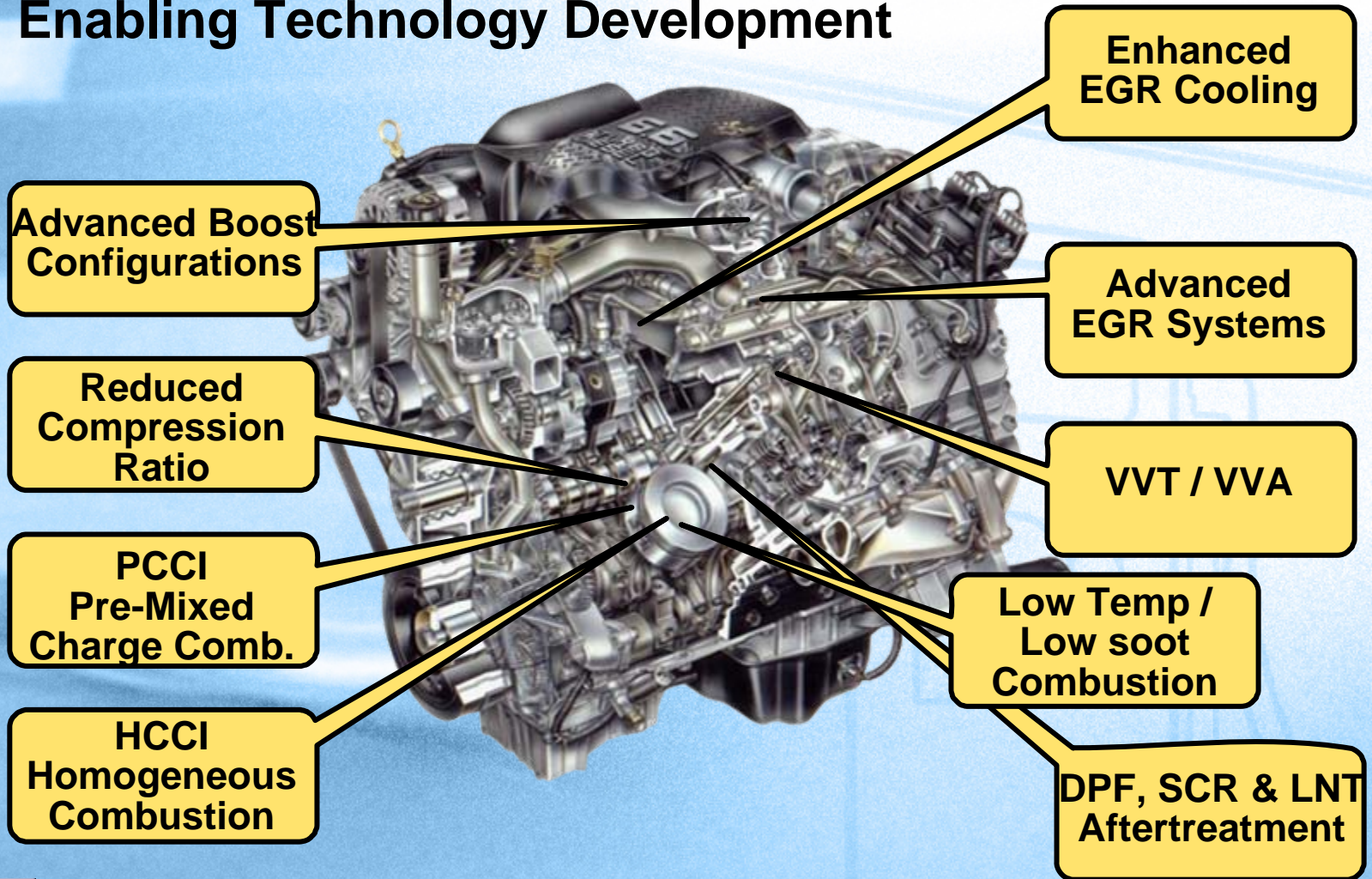


# Homogeneous Charge Compression Ignition (convergence of gasoline and diesel technologies)



