U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overview of the VTO Fuel and Lubricant Technologies R&D

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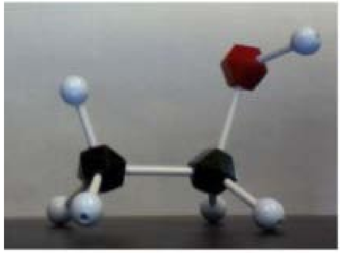
Fuels R&D

Expanding the use of alternative fuels and fuel-controlled combustion

Fuel and Lubricant Technologies

Accomplishments

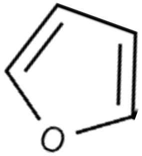
- Demonstrated 2% fuel economy improvement with advanced additives, relative to SOA synthetic SAE 5W-20 (2015 goal)
- Demonstrated RCCI operating range of 75% of non-idling portions of the city (UDDS) and highway (HWFET) light-duty federal drive cycles
- Successful launch of U.S. DRIVE Fuels Working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

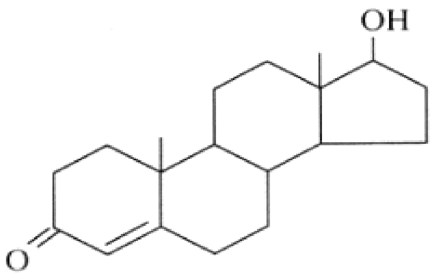
- On-track to meet goals for both fuels and lubricants

FY 2020 Goals

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

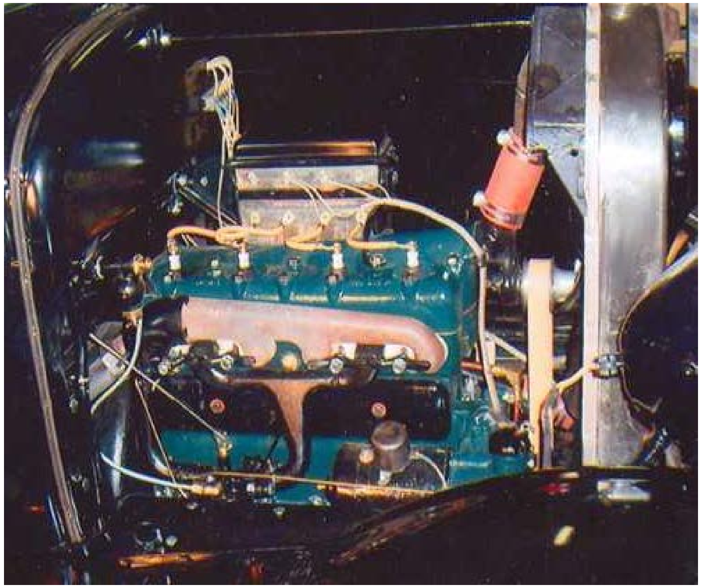
Demonstrate expanded operational range of advanced combustion regimes to >95% of LD Federal Test Procedures

Fuel and Lubricant Technologies



Funding in millions	**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

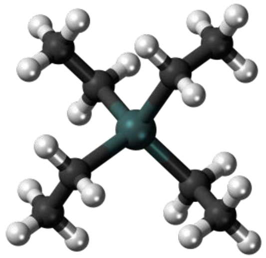


- 1908 – 1927
- Peak sales of 2M in 1923
- Early models allowed kerosene as well as gasoline – not well-defined difference
- Early fuels had AKI of 50-60

