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Filtration Solutions

Development of an Active Regeneration Diesel Particulate Filter System

Donaldson Company Inc.

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Regeneration Methodology

- Diesel Particulate Filter (DPF)
  - Highly efficient but requires regeneration
- Passive DPF Technology
  - Has limitations - need to verify each application
- Active DPF Technology
  - Broader application, but more complex
  - Keys to success
    - Transient control, regeneration strategy, minimal fuel penalty, durability, ……..

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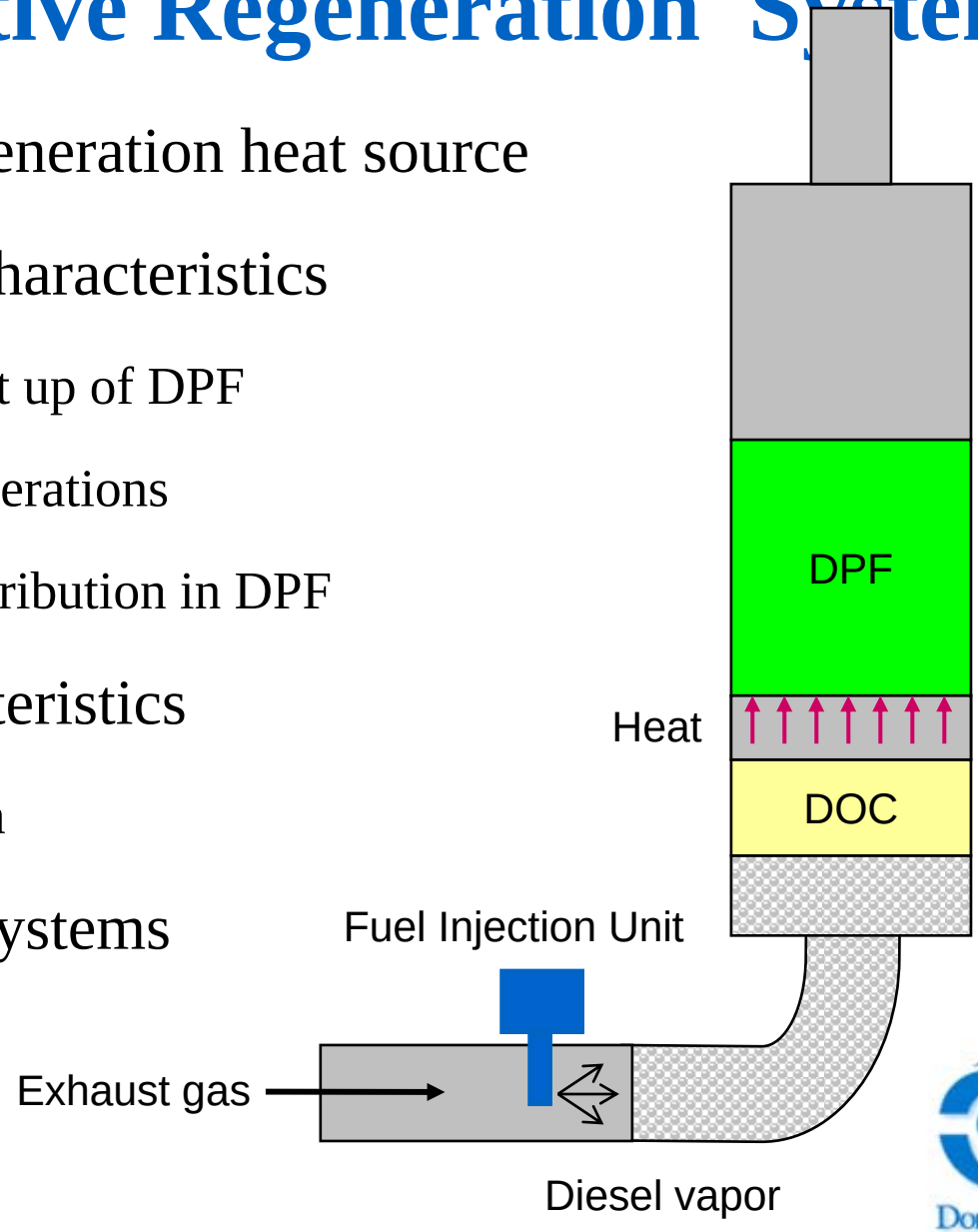
Fuel Injection Active Regeneration System

- Diesel fuel provides regeneration heat source
- Preferred regeneration characteristics
  - Faster, more uniform heat up of DPF
  - Quick and efficient regenerations
  - Uniform temperature distribution in DPF
- Preferred system characteristics
  - Simple, single-leg system
- Compatible with NOx Systems



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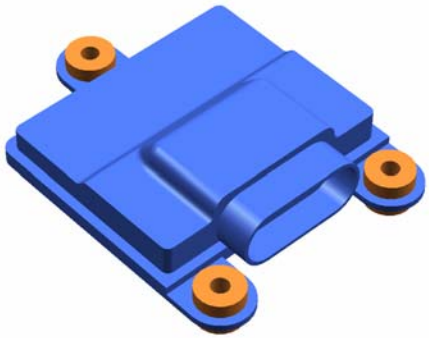
Three Main Subsystems



