The Natural Evolution of Power

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Technology Evolution For Heavy Duty Automotive Natural Gas Engines

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Cummins Westport Inc.

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Agenda

- HD Gas Engine Development
  - Where we were
  - Where we are
  - Where do we go from here
- Areas of Interest
  - Oil control and PM
  - Fine particles
  - Hydrogen
- New Technology
- Outlook

Where we were

- In ‘92; Cummins L10G was the first HD automotive Natural Gas engine to be certified at 2.5 g NOx
- In ’95, Cummins B5.9G was the first HD Natural Gas engine employing closed loop electronic control system

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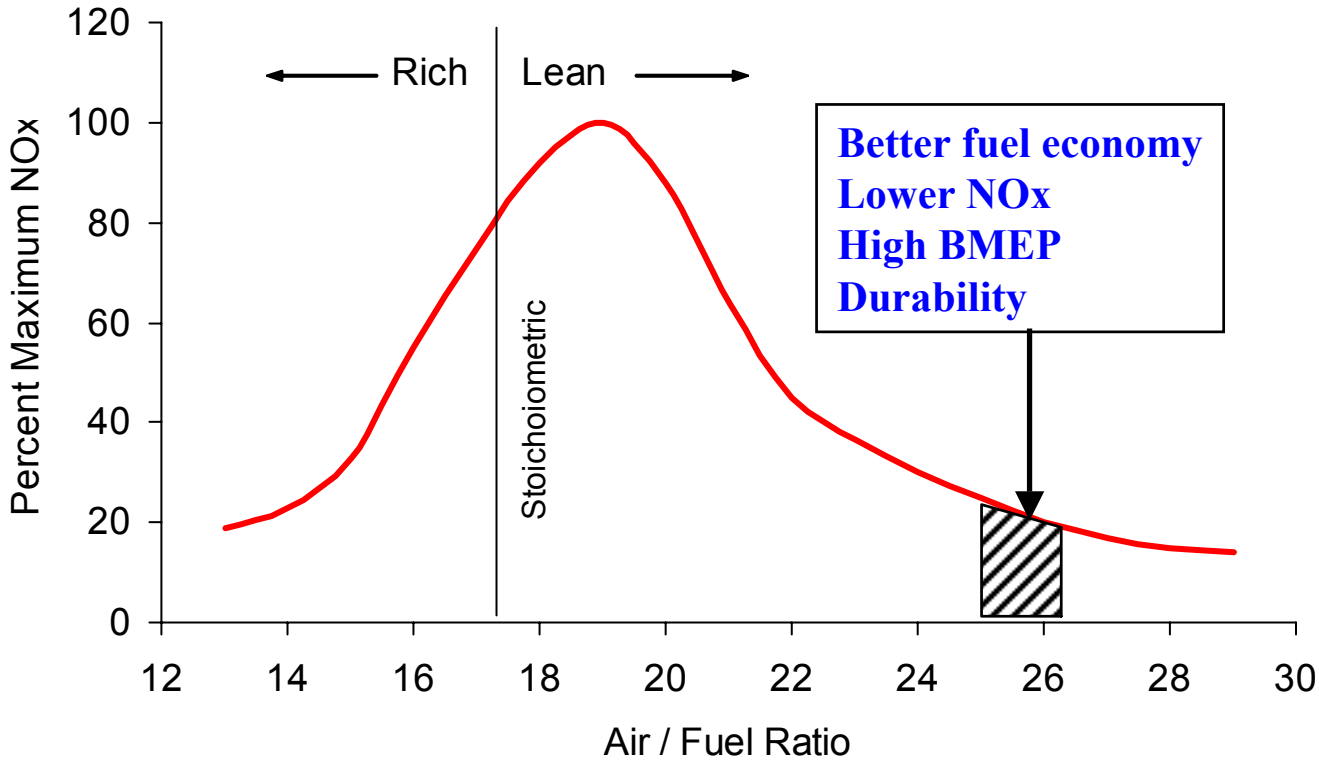
Lean Burn Combustion System



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Where we were…..

- Half diesel NOx and 10% of diesel PM
  - LBSI
  - 2-way CATs
- More products
  - Cummins C8.3G engine at 280HP
- More competitors with electronic engines

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Where we are

- Focus on Reliability
  - Closer to diesel
  - Diagnostics
- Lower Emissions
  - 1.5 g NOx
  - 0.01 PM

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Where we are ….

