



Heavy Duty Truck Engine

2007 Emissions with Excellent Fuel Economy

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- Combustion/Performance/Emissions Tuning
- Engine Thermal Management for Aftertreatment Optimization
- Cold Weather Testing Experience
- Conclusions
- Questions



Phase I

- Demonstrate
 - **45%** BTE
 - **2002** Emissions
 - 2.5 gm
BSNOx
 - 0.1 gm
BSPM

Complete

Phase IIA

- Demonstrate
 - **45%** BTE
 - **2007** Emissions
 - 1.2 gm
BSNOx
 - 0.01 gm
BSPM

Complete

Phase IIB

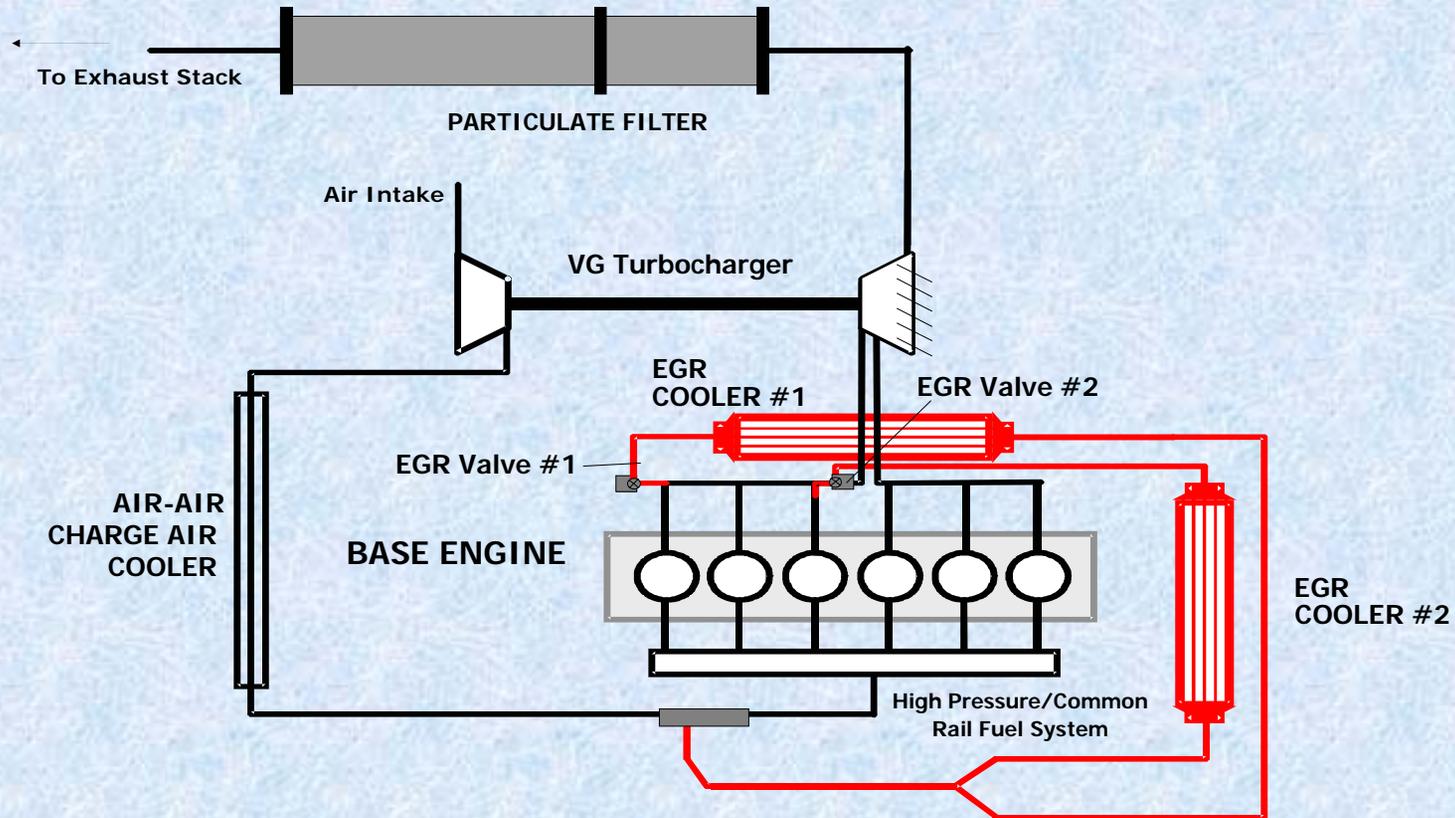
- Demonstrate
 - **50%** BTE
 - **2010** Emissions
 - 0.2 gm
BSNOx
 - 0.01 gm
BSPM