Controller

Active System

Fuel Delivery

Catalyst & Substrates

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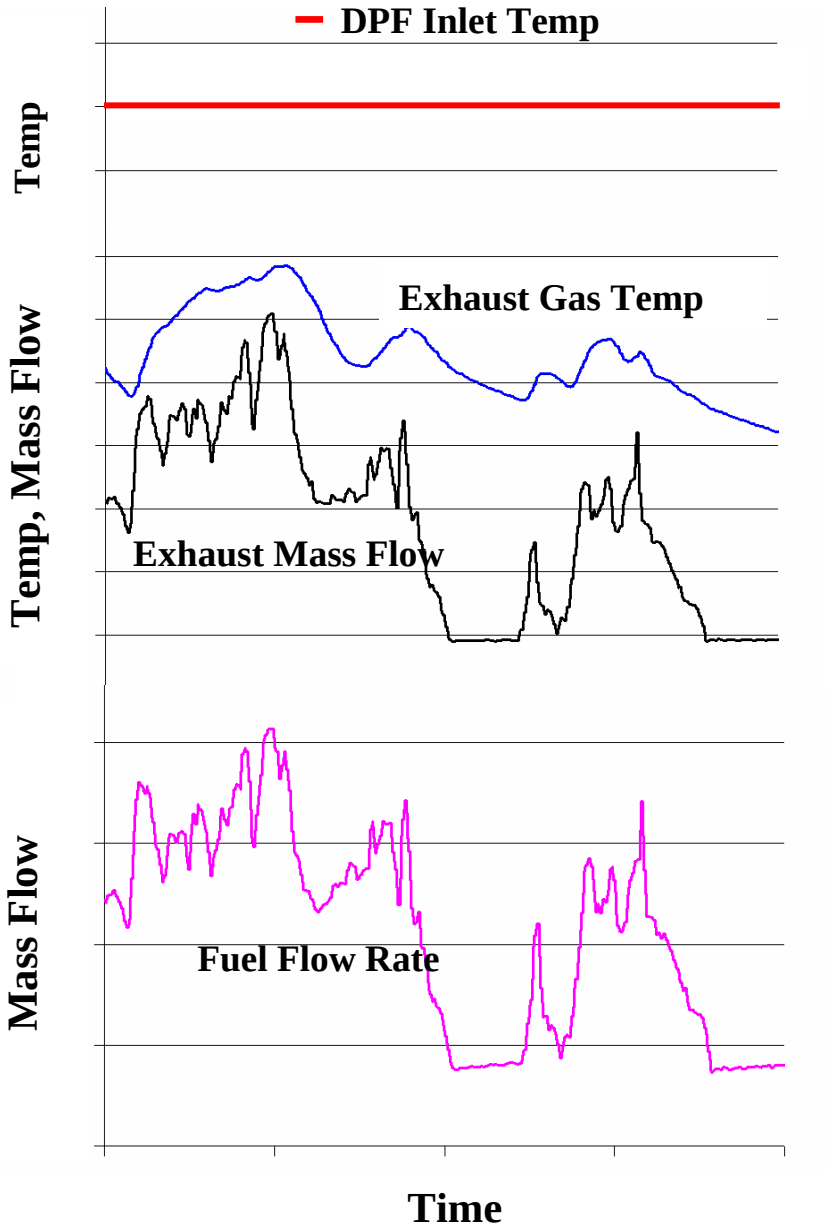
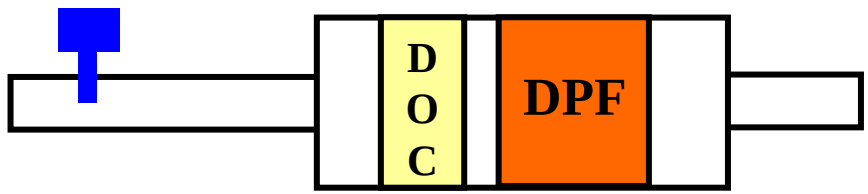
Control Challenges



- **Target** – precise control of DPF inlet temperature
- **Input** – transient exhaust mass flow and temperature
- **Output** – transient control of fuel delivery rate
- **Best Control Method?**
  - Empirical
  - Model-based



Control Challenges

- **Problem:** White smoke under some transient conditions
  - Simple inputs (temperature, pressure) not sufficient
- **Solution:** Characterize system response through model

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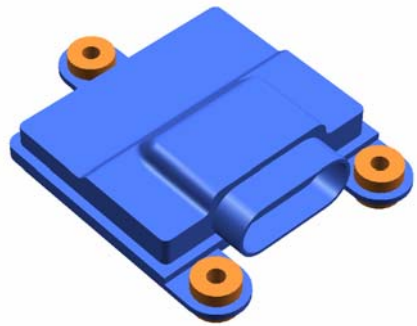
Control Method
Model-Based Feed-Forward Adaptive Control

