



Overview of the VTO Fuel and Lubricant Technologies R&D

June 9, 2015

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Fuels R&D

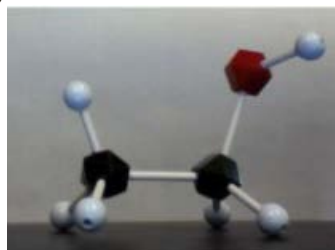


Expanding the use of alternative fuels and fuel-controlled combustion

Fuel and Lubricant Technologies

Accomplishments

- Demonstrated 2% fuel economy improvement with advanced additives, relative to SOA synthetic SAE 5W-20 (2015 goal)
- Demonstrated RCCI operating range of 75% of non-idling portions of the city (UDDS) and highway (HWFET) light-duty federal drive cycles
- Successful launch of U.S. DRIVE Fuels Working Group

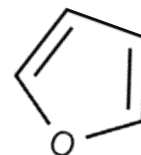


Ethanol Puppy:
Ball-and-Stick Model



Future Directions

- Maintain lubricant research activities
 - Develop retrofittable, low-friction lubes for use as drop-in replacement in existing vehicle engines
 - Expand to include gear oils
- Expand understanding and exploitation of fuel-controlled combustion
 - Investigate potential engine efficiency improvements from increased octane
 - Determine optimum set of fuel properties for low temperature combustion
- Continue fit-for-service evaluations of alternative fuels – with emphasis on candidate “drop-in” biofuels



Status

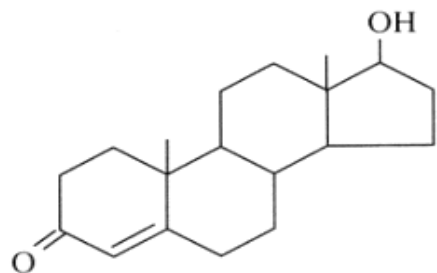
- On-track to meet goals for both fuels and lubricants

FY 2020 Goals

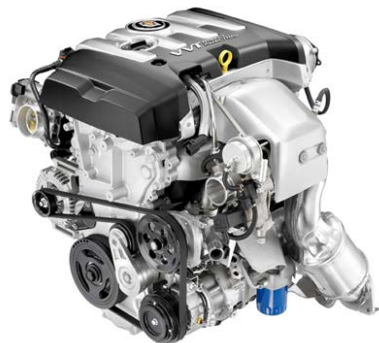
Demonstrate cost effective lubricant system with 4% fuel economy improvement relative to 2013 base fluids

Demonstrate expanded operational range of advanced combustion regimes to >95% of LD Federal Test Procedures

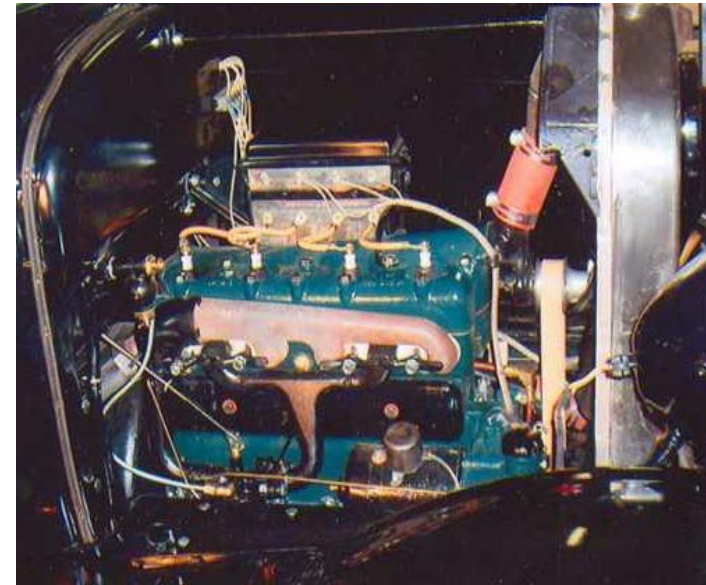
Fuel and Lubricant Technologies



<i>Funding in millions</i>	FY 2014 Enacted	FY 2015 Enacted	FY 2016 Request
Fuel and Lubricant Technologies	\$15.5	\$20.0	\$37.0



