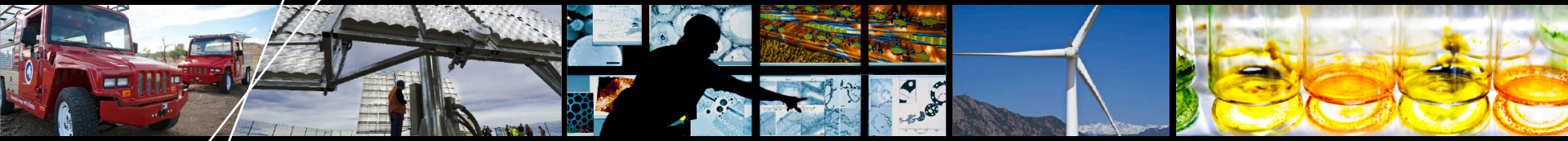
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Vehicle Emissions and CNG Vehicle Safety



John Gonzales

April 14, 2016

History of Early Air Policy in California

- **Smog in the Los Angeles basin**
  - Visible and felt before World War II
  - **Initial concerns emphasized crop and forest damage**
  - First thought to be "smoke + fog" trapped by air inversion; scientific studies then identified ozone (O_3) as the culprit
  - Initial reduction efforts targeted industrial and agricultural sources, but little progress was made
- **Policy responses**
  - Los Angeles County Air Pollution Control District* was formed in 1947 with Calif leg. votes of 73-1 (Assembly), 20-0 (Senate)
  - California Air Resources Board (CARB) formed in 1968

*Now known as South Coast Air Quality Management District (SCAQMD); see www.aqmd.gov

History of U.S. Clean Air Policy

- **Early federal laws**
  - Air Pollution Control Act of 1955: fund research
  - Clean Air Act of 1963: monitor and develop control measures
  - Air Quality Act of 1967: expand authority; interstate pollution
- **Clean Air Act Amendments of 1970 (the "CAA")**
  - Created comprehensive authority and enforcement procedures, including provision for citizen lawsuits
  - Coverage for both stationary and mobile sources
  - National Ambient Air Quality Standards (NAAQS)
  - Authority to address any air pollutant determined to endanger public health and welfare, regardless of cost
- **National Environmental Policy Act of 1970 (NEPA)**
  - Established the U.S. Environmental Protection Agency

EPA Criteria Pollutants

- **Criteria Pollutants**
  - Oxides of Nitrogen and Sulfur (NOx/SOx)
    - respiratory effects including airway inflammation
    - increased asthma symptoms
  - Carbon Monoxide (CO)
    - reducing oxygen delivery to the body's organs (like the heart and brain) and tissues
  - Ozone
    - can reduce lung function and inflame the linings of the lungs. Repeated exposure may permanently scar lung tissue.
  - Lead
    - Can cause neurological effects in children and cardiovascular effects
  - Particulate Matter (PM)
    - Numerous scientific studies have linked particle pollution exposure to a variety of heart and lung problems

Non-Criteria Pollutants

- **Green House Gases (GHGs)**
  - Total Hydrocarbons (THC)
    - hexane, benzene, toluene, xylenes, naphthalene, and fluorine, as well as other petroleum products and gasoline components
  - Methane (CH_4)
    - emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and by the decay of organic waste (RNG)
  - Carbon Dioxide (CO_2)
    - Results from the combustion of fossil fuel, solid waste, wood products and as the result of certain chemical processes
  - Fluorinated Gases
    - Hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes

