Heavy-Duty NOx Control: A California Perspective

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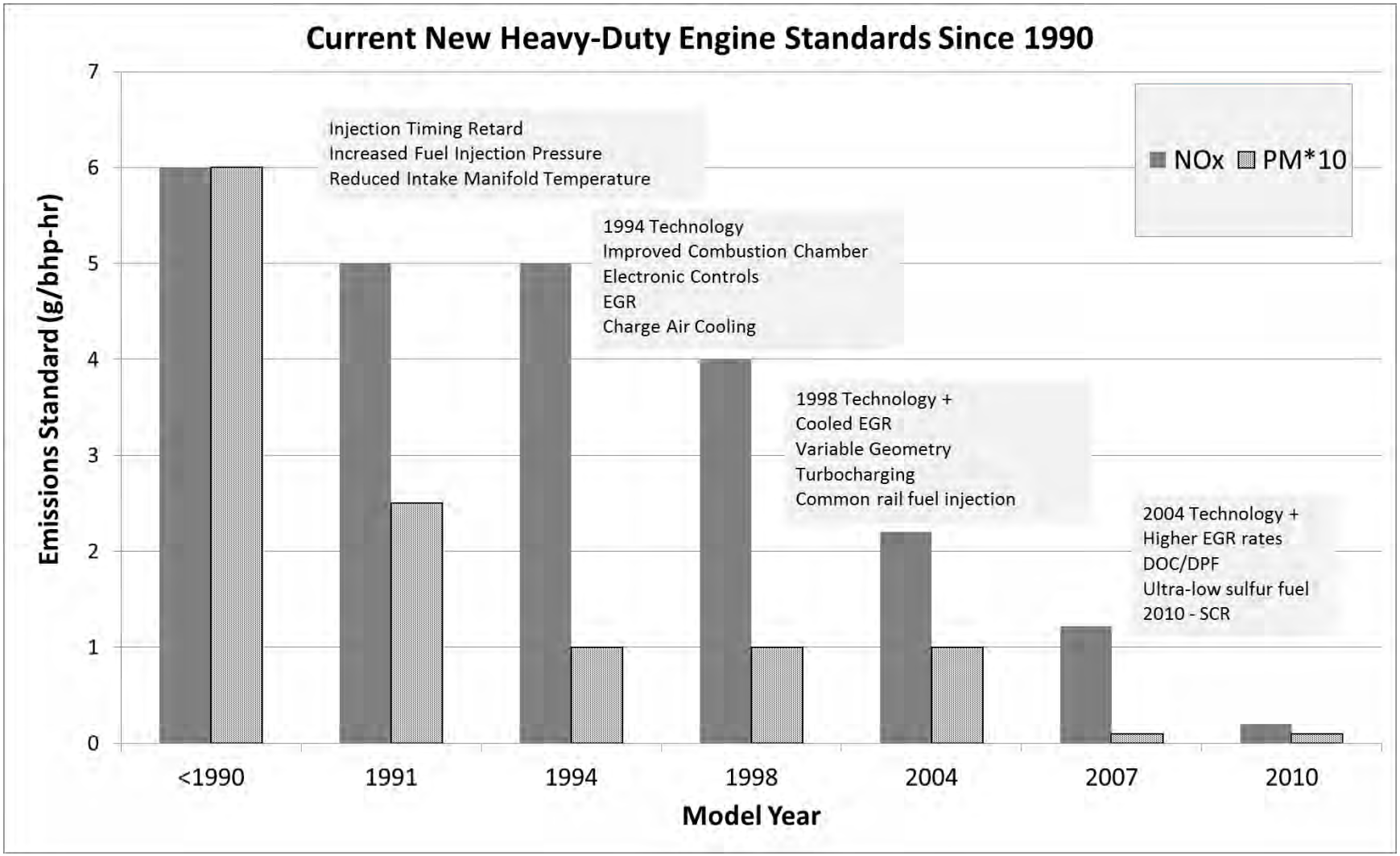
Outline

- California Emission Reduction Needs
- Current Standards
- Current Concerns
- Future Approaches for NOx Control
- Conclusion