Early cars took advantage of the fuels that were available

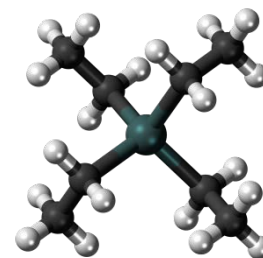


- 1908 – 1927
- Peak sales of 2M in 1923
- Early models allowed kerosene as well as gasoline – not well-defined difference
- Early fuels had AKI of 50-60

- 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



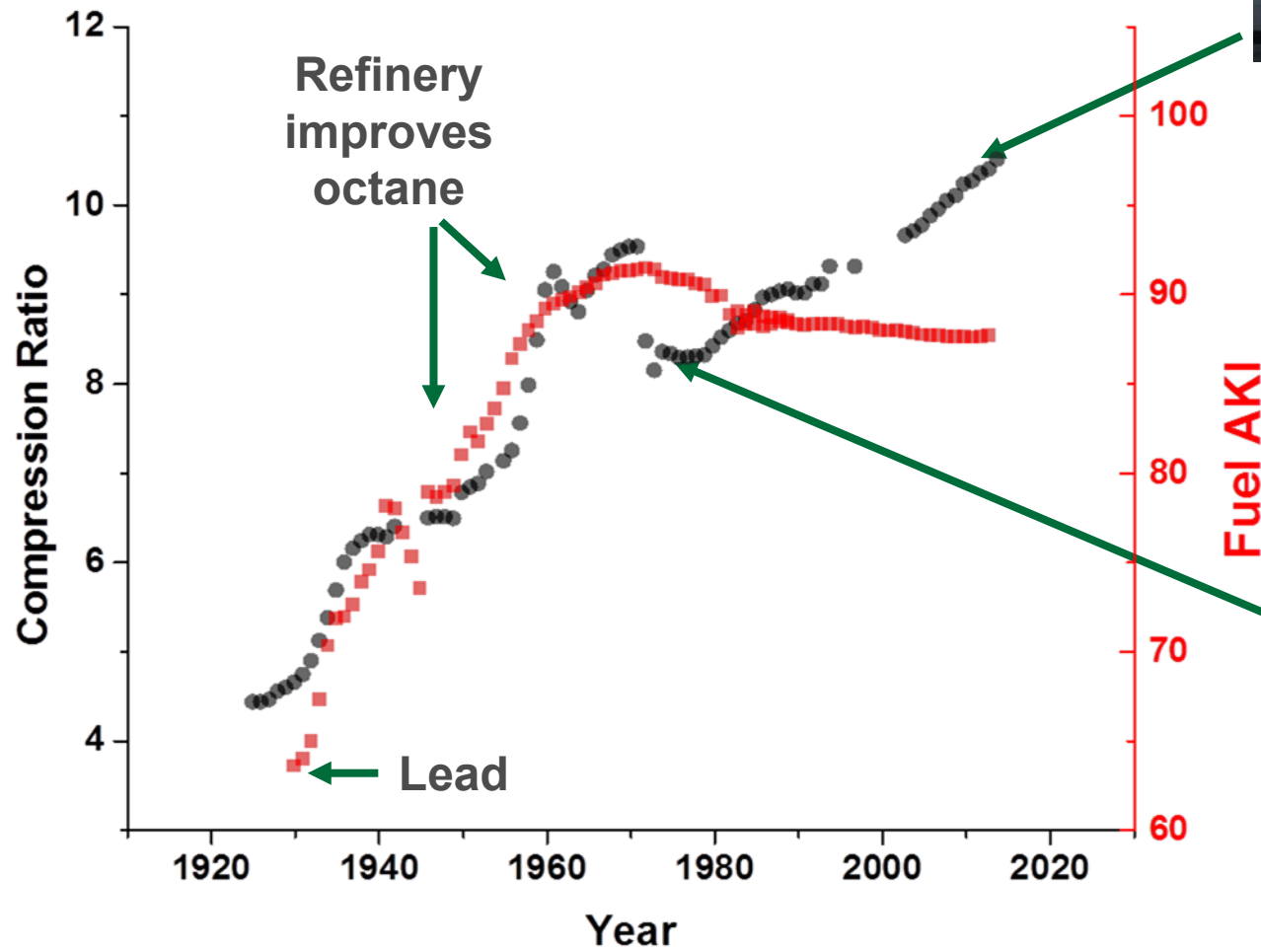
"the ear-splitting knock of their test engine turned to a smooth purr when only a small amount of the compound (tetraethyllead) was added to the fuel supply ... and all the men danced a non-scientific jig around the laboratory"



Desire to raise compression ratio above 4:1!

