DETROIT DIESEL

# Demonstrating and Validating a Next Generation Model-Based Controller for Fuel Efficient, Low Emissions Diesel Engines

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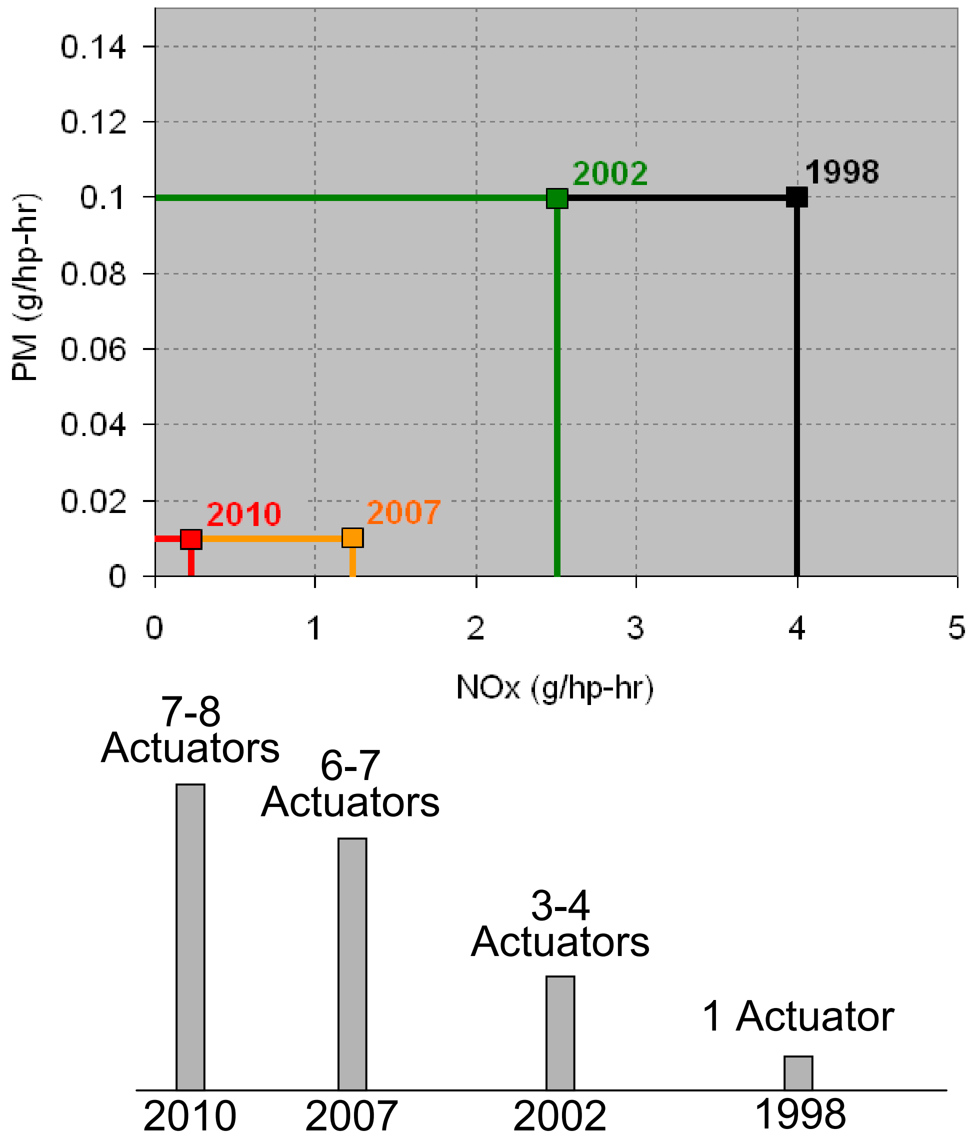
# Outline

- The need for advanced engine control
- Proposed alternative to traditional control techniques
- Viability demonstration
- Limitations & next steps

# Control Systems Complexity

- Increased number of sensors and actuators
- More degrees of freedom
- New control logic required
- More calibration flexibility
- Calibration optimization more complex