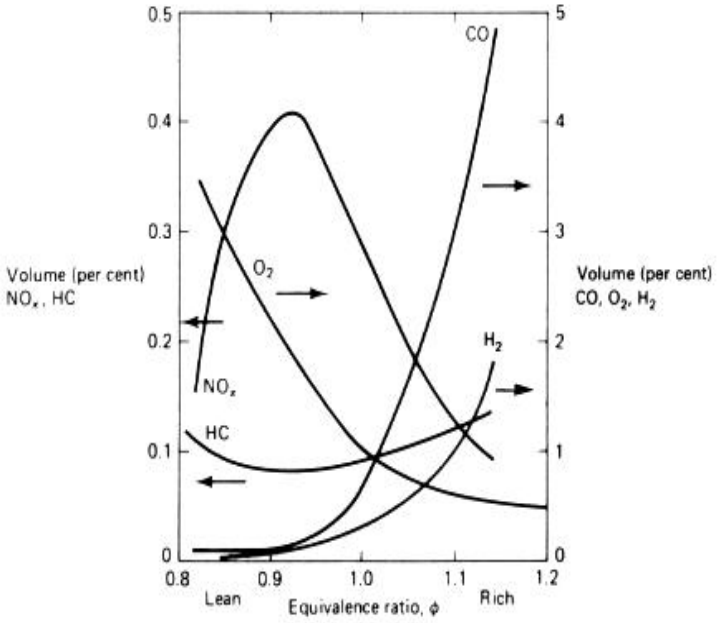
Vehicle Emissions & Regulation

- **Problematic Vehicle Emissions**
  - Oxides of Nitrogen and Sulfur (NOx/SOx)
  - Carbon Monoxide (CO)
  - Unburned Hydrocarbons (NMHC)
  - Particulate Matter (PM)
  - Formaldehyde (HCHO)

- **Regulated by the EPA and CARB**

Vehicle Emissions: Definitions

- **Compression Ignition (No spark plugs)**
  - Diesel
  - Lean A/F ratio (excess O_2)
  - Low exhaust gas temperatures
- **Spark Ignition (Spark plugs)**
  - Light-duty gasoline, HD CNG/LPG
  - Stoichiometric A/F ratio (Very low O_2)
  - High exhaust gas temperatures
- **Engine-out emissions**
  - Raw, untreated exhaust gases
- **Aftertreatment**
  - Hardware required for the treatment of E.O. exhaust gases
- **Tailpipe emissions**
  - Post aftertreatment exhaust gases - Regulated



Vehicle Emissions – Engine Out

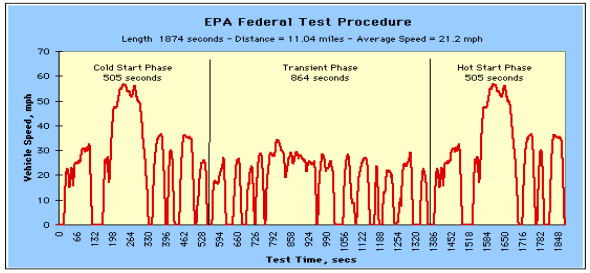
- **HC and CO Forms in Rich Mixtures**
  - Not enough oxygen to complete reaction
- **NOx Forms in Lean Mixtures**
  - Needs oxygen and high temperatures
  - Once formed it is hard to remove
  - Diesel Issue/DI Gasoline
- **PM Formed Mainly in D.I. Engines**
  - Produced in heterogeneous charge rich fuel pockets
  - Both Gasoline and Diesel

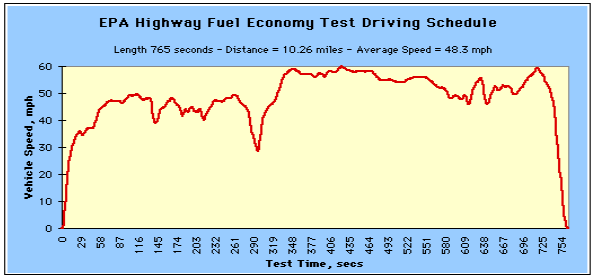
Emissions Regulation - Testing

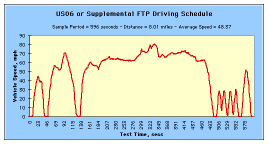
Light-duty Federal Tier II

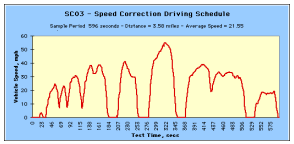
- Light-Duty Vehicle (GVWR < 8,500 lbs)
- Medium-Duty Passenger Vehicle (GVWR <10,000 lbs)