- 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

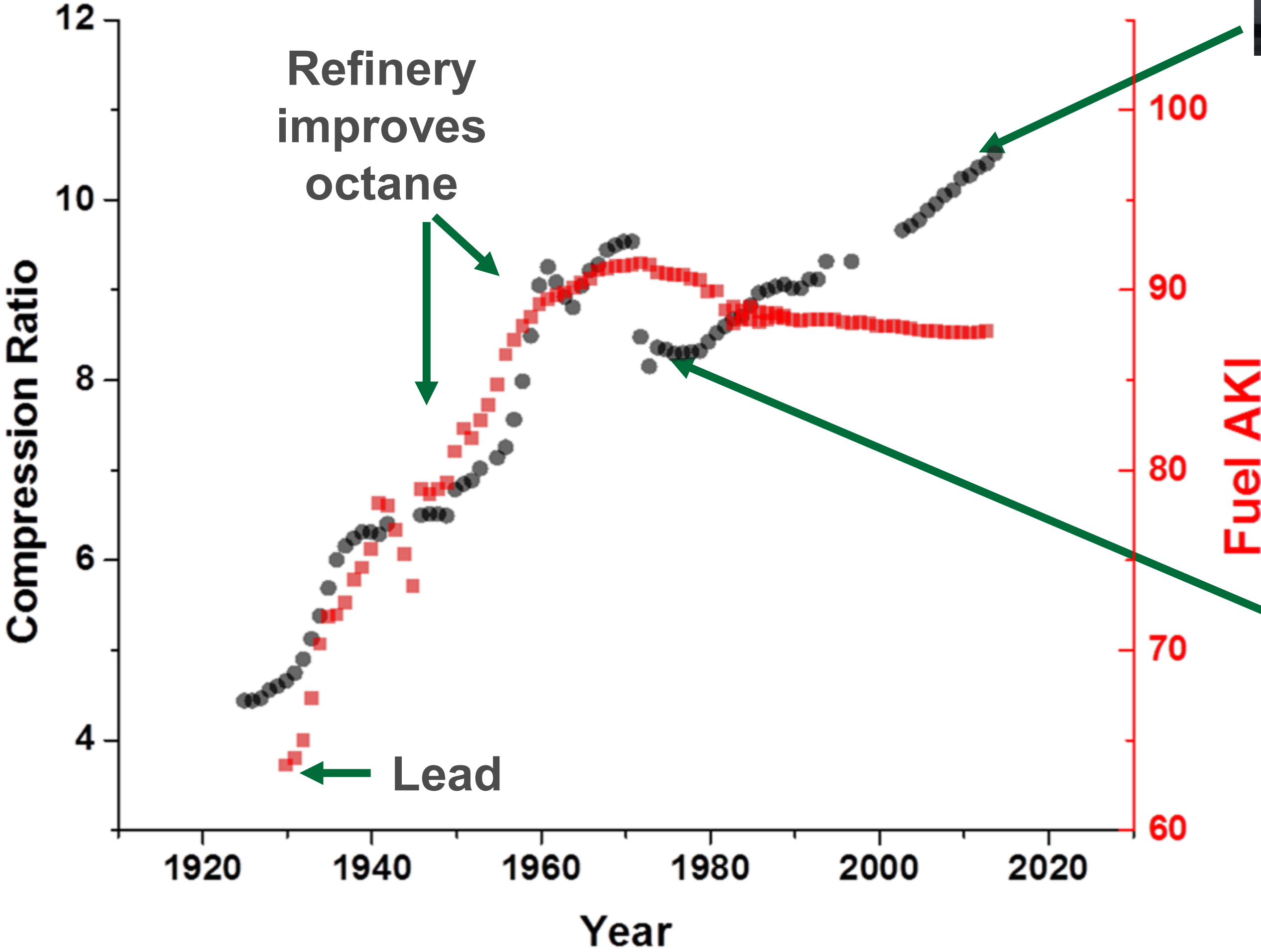
- Charles Kettering, electric starter (Delco)
  - Cars w/ starters happened to knock
  - Refining technology for +ON not deployed
  - Invests efforts in fuel & antiknock additives
- Thomas Midgley investigated over 33,000 compounds in 6 years
  - Several suitable compounds identified
  - Tetraethyllead (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