- Diesel emission greatly reduced
  - 2.5 g NOx
  - 0.08 g PM
- Gas engines reaching LBSI limits
  - 1.0 g NOx
  - 0.01 g PM
- Both diesel and natural gas engines are challenged to become even cleaner and more efficient to meet environmental and end-user demands

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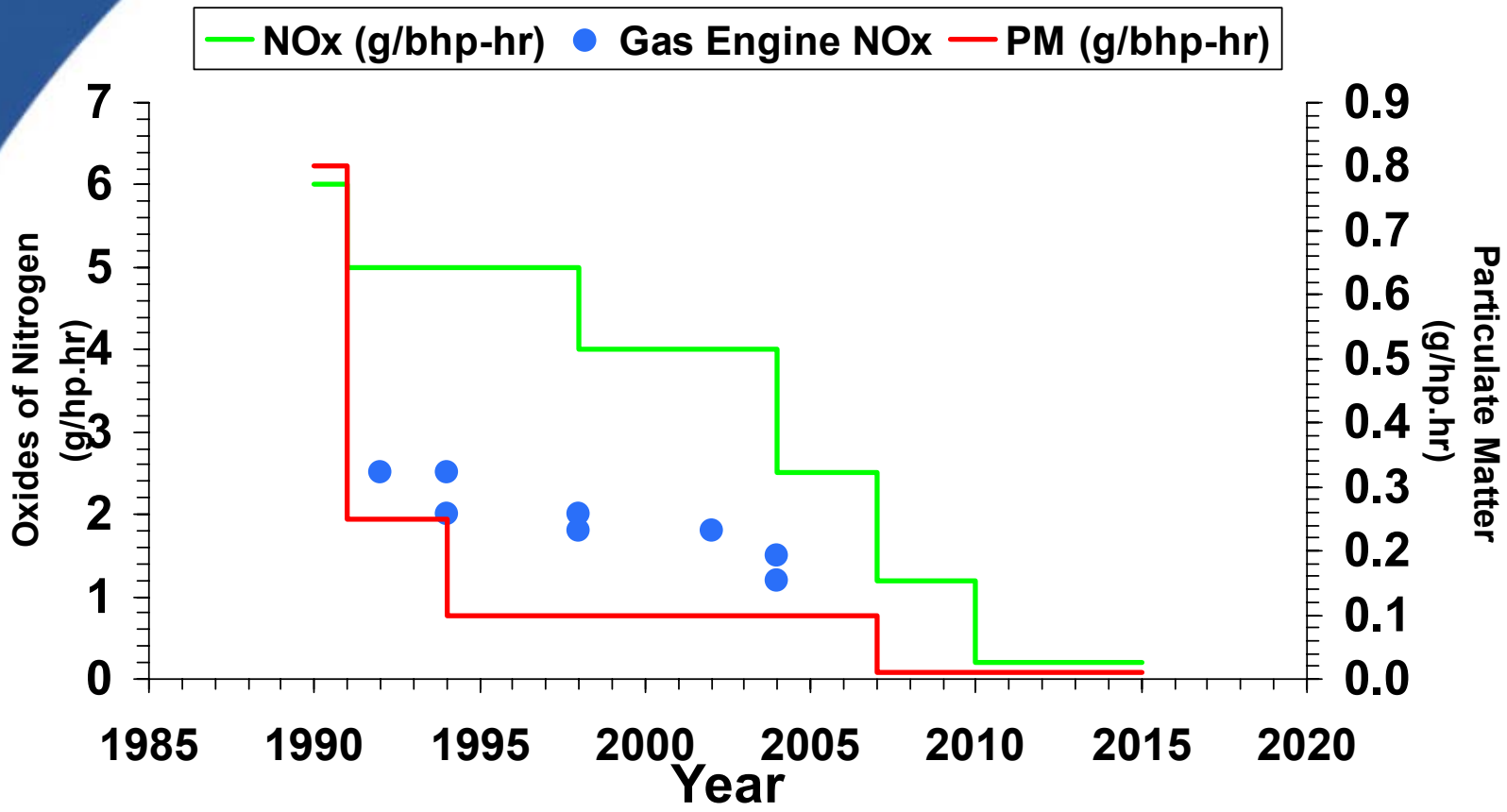
U.S. Emission Standards



Year

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Where do we go from here

- Emissions requirements driving lower
  - 1.2 NOx in 2007
  - 0.2 NOx in 1010
- Diesel technology
  - Efficiency drops as NOx level drop
  - Engine system costs go up as NOx and PM levels drop
  - Diesel fuel cost increases, specially with ULSD