# Several Levels of Control

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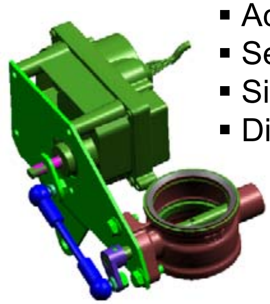
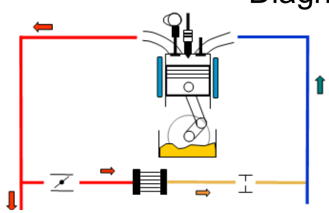


- Actuator position control
- Sensor drift
- Signal processing
- Diagnostics

Individual Component Level



- Parameter control
- System Interactions
- Diagnostics

System Level

- Emissions
- Fuel economy
- Diagnostics

Engine Level

- Drivability
- Heat rejection
- Diagnostics

Truck Level

Constraints:

- Control stability
- Transient response
- Diagnostics

Must integrate systems with:

- Different response times
- Nonlinearities
- Part-to-part variability

# Control Components

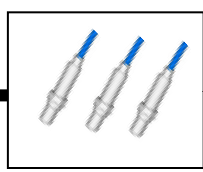


- Control logic requires extensive mapping of control gains
- Control gains are tuned to ensure stability
- Trade-off is steady-state stability vs. transient response

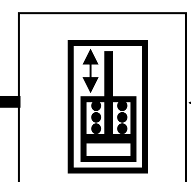
**Control Logic**

**Setpoints**

- Setpoint calibration is increasingly time-consuming
- "Manual" setpoint optimization is less and less practical