Fuel Neutral – Diesel, CNG, LNG, LPG like gasoline



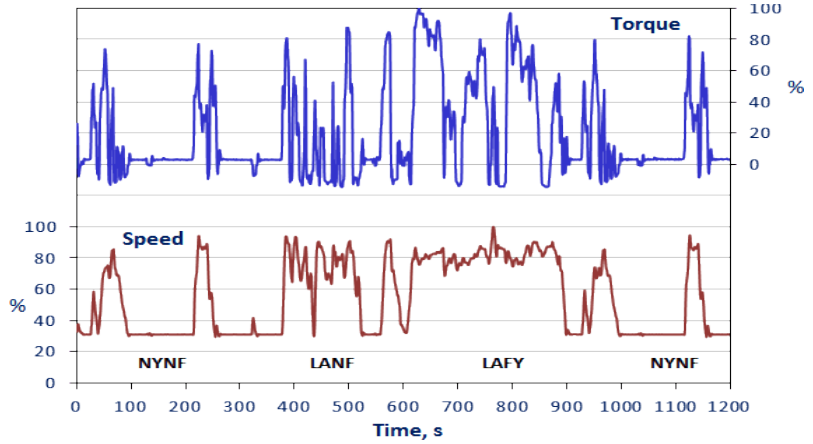




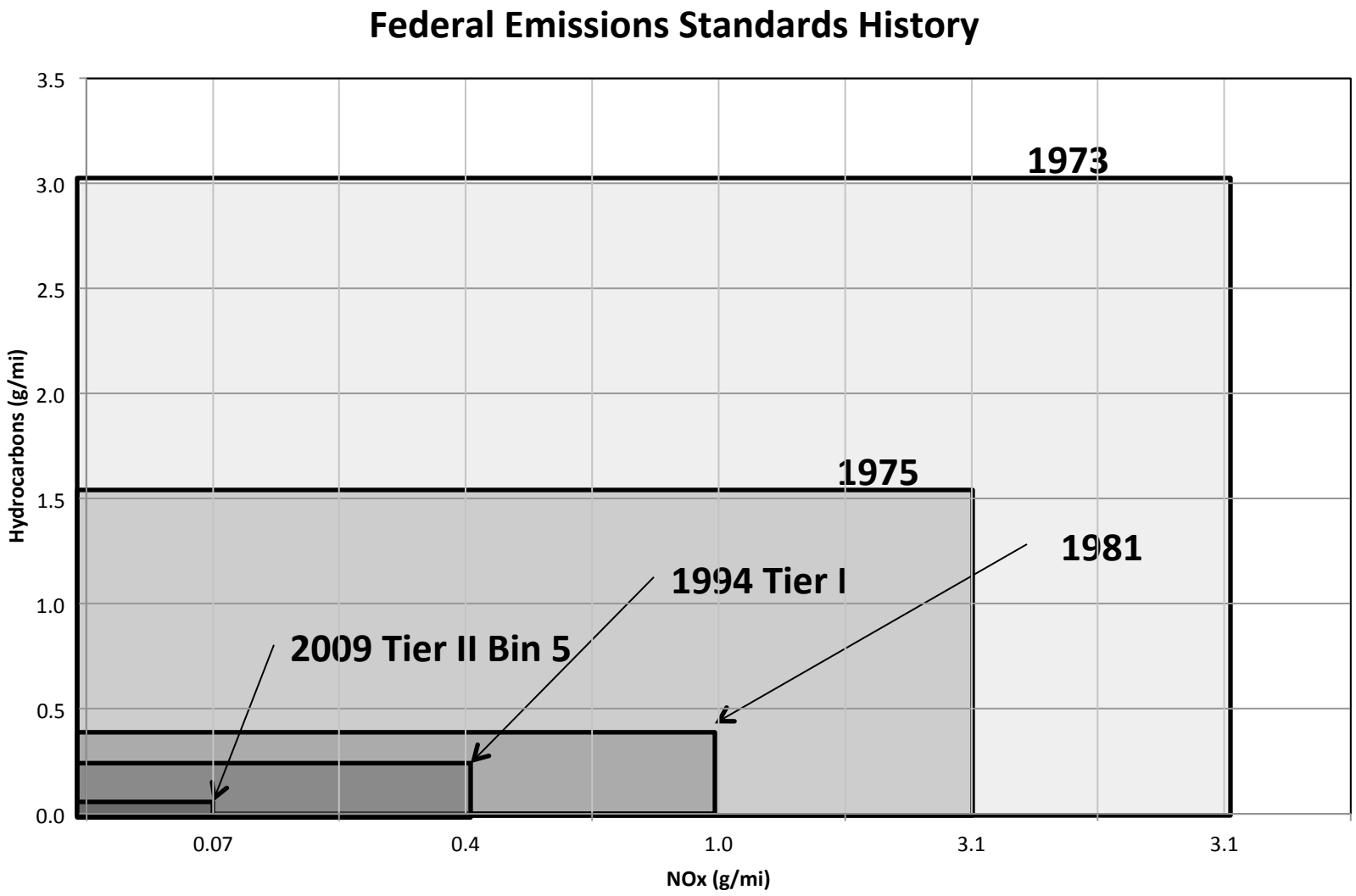