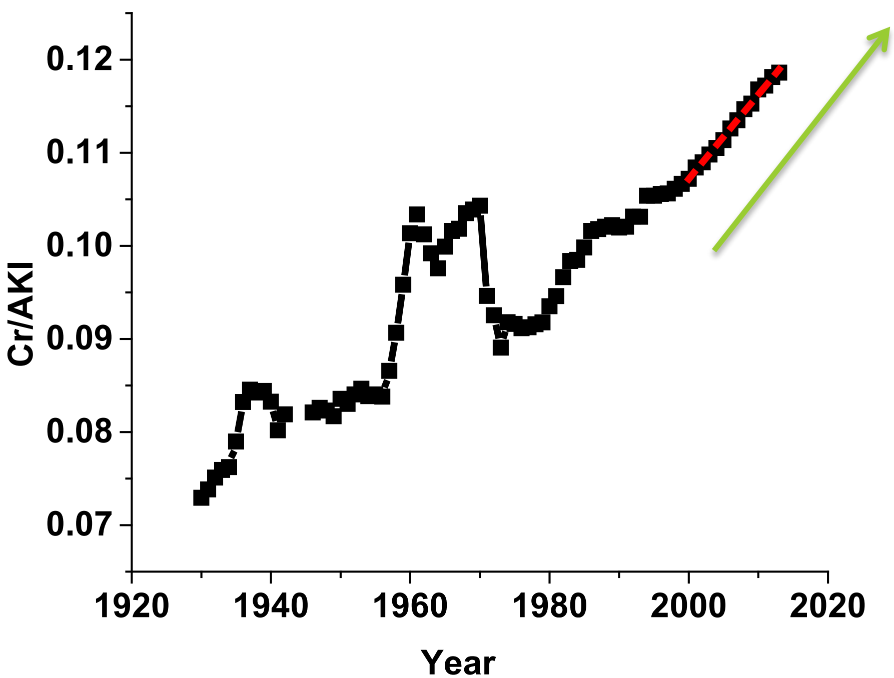


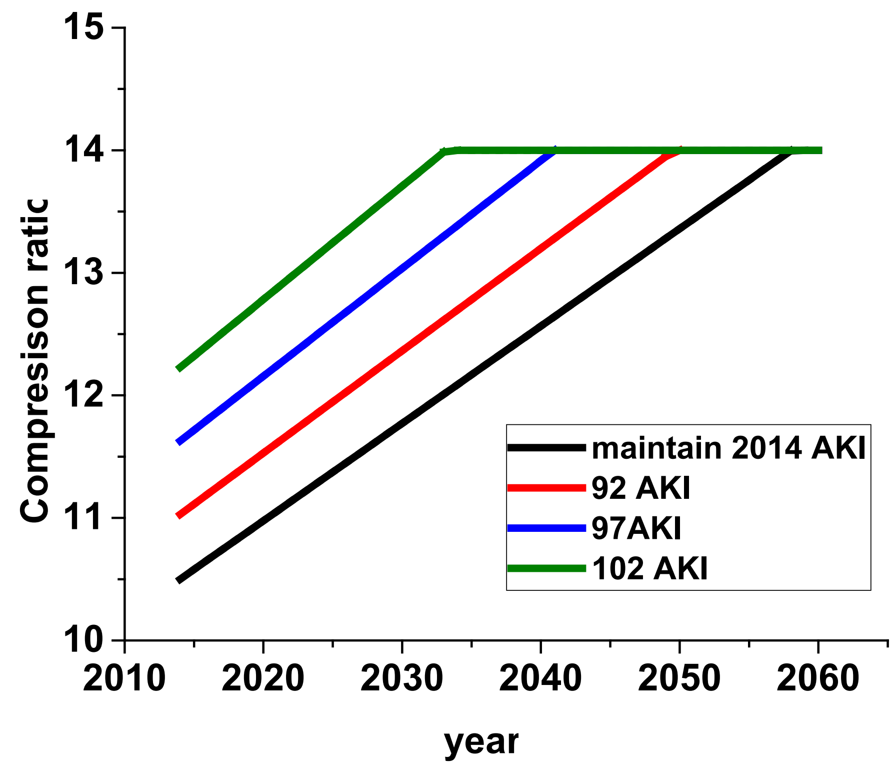
272 hp, 2.0 L disp
0-60 in 5.6 s
21/30 MPG