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Where do we go from here…

- Natural Gas engine technology
  - Need to get to 2010 emissions levels several years ahead of diesel
  - Need new technologies
  - Continue to improve reliability
  - Improve efficiency
  - Compete with diesel LCC

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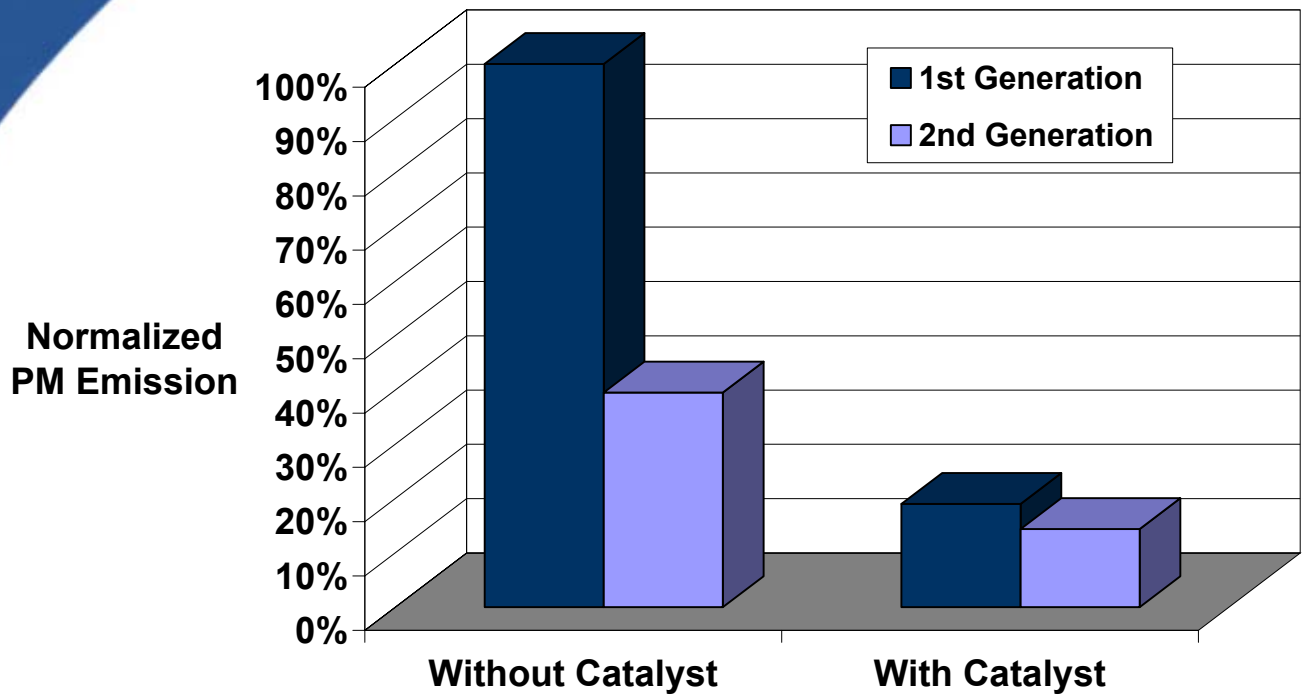
Use of Oxidation Catalysts

- Natural gas is inherently ultra-low Sulfur therefore very active catalysts can be used
  - NMHC, Aldehydes, CO control
  - Also reduces PM
  - Significant reduction in ultrafine particles
    - Generally accepted to consist predominantly of VOCs[1]
    - Lubricating oil is a major contributor

1.Andersson, J & Wedekind, B, 2001. DETR/SMMT/CONCAWE Particulate Research Programme, Summary Report. Ricardo Report DP01/0515

Oil Control and PM Emissions



- Oil control has been significantly improved
  - important for PM emission reduction without catalyst
- Oxidation catalyst highly effective at controlling heavier hydrocarbons
  - mitigates nucleation of ultrafine particles after dilution leaving the exhaust pipe