Heavy-Duty Highway Compression-Ignition Engines And Urban Buses

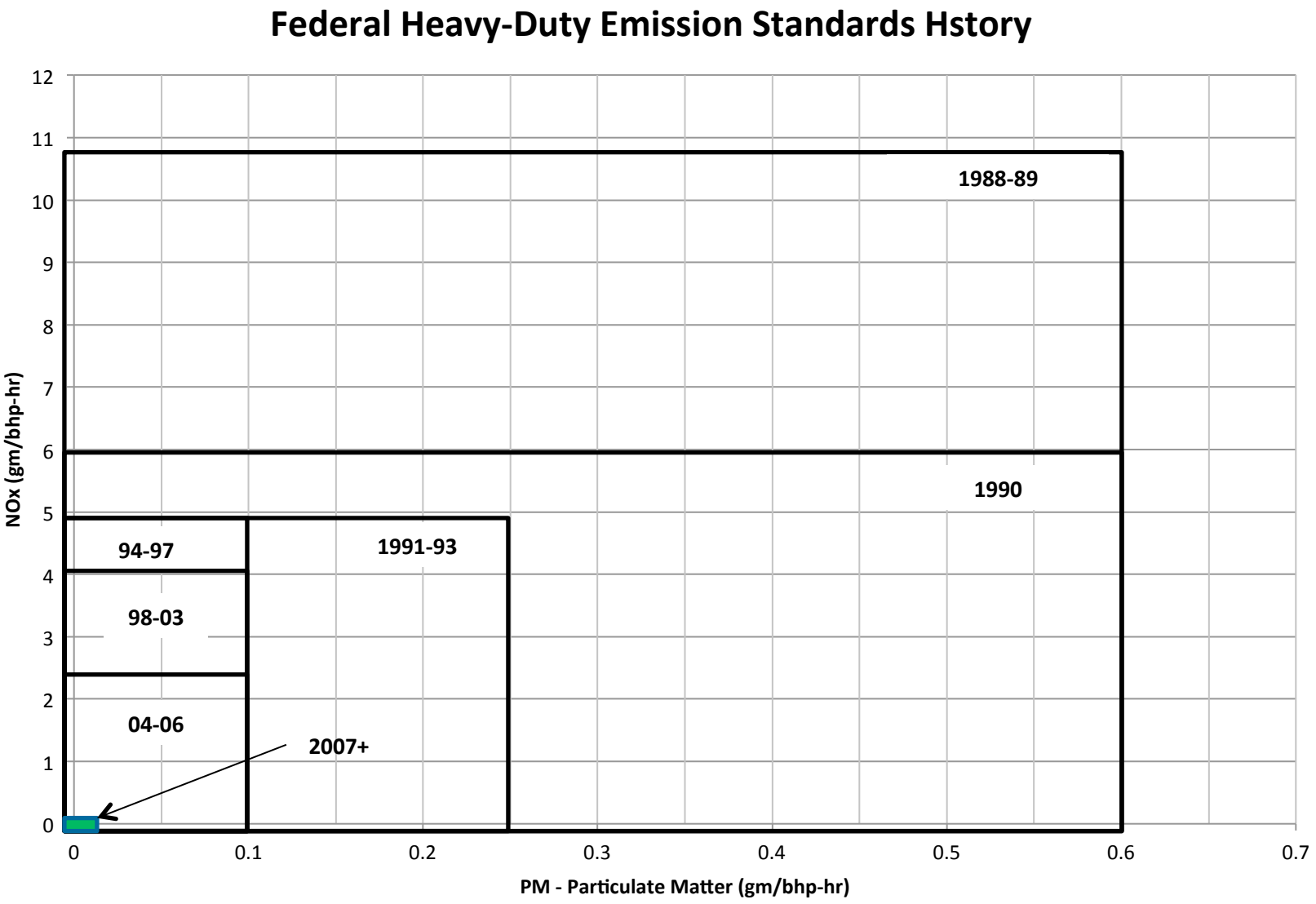