California Emission Reduction Needs

- Based on preliminary 8-hour ozone modeling:
  - South Coast needs **90 percent reduction in NOx** from 2010 levels by 2032
  - San Joaquin Valley needs similar magnitude of reduction in NOx
  - On- and off-road mobile sources comprise approximately 80 percent of the NOx inventory in these two regions
- California laws and policy call for:
  - Reducing GHG emissions to 1990 levels by 2020 (AB 32)
  - Reducing **GHG** emissions to **80 percent below 1990** levels by 2050 (Governors' Executive Orders)

Evolution of Heavy-Duty Engine Standards and Technologies



Current Heavy-Duty Engine Standards

Current Mandatory Standards (g/bhp-hr)	
NOx	0.20
PM	0.01

Optional Low NOx Standards	
NOx Level (g/bhp-hr)	% Below Current Standard
0.10	50
0.05	75
0.02	90

The California Truck Fleet

- >30% of statewide mobile source NOx
- Heavily influenced by the national fleet
  - One million interstate trucks operate in CA
  - More than half of California's in-state heavy trucks originally purchased outside of California
- National action is needed in the heavy-duty sector

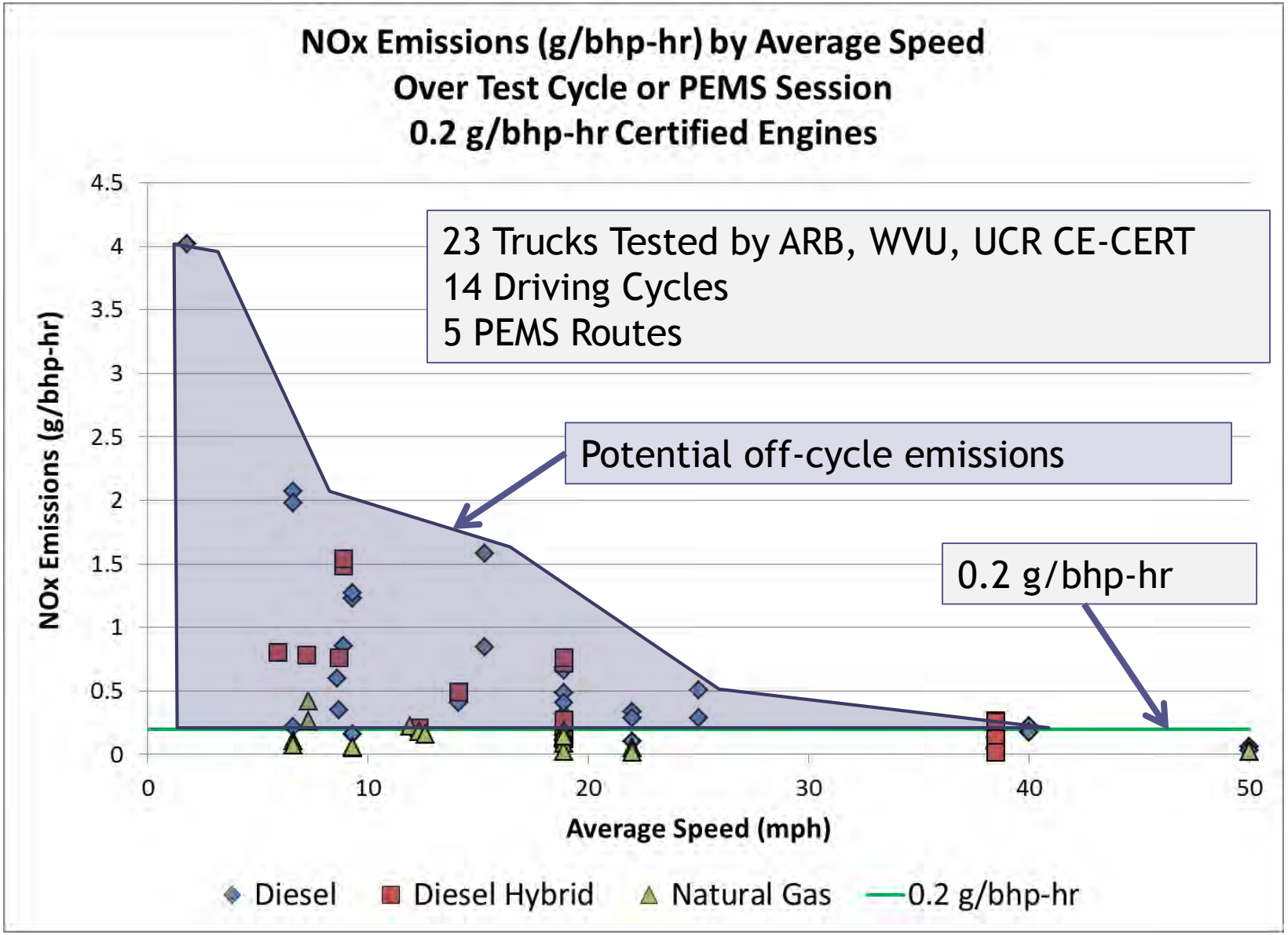
Current Concerns

Are the standards getting us the NOx reductions we need?

Emissions In-Use Not As Low As Expected

- SCR highly effective under high-speed cruise conditions
- ARB and other testing suggests potential issues with performance in the real world
  - Temperature impacts on SCR
    - Cold starts and low-load, low-speed operations
  - Engine mapping and dosing
- Deterioration is a concern

Evidence for Off-Cycle Emissions



Deterioration Is a Concern

- Unscreened claims; averaged across engine families by MY
- Reported within 100,000 mile warranty period (claims/sales)

MY	All Claims	EGR	Electronics	Engine	Injectors	NOx Sensors	Filter	Turbo
2002	45%	2%	3%	21%	12%	0%	0%	4%
2003	194%	37%	13%	7%	89%	0%	10%	31%
2004	65%	17%	8%	4%	21%	0%	0%	13%
2005	77%	24%	8%	6%	21%	0%	0%	17%
2006	50%	17%	4%	3%	12%	0%	0%	12%
2007	143%	41%	22%	9%	38%	2%	7%	16%
2008	122%	41%	24%	8%	22%	1%	3%	13%
2009	104%	30%	14%	6%	31%	0%	2%	12%
2010	65%	19%	13%	8%	11%	8%	1%	4%