In-Progress



Concept ISX: Dual EGR Valves / EGR Coolers Engine System Configuration

- Built on existing 2002 Platform technology

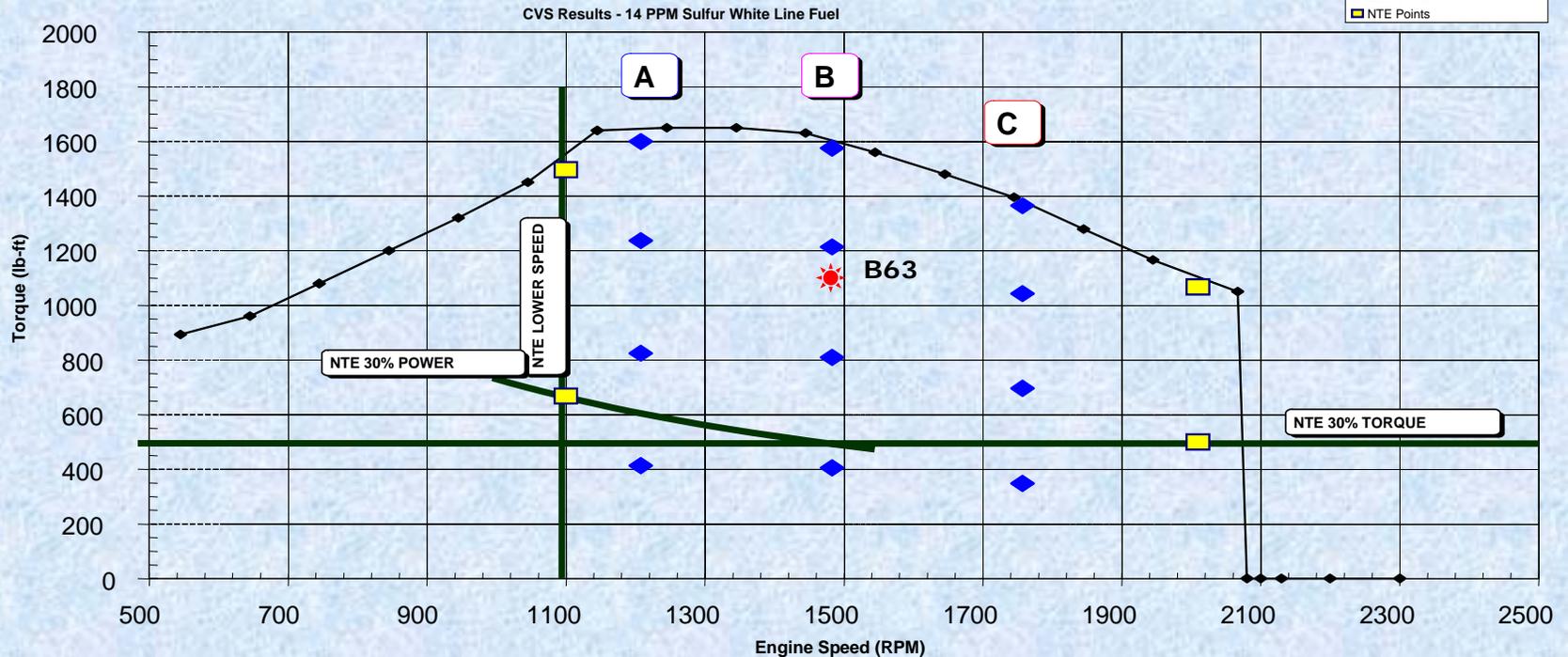




Combustion Performance and Emissions Tuning (for Phase IIA)