Fuel Neutral –CNG, LNG like diesel



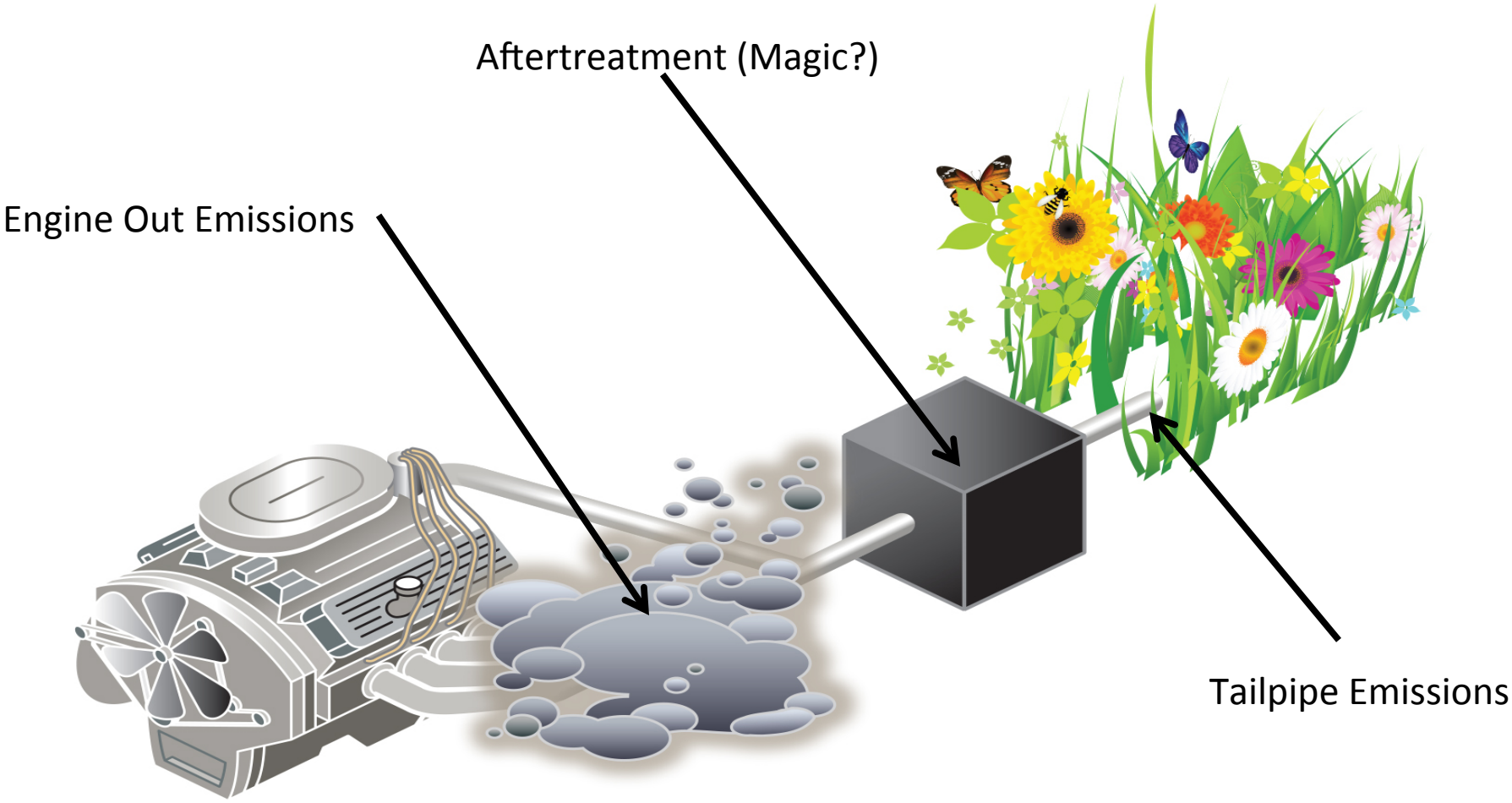
Emissions Regulation Trends – Light-duty