**Sensors**



**Actuators**

# Illustration of Engine Control Maps

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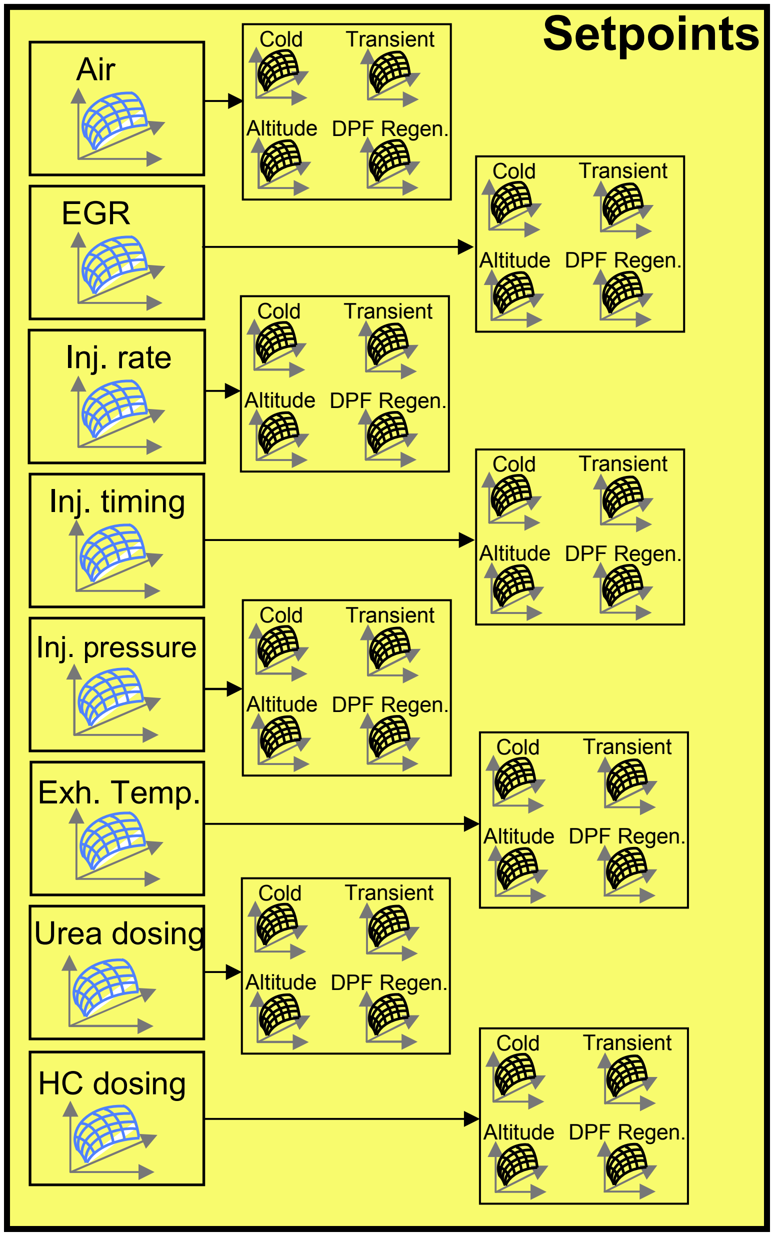
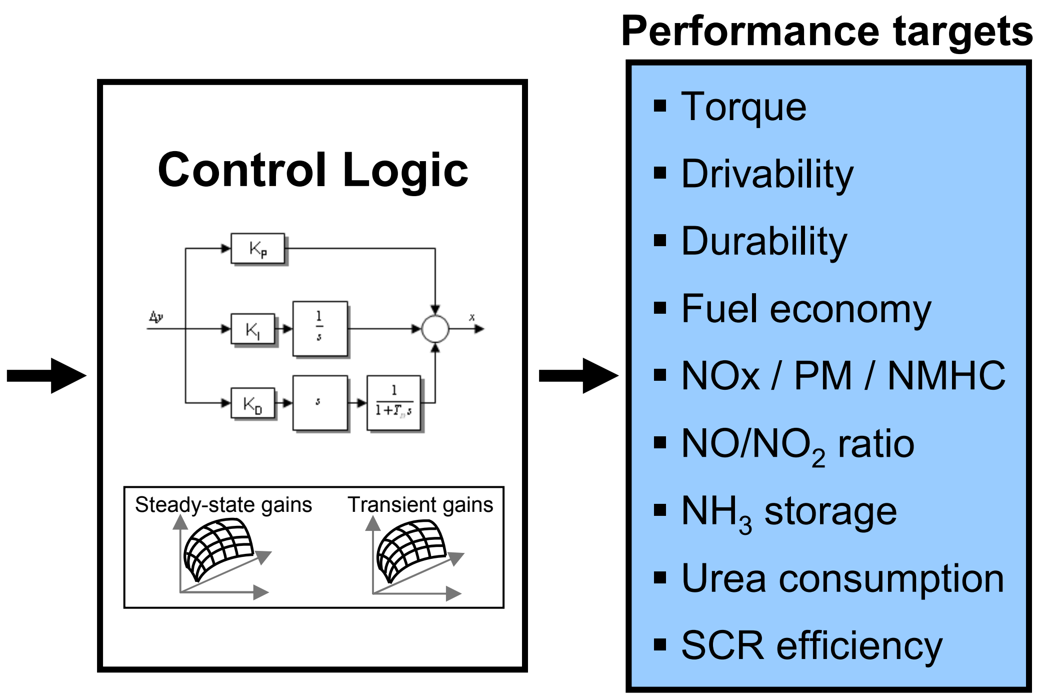
- Factorial increase in calibration space
- Multiple performance targets