# Diesel Engine

## Enabling Technology Development

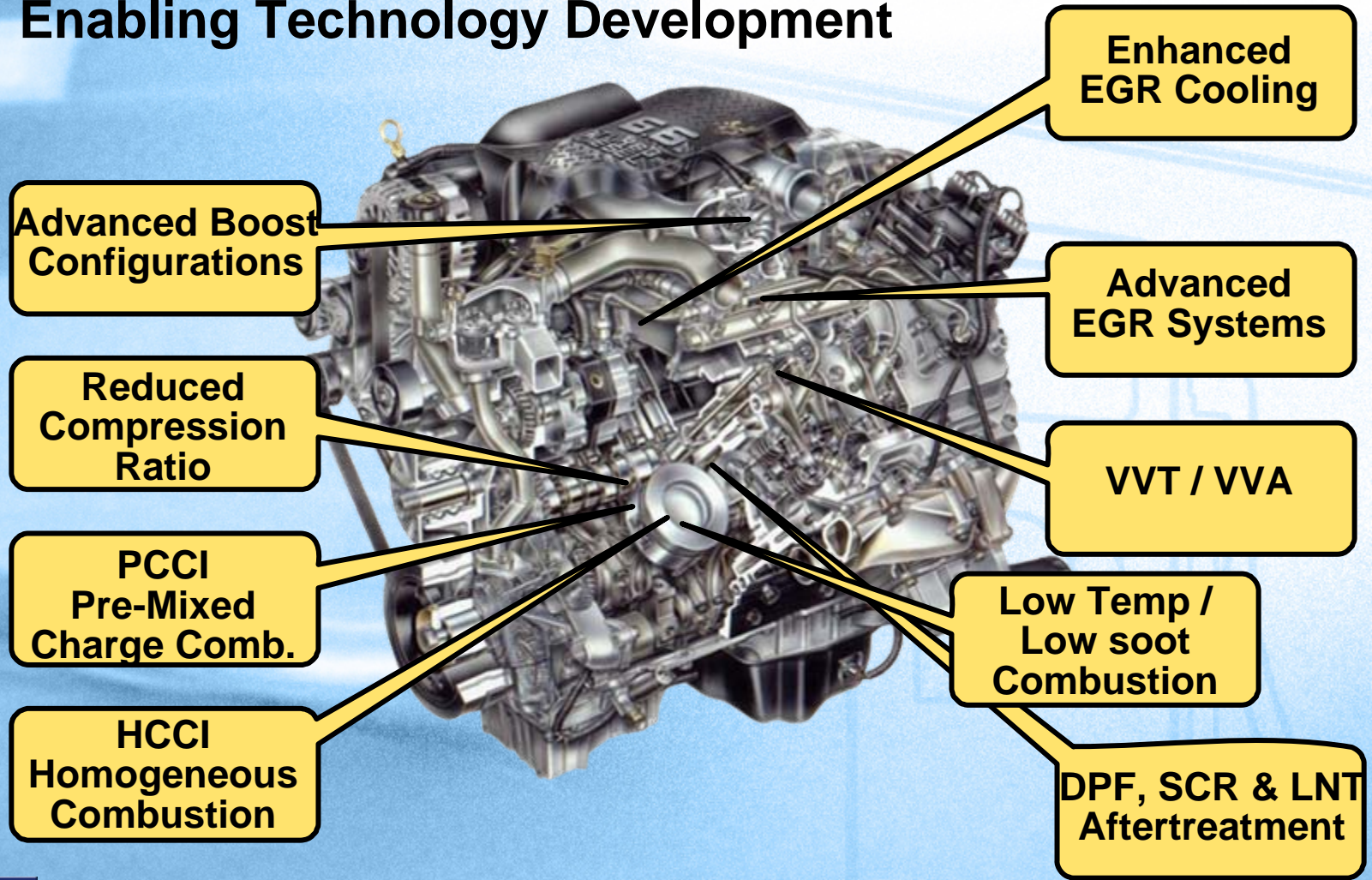


# Advanced EGR Cooling

