Next Generation Natural Gas Engine

Mark Walls
Next Generation Natural Gas Engine

- NREL Project Overview
- SwRI’s Dedicated EGR Concept
- Thoughts
Southwest Research Institute
National Renewable Energy Laboratory
California Energy Commission
South Coast Air Quality Management District
SoCal Gas
Doosan Infracore
Woodward, Inc.
LA Metro
Project Overview

Production Lean Burn Engine

- Lean Burn to Stoichiometric operation
- Cooled EGR
- Advanced Ignition System
- High efficiency turbo matching
- Optimized Aftertreatment
- Optimized in-cylinder turbulence
- Optimized Piston Design
- Optimized Camshaft Profile

Testing
- Thermal Analysis
- Structural Analysis
- Steady State and Transient Calibrations
- Durability Testing
- Certify to 2010 emission levels

Task A

Engine Brought to Production Levels
- Collaboration with engine OEM and their suppliers

Engine Integrated into Chassis
- Collaboration with chassis OEM and their end users
- Vehicle Emissions Measurements
- Engine sensor data logging to compare to baseline vehicles

Tasks B and C

Modified Engine

Chassis Integration
2010 Lean Burn Engine

- Cert Data
  - NMHC = 0.08 g/bHp-hr
  - NO$_x$ = 0.156 g/bHp-hr
  - CO = 0.08 g/bHp-hr
  - NH$_3$ < 10 ppm

- Power = 220kW
- Torque = 1220Nm
- Peak Efficiency ~ 40%
- 11.1L
- Inline 6 cylinder
- Turbocharged

Low swirl head
10.5:1 compression ratio, low squish, non-gallery cooled Pistons
Converted Diesel Engine

SCR/Urea
Low Energy Ignition
Fumigated Fueling
Stoich EGR Engine

12:1 compression ratio, high squish, gallery cooled Pistons

- Low swirl head
- Intake UEGO
- EGR valve
- EGR cooler

Higher Energy Ignition

Knock & misfire detection

Higher temp exhaust components

Three way catalyst

Reduced cost control system

- Estimated Cert Level
  - NMHC = 0.08 g/bHp-hr
  - NOx = 0.05 g/bHp-hr
  - CO = 0.1 g/bHp-hr
  - NH3 < 10 ppm
  - CH4 lower than lean burn

- Power = 250kW
- Torque = 1630Nm
- 18.5 bar BMEP
- Peak Efficiency = 41%
Current Status

- **Engine Calibration** 95% complete
  - One Engine
  - Working on safeties and engine protection
  - $\text{NO}_x / \text{NH}_3$ tradeoff

- **Durability testing started** (SwRI Facility)
  - Four engines
  - High coolant temperature test
  - Rated power
  - Thermal shock
  - Preliminary DF Testing

- **Certification**
  - Two engines
  - DF Testing
  - Certification Testing
Current Comparison of Efficiency

• **Doosan 11.1L**
  - Peak Power = 250 kW
  - Peak Torque = 1630 Nm
  - Peak BMEP = 18.2 bar
  - Peak Efficiency = 40.6%
  - NOx = 0.05 g/bhp-hr (Preliminary)
  - CO = 2.2 g/bhp-hr (Preliminary)

• **Cummins Westport 8.9L**
  - Peak Power = 239 kW
  - Peak Torque = 1356 Nm
  - Peak BMEP = 19.8 bar
  - Peak Efficiency = 38.7%
  - NOx = 0.13 bhp-hr
  - CO = 8.1 g/bhp-hr
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SwRI’s Dedicated EGR (D-EGR™) Concept

- LPL EGR works well, but has limits
  - Long burn durations
  - Limited EGR rate
- Hydrogen enhanced combustion
  - Enabling technology for further efficiency and emission improvements
H₂ Augmentation for Dilute Engines

• Pros
  • H₂ increases dilution tolerance (air or EGR)
  • H₂ decreases ignition energy requirement
  • H₂ increases flame speed
  • H₂ improves combustion efficiency
  • Smaller quench distance (surface and crevice)
  • Overall can improve engine thermal efficiency

• Cons
  • H₂ decreases effective MN
  • Fumigated H₂ negatively impacts VE and TC efficiency
  • Creating H₂ has historically been energy intensive and sometimes outweighs its benefit
What is Dedicated Exhaust Gas Recirculation

- Dedicated Exhaust Gas Recirculation, D-EGR™, takes the exhaust from one or more cylinders of a multi-cylinder engine and route its exhaust to the intake to create the entirety of the EGR for the engine
- In-cylinder reformation
Benefits of D-EGR™

- Hydrogen enhanced combustion
  - $H_2$ is produced in-cylinder
  - Accelerates combustion
  - Lowers ignition energy requirement
  - Improves combustion efficiency
  - Improves combustion stability
- Low complexity EGR control
- No EGR through the turbo-machinery
- Lower H2O concentration than stoichiometric EGR
- More efficient than LPL EGR
- Criteria pollutants fully controlled with three way catalyst
- LPL EGR greater than 40% BTE
- D-EGR minimum expected 43% BTE
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Thoughts – Cold Start

• Focus on NO\textsubscript{x} cold start emissions
  • 1/7 of composite FTP
  • 90% of NO\textsubscript{x} emissions come from cold start

• Cold start options
  • Close-coupled catalyst
  • Electrically heated catalyst
  • Turbocharger bypass
  • Insulated Exhaust
  • Lean/Rich operation
Thoughts NO$_x$ and Ammonia

- Improve transient control
  - Lean / Rich excursions
- Investigate hardware changes
  - Multiport injection
- Investigate after-treatment
  - Passive SCR or AOC
Thoughts D-EGR™

- Dedicated EGR
  - Significantly improvement in efficiency with natural gas
    - Favorable Hydrogen to Carbon ratio for in-cylinder hydrogen reformation
    - Reduces cold start emissions
    - Reduces catalyst light off times
  - Lower greenhouse gas emissions
    - Greater Hydrogen to Carbon ratio
    - Improved fuel economy over LPL-EGR
  - SwRI has successfully implemented
    - Light duty application
  - Working internally with D-EGR natural gas
Thank You

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