MD/HD Natural Gas Engine Efficiency Research Needs

Thomas Wallner – Argonne National Lab

Scott Curran – Oak Ridge National Lab

Brad Zigler – National Renewable Energy Lab

Mark Musculus – Sandia National Labs

Natural Gas Vehicle Research Workshop
Golden, Colorado
25 July 2017

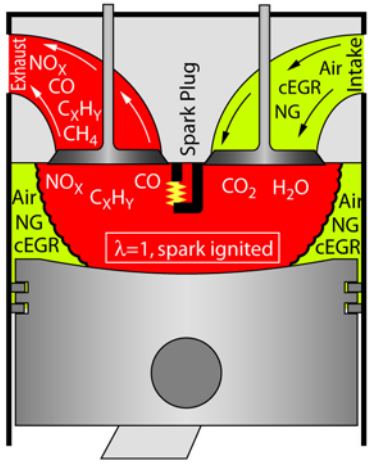
MD/HD Natural Gas Vehicles – Current State

- Recent significant growth in natural gas production
- Relatively low and stable natural gas prices
- Growing CNG/LNG availability
- Increasing MD/HD engine options / vehicle availability
- Growing interest in renewable NG pathways
- California's ultra-low NOx emissions targets

Four production NG combustion strategies today; balance of economics, regulation, & performance

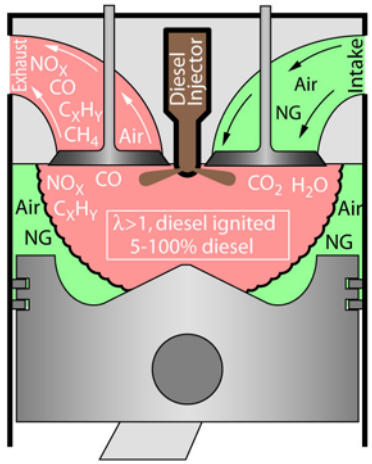
Spark/Prechamber Ignition

Diesel-Pilot Ignition



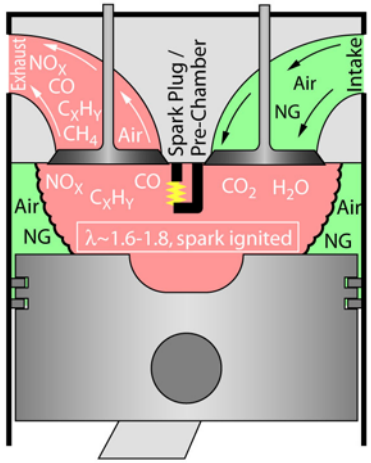
Stoichiometric Spark Ignition

- Port/DI, premixed, cooled EGR
- 3-way catalyst
- ~36% efficiency
- 100% NG
- Cummins, Scania, Waukesha, IVECO



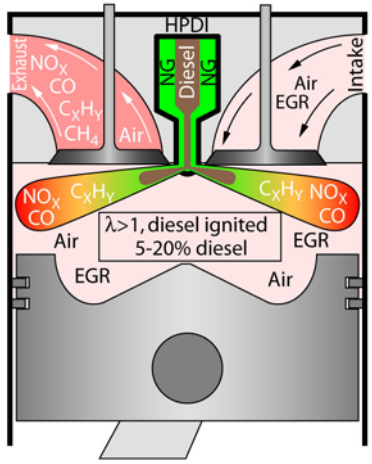
Lean Premixed Diesel Pilot

- Port/DI, premixed or stratified, cEGR
- Oxy-catalyst
- ~45% efficiency
- 0-95% NG
- Volvo (Hardstaff, G-Volution retro.)



Lean Premixed Spark Ignition

- Port/DI, premixed or stratified, EGR
- Oxy-catalyst
- ~43% efficiency
- 100% NG
- Cummins, MAN, Doosan, GE



Direct Injection Diesel Pilot

- DI stratified/jets NG+diesel, EGR
- Catalyzed DPF, Urea SCR
- ~46% efficiency
- ~90% NG
- Westport, Volvo

Each NG strategy faces unique combustion challenges

Natural Gas Engine Lubricants

Oil drain intervals of CNG engines shorter than Diesel

- Empirically* NG engines run hotter than diesel engines and can accelerate lubricant degradation
  - Accelerated oxidation and nitration**
  - Earlier onset of HTHS degradation**
  - Faster loss of oil RUL (Remaining useful life)**
  - More rapid TBN depletion and acidic corrosion***
- Oil Drain Intervals****
  - Diesel 25K- 40K/60K miles
  - Nat. Gas 7K to 18K miles

- With NGV, there is no liquid hydrocarbon fuel to lubricate the intake/exhaust valves
  - Must rely on lubricant to supply beneficial metallic ash to protect valves against valve recession and valve burning – delicate balance of ash content

- Research Opportunities
  - Stronger Anti-Nitration additives - increase ODI
  - Enhanced acid neutralization additives
  - Mitigation/control of ash deposition on valves

*** Am. J. Eng & App Science 2 (1), 212-216**
**** SAE 2010-01-2100**
***** Bansal 2013 STLE, Detroit**
****** On-Highway Heavy Duty Engine Manufacturer's Recommended Oil Drain Intervals**

MD/HD Natural Gas Engines – Future State

- Continued growth in the MD/HD natural gas vehicle market requires additional focus on natural engine efficiency
  - EPA and NHTSA Phase 2 standards for MD/HD trucks through model year 2027
  - MD/HD diesel engine efficiency continues to increase, in part due to DOE early stage, low Technology Readiness Level (TRL) research support
  - Current MD/HD natural gas engine technology pathway trend to support near-zero emissions in U.S. (stoichiometric, spark ignition, high EGR, with three-way catalyst) is efficiency challenged compared to other strategies

MD/HD Natural Gas Engines – Future State

- Several low TRL research topics related to gasoline and diesel engine efficiency and emissions improvements may also apply to future high efficiency (and low emissions) NG engines
  - Advanced low temperature combustion strategies
  - Direct injection
  - Advanced ignition systems
  - Controls for lean operation
  - High dilution tolerance
  - Advanced aftertreatment for low T, lean, and/or dilute
  - Lubricants

Facilitated Discussion on High Efficiency Research Needs

- How do the unique aspects of NG impact the R&D scope compared to gasoline and diesel?
- What advanced combustion strategies will significantly improve NG engine efficiency?
- Which of these pathways need early-stage, low TRL research support?
- How important is it to consider near zero emissions (i.e., 0.02 g NOx) for potential DOE-sponsored NG engine efficiency focus?
- What specific research topic areas need to be addressed?
- How does future hybridization fit in?
- How do we prioritize these topics?
- Other stakeholder input?