# What's the Alternative?

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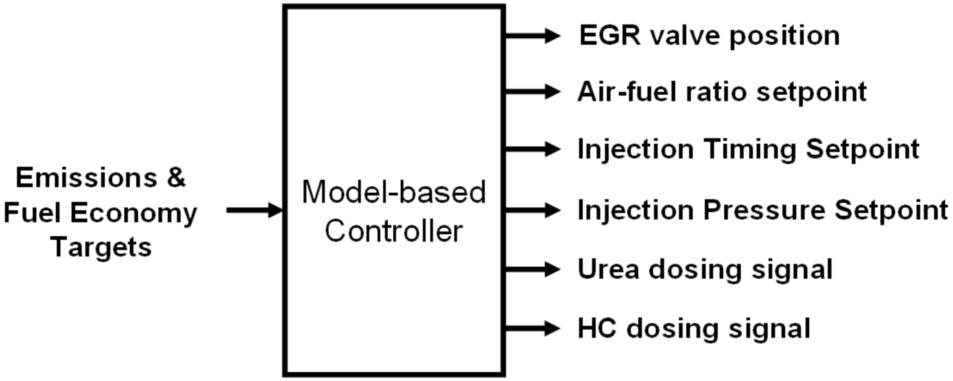
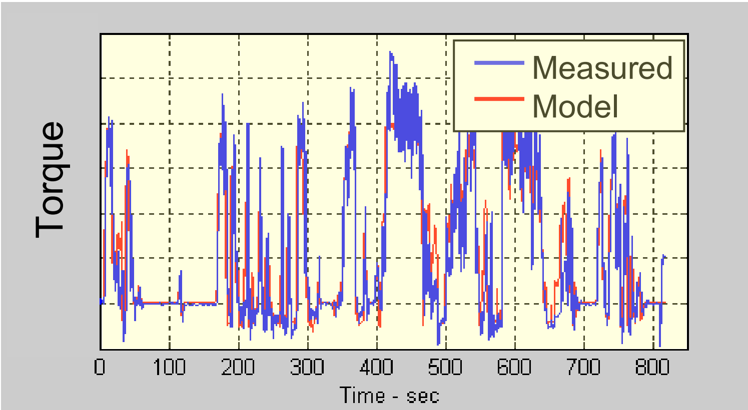
- A practically-mapless control system
- Based on predictive engine models
  - First principle models
  - Neural networks trained with transient engine data
- A controller with built-in knowledge of system interactions
  - Nonlinearities
  - Individual system response times
- Inputs: Performance targets
- Outputs: Actuator signals
- Includes an optimizer
  - Cost function that minimizes emissions and fuel consumption
  - Optimizes engine operation in real-time

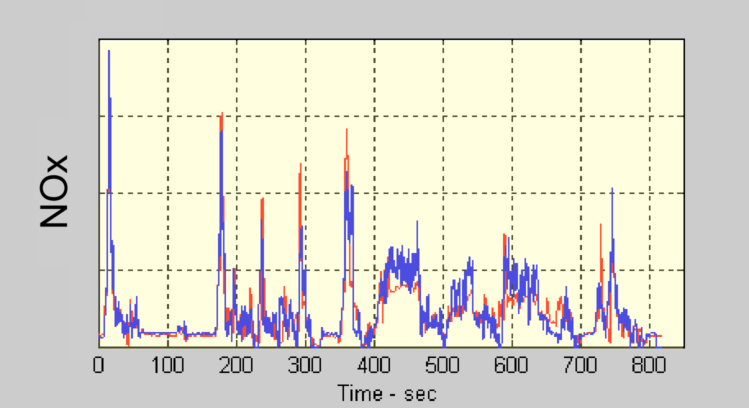


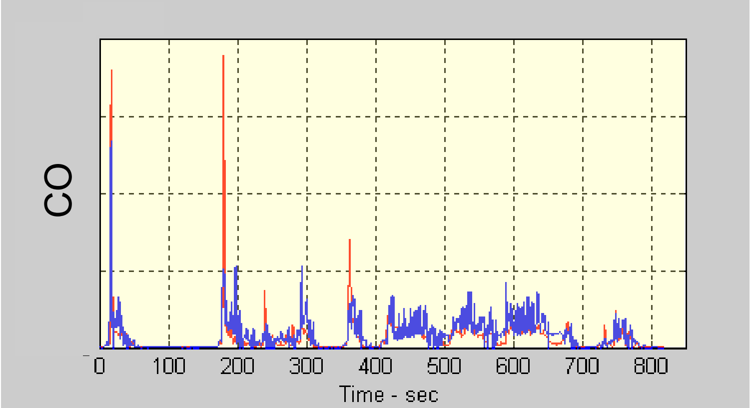
# 1st Step: Performance Model Evaluation