- Model-Based
  - Energy balance to model system (uses a few key inputs)
  - Accounts for heat transfer, thermal inertia, transient effects, etc.
  - Scalable to different size systems (substrate size, flow rates, etc.)
- Feed-Forward
  - Predicts energy (fueling rate) requirement to achieve desired DPF Inlet temperature
  - System responds very slowly (thermal delay) – feedback alone insufficient
- Adaptive
  - Learns and adapts over time

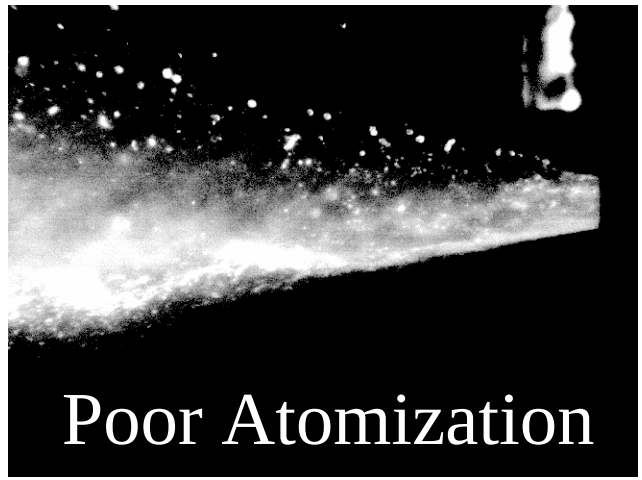


Controller Features

- Diagnostics
  - Monitors and provides feedback on system status
  - Archives key system parameters
- Service Tool
  - PC-based graphical user interface (GUI)
  - Data logging function
  - Trouble shooting tools
- Controller – Flexible implementation
  - Stand alone controller for Retrofit
  - Software transferable to Engine ECU
  - ECU can communicate with active system controller

Fuel Delivery System

- Performance Requirements
  - Fast transient response
  - Uniform temperature distribution
  - Installation flexibility
- Self-contained, exhaust mounted unit
  - Automotive-production components
- Fuel atomization and spray pattern
  - Air-assist
  - Vaporization at low air/fuel pressures
  - Minimal air consumption



Catalyst, Substrates & Regeneration

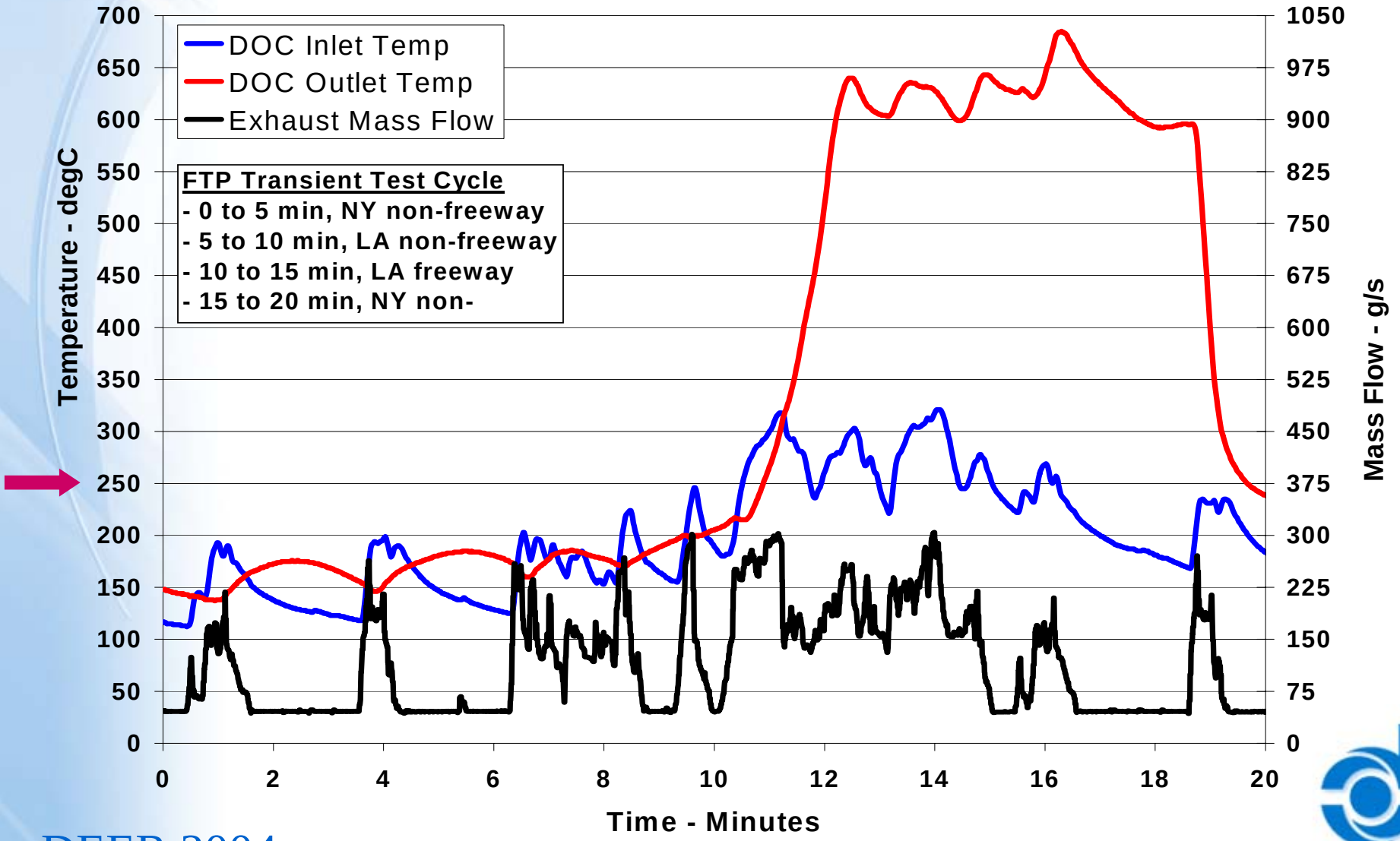
- Diesel Oxidation Catalyst (DOC)
  - Conversion of fuel to heat
- Diesel Particulate Filter (DPF)
  - Catalyzed to enhance regeneration performance
  - Production intent is cordierite
- Regeneration Strategy
  - When and how to regenerate?
    - Soot loading, duration, DPF inlet temperature, mass flow, frequency, etc.
  - This topic is a presentation in itself