SET (NO_x) Emissions Region Map - HCEGR



BSNO_x SET comp. 1.07 g/hp-hr
 BSPM SET comp. 0.002 g/hp-hr

Conclusion : SET BSNO_x and BSPM are well below the 2007 targets



Target FTP Tailpipe Out Emissions

BSNO_x: 1.149 g/hp-hr

BSPM: 0.0149 g/hp-hr

NMHC: 0.1450 g/hp-hr

Actual FTP Tailpipe Out Emissions

BSNO_x: 1.295 g/hp-hr

BSPM: 0.001 g/hp-hr

NMHC: 0.03 g/hp-hr

Note: FTP NO_x measured values did not meet our targets due to transient control issues with the dual EGR valves. Cummins viewed this as being acceptable given that composite SET NO_x values were well within limits.



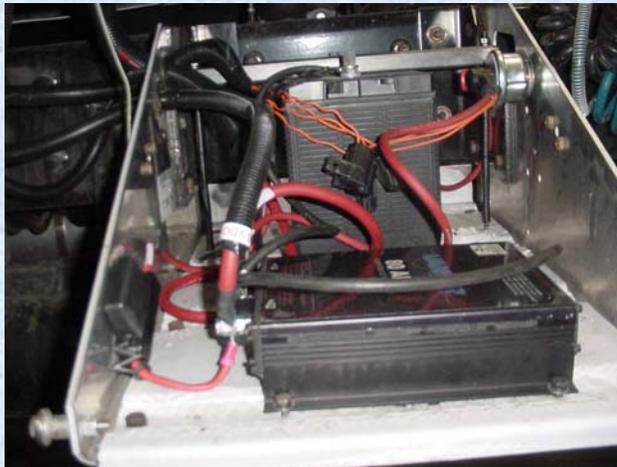
Parasitic Load Reduction (for Phase IIA)



- Two approaches to Parasitic Load Reduction were investigated for Phase IIA
 - *An Electric Water Pump*
 - The Mechanical Water Pump was replaced with an Electrical Pump
 - Coolant Flow could be tailored to specific engine need
 - *A Variable Flow Lube Pump*
 - Data was collected on a 'Variable Flow' pump design at required flowrates and pressures to support ISX operation.

Electric Water Pump

- EMP (Engineered Machine Products) Designed and Controlled
- 42 VDC Powered Unit
- Leece-Neville 42VDC, 90Amp Alternator





Actual Electric Water Pump Performance

- **Efficiency Improvement at Cruise Point
(1480 rpm, 63% load)**

0.3% BTE Improvement

Baseline (Mechanical Water Pump) BSFC = 0.324
(+/- 0.004)

Electric Water Pump BSFC = 0.321 (+/- 0.004)