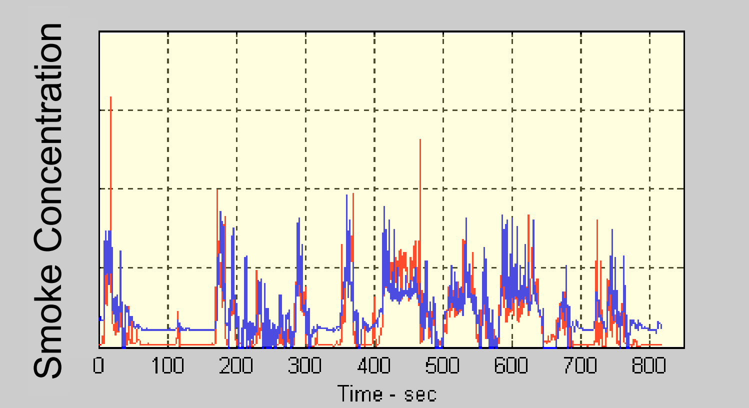


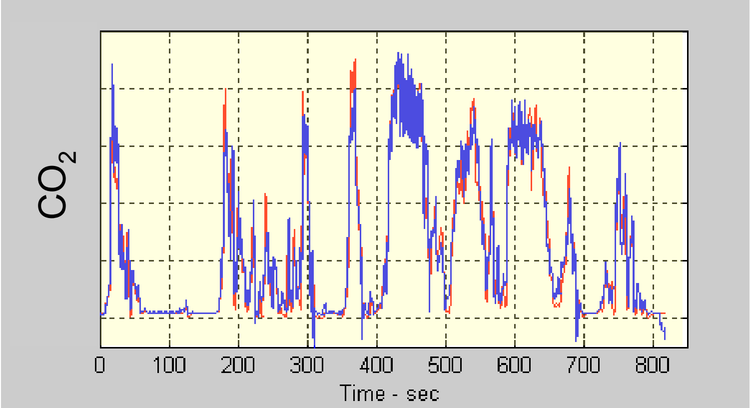



Performance model accuracy is satisfactory over a wide range of operating conditions