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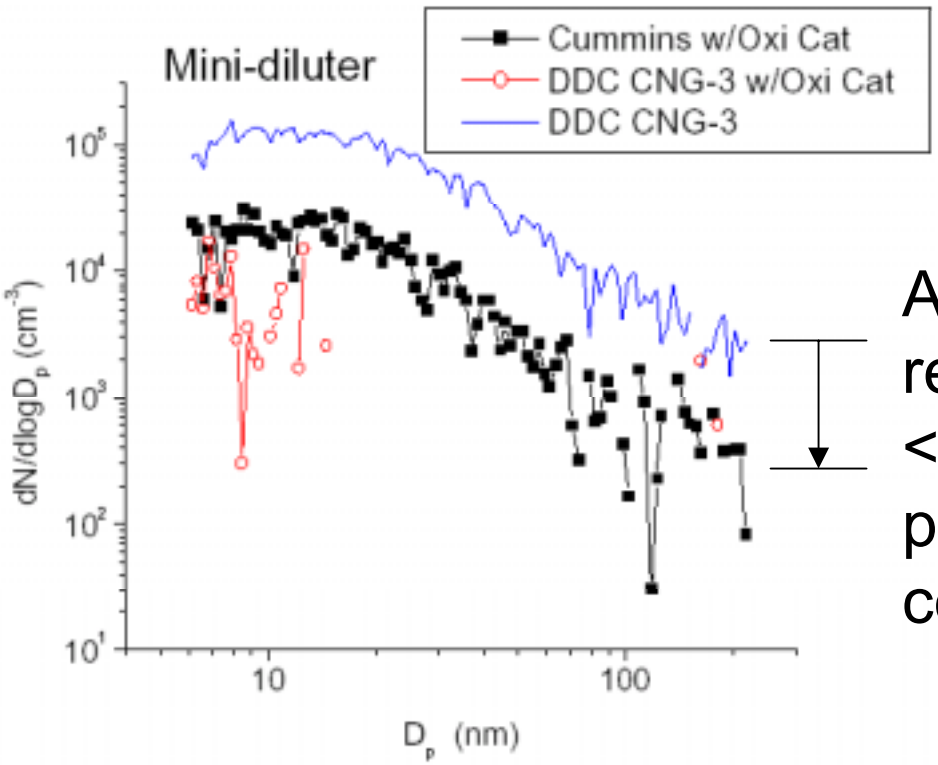
Oxidation Catalyst & Ultrafine PM

CNG buses: Steady-State 55 MPH



Approx 90% reduction in <100nm particle concentration

Ref: Holmen B, Ayala, A. Oxidation Catalyst Effects on Natural Gas Transit Bus Ultrafine Particle Emissions. 6th International ETH Conference on Nanoparticle Measurements August 19-21, 2002, Zurich.

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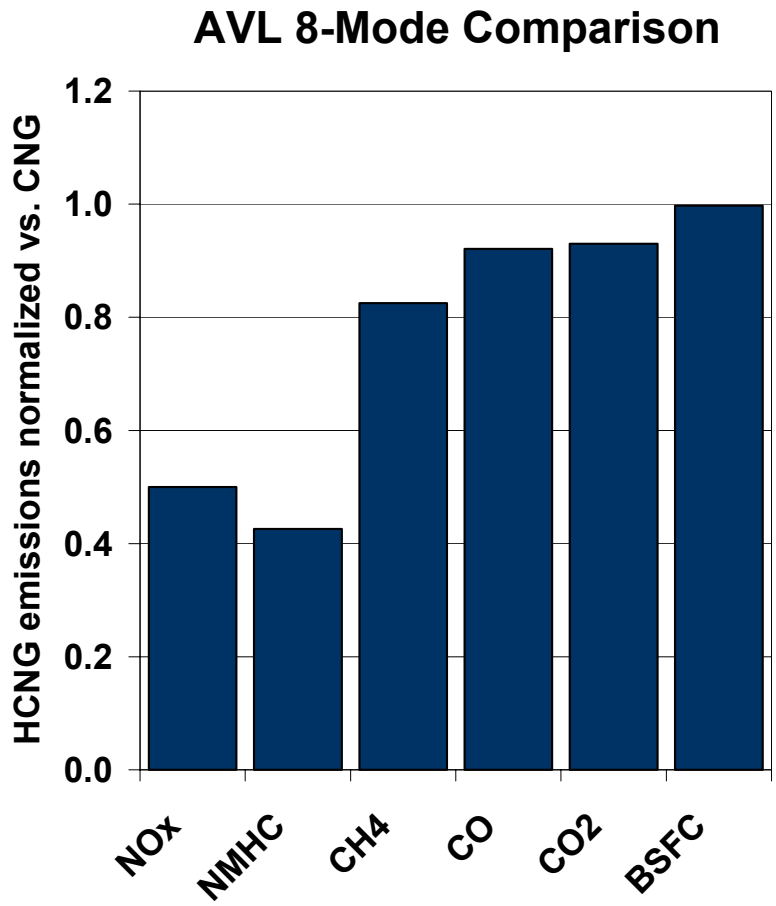
Hydrogen / Natural Gas Blends

