University of Houston Diesel Vehicle Research and Testing Facility

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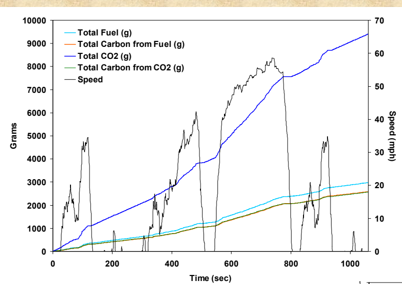
Emissions and Fuel Economy Measurement

Fuel Economy Measurement

- **Conventional Method: Carbon Balance**
  - The total amount of CO_2 in the exhaust is measured and a carbon balance is used to determine the amount of fuel consumed
- **Fuel Column Method:**
  - Fuel consumption is measured with instrumented fuel column
  - Description of Method:
    - Equipment: fuel column with DP cell on the bottom (Rosemount, model# 3015S)
    - Setup: bypass vehicle's fuel tank, fuel supply and return lines go to and from fuel column
    - Column: volume of 3.7 gallons, glass
    - Determination of fuel consumption: grams of fuel calculated by using DP and the cross-sectional area of the column
- **Advantages to Fuel Column:**
  - Does not depend on the accuracy of the CO_2 quantification method

Quantification of Pollutants (g/mile)

- **Conventional Method: Continuous Volume Sampling (CVS)**
  - The gaseous species are quantified by diluting the exhaust sample to a constant volume and measuring the concentration of that species in the diluted sample
  - The exhaust flow rate is back-calculated by determining the total flow of the dilution air used and subtracting that from the flow rate of the entire diluted sample
- **Raw Gas Analysis Method:**
  - The g/mile of exhaust constituents such as NOx, CO2, CO and THC are calculated from the exhaust concentrations and the exhaust flow rate
  - Equipment Used:
    - Raw Gas Analyzers - Horiba MEXA 7100 raw gas analyzer and MKS FTIR raw exhaust gas analyzer, both analyzers measure gas concentrations in *undiluted* exhaust samples
    - Exhaust Gas Flow Meter - Rosemount Annubar Flow Meter (Model #485), this is a differential pressure flow meter that can be used in gas streams which are hot and dirty such as diesel exhaust, this flow meter measures the *actual* exhaust flow rate in SCFM
- **Advantages to Raw Gas Analysis:**
  - Avoids reduced analyzer accuracy that comes with measuring a diluted sample
  - Increased accuracy by measuring the exhaust flow rate directly



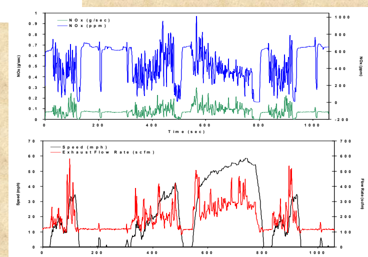
Equipment Type: 2003 Sterling 10yd Dump Truck
Engine: Cummins ISL, 310 HP

Grams of Carbon determined by two techniques, (a) quantification of the exhaust and (b) fuel economy measurements.

Run	Grams of Carbon - From Quantification of Exhaust (CO_2)	Grams of Carbon - From Fuel Economy Measurement	% Difference
1	2564.7	2582.0	0.7
2	2564.7	2576.0	0.4
3	2515.4	2562.9	1.9

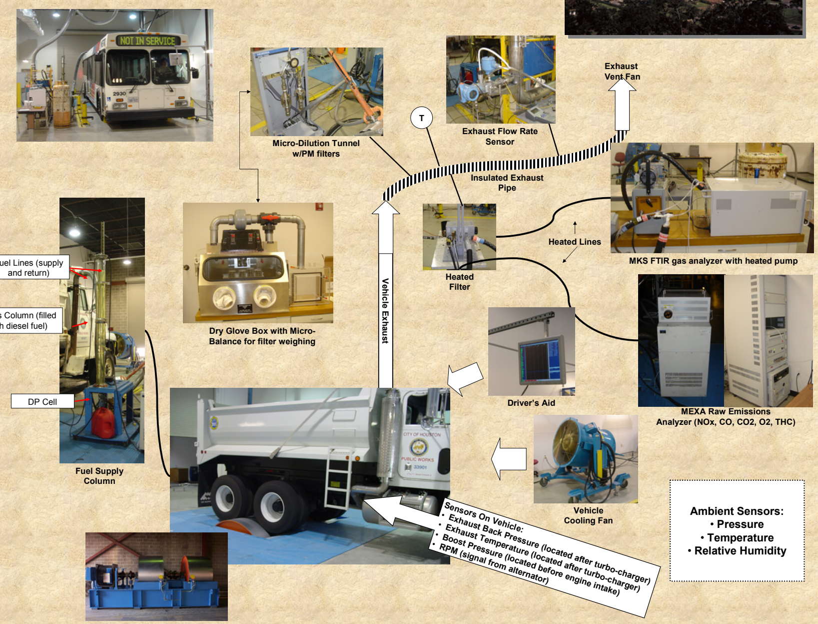
NOx, THC, CO, CO_2, and total fuel for three consecutive hot-start runs.