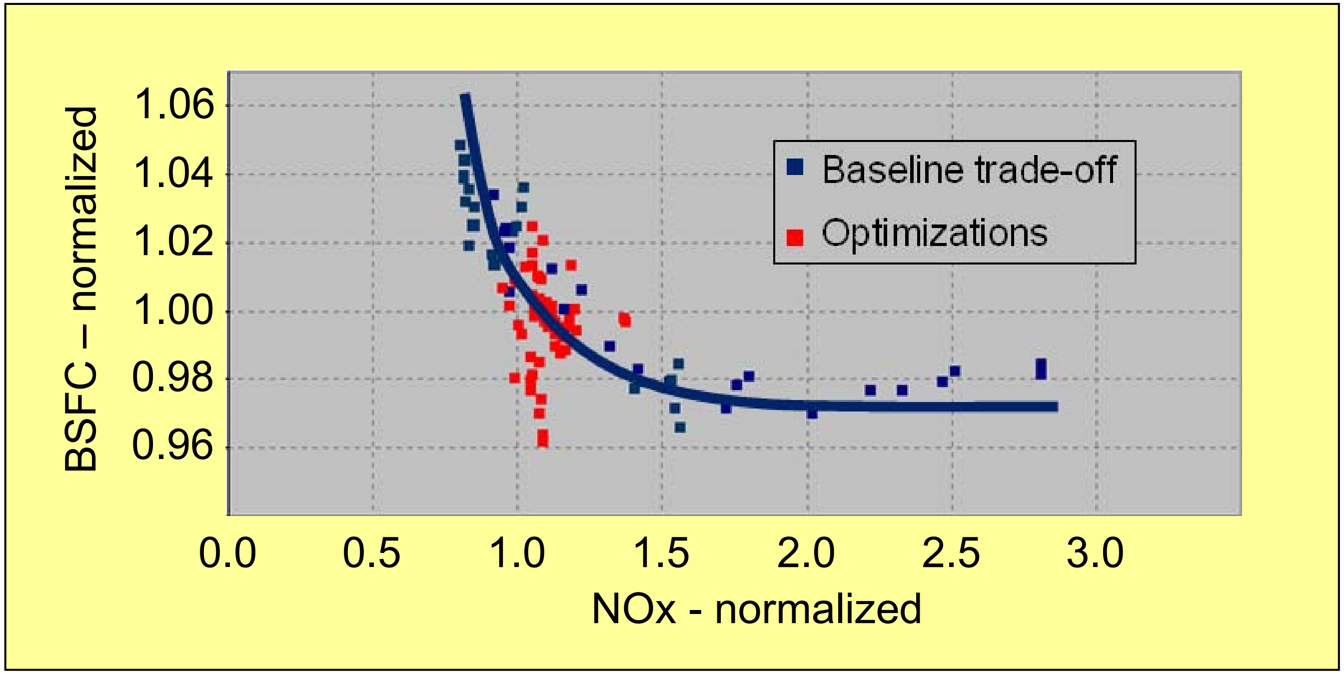



# 2nd Step: Optimized Setpoint Evaluation

- Exercized the controller model offline
- Resulting engine setpoints were evaluated at the test cell
- Measurable gains in fuel economy



