# Event Summary and Key Observations

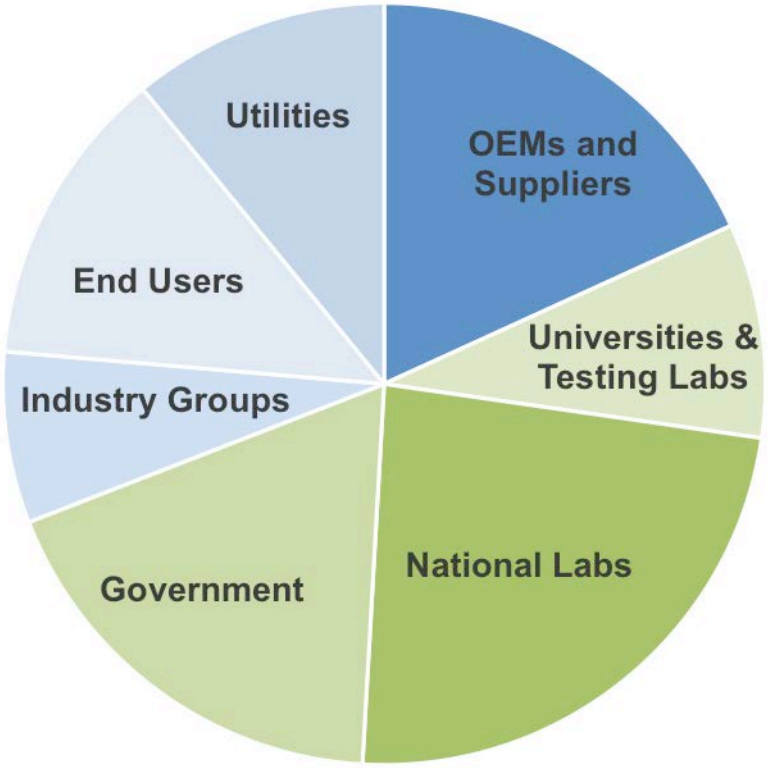
Event: Natural Gas Vehicle Research Workshop

Date: July 25, 2017

Location: National Renewable Energy Laboratory

# Participant Overview and Statistics

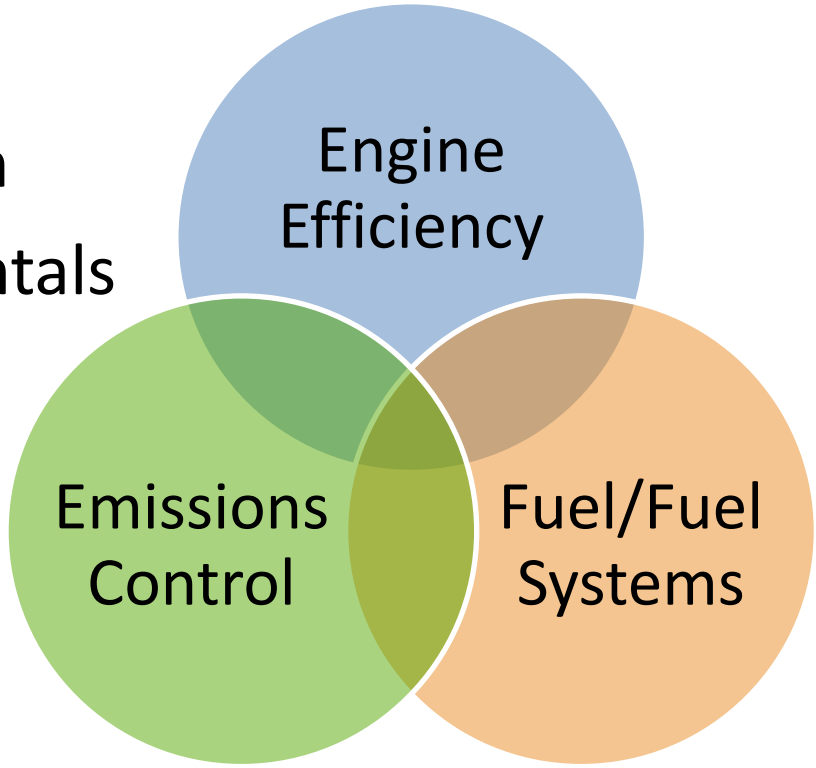
- 55 participants
  - OEMs and Suppliers (18%)
  - Utilities (11%)
  - End Users (13%)
  - Industry Groups (7%)
  - Government (18%)
  - National Labs (24%)
  - Universities and Testing Labs (9%)




**All relevant sectors were covered and key stakeholders represented at the event**

# Workshop Agenda and Structure

- Workshop structured by subject area for MD and HD natural gas engines and vehicles
- Introductions including ongoing R&D efforts (ARPA-E, CEC)
- 'State-of-the-art' presentations followed by facilitated discussion
- Discussion focused on fundamentals (low TRL) with all comments captured