Historically a tight coupling between engines and fuels

Divergence begins ~1975



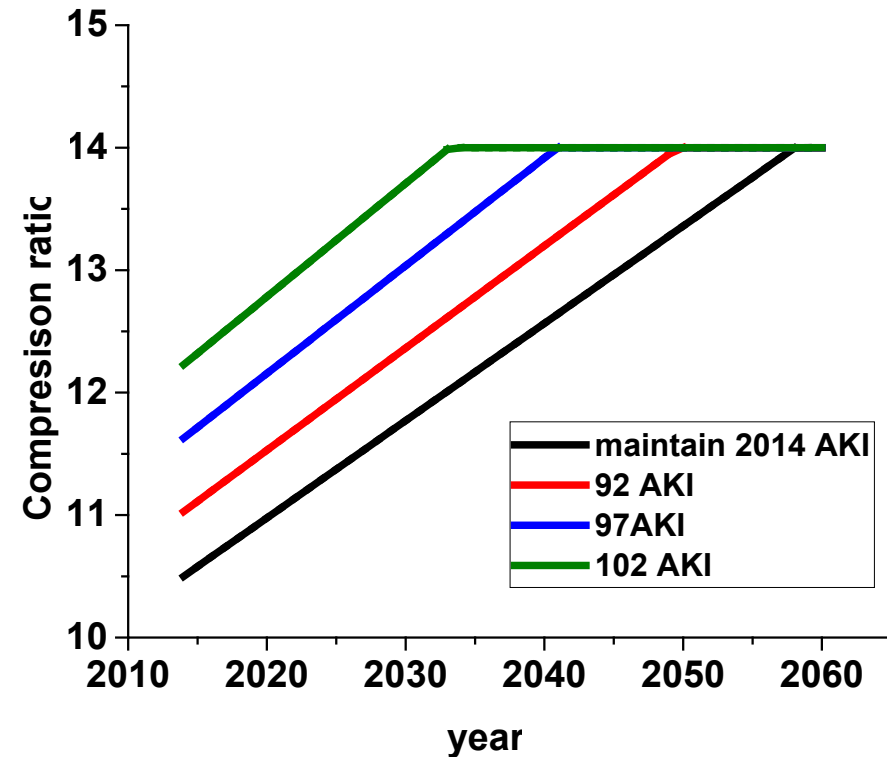
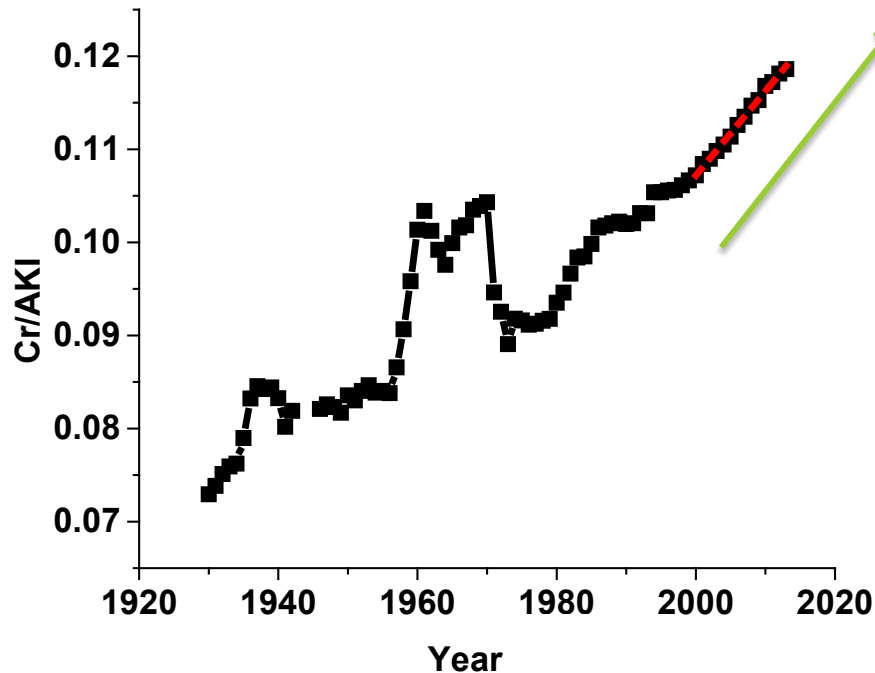
272 hp, 2.0 L disp
0-60 in 5.6 s
21/30 MPG