Run	NOx (g/mile)	THC (g/mile)	CO (g/mile)	CO_2 (g/mile)	Fuel (total grams)
1	14.33	1.14	5.94	1685.2	2976
2	14.28	1.11	5.88	1684.2	2969
3	14.18	1.14	5.80	1651.5	2954
Coefficient of Variation (%)	0.52	1.37	1.21	1.15	0.38



Diesel Emission Facility

- The University of Houston Diesel Vehicle Research and Testing Facility is a heavy-duty diesel vehicle emissions testing laboratory
- Capabilities range from bench scale reactor testing of emerging emission reduction technologies through chassis dynamometer testing of heavy-duty diesel vehicles
- The facility provides valuable information on many of the new air pollution control measures that will soon be in effect for the Greater Houston area



Ambient Sensors:
- **Pressure**
- **Temperature**
- **Relative Humidity**

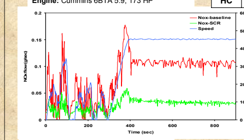
Acknowledgements: Dynamometer Facility supported by The City of Houston

Anhydrous Ammonia SCR

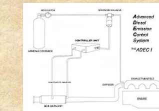
In the Selective Catalytic Reduction (SCR) process, NOx reacts with ammonia, which is injected into the exhaust gas stream before the catalyst.

	% Reduction
NOx	66
CO	87
HC	75

Equipment Type: 1992 Gradall Excavator
Engine: Cummins 6BTA 5.9, 173 HP



SCR technology supplied by Extengine Inc.



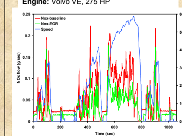
Source: Extengine Inc. website

Observations and Opportunities for Improvement:
- *NOx conversion:* Demonstrated potential for NOx conversions of 70-80% as retrofit technology
- *Ammonia injector reliability and durability:* Continuity of ammonia delivery critical for NOx conversion
- *Control system design and reliability:* Ammonia feed determined by measured engine load and RPM; NOx sensor based system needed to provide improved performance
- *Optimization of performance:* Use of dynamometer to optimize ammonia injection for NOx reduction for individual vehicle

Exhaust Gas Recirculation

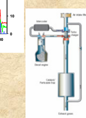
Exhaust gas recirculation (EGR) is a method by which a portion of engine's exhaust gas is returned to its combustion chambers via the inlet system in order to reduce NOx emissions. The EGR method involves displacing some of the oxygen inducted into the engine as part of its fresh charge air with inert gases, thus reducing the rate of NOx formation.

Equipment Type: 1999 Volvo Garbage Truck
Engine: Volvo VE, 275 HP



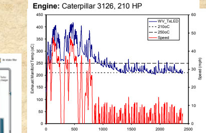
EGR technology supplied by STT Emtec

	% Reduction
NOx	42
CO	83
HC	92



Source: STT Emtec website

Equipment Type: 2000 Chevrolet Tree Grapple
Engine: Caterpillar 3126, 210 HP



Plot of Vehicle Exhaust Temperature using a West Virginia Refuse Truck Drive Cycle.

Observations and Opportunities for Improvement:
- *NOx conversion:* Demonstrated potential for good conversion (30-40%) as retrofit technology
- *Vehicle maintenance:* Baseline particulates must be within engine specifications.
- *Vehicle duty cycle:* Low exhaust temperatures prevent complete DPF regeneration leading to excessive pressure and/or filter blowout; Typical DPF requires a significant fraction of the operating time (~50%) to have an exhaust temperature >250°C

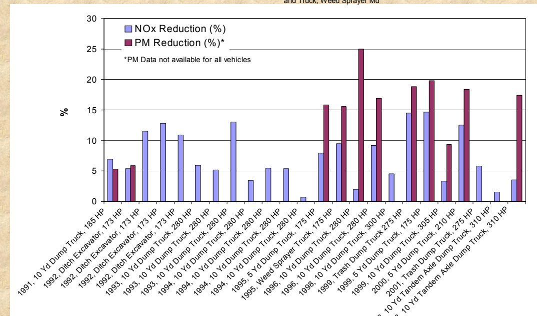
Fuel Testing

TxLED ULSD

- **New Diesel Fuel Requirements:**
  - *Federal Government:* In September 2006, the federal government requires that retailers and wholesalers sell only ultra low-sulfur diesel (ULSD) with a maximum sulfur content of 15 ppm
  - *Texas:* Requires further changes to the diesel formula to deal with NOx emissions in the eastern portion of the state
    - Texas low emission diesel (TxLED): Builds on the federal requirement, places a 10% cap on aromatic hydrocarbons and a minimum cetane number of 48 (these standards help reduce the amount of NOx produced during combustion)

	Average Experimental Reductions (%)	State Mandated Reductions (%)
NOx	7.3	5.7
PM	15.3	10.5