Emissions Regulation Trends – Heavy-duty



Aftertreatment - General

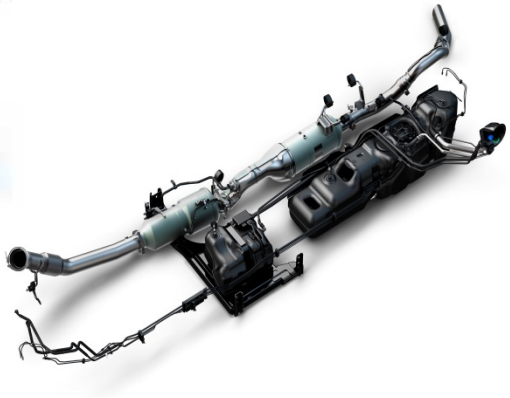


Aftertreatment

Gasoline (Stoich) Aftertreatment

(CNG & LPG)

- **EGR**
  - Reduces peak cylinder temperatures affecting NOx formation
- **O2 Sensor**
  - Provides feedback for A/F control
- **Three-way Catalyst (s)**
  - Contains Pt, Pd, Rh
  - Oxidizes HC, Reduces NOx



Diesel Aftertreatment

- **EGR**
  - Reduces peak cylinder temperatures affecting NOx formation
- **Diesel Oxidation Catalyst**
  - First line of defense for HC, CO, NO
  - Buffers HC during cold starts
  - Produces NO_2 for use down stream
- **Selective Catalytic Reduction (SCR)**
  - NOx is reduced in the presence of NH_3
  - Adapted from industrial process
  - Automobiles rely on Urea injection in the exhaust
- **Lean NOx trap**
  - Two mode operation
  - Lean – NOx (NO_2 preferred species) is stored on Barium or a similar material
  - Rich - NOx is regenerated similar to gasoline TWC
  - Very Sulfur sensitive – low sulfur fuel requirement
  - Regeneration causes a direct fuel penalty
- **Diesel Particulate Filter (DPF)**
  - Alternating Flow Channel Pattern
    - Exhaust travels through a porous wall
  - Stores PM on Inlet Channel Walls
  - At high enough temperatures, soot oxidizes - large exothermic reaction
  - Nearly 100% Effective at Trapping Soot
  - Issues: Increasing pressure drop with soot loading
  - Ash accumulation
  - Regeneration causes a direct fuel penalty

CNG – Diesel Emissions Comparison

- **For a given engine displacement and application both fuels must certify to the same Standard.**