90 hp, 3.7 L disp
0-60 in 15.5 s
17/23 MPG

Can we accelerate our current trajectory?

- Fuel caused a step change before – Can it occur again? What is required?
- Assume max CR is 14:1
- If last 14 years' trend continues → 40 years to reach max CR
- Radical change today – 102 AKI → 15 years to reach max CR



Convergence of three automotive challenges underlines the importance of advanced research

54.5 mpg CAFE by 2025

- EPA / DOT standards
- Currently 30.1 mpg for “cars”
- Gasoline dominating LDVs

Fuel Economy Standards

Automotive Industry



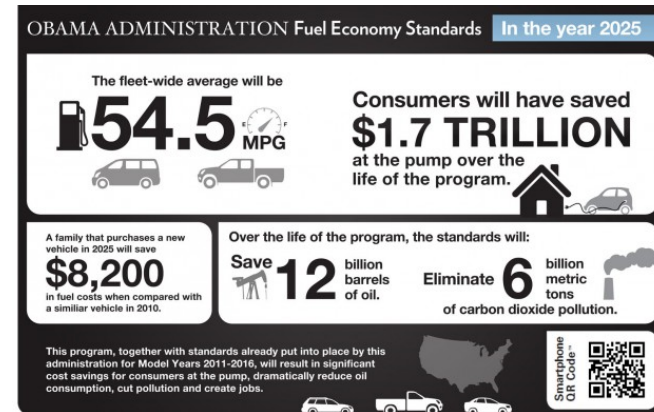
>70% less NOx

>85% less NMOG

70% less PM

EPA Tier 3 Emission Regulations

<70% less NOx, >85% less NMOG and 70% less PM emissions by 2017-2025 (phased in)
- EPA Tier 3 regulations



Renewable Fuel Standard



36 billion gallons of renewable fuel by 2022
- Energy Independence and Security Act of 2007

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.

