Fuel/Engine Co-Optimization: A Not-so-new Idea for the Future

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Expanding the use of alternative fuels and fuel-controlled combustion
Early cars took advantage of the fuels that were available

- Model T: 1908 – 1927
- Peak sales of 2M in 1923
- Early models allowed kerosene as well as gasoline – not well-defined difference
- Early fuels had AKI of 50-60

- 2.9 L engine
- 22 bhp @ 1600 rpm
- 83 ft.lbs peak torque
- 4:1 Compression
Market demand in the 20’s brought on Anti-Knock additives

• Charles Kettering, electric starter (Delco)
  – Cars w/ starters happened to knock
  – Refining technology for +ON not deployed
  – Invests efforts in fuel & antiknock additives
• Thomas Midgley investigated over 33,000 compounds in 6 years
  – Several suitable compounds identified
  – Tetraethyllead (TEL) in fuel, 1922
    • U.S. Patent #1,592,955, “A Motor Fuel”, 1926

"the ear-splitting knock of their test engine turned to a smooth purr when only a small amount of the compound (tetraethyllead) was added to the fuel supply ... and all the men danced a non-scientific jig around the laboratory”

Desire to raise compression ratio above 4:1!
The 1920’s-1940: Compression and Octane Increase

AKI = Anti-Knock Index

Compression Ratio (-)

Fuel AKI (-)

Year

12 hp/L

Lead added
Post War – 1970: Compression and Octane Increase

Demand for power and smoother operation increased with consumer preferences.

Post-war refinery octane improvement

WW2: Octane for aircraft only

48 - 60 hp/L

37- 54 hp/L
1970’s-90’s: Compression decreases and Octane declines

Electronic controls allow compression ratio/power density to climb from 1979 low

- Compression decreases
- Octane declines
- Lead removal begins
- CR drops
- 24 hp/L
- 48 hp/L
2000’s - Present: Compression increases and Octane flat

Turbocharging, direct-injection all help increase power density

Fuel price \(\uparrow\) limits demand for octane?

Knock sensor helps CR increase

Timing retard to prevent knock

117 hp/L
Current fuels constrain engine design

- Increase Compression (CR) for higher efficiency
- Move map to higher power
- High octane avoid knock
- Efficiency gain > 4.5%
Likely near-term approach to increasing fuel economy

- Downsizing: reduced engine displacement
- Downspeeding: reduced engine speed
- These are limited by: knock, retaining acceptable power and torque
- Require improving the engine power density
  - Turbochargers, superchargers
- Power density is limited by available fuel octane rating

New reality: Fuel octane rating now influences fuel economy rather than just off-cycle engine power.

Ford Fusion:
- 1.6L Turbo: 24/37 MPG, 178 HP
- 2.5L NA: 22/34 MPG, 175 HP
fuel properties for different combustion regimes?

- Spark Ignition (gasoline)
- Compression Ignition (Diesel)
- LTC (HCCI)
Longer-term opportunities

Kinetically-controlled combustion

- High Reactivlty Fuel
  - High Cetane
- Range of Fuel Properties
  - TBD
Longer-term opportunities

- Co-Optimize fuel properties and combustion strategies
- Many different approaches, each with pros and cons.
- Builds upon previous DOE work on fuels and engines

- Advanced combustion + new fuel technologies: better navigation of combustion to minimize GHG and criteria pollutants.

+ new fuel development of low-G and criteria conditions.
New Fuel Introduction
Lead-Free Gasoline Was Introduced in 1974

- Very important change
- Allowed for exhaust catalysts on 1975 vehicles → cleaner air
- Very informed decision
How did E10 become a legal fuel?

- EPA declared gasohol (E10) not legal per 1977 Clean Air Act
- Waiver filed by Gas Plus in 1978
  - Waiver application contained no E10 data
- EPA did not grant waiver
  - EPA did not deny waiver, either!
- Clean Air Act at the time granted waiver by default in 180 days if no action by EPA

Informed decision?

“If you choose not to decide, you still have made a choice”
  – Rush, “Free Will,” Permanent Waves
EPA cited DECSE and DVECSE Studies in Final Sulfur Rule

• “DOE has funded several test programs... in partnership with industry to investigate NOx adsorber technology. ORNL...[has] shown that a NOx adsorber...can reduce NOx by more than 90 percent...on a diesel-powered Mercedes A-class passenger car.”

• “Beginning June 1, 2006, refiners must begin producing highway diesel fuel that meets a maximum sulfur standard of 15 parts per million (ppm)*...”

*Previous limit 500 ppm
U.S. DRIVE FWG Primary Objective

- Evaluate potential properties of lower carbon fuels* for future, high efficiency engines and combustion regimes meeting U.S. DRIVE ACEC targets.