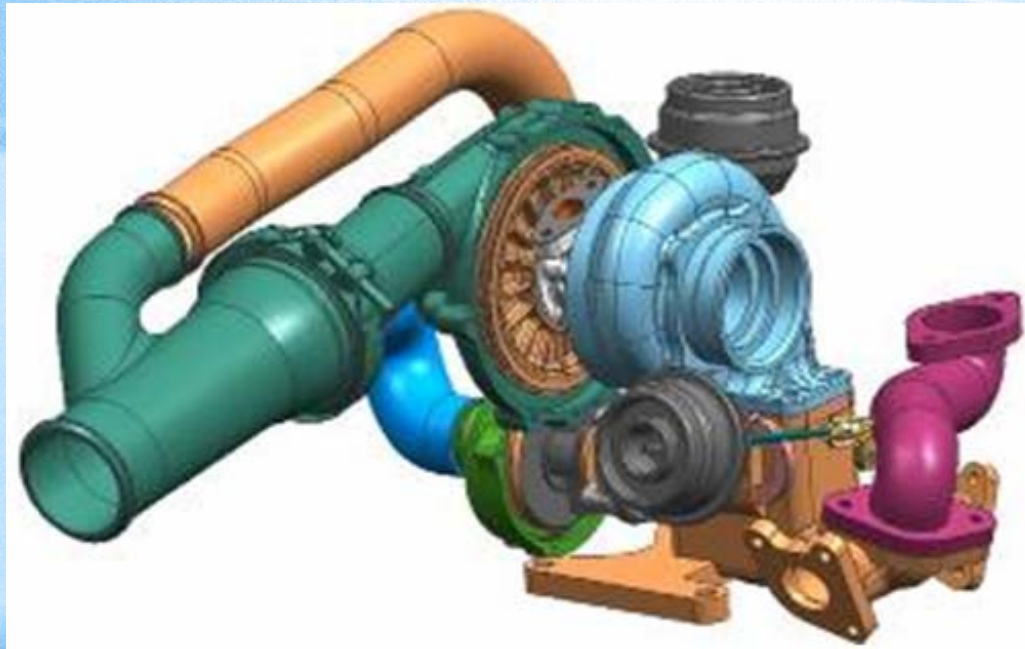


# Diesel Engine

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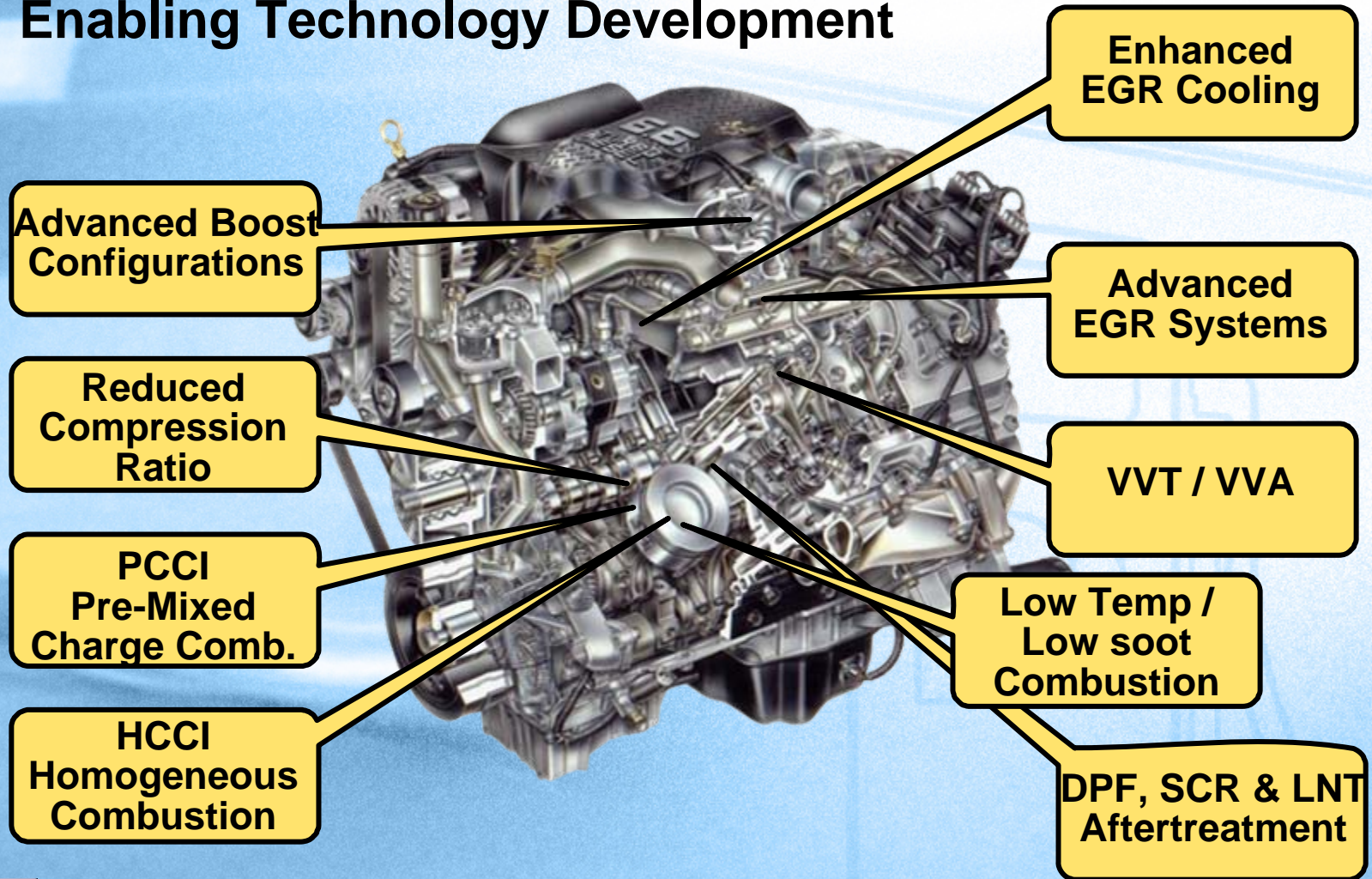