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





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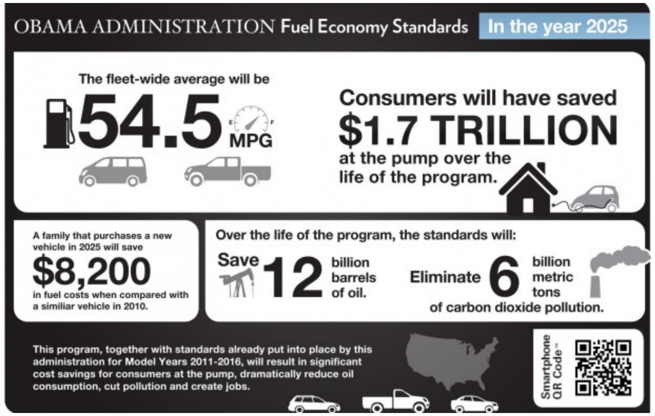
Convergence of three automotive challenges underlines the importance of advanced research

54.5 mpg CAFE by 2025

- EPA / DOT standards

- Currently 30.1 mpg for "cars"

- Gasoline dominating LDVs



Fuel Economy Standards

EPA

>70% less NOx

>85% less NMOG

70% less PM

Automotive Industry

EPA Tier 3 Emission Regulations

Renewable Fuel Standard

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

- EPA Tier 3 regulations

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.

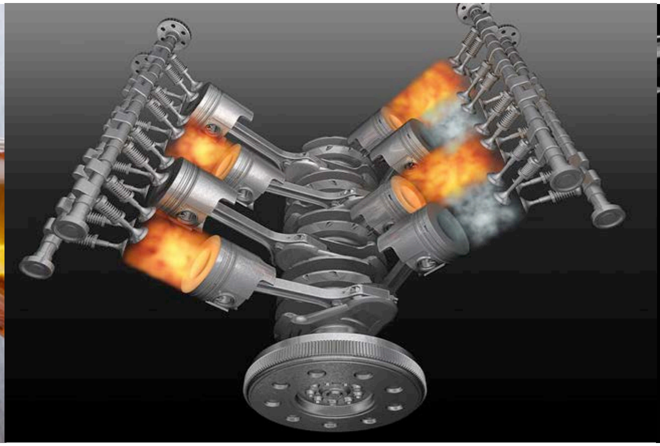
Ford Fusion:

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

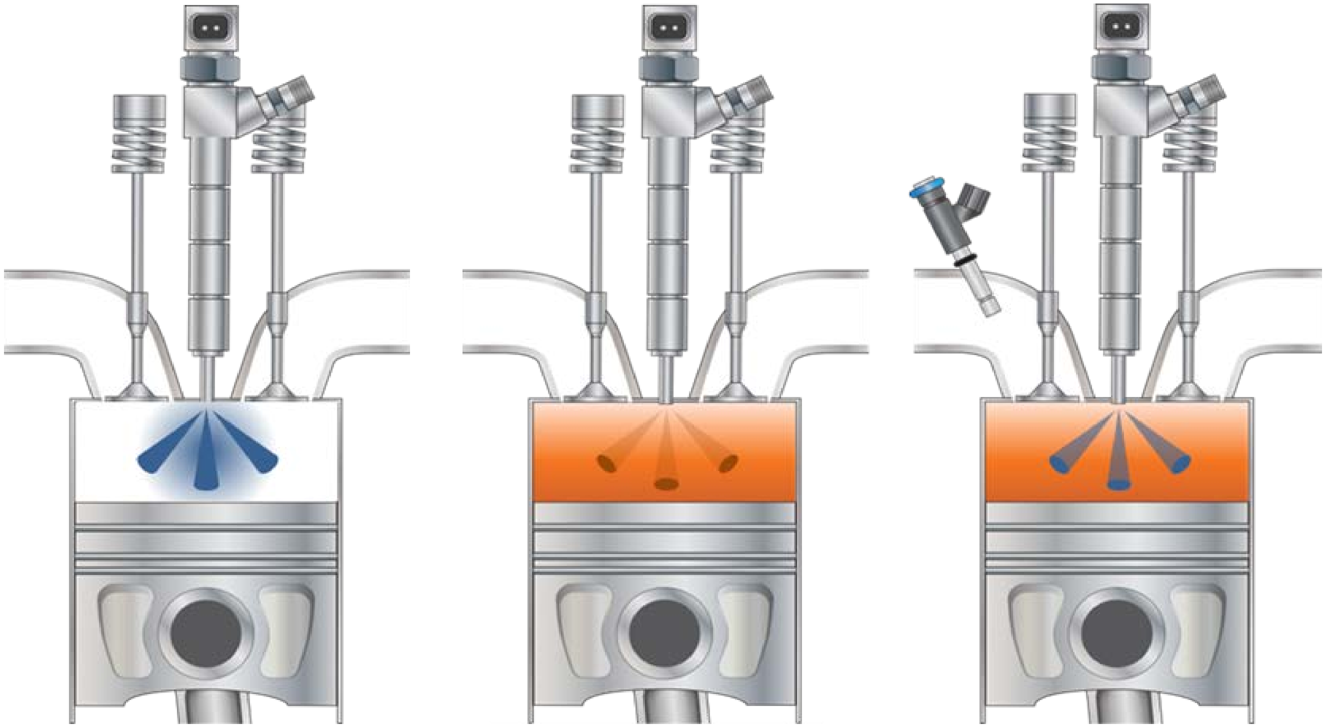
Now is the time for low-carbon fuels!