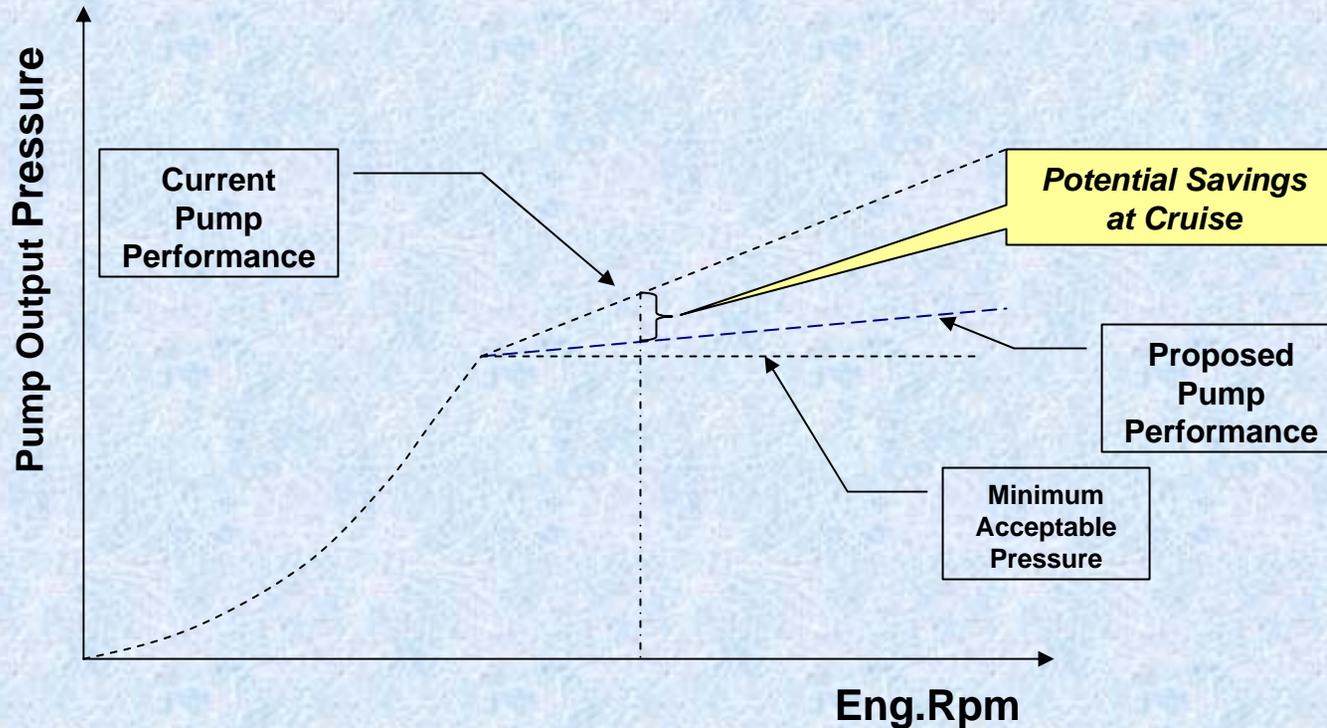
Variable Flow Lube Pump

- Proposed replacement for current Fixed-Gear pump
 - Adjustable rotor – flowrate controlled by pump output pressure.
 - Sought to minimize flow while maintaining system pressure.
- Would provide adequate flow and pressure for engine operation
- Pressure/flow/power consumption performance data collected from a Supplier prototype (similarly sized to the ISX pump)



Variable Flow Lube Pump

Variable Output Lube Pump
Proposed Performance vs. Current Product





Variable Flow Lube Pump

- Data applied to engine and vehicle simulations and produced a 0.2% BTE improvement – a 0.002 point BSFC improvement at the cruise point.
- Vehicle drive-cycle simulations showed very little MPG improvement. The amount of time spent at higher speed points didn't contribute much to the overall MPG.



- Maximum BTE from the base engine at cruise was 43.2% while meeting 2007 emissions
- Additional BTE was shown to be available from Parasitic Reductions -
 - Electric Water Pump (engine data) – 0.3%
 - Variable Flow Lube Pump (simulation) – 0.2%
- With the additional benefits of the parasitic load reductions, a peak efficiency of 44% was achieved at the 2007 emissions level.