# Advanced Boosting



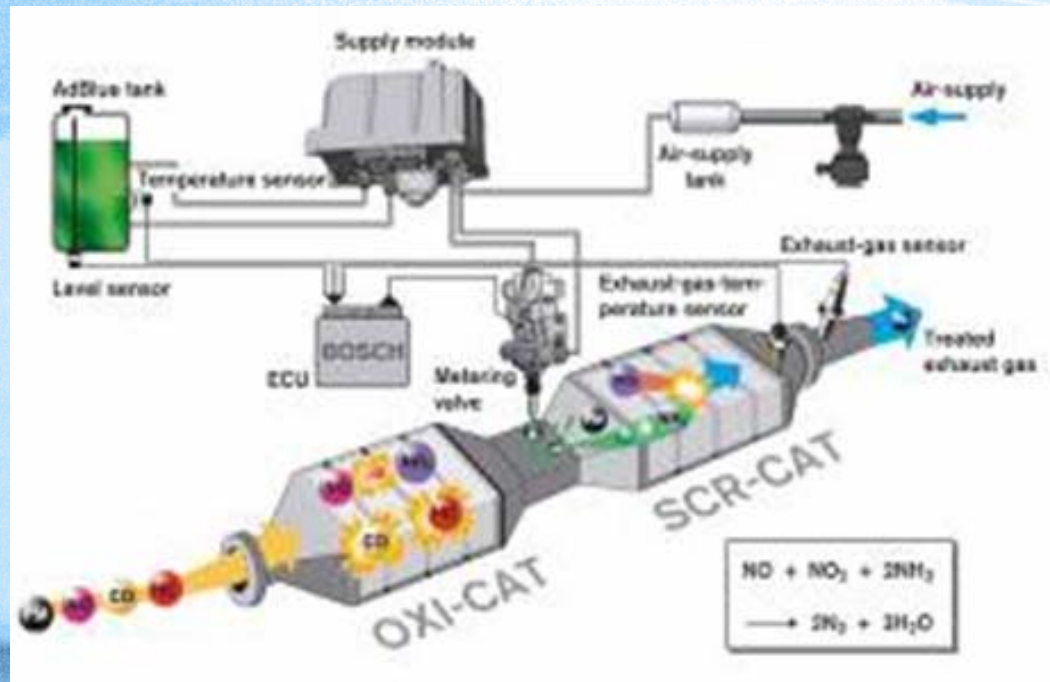
# Diesel Engine

## Enabling Technology