- Natural gas is an ideal carrier for Hydrogen
- Higher flame speed extends lean operation and leads to lower NOx for same efficiency
- Under demonstration using B Gas Plus platform at SunLine Transit
  - 20% H2/CNG blend
  - ~50% reduction in NOx, NMHC
  - 7% reduction in CO2



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Near Term Developments

- Application of Plus technology to larger 8.9 liter engine (L Gas Plus)
  - 320hp, 1000ft-lbs
- Investigation of hydrogen / natural gas blends
- Hybrid

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2007/10 Technology Developments

- Focus will remain on highly diluted combustion
  - Spark Ignition
- Level of in-cylinder versus post-combustion emissions control remains under review
  - Lean NOx aftertreatment can be used (simplified relative to diesel due to lower engine-out emissions)
  - EGR with 3-Way Catalyst

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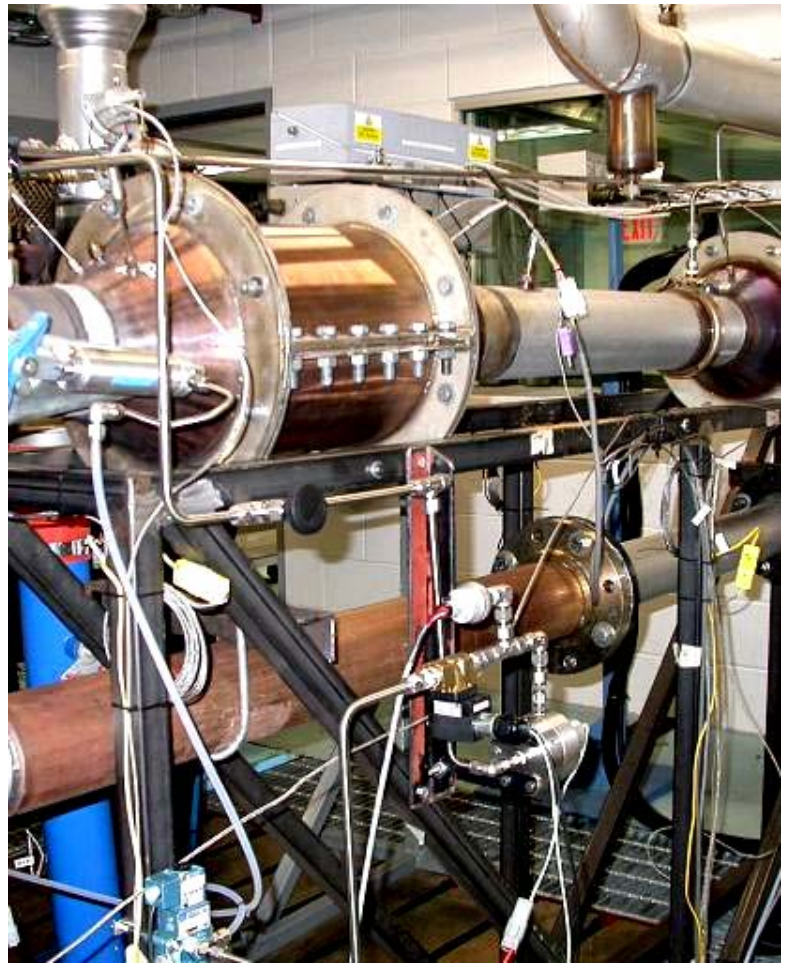
Natural Gas with NOx Storage And Reduction

- Possible to achieve regeneration & desulphation with natural gas as reductant
- Single bed system
  - 90% conversion efficiency with 2.5% fuel penalty (de-greened condition)
- High deterioration factors at present
  - due to desulphation
  - ~10ppm fuel Sulfur with CNG
  - ~1ppm fuel Sulfur with LNG



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Spark Ignition with Cooled EGR

- Published examples of SI engines operating with cooled EGR
  - Cooled EGR can improve in-cylinder NOx control (stability/HC emissions concerns)
  - Stoich-EGR-TWC offers low cost aftertreatment approach but is in infancy for HD automotive applications
- CWI SI engines can take advantage of Cummins diesel engine cooled EGR technology

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CWI Plans

- CWI plans to offer new products in 2007 that meet the 2010 emission standards
  - Technology development is underway
  - Product development starts later this year