Engine Thermal Management for Aftertreatment Optimization



- 2007 emissions levels essentially mandate the use of Particulate Filter aftertreatment
- Soot Loading and resultant performance issues are a key consideration in the application of this technology
 - Trap regeneration/cleaning is a necessity
- Optimized engine thermal management strategies seek to reduce the fuel consumed in A/T regeneration
 - Aftertreatment hydrocarbon/fuel dosing to the Particulate Filter creates regeneration heat
 - Maintaining exhaust gas temperatures high enough to maintain regeneration without extra dosing is the goal

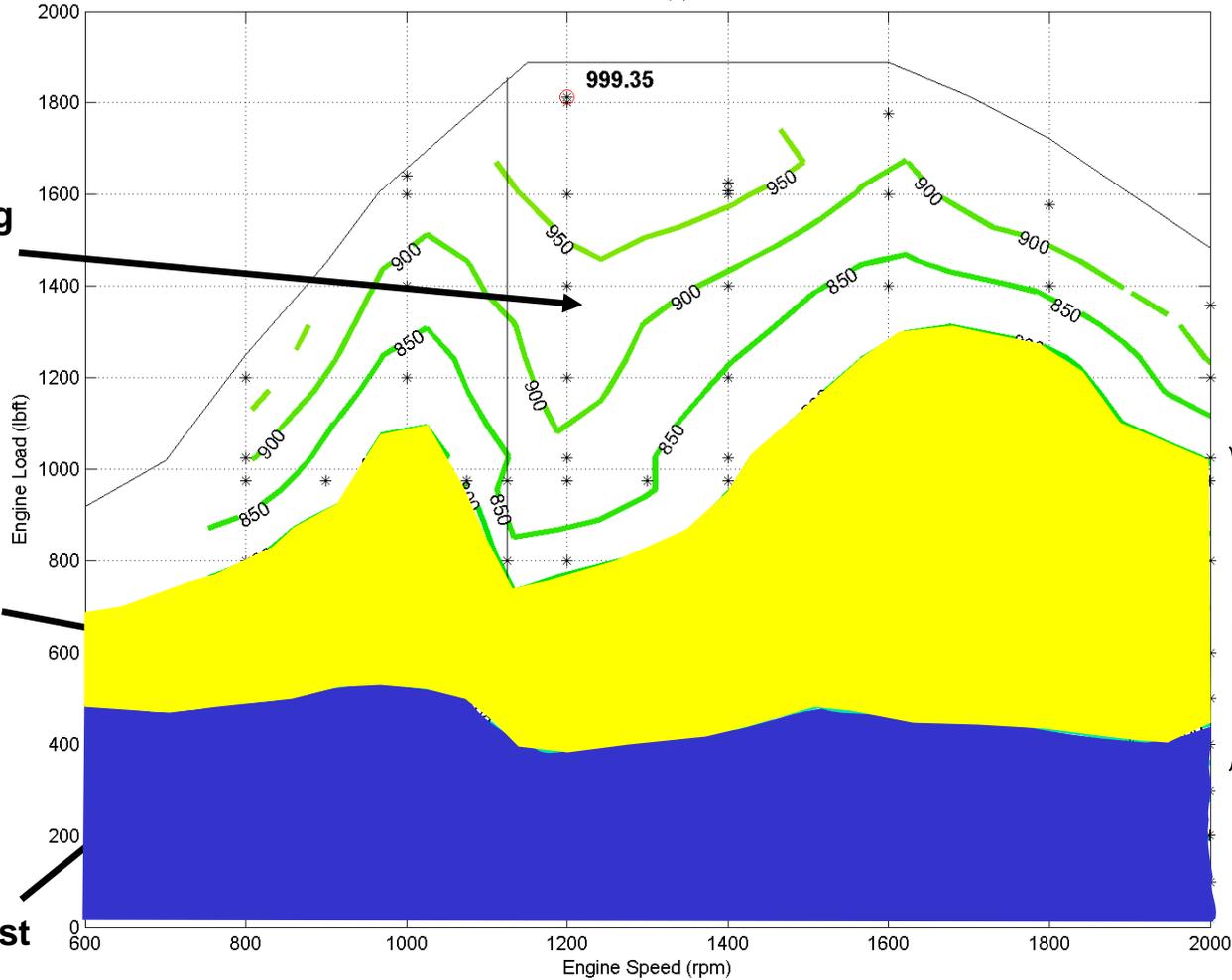


Downstream Temperature control 12/10/03 ESN 79009605 Points 20017-20135
T out T (F)

