OUTLINE OF PRESENTATION

- **NOx Background**
  - Air quality
  - Regulation
  - Vehicle controls
  - In-use vs. regulatory emissions

- **AFLEET Tool 2017 Updates**
  - Argonne tool development for Clean Cities
  - AFLEET background
  - AFLEET 2017 updates
NO$_x$ BACKGROUND
NO\textsubscript{X} ARE A SIGNIFICANT CONTRIBUTOR TO AIR QUALITY CONCERNS

- **Nitrogen oxides (NO\textsubscript{x} = NO + NO\textsubscript{2})**
  - N\textsubscript{2} + O\textsubscript{2} + heat = NO
  - NO + O\textsubscript{2} = NO\textsubscript{2}
  - Contributes to air quality issues:
    - Secondary PM, ozone, haze, acid rain
  - Responsible for brown color of “smog”

- **Particulate matter (PM)**
  - NO\textsubscript{x} + H\textsubscript{2}O + O\textsubscript{2} = HNO\textsubscript{3}
    - HNO\textsubscript{3} + NH\textsubscript{3} = NH\textsubscript{4}NO\textsubscript{3} (secondary PM\textsubscript{2.5})
  - Impacts lungs & heart function
  - Health impacts depend on size
    - Fine PM (PM\textsubscript{2.5}) cause more damage

- **Ground-level ozone (O\textsubscript{3})**
  - NO\textsubscript{x} + VOC + sunlight = O\textsubscript{3}
  - Impacts lung function
  - Damages plants & crop yields
SIGNIFICANT PROGRESS MADE REDUCING EMISSIONS BUT PROGRESS IS NEEDED

- Sensitive groups include people with heart or lung disease, older adults, children, & people who are active outdoors

EPA, 2017, Air Trends; EPA 2017 AirNow
REGULATORY FOCUS FOR VEHICLES HAS BEEN ON PM AND OZONE (AND THEREFORE NO$_X$)

- 119 million in O$_3$ nonattainment
  - 2008 std. = 75 ppb
  - 2015 std. = 70 ppb
  - More counties will be in non-attainment

- 39 million people in PM$_{2.5}$ nonattainment areas

8-Hour Ozone Nonattainment Areas (2008 Standard)

Nonattainment areas are indicated by color. When only a portion of a county is shown in color, it indicates that only that part of the county is within a nonattainment area boundary.

Cai, 2017
**BOTH LIGHT- & HEAVY-DUTY VEHICLES ARE SIGNIFICANT CONTRIBUTOR TO NO$_x$**

- Gasoline light-duty vehicles & diesel heavy-duty trucks = large source of NO$_x$
- Total PM$_{2.5}$ concentrations: primary ~20% & secondary ~80%
  - NO$_x$ accounts for ~15% of secondary PM$_{2.5}$

*Excluding fires, dust, agriculture, vegetation*

EPA, 2017, National Emissions Inventory 2014
EPA’S HEAVY-DUTY NOX AND PM STANDARDS TIGHTENED BY 98% SINCE 1988

- 2013* - CARB introduced optional low-NOx standards (0.10, 0.05 or 0.02 g/bhp-hr)
- 2016 - Gov’t agencies in 10 states petitioned EPA to adopt 0.02 standard
  - EPA later announced intentions to propose new (level TBD) standards for MY2024
- CO standard looks to go up but this is due to changes in testing procedure
- Tier 1 HC -> Tier 2 NMOG
- Tier 2 NOx and NMOG separate, Tier 3 NOx + NMOG
DIESEL ENGINES: “YOU HAVE POWER, YOU HAVE ENERGY, YOU HAVE EMISSIONS: YOU GET TO CHOOSE TWO OF THEM”

- **Compression ignition engine**
  - Heterogeneous air/fuel mixture
  - Harder to control NOx
    - Exhaust gas recirculation (EGR)
    - Lean NOx trap (LNT)
    - Selective catalytic reduction (SCR)

- **Spark ignition engine**
  - Homogenous air/fuel mixture
  - Easier to control NOx
    - Three-way catalyst (TWC)

Ghose, 2015; Zhao 2012; Johnson Matthey 2016; Nett Technologies 2017
IN-USE DIESEL HDV & LDV NO$_x$ IS MUCH HIGHER THAN REGULATORY LIMITS

Anenberg, 2017, Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets
doi:10.1038/nature22086
DIESEL HAS SIGNIFICANT NO\textsubscript{X} VARIABILITY ABOVE 2010 STANDARD, WHILE NGV CONSISTENTLY LOW

**EPA 2010 Compliant Freight Trucks**

- **Near-dock** (avg 7 mph)
- **Local** (9 mph)
- **UDDS** (19 mph)
- **Regional** (22 mph)
- **Transient** (15 mph)
- **UDDS** (19 mph)
- **FTP** (19 mph)
- **MOVES nat'l run** (58 mph)

**Duty-Cycle**
- **(Carder 2014; Johnson 2016)**
- **(Sandhu 2017)**

- □ Diesel
- ♦ LNG, current NG engine
- ▲ LNG, near-zero NG engine

**Diesel NO\textsubscript{x} impacted by real world SCR performance**
- Low-speed, low-load operations
- Cold starts

Cai, 2017. Wells to Wheels: Environmental Implications of Natural Gas As A Transportation Fuel
NO\textsubscript{x} BACKGROUND SUMMARY

- NO\textsubscript{x} has several air quality impacts
  - Primary concerns are PM\textsubscript{2.5} & ozone formation

- Motor vehicles account for ~40% of NO\textsubscript{x} emissions
  - Gasoline LDVs and diesel HDVs each account for ~20%