Diesel combustion and aftertreatment
- Lean combustion, excess 0_2
  - Oxidizes CO -> CO_2
- Combination of aftertreatment strategies
  - EGR, DPF, SCR, LNT…

CNG combustion and aftertreatment
- Stoich combustion, no excess 0_2
  - Less oxidization CO -> CO_2
- Aftertreatment strategies
  - EGR
  - O_2 feedback
  - 3 way catalyst

Cummins 8.9L ISL/ISL-G Certification Comparison

	NMHC (g/ bhp-hr)	CO (g/bhp-hr)	NO_x (g/bhp-hr)	PM (g/bhp-hr)
EPA Std	**0.14**	**15.5**	**0.2**	**0.01**
Diesel	0.01	0.14	0.2	0.0
CNG	0.1	7.8	0.1	0.0

Gasoline – LPG & CNG Emissions Comparison

- **For a given engine displacement and application both fuels must certify to the same Standard.**

Gasoline combustion and aftertreatment

- Stoich combustion, no excess 0_2
  - Less oxidization CO -> CO_2
- Aftertreatment strategies
  - EGR
  - O_2 feedback
  - 3 way catalyst

LPG combustion and aftertreatment

- Stoich combustion, no excess 0_2
  - Less oxidization CO -> CO_2
- Aftertreatment strategies
  - EGR
  - O_2 feedback
  - 3 way catalyst

Ford 6.8L V-10 Certification Comparison – HD On-Road Spark Ignited

	NMHC (g/ bhp-hr)	CO (g/bhp-hr)	NO_x (g/bhp-hr)	PM (g/bhp-hr)
EPA Std	**0.23**	**8.1**	**0.4**	**0.02**
Gasoline	0.05	2.7	0.03	0.0
LPG	0.07	2.2	0.08	0.0
CNG	0.01	4.1	0.1	0.0

Emissions Regulation Future

Light-duty Tier III

- NMOG + NO_x Standard
- Lowered PM Standard
- Useful Life extended to 150k miles
- Includes Class 2b (8,501-10,000lbs GVWR) & Class 3 (10,001 – 14,000lbs GVWR) Trucks and Vans
- Test fuel to contain lower octane, lower sulfur and 10% Ethanol

Medium- and Heavy-duty Truck Phase II

- 2018+ GHG Standards
- Combined F.E. Standard

Medium- and Heavy-duty Alternative Fuel Conversions

- New
- Intermediate Age
- Outside Useful Life

Compressed Natural Gas Vehicle Fuel Tank Safety

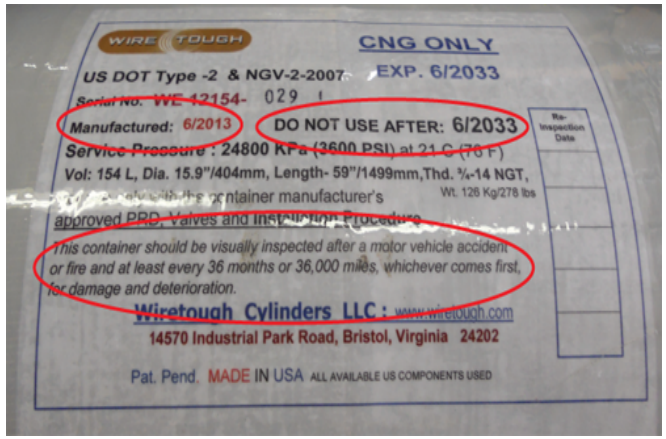
- **Project Background**
- **CNG fuel Tank Code Requirements**
- **CNG Fuel Tank End of Life**
- **Awareness/Involvement**

Education Project Background

- NGVs operate using natural gas that is compressed to 3,000-3,600 psi and stored in high-pressure fuel tanks (cylinders).
- CNG fuel tanks have safety standards associated with periodic inspections and tank expiration.
- Some of the first CNG vehicles put into service have reached or are approaching the 15 year lifespan of fuel tank.
- To ensure safe operation and decommissioning of these fuel tanks, a government-industry partnership was been started to provide resources related to training, best practices, case studies, and general outreach/awareness.