Active System Testing

- Dynamometer Tests
  - 1995 Cummins M11
  - 2002 Cat 3126
  - 1988 Cummins L10
- Durability Bench Testing: Component durability
- Field Testing
  - Line Haul Fleet Truck - 1997 DDC Series 60
  - Residential Refuse Hauler – 2002 Mack E7
- Future Test Plans
  - Larger Scale Field Testing this Fall
  - Off-Road Field Test by December

Dynamometer Testing

Regeneration during FTP Cycle – CAT 3126



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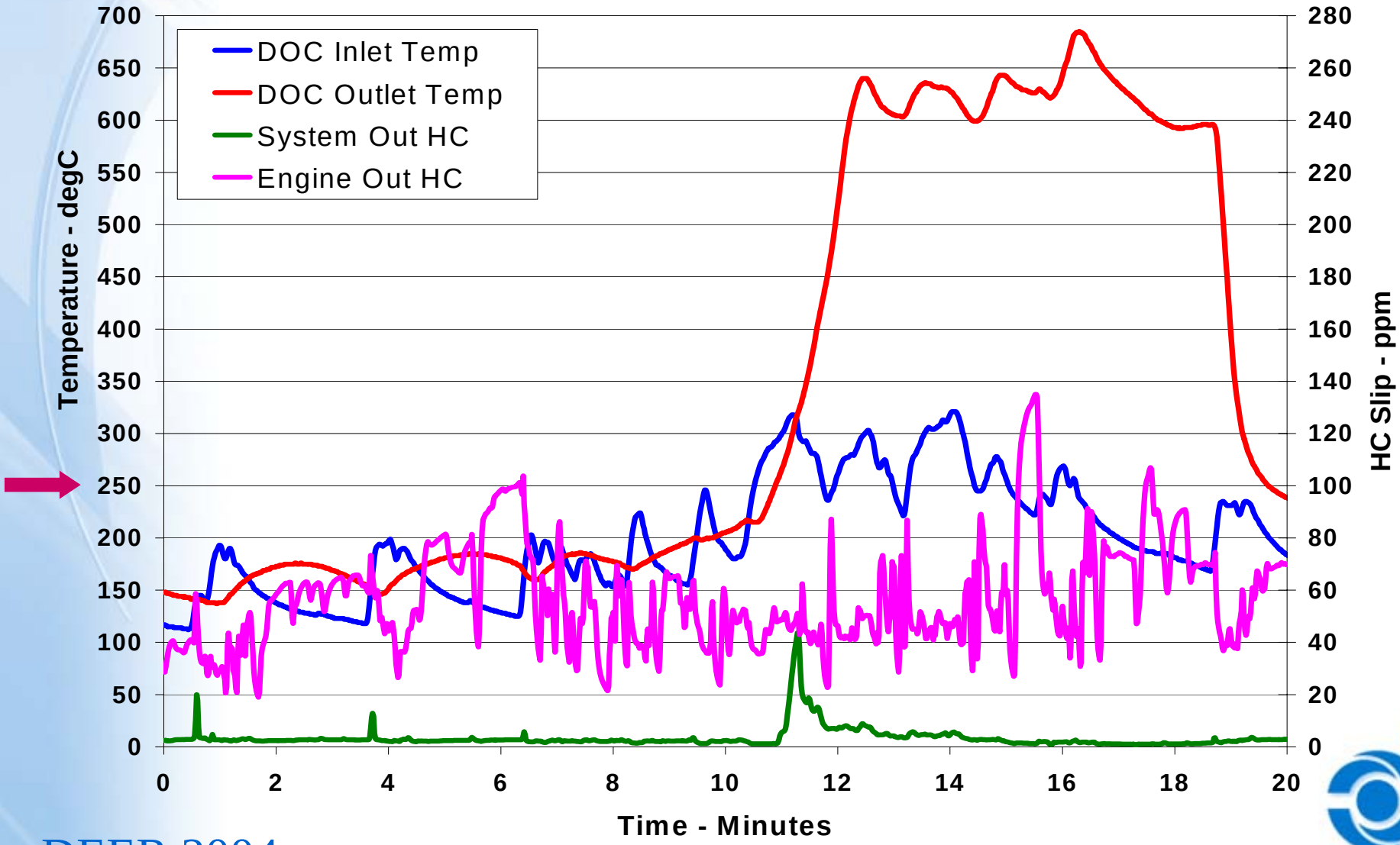
Dynamometer Testing