**Agenda structured to capture key low TRL R&D opportunities relevant to VTO mission**

# Summary Concepts and Observations

- Received wide ranging input from stakeholders along the NG engine and vehicle R&D continuum
- Workshop participants identified opportunities in lower TRL work to include experimentation and modeling
- Identified opportunities for research across the industry, engaging universities, labs, and industrial partners
- Interest in having DOE to apply liquid fuel work to NGVs
- Significant California based activity in NGV R&D
  - Cooperation and collaboration with California to identify overlapping goals
  - Understand AQMD air quality drivers and how they may differ with state and federal standards
- Fuel quality and materials were cross-cutting topics – understanding unique NG related needs

# NG Engine Efficiency

| Research Need | Key Observations |
|---|---|
| **Research needed to address barriers for achieving diesel like-efficiency for NG engines** | • Industry feedback showed interest in low TRL level aspects of NG efficiency, chemistry, flame speed, mixing,<br>• Categorize efficiency factors into mixing, chemistry and wall effects<br>• Fast/full mixing not guaranteed with gaseous fuel<br>• Ways to improve NG flame speeds and dilution tolerance |
| **Ignition technology to enable ultra-lean operation (pre-chamber, volumetric ignition)** | • Advanced ignition systems are of interest as enabling technology, low TRL durability aspects |
| **Fundamentals for improving NG combustion efficiency (physics, thermodynamics and chemistry)** | • Chemistry and mixing effects discussed broadly<br>• Also discussed were aspects such as crevice volume |
| **Low temperature combustion concepts conceivable for NG engines, ensure real-world mode switching and emissions control compatibility** | • Low temperature combustion concepts discussed broader especially in terms of dual fuel<br>• Better understanding of mode switching with LTC came up many times |
| **Advances in the use of CFD and modeling for NG engines** | • Predictive simulations for NG engines was desired by stakeholders<br>• Need for advanced CFD for understanding mixing, placement of sensors<br>• Stakeholders discussed need for cycle simulations for air handling |
| **Avoiding knock and abnormal combustion (i.e. low speed pre-ignition) with spark ignited NG engines** | • Significant discussion on better understanding unique aspects of methane on avoiding abnormal combustion – especially with downsizing<br>• Discussion of advanced sensors/ diagnostics to help with problem |
| **Root cause of end-use emissions compliance from engine system perspective** | • What are the fundamental issues with why real world emissions are higher than what is calibrated for compliance – mode switching discussion |
| **Understanding lube needs/impacts on NG engines** | • Need material/lubricant pairings for improved durability (and possible resistance to preignition) without negative emissions controls impact |

**Industry feedback showed interest in low TRL level aspects of NG efficiency, as well as lubricant effects and advanced modeling - would like to see DOE continue building on expertise with liquid fuel engine systems**

# NG Emissions Control

| Research Need | Key Observations |
|---|---|
| **Fundamental catalysis research for methane conversion is needed due to challenge of methane activation** | • Includes research of surface chemistry effects like oxidation of Platinum Group Metals (PGMs) |
| **Research needed for both stoichiometric and lean engine (LTC and conventional) emission control** | • Current Three-Way Catalyst (TWC) technology for stoichiometric engines is effective and achieves <0.02 g/bhp-hr NOx levels; more research needed to enable lower temperature performance (wider drive cycle applicability), lower cost (reduced PGM content), and increased durability<br>• Lean NOx and PM control (mass and number) remain challenges for lean engines; low temperature performance and reduced cost are goals |
| **Modeling needs exist and range from catalyst-to-vehicle-to-fleet level** | • Accurate inputs and model results are needed as models (e.g. GREET) are utilized by key stakeholders to analyze NG engine benefits<br>• Capture of both criteria air quality and greenhouse gas emissions is needed |
| **Enabling technologies to aid emissions control** | • Durable and stable sensors are needed for controls but need to discern specific needs for NG engine systems<br>• Low temperature performance can be aided by advanced thermal management approaches/technologies (and understanding/addressing hybridization effects) |
| **Fundamental understanding of catalyst aging is needed (specific to NG applications)** | • Catalysts will have unique hydrothermal exposure and fuel/lubricant-based poison exposure specific to the NG engine application |

**Both criteria air pollutants and GHG control are of interest for NG vehicles, research needs exist for addressing the unique NG challenges of methane conversion for all combustion strategies**

# NG Fuel and Fuel Systems

| Research Need | Key Observations |
|---|---|
| **Sensor development and calibration for fuel systems** | • Development of more sophisticated fuel quality monitoring could help with fuel quality variability or advanced combustion<br>• Support CNG tank safety and end of life information |
| **CNG full fill technology development** | • Full fill has impacts on tank size needs and overall efficiency<br>• Advanced communications and sensing could help achieve full fills |
| **Injector technology development** | • High flow rate PFI and DI gaseous injectors<br>• High fidelity flow control for mixing and stratification |
| **Fuel variability impact on engine and system emissions needs to be determined** | • The effects of Renewable NG and variants since RNG has been critical to market penetration of NG trucks<br>• Separation technologies may allow higher levels of siloxanes to be present in RNG, reduce cost of RNG treatment for most applications, grow the RNG market, and allow higher siloxanes levels while still protecting engines |

**There are several low and medium TRL research topics related to NG fuels and fuel systems which can increase of MD/HD NG vehicles. These may not be directly related to FY17 goals of engine efficiency improvements but represent a critical piece of overall NGV efficiency.**