**Focus Areas** (Fuel Effects Studies Aligned with ACEC)

1. Premixed, Flame Propagation, Spark Ignition Combustion Mode (SI)
2. Mixing/Diffusion Compression Ignition Combustion Mode (CI)
3. Chemical Kinetics Dominated Low Temperature Combustion Modes (LTC)
4. New Combustion Quality Metrics
   a. Anti Knock for SI
   b. Ignition Delay for LTC

*Lower carbon as measured by well-to-wheels greenhouse gas emissions measured in g/mi, compared to a baseline case (reference fuel and vehicle)*
FWG fuel set compares octane effects for bio-gasolines

Fuels V1 – V4 are Bioreformate Surrogate blends.

Fuels B2 and B4 Wood Derived Biogasoline

B2 and B4 Wood Derived Biogasoline
Real-World Emissions & In-Use Fuel Economy

In Europe, automakers forced back to bigger engines in new emissions era

PARIS — Tougher European car-emissions tests being introduced in the wake of the Volkswagen Group scandal are about to bring surprising consequences: bigger engines.

Automakers that have spent a decade

Is right-sizing always downsizing?

Turbocharged cars’ gas mileage may be lackluster after all

As the technology makes a comeback, Consumer Reports finds that most turbos don’t deliver on advertised fuel economy or outperform non-turbo rivals with bigger engines. GM and Ford disagree.

February 05, 2013 | By Brian Thevenot, Los Angeles Times

While electric vehicles continue to grab the green-car spotlight, an older technology has quietly emerged as a player in the fuel economy wars: turbocharging.

Once the province of performance cars, turbochargers now power economy cars, family sedans and even full-sized trucks. Turbos now account for an estimated 13% of U.S. auto sales, according to Honeywell International Inc., a leading turbo supplier. That’s double what it was in 2010.

The increase is driven by ever-stricter federal fuel economy standards. Turbochargers, which inject compressed air into engine cylinders, enable automakers to squeeze more oomph out of smaller motors.

Complete results: Turbo vs. non-turbo fuel economy

But not everyone is sold on turbos. Toyota and Honda continue to avoid the technology. And critics including Consumer Reports question its efficiency and performance advantages. In a new report, the product testing organization found that most turbos failed to deliver on advertised fuel economy or to outperform non-turbo rivals with bigger engines.

How will technology be perceived by the consumer?
Thank You!

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Web site:
http://energy.gov/eere/vehicles/vehicle-technologies-office
Government/Industry Program Conducted to Determine Effects of Fuel Sulfur on Advanced Diesel Emissions Controls

- Cost shared program (<$4M)
- Multiple sites/participants
  - DOE
  - ORNL
  - NREL
  - EMA
  - MECA
  - WVU
  - ETS
  - FEV

Diesel Emission Control – Sulfur Effects (DECSE) Program
Phase I Interim Data Report No. 3:
Diesel Fuel Sulfur Effects on Particulate Matter Emissions
November, 1999
More Recently in Mid-level Ethanol Blends....

“Let’s not bicker and argue about who killed who...”

― Monty Python and the Search for the Holy Grail
Highlights of Vehicle Aging Program – E15/E20

- 3 test sites
- 86 vehicles, >6.5 million miles
- >300,000 gallons of fuel
- About 1000 emissions tests
- Routine scheduled maintenance
  - >900 oil changes
    - About once per week per vehicle
  - Tires, brakes, timing belts, etc
- Unscheduled maintenance/downtime
  - Resolving testing issues
  - Transmission repair/replacement, wheel bearings, radiators, electronics, fuel pumps, etc
  - Animal collisions on track
  - Heavy snow/fog
MLB Vehicle Aging Summary

- Aging vehicles on the Standard Road Cycle increased emissions over time, as expected.
- Aging vehicles with ethanol blends did not affect emissions changes over time differently than aging with ethanol-free gasoline.
- Compared to certification gasoline, the addition of 10% to 20% ethanol caused general fleetwide changes in measured tailpipe emissions and fuel economy consistent with prior studies:
  - CO, NMHC, and fuel economy decreased.
  - NOx, ethanol, and aldehyde emissions increased.
  - No fuel-related emissions failures were noted in the DOE catalyst study.
EPA cited DOE Studies in Partial Waiver Rulings in 2010 & 2011

“...E15 will not cause or contribute to [2001 and newer] motor vehicles exceeding their applicable exhaust emission standards”

DOE work also cited in Tier 3 Emissions Rule

ORNL developed a method for calculating NMOG from NMHC during iBlends to more rapidly provide emissions results to EPA staff monitoring the program.

EPA adopted the ORNL method in the Tier 3 rule, allowing manufacturers to compute NMOG rather than requiring speciation of tailpipe emissions measurements (substantial time and cost savings).