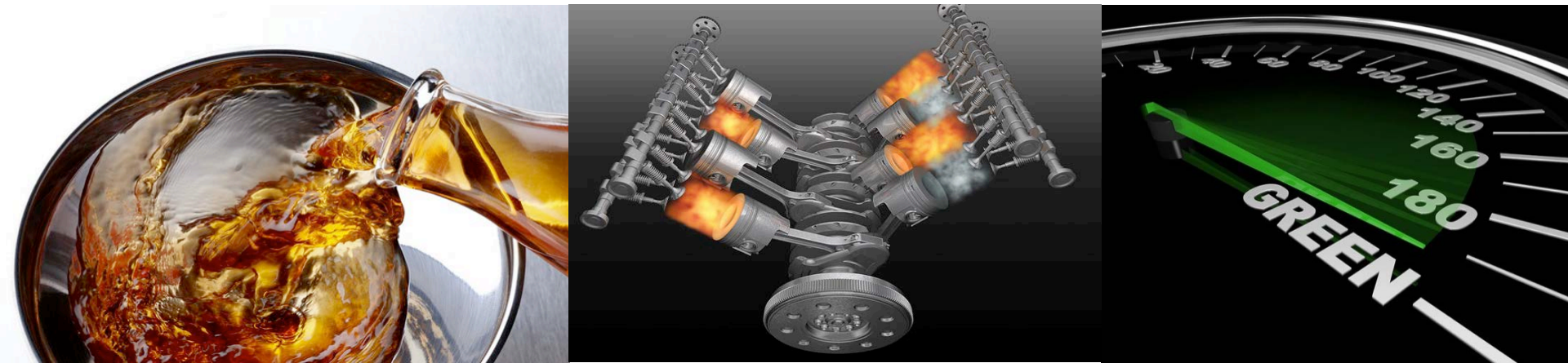


Ford Fusion:	
1.6L Turbo	2.5L NA
24/37 MPG	22/34 MPG
178 HP	175 HP

Fuels-Engines Co-Optimization

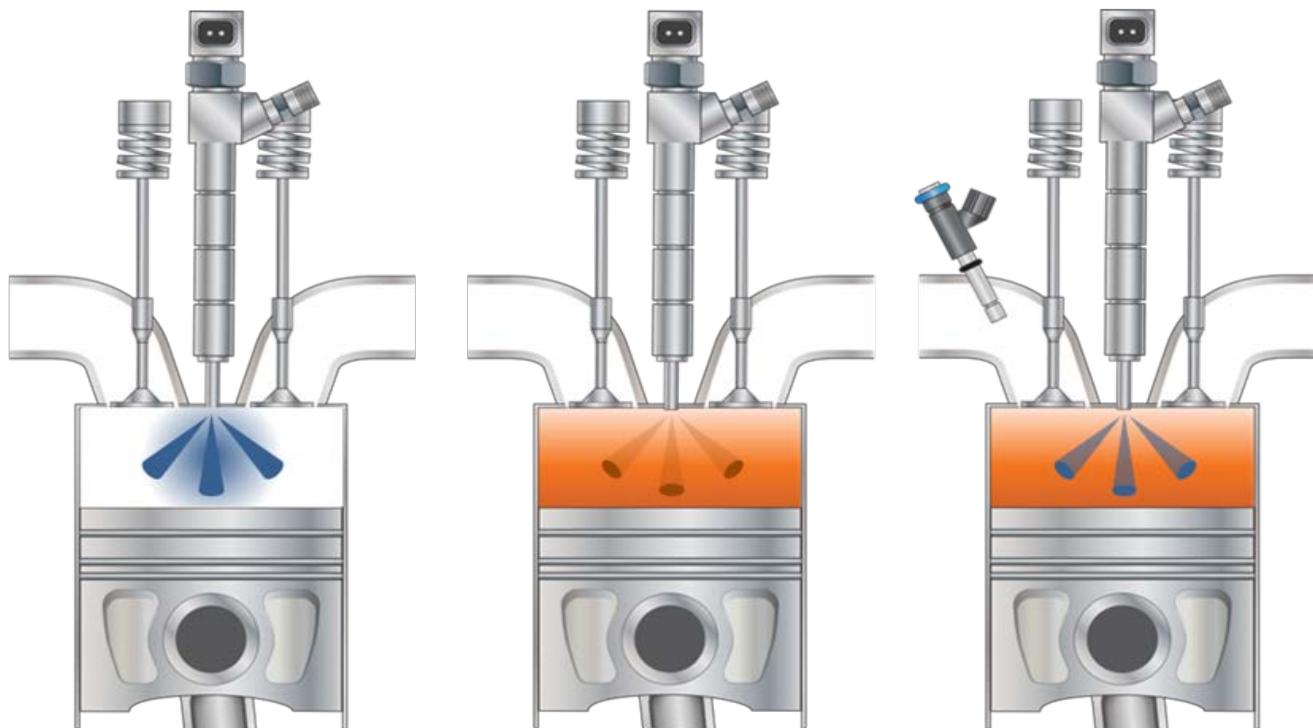
- Need better fuels and engines to meet goals
- Current fuels constrain engine design
- Co-optimization offers near and long-term fuel economy gains

Now is the time for low-carbon fuels!



