Promising Alternative Fuels for Improving Emissions from Future Vehicles

Research Seminar: CTS Environment and Energy in Transportation Council

Will Northrop – 12/17/2014
Outline

1. Alternative Fuels Overview

2. Current Research Activities
   1. Hydrous Ethanol
   2. On-Board Fuel Reformation
   3. Dimethyl Ether

3. Summary
Engine fuels traditionally fall in two categories

**Spark-Ignition (SI)**
- Premixed air and fuel
- Load control – intake density
- Spark initiates a flame
- Fuel: low reactivity, high volatility (gasoline)

**Compression-Ignition (CI)**
- Air inducted, fuel injected
- Load control – fuel quantity
- Autoignition starts diffusion flame
- Fuel: high reactivity, low volatility (diesel)
Alternative Fuel Trajectory

Fuels for Engine-Powered Vehicles

Traditional Petroleum-Derived
- Diesel

1st Generation Oxygenates
- Biodiesel

Low Carbon Fossil
- Gas to Liquid
- "Renewable" Diesel

Drop-In Biofuels
- Dimethyl Ether

Future Energy Carriers
- ?

Current
- Ethanol
- Natural Gas
- "Renewable" Gasoline

Future
- Compression Ignition
- Spark Ignition
- Hydrogen
- ?
Technology Introduction

Light-Duty AFV, HEV, and Diesel Model Offerings, By Fuel Type

Alternative Fuels Data Center http://www.afdc.energy.gov/data/

- E85
- CNG (Dedicated and Bi-Fuel)
- Diesel
- Electric Vehicle
- Hybrid
- Propane (Dedicated and Bi-Fuel)
- Hydrogen
- Methanol (M85)
Motivation

• Alternative fuels must meet criteria for either engine technology category
  – Safety
  – Reliability
  – Cost
  – Performance
  – Availability
  – Emissions (both in production and in use)

• Three areas of research interest:
  1. Crossing SI/CI boundary may have advantages
  2. Onboard fuel processing may enable greater flexibility
  3. Energy carrier fuels may be the future for engines
Example, hydrogen as an energy carrier

- **Renewable**
  - Direct Solar
  - Biomass
  - Solar PV
  - Wind
  - Geo-Thermal

- **Fossil**
  - Coal
  - Petroleum
  - Natural Gas

- **Process**
  - Direct Water Splitting
  - Bio or Gasification
  - Electrolysis of Water
  - Catalytic Reforming

- **Hydrogen**
  - Purification, Compression, Storage, and Use
Research Areas

- Engine-Generated Nanoparticles, Gaseous Emissions
- Emissions
- Alt. Fuels
  - DME, Syngas, Hydrous EtOH, LPG, 2nd Gen Biofuels
- Combustion Systems
  - Low Temperature Combustion, Dual Fuel Modes, Reactivity Control
- Energy
- Real-world vehicle energy, CO₂ emissions and impacts
Research Project 1: Hydrous Ethanol

- Ethanol in US currently anhydrous (>99% EtOH)
- Can save production energy by producing hydrous EtOH
- Recent modeling work:
  - 180 proof saves 10% in plant energy use over 200 proof
  - Lowers plant net water use
- Hydrous ethanol has advantages for diesel engines when in dual fuel modes
  - No PM and NOx aftertreatment
  - Reduced need for EGR
  - Increase fuel renewability
Hydrous ethanol reduces traditional emissions from diesel engines

- Single-cylinder research engine
  - Isuzu medium duty
  - Engine parameters controlled
- 80% fumigant energy fraction
- 150 proof hydrous EtOH
- Results:
  - Meets Tier 4 NO$_x$/soot, engine out
  - Same power range as diesel-only
  - Efficiency the same as diesel
- Aftertreatment not required for soot or NOx
- Efficiency unchanged from diesel-only operation

Development of an aftermarket system

- Diesel engine manufacturers unlikely to embrace alternative fuels until market develops
- Goal: develop an aftermarket ethanol injection system for off-highway diesel engines
- Approach: 60%, 180 proof ethanol by energy – timed port-injection of preheated EtOH
- Designing port ethanol injection system for a John Deere Diesel Engine

Hydrous Ethanol Injection System
Research Project 2: Onboard Fuel Processing

- Strategy to enable greater fuel flexibility
- Improve engine thermal efficiency and reduce CO₂
- Reform portion of diesel using exhaust gas recirculation (EGR)
  - Enable clean “dual-fuel” combustion with single fuel
  - Thermo-chemical recuperation
- High enthalpy of EGR and water improves engine performance
High Equivalence Ratio Reforming

- Non-catalytic partial oxidation (POX) reformers limited to $\phi<3.0$
  - Limited by carbon and deposit formation
- Engines not concerned about $H_2$ yield – olefins are fine
- Goals:
  - High reforming efficiency
  - No soot formation
  - Complete diesel conversion to partially reacted species
  - Vaporize diesel fuel

$$\eta_{\text{reformer}} = \frac{\text{LHV}_{\text{products}}}{\text{LHV}_{\text{reactants}}} \cdot \text{LHV}_{\text{products}}^{-1}$$

Adiabatic Constant Volume Reactor

$n$-heptane reduced mechanism (LLNL)

High $\phi$ POX via Reactive Volatilization

Project Underway: Use an opposed flow vaporizer concept for evaporating and partially reforming liquid fuels in compression ignition engines.
Research Project 3: Dimethyl Ether

- Energy carrier
- When produced as a renewable biofuel:
  - Lowest lifecycle greenhouse gas emissions
  - Highest well-to-wheel efficiency
- Ideal diesel fuel:
  - High Cetane number (>55)
  - High volatility
  - No soot emissions from combustion (no C-C bonds)
- Nanoparticles can still be emitted:
  - From engine lubricating oil
  - Fuel lubricity additives
  - Semi-volatile species from combustion
- Engine tested in laboratory to examine particle emissions from DME combustion
Regulated solid particle number emissions much lower with DME

Eliminates the need for very costly diesel particle filter

Summary

• Research in engines and propulsion must seek ways to improve fuel flexibility:
  – Cross-over technologies like dual fuel combustion can improve emissions and efficiency
  – On-board fuel reforming can enable greater fuel flexibility and low emissions
  – Energy carrier fuels like H₂ and DME have great potential for lowering emissions from engines

• Future work:
  – Increasing efficiency and reducing emissions from SI and CI engines
  – Enabling greater renewable H₂ and DME use in engines and fuel cells utilizing Minnesota resources