Development



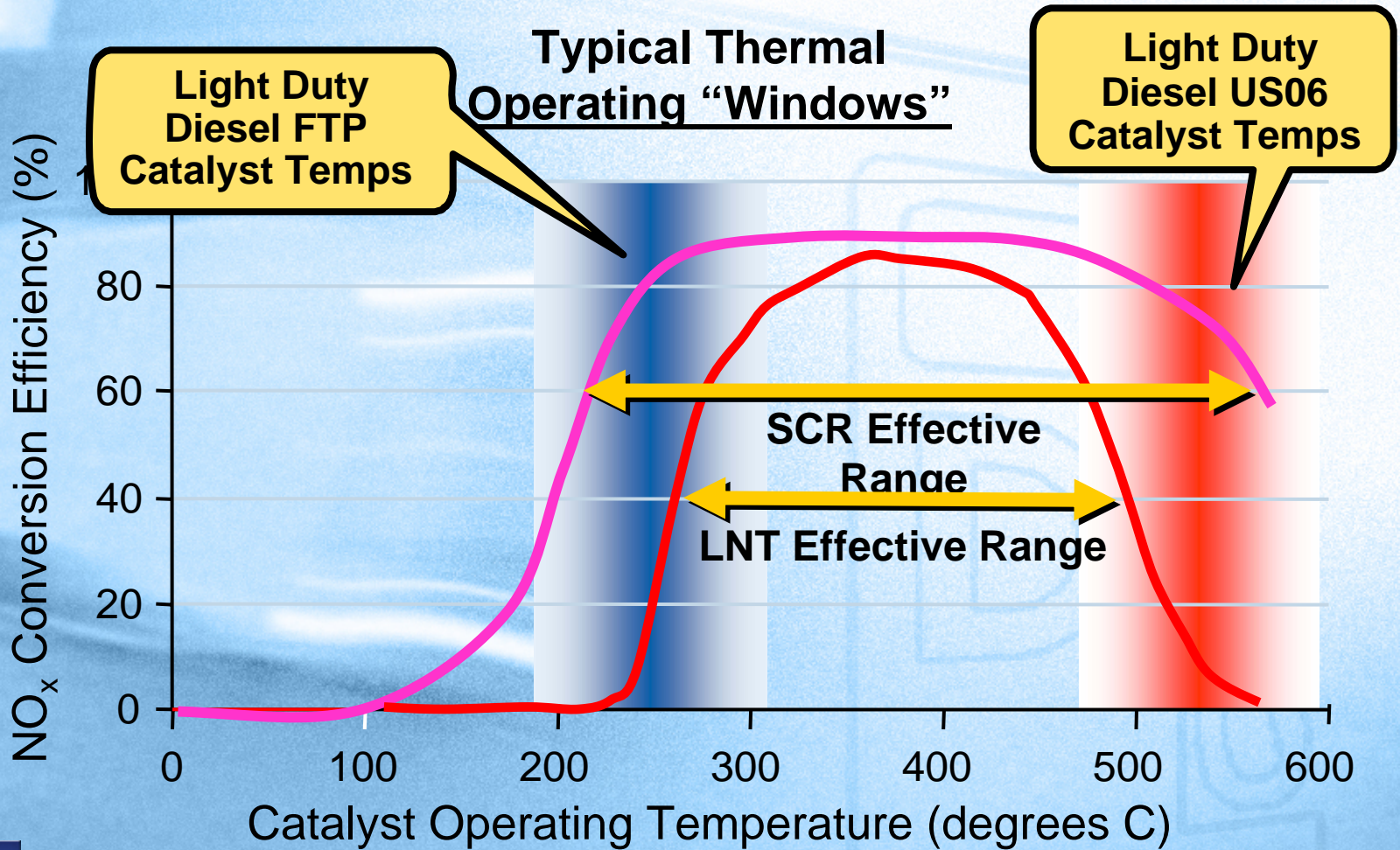


# NOx Aftertreatment



# Aftertreatment