Regeneration during FTP Cycle – CAT 3126



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Field Test Results: Line Haul Fleet Truck

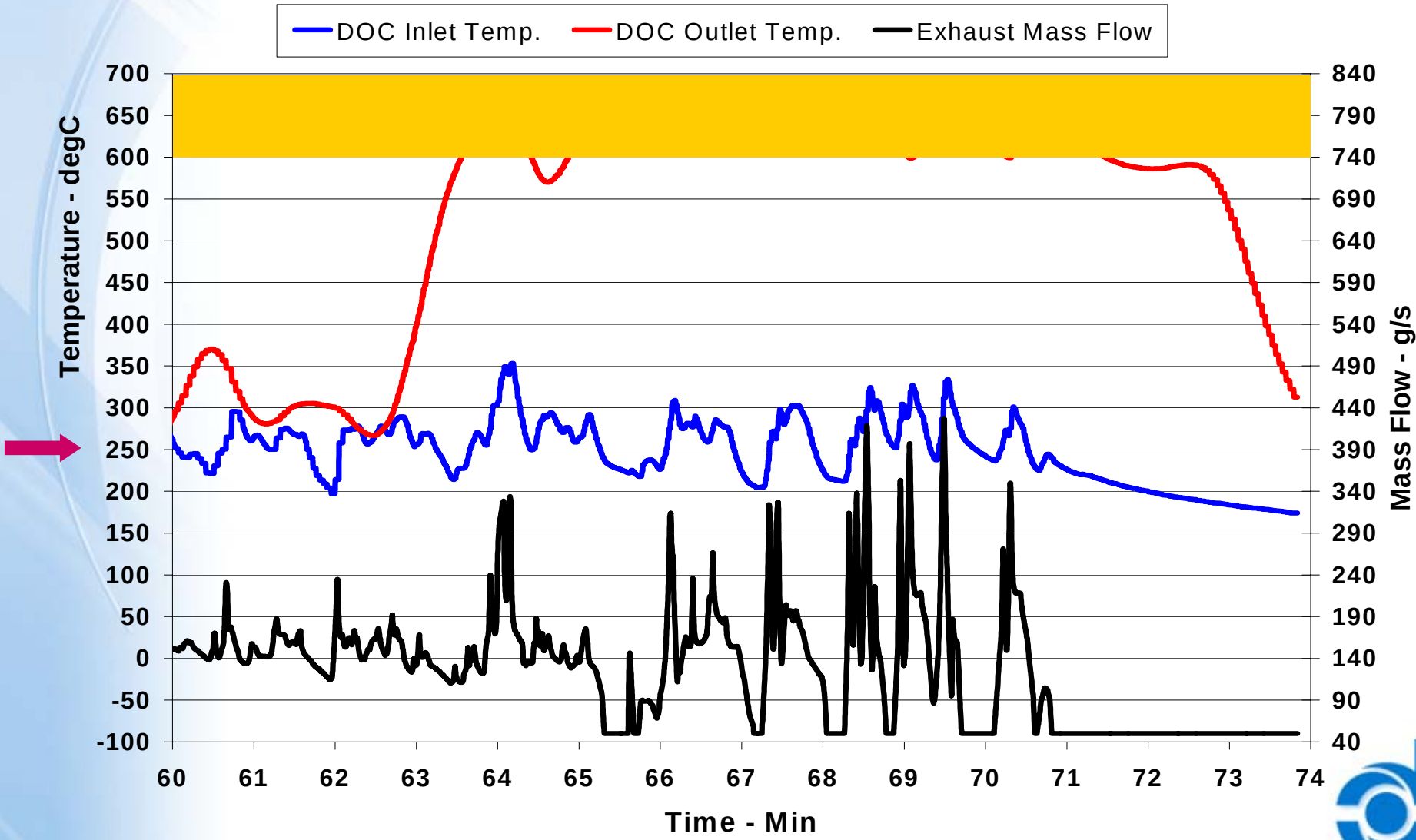
- **1997 Freightliner FLD 120**
  - **DDC Series 60 Engine (11.1 liter)**
- **System installed summer ’03**