- LD & HD NO\textsubscript{x} emission standards tightened by ~99% since 1980s
  - Diesel compression-ignition uses EGR, LNT, and/or SCR
  - Gasoline spark-ignition uses TWC

- In-use diesel NO\textsubscript{x} significantly higher than emission standards
  - Impacts previous & current generations of LDVs & HDVs
  - Aftertreatment technologies have limitations based on duty-cycle
  - HD NGV have consistently low NO\textsubscript{x}
AFLEET TOOL 2017 UPDATES
ARGONNE HAS SUPPORTED DOE’S CLEAN CITIES WITH TOOL DEVELOPMENT FOR 15+ YEARS

- **AirCRED**
  - \( \text{O}_3 \) precursor & CO emission credits from AFVs for SIPs

- **Clean Cities AOI 4 Emissions Benefit Tool**
  - GHG & air pollutant benefits of ARRA grant proposals

- **GREET Fleet Footprint Calculator**
  - Petroleum use & GHG footprints of HDVs & off-road equipment
“AFLEET TOOL” TO ANALYZE AFV COSTS & BENEFITS

- Examines light-duty & heavy-duty vehicle:
  - Petroleum use
  - GHG emissions
  - Air pollutant emissions
  - Cost of ownership

- Contains 18 fuel/vehicle technologies
  - Conventional
  - Hybrids
  - Plug-in electrics
  - Alternative fuels: CNG, LNG, LPG, H₂, ethanol, biodiesel, renewable diesel*

- Includes 7 Major Vehicle Types
  - Cost, MPG, & VMT data on 23 vocations


*red text = new feature
AFLEET TOOL’S MAJOR DATA SOURCES

- Argonne’s GREET model
  - WTW/vehicle cycle petroleum use & GHG, fuel economy data, WTP/vehicle cycle air pollutants

- EPA’s MOVES model
  - Vehicle operation air pollutant emission factors by state

- Clean Cities Alternative Fuel Price Report
  - Fuel pricing by state
AFLEET TOOL’S CALCULATION METHODS

- Tool has 4 calculation methods & which to use depends on your goals

- Simple Payback Calculator
  - Annual emissions & simple payback of purchasing new AFV vs. conventional counterpart

- Total Cost of Ownership Calculator
  - Lifetime emissions & NPV of costs over the years of planned ownership of a new vehicle

- Fleet Energy and Emissions Footprint Calculator
  - Annual & remaining lifetime petroleum use, GHGs & air pollutant emissions of existing & new vehicles

- Idle Reduction Calculator
  - Annual emissions & simple payback of purchasing of IR equipment vs. idling of conventional vehicles
### AFLEET TOOL 2017 UPDATES – DIESEL IN-USE EMISSIONS & LOW-NO\(_X\) ENGINES

- **Added feature to examine diesel in-use NOx emission estimates**
  - Factors based on Anenberg (2017)
  - MOVES needs to revise diesel NOx

- **Added feature to examine HD NGV Low-NOx engines**
  - Factors based on Cai (2017)

---

#### AFLEET 2017 Relative NOx Emissions Versus Diesel Baseline Vehicle

<table>
<thead>
<tr>
<th>Relative NOx emissions vs diesel baseline (1.0)</th>
<th>Diesel Baseline Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>All LDV types</td>
<td>5</td>
</tr>
<tr>
<td>Transit, school, refuse, SU short-haul</td>
<td>3.5</td>
</tr>
<tr>
<td>Comb/SU long-haul, comb short-haul</td>
<td>2</td>
</tr>
<tr>
<td>Refuse</td>
<td>0.6</td>
</tr>
<tr>
<td>Transit, school</td>
<td>0.5</td>
</tr>
<tr>
<td>Comb/SU long-haul, comb/SU short-haul</td>
<td>0.15</td>
</tr>
<tr>
<td>All HDV (except school)</td>
<td>0.05</td>
</tr>
<tr>
<td>School</td>
<td>0.5</td>
</tr>
<tr>
<td>School, SU short-haul</td>
<td>0.55</td>
</tr>
</tbody>
</table>

---

Anenberg, 2017. Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets doi:10.1038/nature22086;

Cai, 2017. Wells to Wheels: Environmental Implications of Natural Gas As A Transportation Fuel
AFLEET TOOL 2017 UPDATES – IDLE REDUCTION

- Developed new calculator to examine emissions & costs of idling & idle reduction technologies
- Expanding on Argonne’s Idle Worksheet
- Argonne’s forthcoming IR compendium
  - Battery APU, diesel APU, air heater, coolant heater, engine stop/start, truck stop electrification (single/dual)
- EPA MOVES emissions
  - Gasoline/diesel LDVs & HDVs, diesel APU
**AFLEET TOOL 2017 UPDATES – GREET UPDATES**

- Added feature to well-to-pump (upstream) & vehicle cycle emissions from GREET
  - Added SOx emissions
- Included renewable diesel
- Updated feedstock options for biodiesel, ethanol, RNG
AFLEET SUMMARY

- AFLEET Tool estimates NOx as well as other economic and environmental costs and benefits of AFVs
  - Updated based on latest research

- AFLEET 2017 updates include:
  - Diesel in-use NOx
  - NGV low-NOx engines
  - Idle reduction calculator
  - GREET updates
    - Upstream & vehicle cycle emissions
    - Renewable diesel
    - New biofuel and RNG feedstocks
THANK YOU!!!

Argonne National Laboratory’s work is supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy

This work has been supported and assisted by:

Linda Bluestein: U.S. Department of Energy
Dennis Smith: U.S. Department of Energy
Marcy Rood: Argonne
Michael Wang: Argonne
Hao Cai: Argonne
Josh Lin, Oscar Hermina-Tosado, Emelia Gold, Stephanie Taylor