Systems

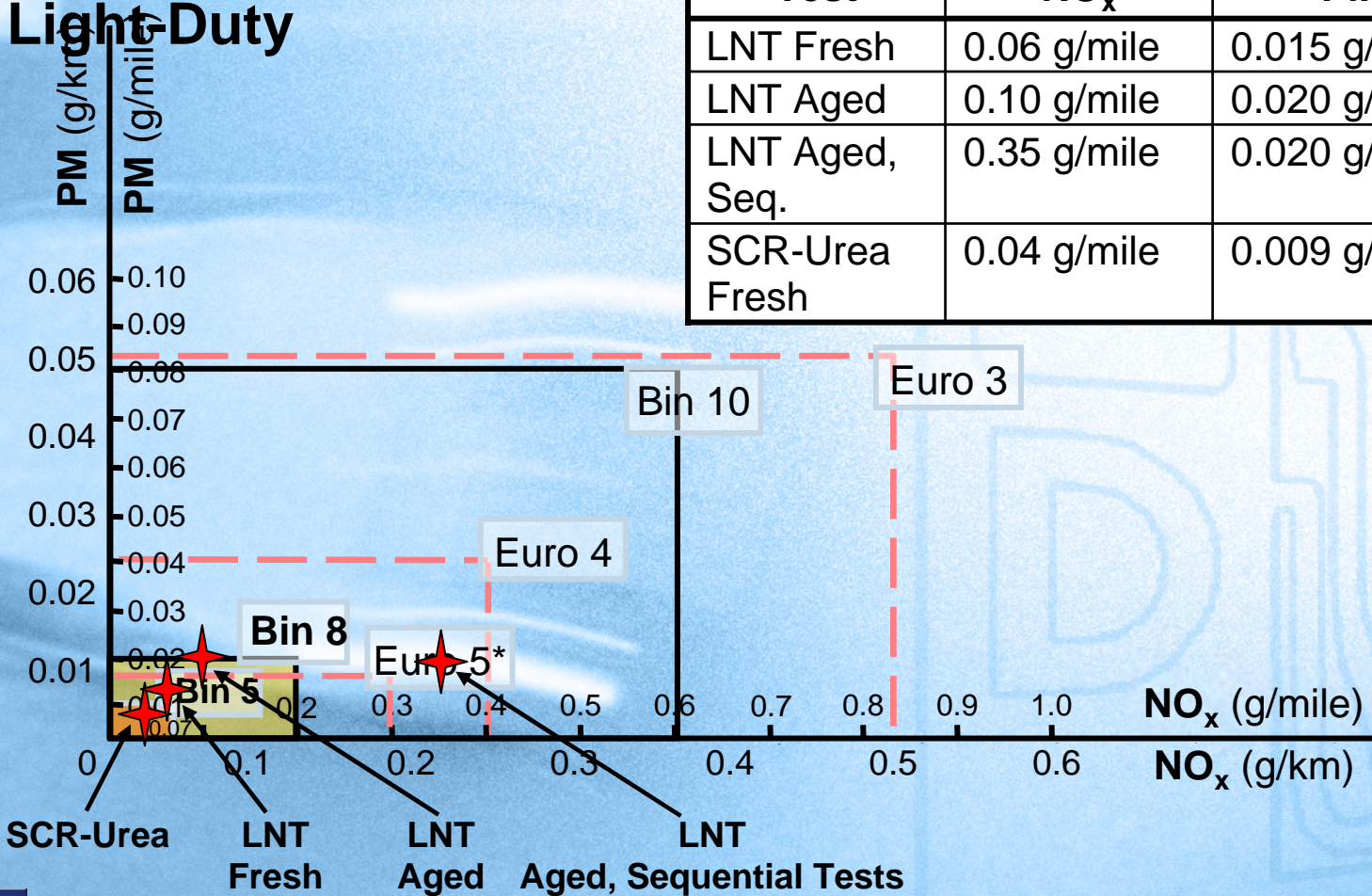
## Balancing the requirements of FTP with US06