Fully Installed Active System

Field Test Results: Line Haul Fleet Truck

Active

System Operation During Stop-&-Go City Driving



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Field Test Results: Refuse Hauler

- Difficult Application
  - Low temperature
  - Extended idling
  - Stop-&-go operation
  - Passive filter?
- Mack LE-613 (300HP E7)
- Manual Loader ~ 400 residential pickups/day
- Active System Installed May 2004

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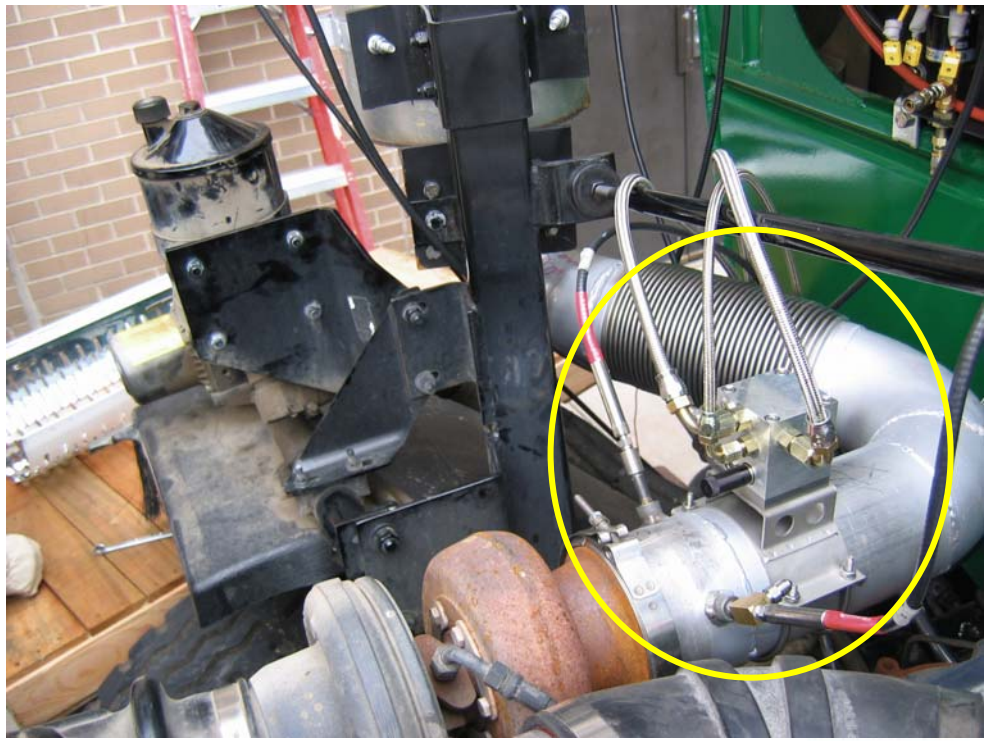
Field Test Results: Refuse Hauler