Convergence of alternative fuels and powertrain development

Kinetically-controlled combustion

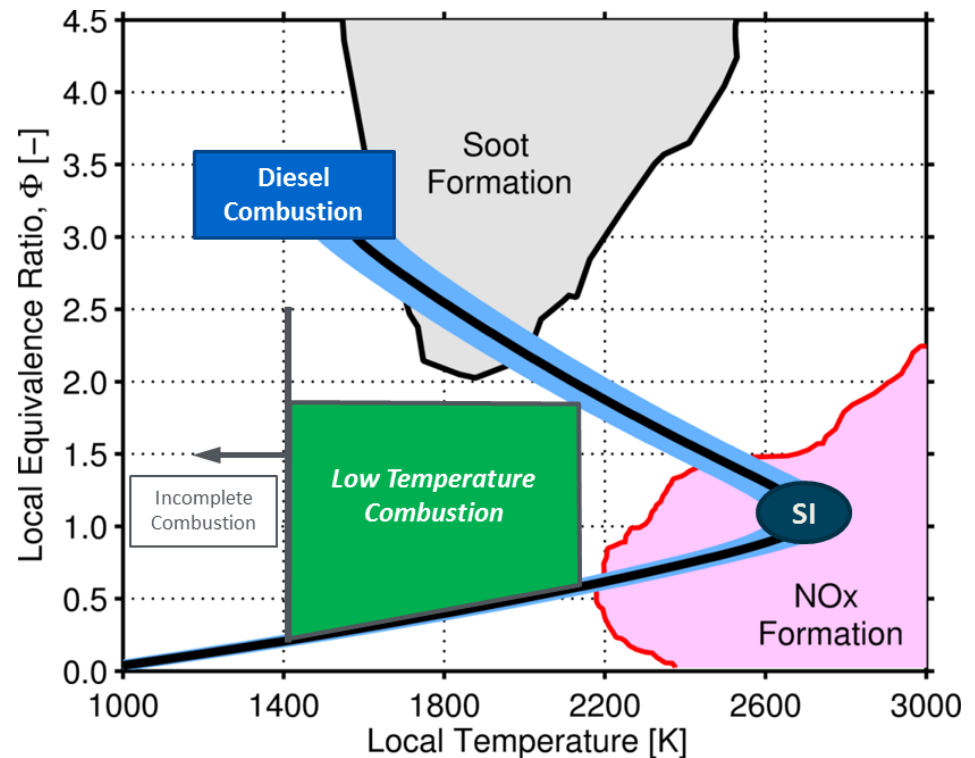


High Reactivity Fuel
High Cetane

Range of Fuel Properties
TBD

Longer-term opportunities

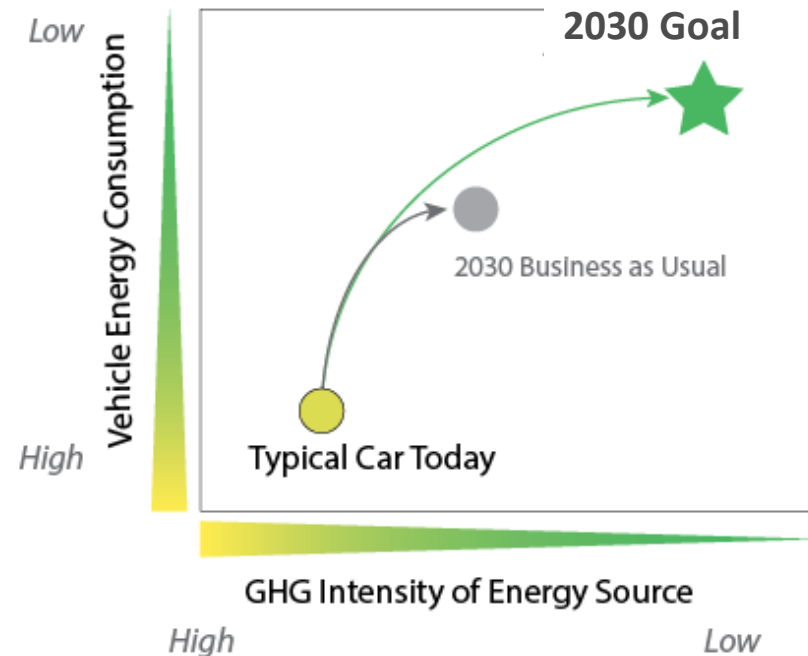
- Synergistic development of advanced CI combustion strategies and fuel properties for further reductions in GHG emissions
- Broad landscape of possibilities with different opportunities and challenges
- Builds upon significant fundamental and applied fuels/engines research across DOE



Advanced combustion + new fuel technologies:
better navigation of combustion to minimize
GHG and criteria pollutant emissions

Big Idea: Optima

- Through co-optimization of fuels and engines, reduce per-vehicle petroleum consumption 30% vs. 2030 base case
 - Additional 7-15% reduction in engine fuel consumption
 - 20% reduction in fuel WTT emissions
 - GHG emissions reduction of the light-duty vehicle fleet by 10-15% relative to BAU within 10 years of market introduction
- Develop new fuels and vehicles with higher performance that can be produced affordably, sustainably, and at scale