CNG Fuel Tank Code Requirements

- **CNG Fuel Tanks (Cylinders) shall be manufactured, inspected, marked, tested, equipped and used in accordance with ANSI NGV 2 or FMVSS 49 CFR 571.304. NFPA 52 allows either standard.**
- **Fuel Tanks should be visually inspected at least every 36 months or 36,000 miles, whichever comes first, and;**
  - After a motor vehicle accident or fire and;
  - After a dispenser malfunction that results in pressure greater than 125% service pressure.
- **Fuel Tanks that have reached their labeled expiration date (EOL) or been condemned by inspection shall be removed from service (and destroyed).**
- **Vehicles shall be labeled at the fueling EOL date and the date for the next inspection.**



CNG Fuel Tank End of Life

- **All CNG fuel tanks carry a label that says "DO NOT USE AFTER (EXPIRATION DATE)." For instance, it might say "DO NOT USE AFTER 01/2027."**
- **CNG fuel tanks have a useful life of 15, 20, or 25 years, depending on their construction and how they were certified by the original manufacturer.**
- **Currently there is no way to safely "requalify" fuel tanks for extended use. So once a fuel tank reaches its expiration date, it must be replaced (and destroyed).**
- **CNG vehicle owners are responsible for compliance with fuel tank end of life requirements.**
  - Currently, there is no state-by-state or national system to track or notify owners when their fuel tanks reach their expiration date

CNG Fuel Tank Service Life Issues

- **Awareness of the inspection and EOL requirements varies.**
- **CNG fuel tanks have a specific service life that may be different than the variable service life of the vehicle.**
- **Fuel tanks that need to be replaced before the end of the vehicle's life introduce concerns regarding proper fitment of replacement fuel tanks, brackets and mounting components compared to the original installation.**
- **Resale and incorrect disposal of fuel tanks that have reached their EOL or been removed due to damage has led to failures and loss of life in other markets.**
  a. **Expired fuel tanks are available for sale on internet** auction /surplus sites because they were not effectively destroyed when condemned as a result of damage or EOL.
  b. **Decommissioning** fuel tanks and/or scrapping CNG vehicles without established procedures (education) **has led to serious incidents**.
- **Enforcement of the requirements is uncertain and not consistent**

Summary: Important Takeaways

- **CNG fuel tanks have a specified expiration date after which the vehicle should not be operated while the tank is installed.**
- **CNG fuel tanks have a specific service life that may be different than the variable service life of the vehicle.**
- **Currently there is no way to safely "requalify" fuel tanks for extended use. So once a fuel tank reaches its expiration date, it must be replaced (and destroyed).**
- **Fuel tanks may be replaced before the end of the vehicle's life, if necessary, but care must be taken to ensure proper installation of the new tank.**
- **The fuel tank expiration can affect the resale value of the vehicle, as well as eliminate the ability to use the vehicle as a spare fleet vehicle once it has reached its expiration date.**
- **Fleets need to be aware of the fuel tank expiration date to ensure replacement vehicles are delivered to support continued operations.**

Resources Currently Available

- Alternative Fuels Data Center – Natural Gas Maintenance and Safety (Clean Cities)
- Alternative Fuels Data Center – Cylinder End of Life, Replacement and Inspection (Clean Cities)
- Safety Advisory: Advisory to Scrap and Recycling Yards Regarding Safe Disposal of High Pressure Cylinders (CVEF, 12/1/10)
- CNG Cylinder Installation In-Service Inspection and End of Life Decommissioning Video (CVEF, 5/31/14)
- CNG Safety Bulletin: Safety Advice for Defueling CNG Vehicles and Decommissioning and Disposal of CNG Cylinders (CVEF)
- Review of Limited Calendar Service Life for ANSI NGV2/FMVSS 304 CNG Fuel Containers (CVEF, 8/14/12)

Thank you

John Gonzales
National Renewable Energy Laboratroy
John.gonzales@nrel.gov