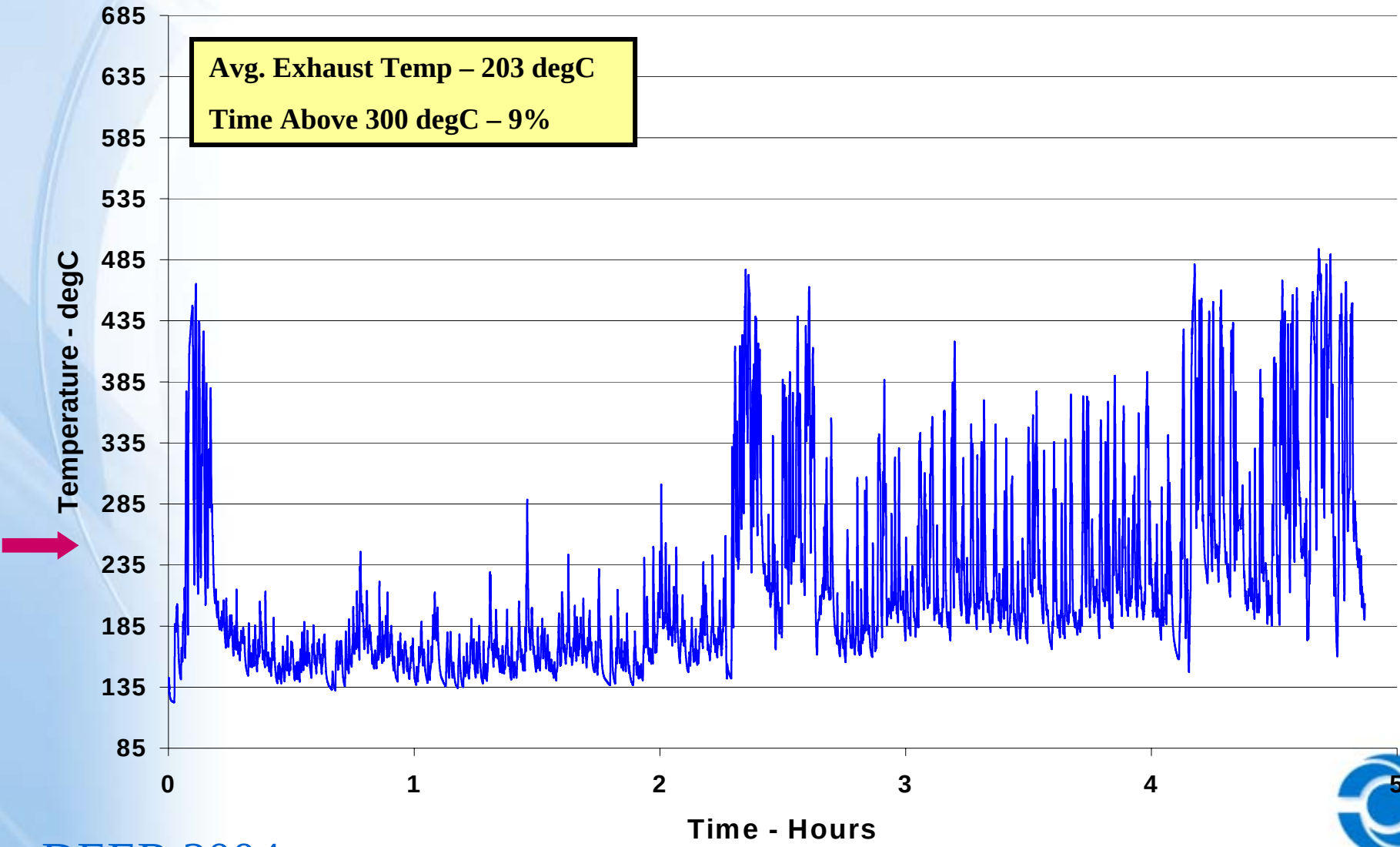
Fully Installed Active System

Fuel Delivery System



Field Test Results: Refuse Hauler

Exhaust Temperature Profile



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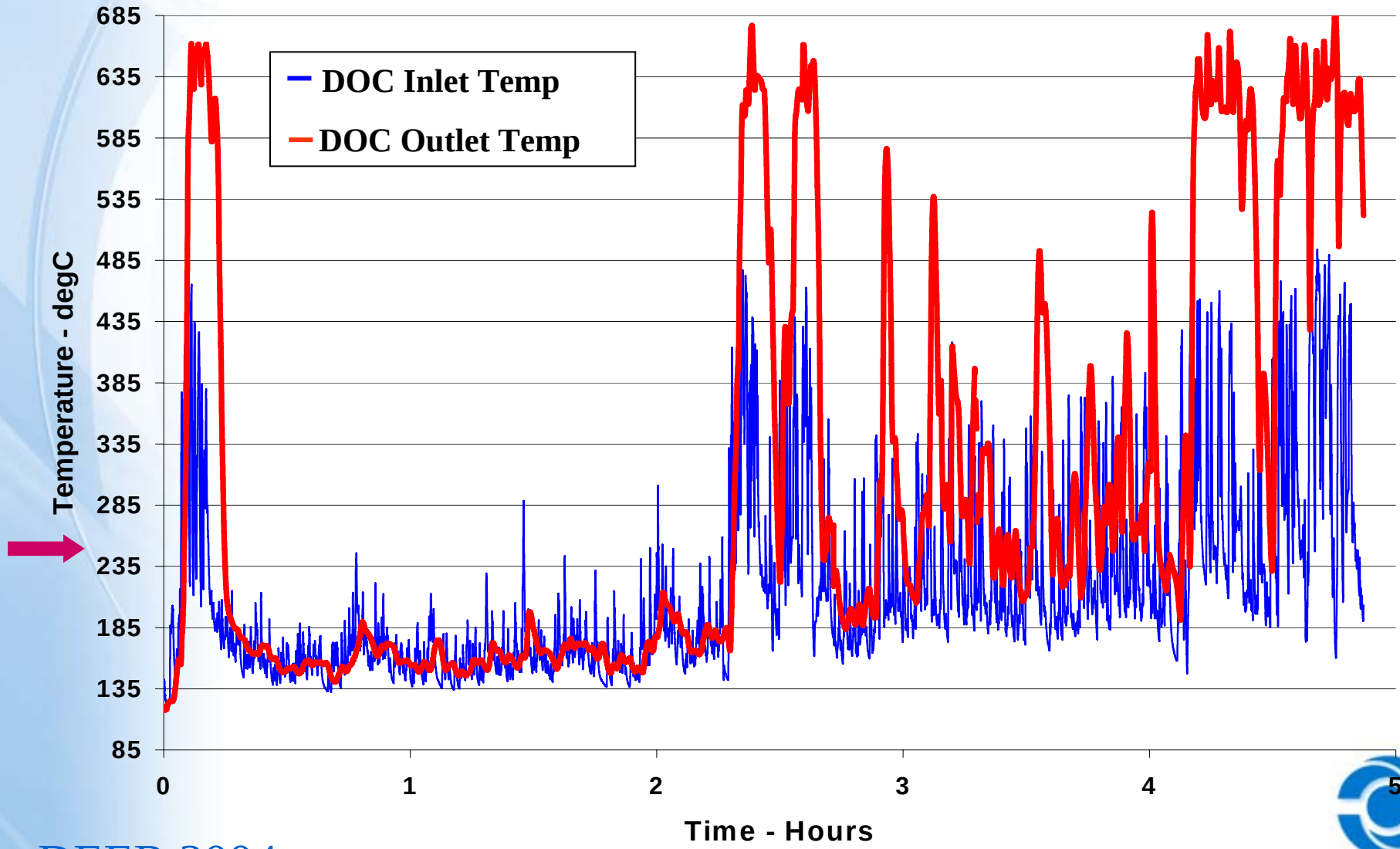
Field Test Results: Refuse Hauler