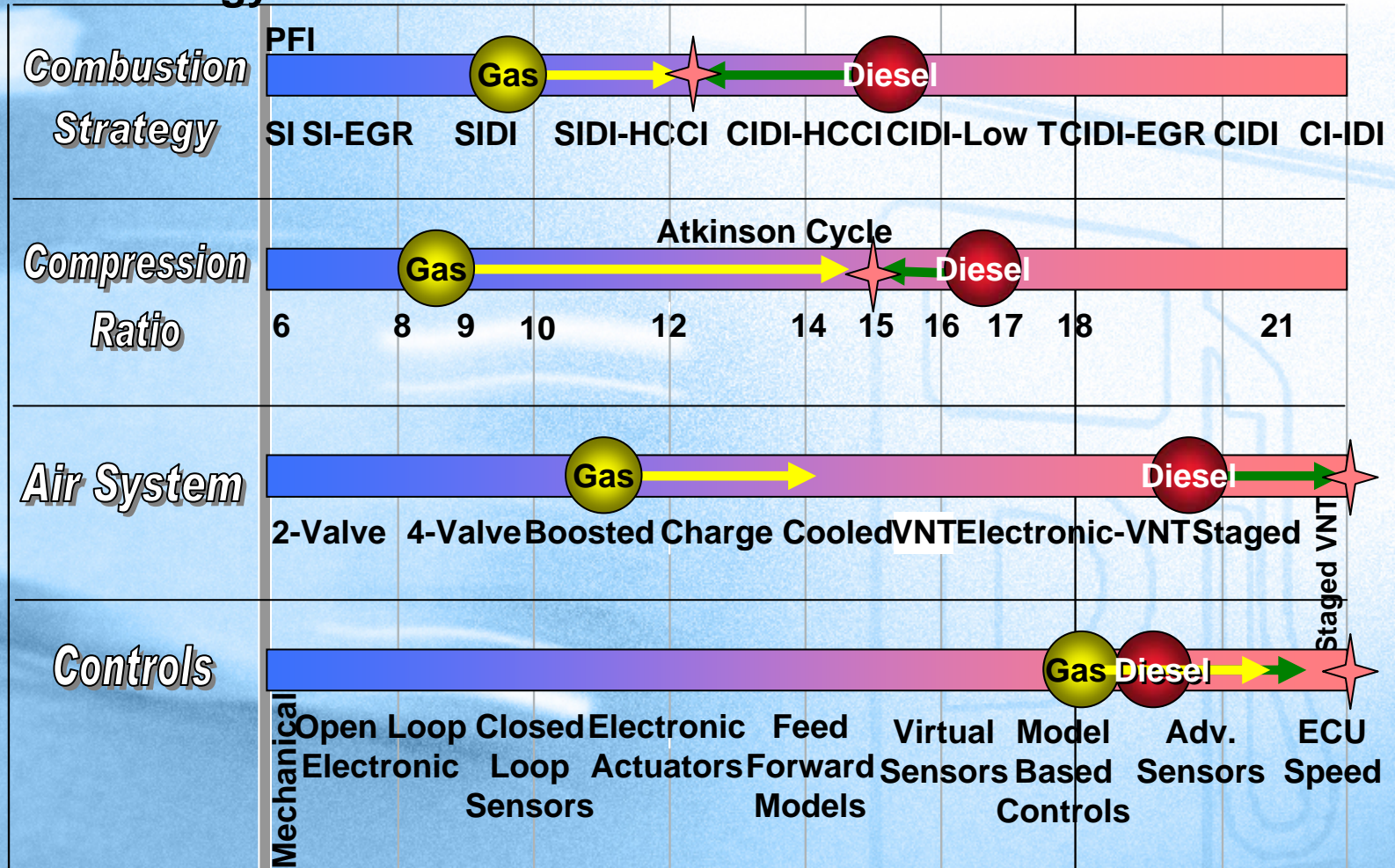
# European versus U.S. Tier 2 FTP-75 Emissions