# 3rd step: Complete Controller Evaluation

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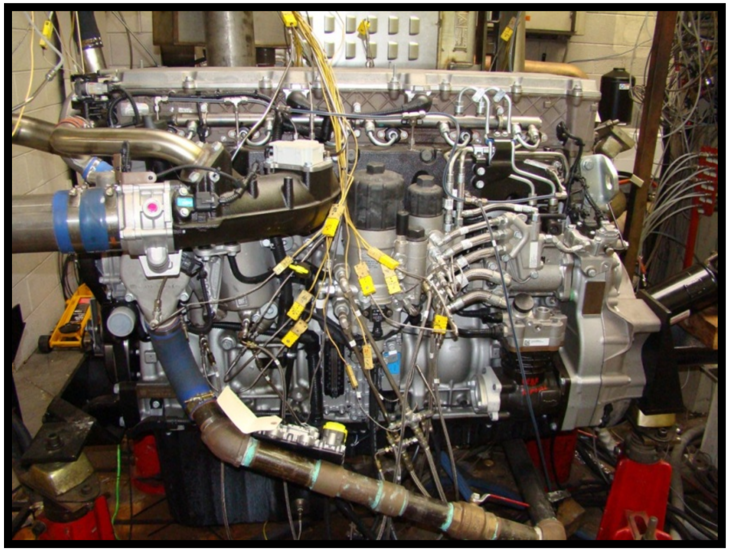
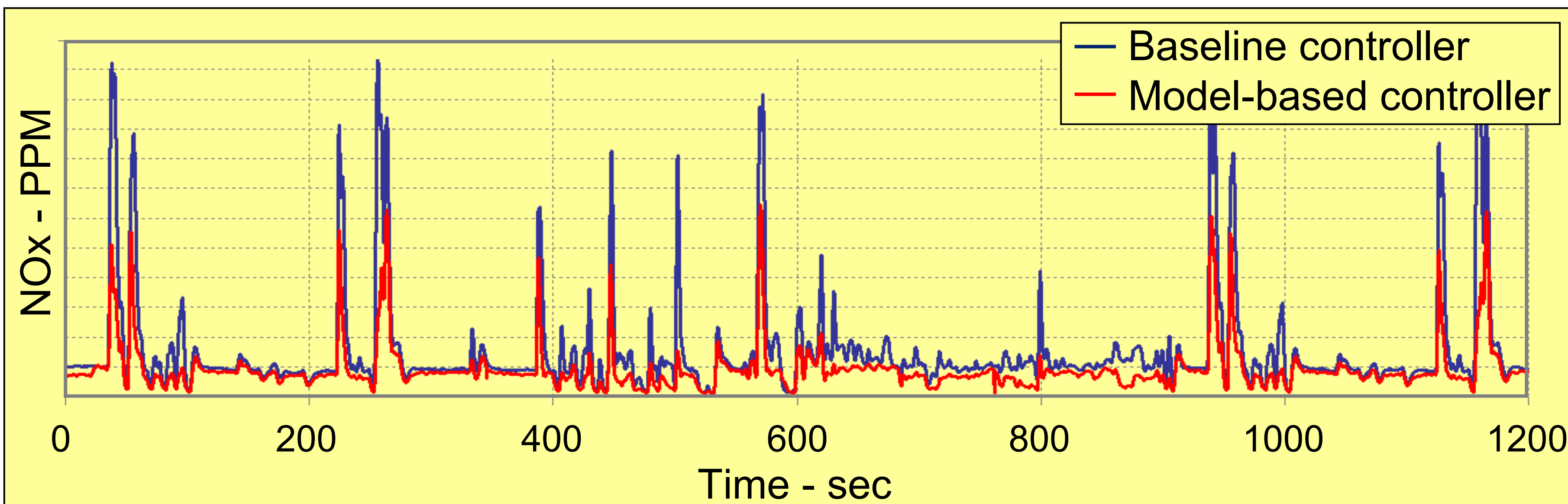
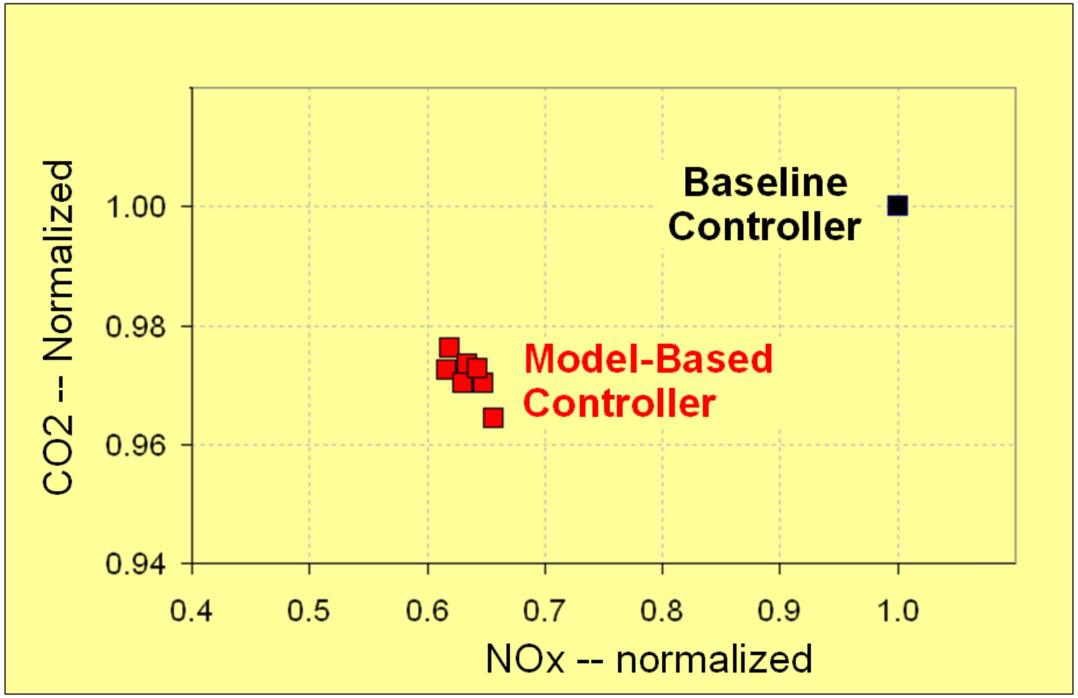


- Full model-based control logic implementation
  - Performance models
  - Controller
  - Optimizer
- Test engine: 2010 Detroit Diesel DD15
- Test cycle: U.S. FTP



# Results To-date

- Controller evaluation in 3rd quarter of the FTP cycle
- Initial results are encouraging
  - Controller operates in real-time
  - Verified controller's ability to "steer" engine performance towards high/low NOx and $CO_2$
  - Control is stable
  - Torque is maintained
  - $CO_2$ vs. NOx trade-off benefit



# Summary & Next Steps

- Fully model-based, practically-mapless engine control concept is viable

- Main limitations of the approach
  - Large amount of transient engine data required
  - Vehicle-to-vehicle variability
  - Increased ECU computing power required

- Next Steps
  - Expand the use of the control technique to additional systems
  - Evaluate the controller over full transient cycles
  - Quantify the potential fuel economy benefits in a vehicle

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