Lubrication Strategies/Activities

1. **Predictive modeling** - Integration of (continuum) component parasitic friction loss models into subsystems and vehicle level packages – ‘what if’ parametric studies
2. **Develop Science/Mechanistic Based Models** of Parasitic Losses and Durability/Reliability and friction and wear
3. **Lubricant Technology Development** – Develop advanced lubricants (base fluids and additives) that reduce frictional losses while maintaining or exceeding other performance metrics (durability, reliability, corrosion, deposits, etc.)
4. **Engineered Surface Technology** Development – Develop advanced engineered surfaces (textures, designs, materials and coatings) that mitigate parasitic losses from a systems approach. Go beyond current ferrous based tribological systems.
5. **Validation of Modeling and Technologies** – Develop protocols to improve the fidelity of models and technologies. Improve correlation between lab-scale tests and engine/vehicle tests. Develop high fidelity databases for models and simulation of parasitic losses. Lab-Rig-Engine-Vehicle Validation Studies

U.S. DEPARTMENT OF
ENERGY

The **TURNOVER TO NEW VEHICLE TECHNOLOGIES** proceeds slowly, but improved lubricants can be rolled out quickly. The **DOE LUBES PROGRAM** aims at **MAKING THESE LUBRICANTS MORE FUEL EFFICIENT**



KEY PATHWAYS TO FRICTION REDUCTION are **REDUCED OIL VISCOSITY** and **IMPROVED FRICTION AND WEAR ADDITIVES**



This would save **\$12.4 BILLION PER YEAR**, **EQUIVALENT TO 124 MILLION BARRELS OF OIL**



These vehicles consume **9.7 MILLION BARRELS OF OIL PER DAY**, with a value of **\$354 BILLION PER YEAR**



There are **240 MILLION CARS and TRUCKS** in the USA, with an average **LIFESPAN OF 16 YEARS**



16.5% OF THIS FUEL ENERGY IS LOST TO FRICTION



IMPROVED LUBRICANTS SAVE FUEL TODAY AND ENABLE IMPROVED VEHICLES IN THE FUTURE

DOE Research Portfolio

- Models for friction and wear
- Rapid, accurate testing methods
- Improved base oils and additives
 - Nano-technology
 - Ionic liquids
 - Self-renewing, smart additives
 - Improved mechanical design
- Validation and demonstration

VTO Fuels & Lubes Directions for FY 2016

- High-performance, low-carbon fuels for high-efficiency engines
 - Optima initiative
 - Optimal biorefinery products for use in fueling infrastructure and vehicle (co- w/ BETO)
 - Refinery-based fuels and blendstocks
 - Co-optimization of fuel properties and combustion
- Next-Generation Lubricants
 - Evaluation methods development, correlation to end use
 - New base oils and VI behavior
 - New friction and wear reducing additives

Directions for FY 2016

- High performance, low carbon fuels for high efficiency engines
→ Optima Program
- Next-Generation Lubricants
 - Evaluation methods development, correlation to end use
 - New base oils and VI behavior
 - Friction and wear reducing additives
 - Liquid, solid, nano

Summary

- Now is the time for beginning serious co-development of engines & fuels
 - Regulatory climate
 - The will to act
 - Octane may be a good starting point, advanced combustion a close second
- Lubricants provide a potential drop-in retrofit for existing vehicles in many cases (depends on vehicle class and part lubricated – e.g., engine oil, but perhaps not light-duty automatic transmission fluid)
 - Many Vehicles \times Small per Vehicle Savings = Large Benefit
 - May be low-hanging fruit
 - May be necessary for meeting future CAFE
 - Opportunities for co-evolution of lubricant and engines/vehicles

Summary, cont'd.

Fuels

- Exhaust emissions will remain the key factor in fuel requirements
- Fuel chemistry can enable more efficient combustion modes
- Octane will play a role
- Ethanol and natural gas aren't used optimally with today's engines

Lubricants

- Lubricants have huge potential due to retrofit capacity
- High-VI base oil will help on cold starts
- Improved additives required for lower viscosity base oils
- Co-development of the engine and lubricant will yield the greatest benefit

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