Future Approaches for NOx Control

Strengthen Current/Future Standard and Test Procedures

- Significantly reduce NOx standard
- Improve certification and durability requirements
  - Re-think durability testing
  - Expand warranty and Recall provisions
- Address low-temp/low-load NOx issues
  - Supplementary test cycles
  - Expand NTE zone(s) to capture broader events
  - PEMS-based in-use compliance testing
- Ultimate focus on zero emissions

How Low Can We Go?

- ARB funding low NOx diesel and natural gas engine research
  - 0.02 g/bhp-hr NOx target
  - $1.6 M
  - Expected completion date: mid 2016
- South Coast AQMD, Cummins Westport and Cummins Inc.
  - 0.02 g/bhp-hr NOx target
  - Expected completion date: end of 2016
- South Coast AQMD, NREL and SwRI to develop a low NO_X natural gas engine
  - 0.05 g/bhp-hr NOx target
  - Engine development nearing completion
  - Test to be conducted on articulated tandem bus by end of 2015

NOx/GHG Policy Considerations

- Focus on integrated approach for NOx and GHG
- Many technologies that control NOx are unlikely to have GHG impacts
  - Increasing catalyst surface area
  - Passive NOx storage catalysts
  - Close coupled SCR on DPF
  - Improved exhaust manifold/catalyst/ insulation
  - Improved dosing strategies
  - Three-way catalyst (natural gas)
- Some technologies need to balance GHG and NOx
  - Engine management strategies
  - Urea dosing (if heated)
  - Heated catalyst

Coordination with Phase-2

- Phase-2 focus is GHG reductions
- Integrate strategies for NOx and GHG benefits
  - Stop-start technologies
  - Hybrid drivetrain certification
  - Idle Reduction
  - Weight and friction reduction
- Ensure GHG strategies do not impact NOx
  - Impact of waste heat recovery on SCR temperature
    - Expand NTE temperature operation
  - Integration between engine control strategies/urea dosing and vehicle operation in-use

Conclusion

- Reduce standard and improve test procedures
- Expand in-use programs
- Increase warranty
- Improve ability to recall
- Focus on Zero Emissions
- Coordinated strategy needed for both GHG and NOx reductions