- **TXLED/ULSD Testing**
  - Fuels: 500ppm Diesel fuel, TXLED/ULSD fuel
  - 24 different City of Houston vehicles were tested
  - Model years: 1991-2003
  - Horsepower: 173-310
  - Types of vehicles: Excavator/Tire, Ditch; Heavy Truck, 10yd Tandem axle Dump; Truck, Dump 10 Yd Md; Truck, Dump 5 Yd Md; Truck, Trash Dump Md; and Truck, Weed Sprayer Md



ULSD/TxLED Fuel supplied by Valero

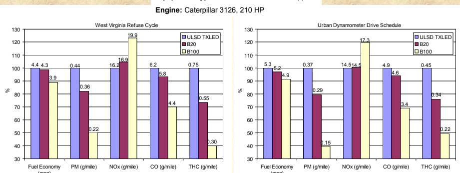
Observations and Opportunities for Improvement:
- This fuel showed reductions which were on average close to the state mandated reductions, but may vary greatly depending on the vehicle

Biodiesel

Biodiesel is a renewable diesel fuel derived from a number of vegetable oils, it is manufactured by reacting processed vegetable oils or animal fats with methanol and a catalyst in a process called "transesterification".

- **Biodiesel Testing**
  - Fuels:
    - TxLED/ULSD fuel (Valero)
    - B100 biodiesel fuel (Dobbins International)
    - B20 biodiesel fuel (made from 4 parts TxLED, and 1 part B100).
  - Drive Cycles:
    - Urban Dynamometer Drive Schedule (UDDS)
    - West Virginia Refuse Cycle
  - Simulated Weight of Vehicle: 34,080 lbs
  - Testing Protocol: All 3 fuels tested with both drive cycles, each run was repeated 3 times
  - Exhaust Measurement: Emissions of NOx, THC, CO, CO_2, O_2 and total PM were measured

Equipment Type: 2000 Chevrolet Tree Grapple
Engine: Caterpillar 3126, 210 HP



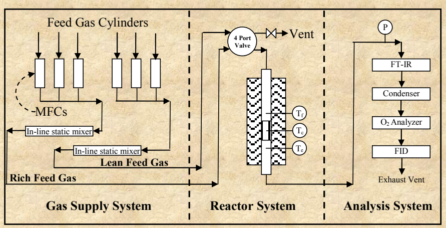
Biodiesel supplied by Organic Fuels Ltd./Dobbins Intl.

- **Fuel economy, PM, NOx, CO and THC percentage differences between a baseline fuel (TxLED/ULSD) and two biodiesel fuels (B100 and B20)**
- **Actual values of each measurement are also shown**

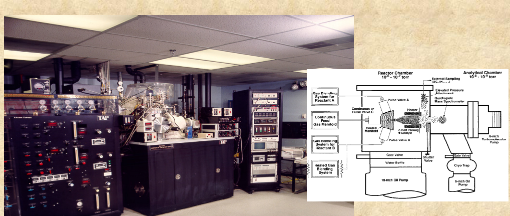
Observations and Opportunities for Improvement:
- NOx increase and PM decrease: B100 caused an average 21.4% increase in NOx and an average 55.0% decrease in PM
- B20 caused an average 2.6% increase in NOx and an average 19.2% decrease in PM with biodiesel blends
- The B20 results show that NOx increases and PM decreases are not linear and that blend optimization is possible
- The marked decrease in PM makes biodiesel well suited for use with EGR

Bench-scale/NOx Trap and TAP Reactor

Unlike catalysts, which continuously convert NOx to N_2, NOx traps store NOx under lean conditions and catalytically reduce the stored NOx under rich conditions.

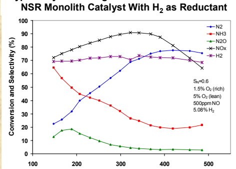


Bench-Scale Reactor Set-up



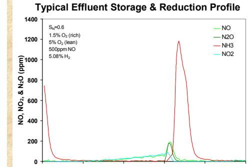
Tap Reactor: Photo and Schematic

Typical Cycle-Averaged Results on Pt/Ba/alumina NSR Monolith Catalyst With H_2 as Reductant



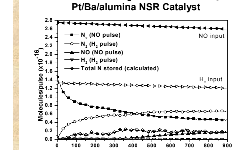
- NOx conversion exhibits maximum at 350 °C
- N_2 selectivity increases with temperature
- NH_3 selectivity decreases with temperature

Typical Effluent Storage & Reduction Profile



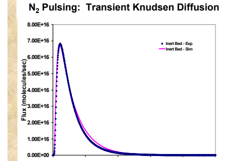
- NO and NO_2 breakthrough during lean storage
- N_2O and NH_3 production during rich pulse (N2 not measured)
- Significant NH_3 appears at end of rich pulse

TAP Results: NO/H_2 Sequential Pulsing on Pt/Ba/alumina NSR Catalyst



- N_2 produced during NO pulse evidence for NO decomposition
- N_2 produced during H_2 pulse evidence for reduction of NOx stored on Barium phase

N_2 Pulsing: Transient Knudsen Diffusion



- Excellent agreement between modeling and experiment confirms diffusion transport

Acknowledgements: Supported by State of Texas TDT, Engelhard Inc. and DOE-NETL (award DE-FC26-05NT42630)