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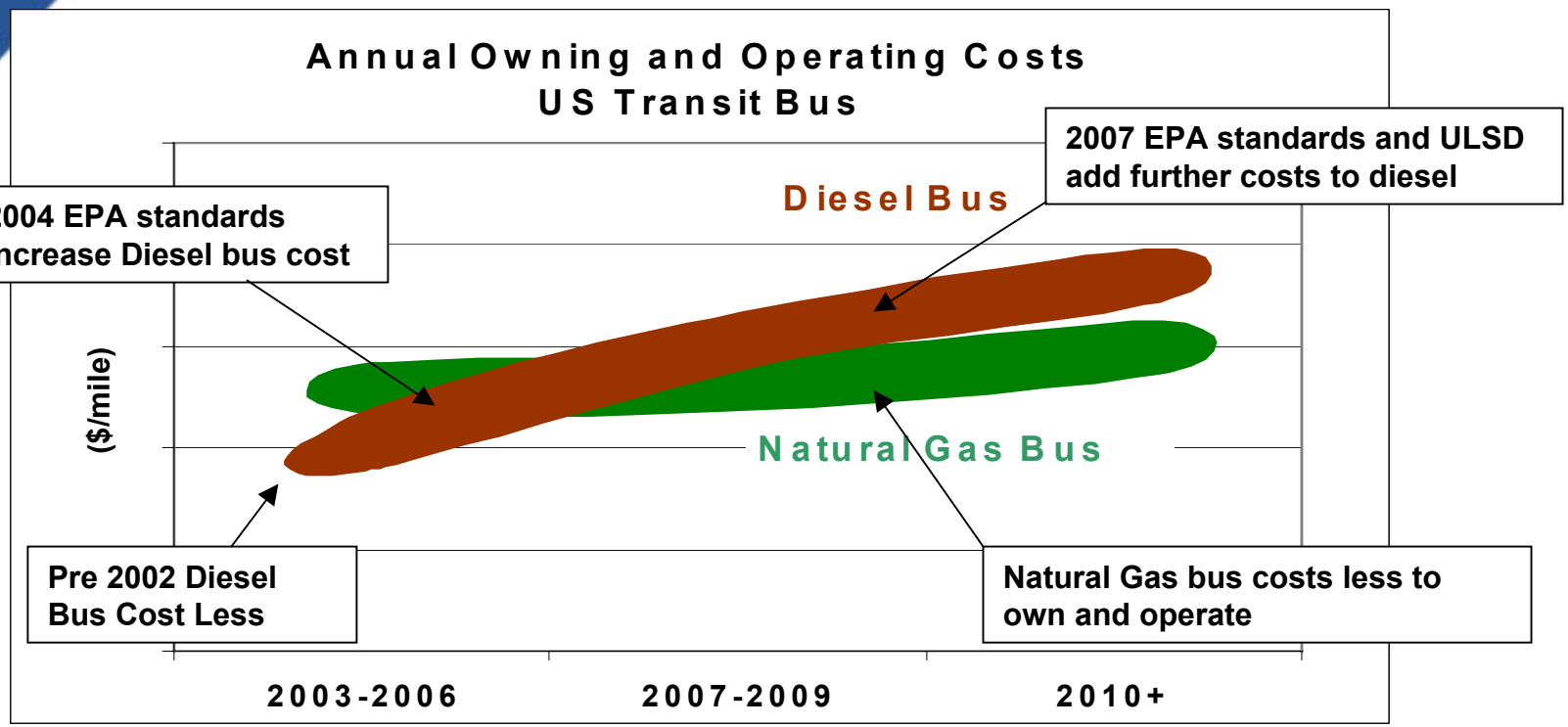
Transit Cost per Mile Trends



Diesel Engine Costs Increase:

- efficiency drops as NOx level drops
- engine system costs go up as NOx and PM levels drop
- Diesel fuel cost increases, specially with ULSD

Natural Gas Engine Costs Remain Relatively Constant

- engine efficiency is expected to improve with EGR strategy
- technology will cost more, but that's offset by improved economy and increased volume
- natural gas fuel prices lower than diesel

Natural Gas Engine Outlook

- Product capability has grown with implementation of latest technologies
- Very low emissions are available in commercial products
- Technical evolution will continue with multiple technologies and development paths
  - New technologies offer the potential for low emissions and efficiency improvement
- A narrowing and possible reversal of the cost gap between natural gas and diesel engines is emerging with onset of evermore stringent emissions regulations
- Natural gas engines offer a pathway to Hydrogen

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