Regeneration Opportunities



DEER 2004

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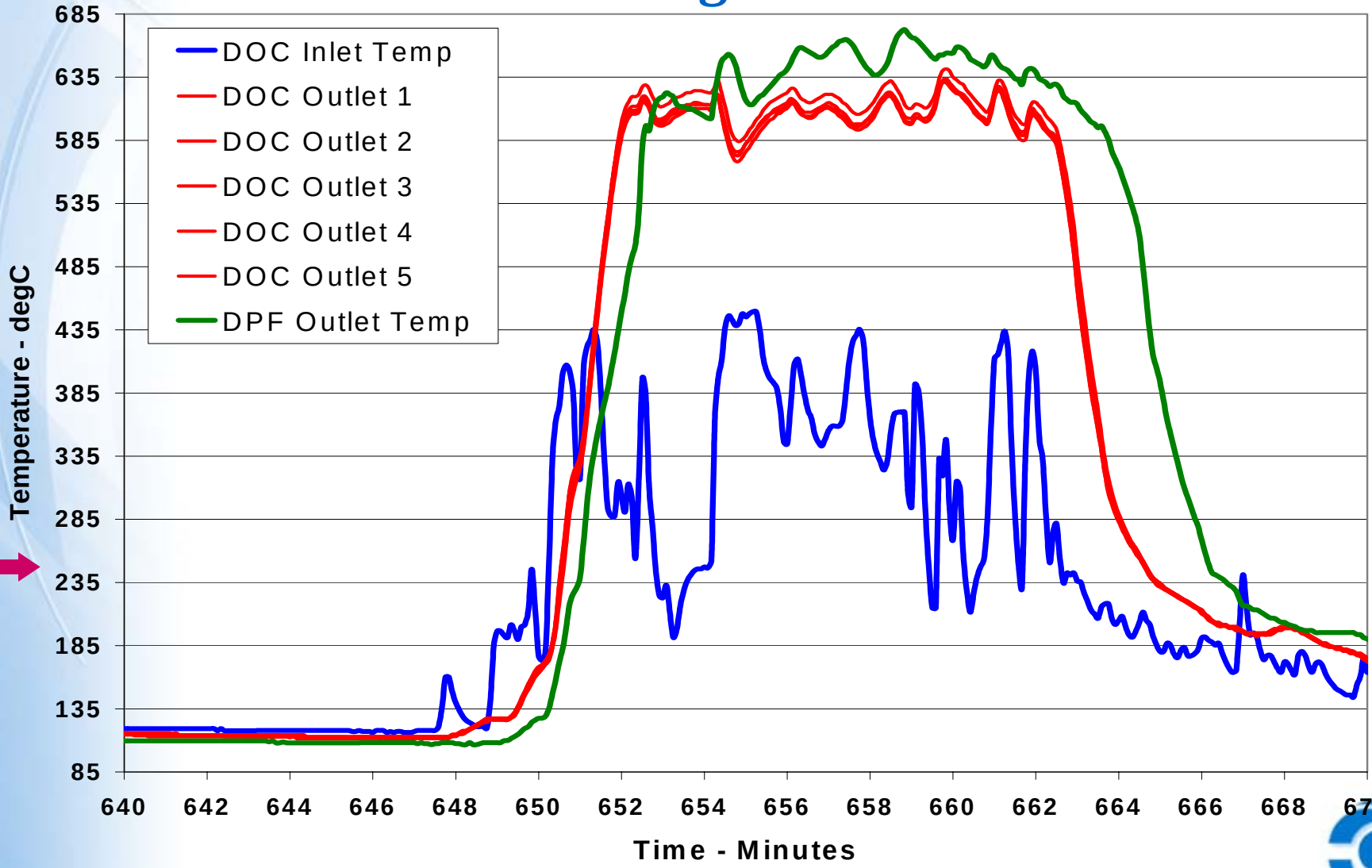
Field Test Results: Refuse Hauler

Filter Regeneration



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Summary

- Successful field-test demonstrations
  - Regenerate DPF on very difficult low-temperature duty cycles
  - Precise temperature control in transient (stop-&-go) operation
  - Compact, non-intrusive exhaust installation
- Developed model-based feed-forward adaptive control
- Developed on-board fuel delivery system