Self Supporting Regeneration

Fuel Dosing Region

Inadequate "natural" exhaust temperature



Target Temps Depend Upon A/T Spec and Losses in Exhaust System



Cold Weather Testing

Do Not Duplicate

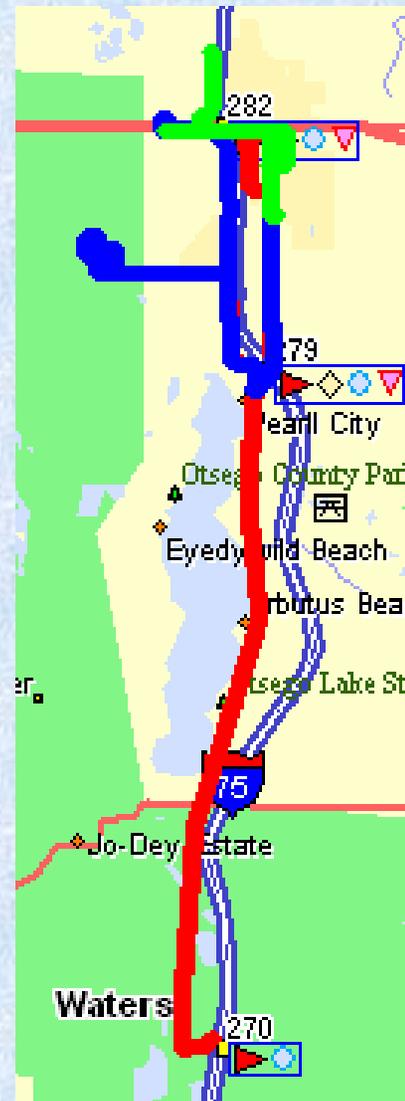
DoE & Cummins Restricted

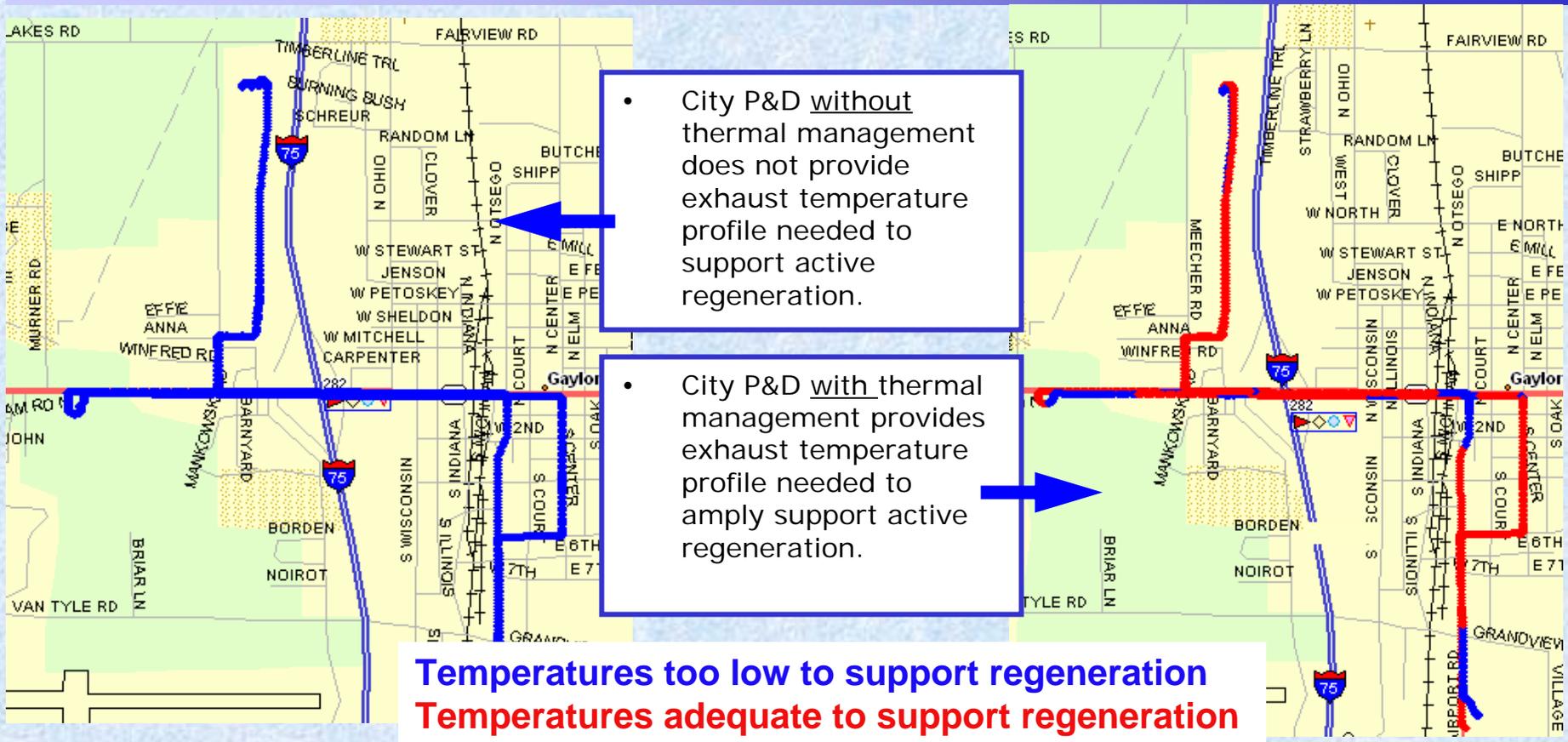


- Cold weather presents special challenges for Particulate Filter system reliability
- Winter test provided a platform for testing of various AT technologies
 - Demonstrate robustness of systems in the presence of noise factors.
 - Demonstrate resolution of previously identified issues.
 - Identify duty cycles & boundary conditions for in-house testing and modeling.
 - Collect data to validate embedded controls models
 - Gain reliability experience in real transient operation
 - Temperature control
 - Diagnostics
 - NOx control
 - Identify unanticipated failure modes.



- **City P&D**
 - 35 mph max speed
 - Frequent stops
 - Engine idles during stops
- **Suburban P&D**
 - City P&D + added stops in industrial park
 - Slightly higher average speed
- **Local P&D**
 - Suburban P&D + state highway
- **Highway/Linehaul**
 - Interstate cruise





Without thermal management

With thermal management

Thermal Management decreases the amount of dosing required to Maintain the Particulate Filter.



Summary and Conclusions



Efficiency

- Transient Performance Tuning to Demonstrate Efficiency Goals
- Vehicle Integration to Demonstrate our Phase IIA System On-Highway performance
- Reduced Parasitics - Analysis and Testing

Emissions

- Demonstration of a compliant Engine System against 2007 emissions standards
- Aftertreatment Thermal Management Strategy

Reliability

- Cold Weather Operation Test Experience
- Aftertreatment Stress Analysis and Noise Factor Analysis



The HDTE Program is proceeding steadily towards program goals at Cummins

- Demonstration of 44% BTE while operating at 2007 Emissions levels, (Phase IIA), (complete)
- Demonstration of 50% BTE and 2010 emissions is now in progress, (Phase IIB), (in progress)



Cummins Inc. thanks –

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