Addressing Stakeholder Concerns

2 Issues: SCR durability & Tier 4 level

1. SCR catalyst durability over locomotive life
   - Maximum exhaust temperature has dominant impact on catalyst durability
     - Fe-Zeolite SCR durability not significantly impacted for temperatures <600°C
     - Fe-Zeolite SCR catalysts have shown gradual degradation at temperatures of ~650-700°C
   - GE raised the potential for exhaust temperatures >700°C during high altitude tunnel conditions
   - OTAQ worked with GE, EMD and Union Pacific (UP) railroad to evaluate worst case tunnel conditions

2. SCR performance with higher NOx concentrations and exhaust flow rates typical of Tier 2 locomotives
   - Temperature and NOx concentration determine in part SCR performance, and hence, the ultimate emission level
   - GE raised concern that EPA's estimates didn't appropriately account for differences between rail and truck
   - NVFEL conducted testing of currently available SCR components under locomotive conditions to validate expectations for SCR based NOx control (see appendix slide 7)
Tunnel Testing to Validate Catalyst Durability

- Purpose: Identify worst case exhaust temperatures with respect to catalyst thermal durability
  - EPA worked with GE, EMD and Union Pacific to identify the most extreme exhaust temperature conditions for locomotive operation
    - Multiple-locomotive “consists” operating on mountain grades and through multiple tunnels pulling heavy trains
      - A consist is a group of locomotives directly connected and operated together using the controls from one of the locomotives
    - The Norden tunnel system at Donner Pass was identified as one of the worst case locations with respect to locomotive consist operation
      - Multiple tunnels in quick succession
      - High altitudes and long grades through the tunnels
      - 2.5-mile long unventilated tunnel (Norden #41) leading up to the summit
        - Oxygen depletion and high temperatures in tunnel
      - Heavy freight trains (8,000 to 14,500 tons of freight per train)

- 2 instrumented Tier 2 locomotives (GE and EMD) were operated in a 4-locomotive consist pulling an 8,500 ton train west-bound through the Norden tunnel system.

- Data was logged for all key engine parameters including exhaust stack temperatures and locomotive power.

A multiple-locomotive consist pulling heavy trains east-bound through Donner Pass

Hot, smoky, oxygen depleted tunnel conditions encountered during heavy train operation west-bound through Donner Pass in August 2007
Tunnel Testing to Validate Catalyst Durability
Tier 2 GE locomotive tested at a high-altitude & through multiple tunnels (Donner Pass Norden Tunnel System)

BNSF7736

Exhaust Stack T
Notch Position

Locomotive is in Norden Tunnel #41
Engine is nearing shut-down to idle condition just as it reaches tunnel exit fresh air

Notch (8 is maximum power demand)

GE Stack Temperature Claim: 700 °C
Max oil temp exceeded in tunnel 13 - power de-rate
Max oil temp exceeded inside tunnel 42 - power de-rate

Tunnel Testing to Validate Catalyst Durability - Results

- Maximum exhaust temperature was well below safety margin for catalysts
  - Maximum exhaust temperatures under extreme conditions are self-limiting due to engine protection measures taken by the engine management system
  - Operating at the highest temperature extremes in Norden Tunnel #41 resulted in peak exhaust stack temperatures of 560 °C
    » Well below the temperature where significant thermal degradation would be expected
DPF/SCR Testing at EPA-NVFEL

- 6L truck engine modified to behave like “scaled down” locomotive engine
  - Parameters were changed within the electronic engine management system to mimic the exhaust gas concentrations of a Tier 2 GE locomotive
  - Exhaust flows and exhaust gas concentration were scaled to mimic GE Tier 2 locomotive power settings
  - Catalyst size versus exhaust flow (i.e., space velocity) was scaled to match the sizing predicted in the Regulatory Impact Analysis
    - 40,000 hr\(^{-1}\) for the SCR system
  - 2010 heavy-duty truck “production intent” components were used for catalysts, urea dosing system, sensors and other components
    - 4 different base-metal zeolite SCR systems will be tested

DPF/SCR Testing at EPA-NVFEL

- Partial-flow metal-substrate DPF
- 4 different base-metal zeolite SCR catalysts
  - With ammonia slip catalysts
- Catalyst size versus exhaust flow (i.e., space velocity) scaled to match EPA draft Regulatory Impact Analysis
  - 40,000 hr\(^{-1}\) for the SCR system
- 2010 heavy-duty truck “production intent” components were used for SCR catalysts, urea dosing system, sensors and other components
  - Closed-loop urea dosing with post-SCR NOx sensor and predicted ammonia storage
Notes:
• Air-gap construction on all cones and transition piping
• 40,000 hr⁻¹ space velocity for SCR system

DPF/SCR Testing at EPA-NVFEL

- Initial test results on the first of four systems that will be tested:
  - NOx emissions levels at low hours were less than 50% of the original EPA staff projection in the Regulatory Impact Analysis and less than 20% of the GE projection
    » EPA's staff estimate in the RIA assumed 95% NOx control at the maximum power setting when new
    » EPA testing at NVFEL shows 98% NOx control at the same condition
    » GE projection was based on 90% control NOx control at maximum power
Fe-Zeolite Urea SCR Low Hour System Performance

- Tier 2/Tier 3 NOx Standard
- Tier 4 NOx Standard
- EPA Testing @ Low Hours

Brake-Specific NOx Emissions (Line-haul, g/bhp-hr)

- GE Estimate of in-use low-hour catalyst performance (1.3 g/bhp-hr)
- Original EPA Estimate of low-hour catalyst performance (0.70 g/bhp-hr)

DPF/SCR Testing at EPA-NVFEL

- Accumulation of hours
  - 2000 hours of operation will be accumulated at exhaust conditions equivalent to operation in locomotive notch 8 (maximum power)
  - 100 hours of operation at higher temperatures consistent with tunnel operation
  - Emissions measured at ~250 hour intervals
  - Accelerated ash accumulation
    - Similar accelerated oil dosing procedure to that used in SAE 2004-01-3013
    - Approximately 6X acceleration in ash accumulation
Thank you

Without the active participation and support of MECA member companies, this testing would not be possible.