## Light Duty

Test	NO <sub>x</sub>	PM
LNT Fresh	0.06 g/mile	0.015 g/mile
LNT Aged	0.10 g/mile	0.020 g/mile
LNT Aged, Seq.	0.35 g/mile	0.020 g/mile
SCR-Urea Fresh	0.04 g/mile	0.009 g/mile



# Internal Combustion Engine (ICE) Technology Continuum



# Summary

## Advanced Propulsion Solutions

- Portfolio approach is required for advanced powertrain strategies
  - Market, vehicle, & customer requirements influence powertrain usage
- Diesel engines are critical to GM's global product portfolio
- Emission regulations, fuel price, taxation based on engine displacement and fuel consumption largely dictate markets where diesels are popular today
  - Voluntary 140 g/km CO<sub>2</sub> commitment is a European driver
- Increased fuel prices may encourage additional diesel penetration



# Summary

## Technology Driven Trends

- Diesel technological advancements over past 15 years have radically changed public perception of diesels
  - High performance (torque)
  - Fun to drive
  - Refined
  - Significant penetration in European luxury vehicle segments
- Diesel & gasoline technologies are converging
  - boost, direct injection, controls, & HCCI
- Must retain fuel economy advantages while meeting new emissions standards
- Diesel must overcome cost disadvantages



# Summary

## Market Factors in North America

- GM continues to apply North American diesel engines where they maximize customer benefits:
  - Large vehicles
  - Towing & hauling utility applications
- U.S. market, with its larger vehicles, could benefit from diesel technology introduction
- Growing large truck diesel market share implies improved U.S. consumer acceptance of diesel engines
- Must address North American NO<sub>x</sub> standards (one sixth that of Europe) at an acceptable cost







# Diesel Powertrain Technology

## Advantages

- Improved high load fuel economy versus alternatives
- Improved low speed torque capacity
- Consistent performance
  - Robust fuel economy advantages are relatively insensitive to driving cycle
  - Consistent utility attributes (gradeability, altitude performance)
- Fun to drive (even with small displacement powertrains)
- Image powertrain for utility vehicles (customer willing to pay premium)
- Favorable taxation & fuel prices in specific markets

# Diesel Powertrain Technology

## Disadvantages

- Higher cost than gasoline alternatives
- Poor diesel fuel quality in some regions
- Emissions & NVH are more challenging than for gasoline applications