Convergence of alternative fuels and powertrain development

Longer-term opportunities

Kinetically-controlled combustion

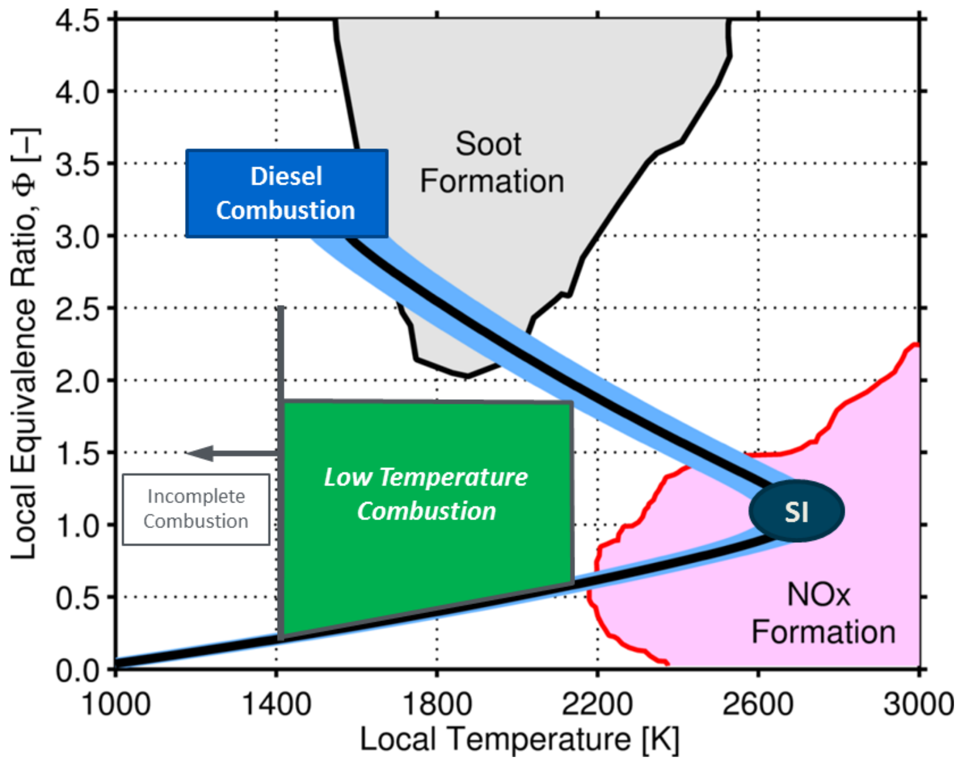


High Reactivity Fuel
High Cetane

Range of Fuel Properties
TBD

Longer-term opportunities

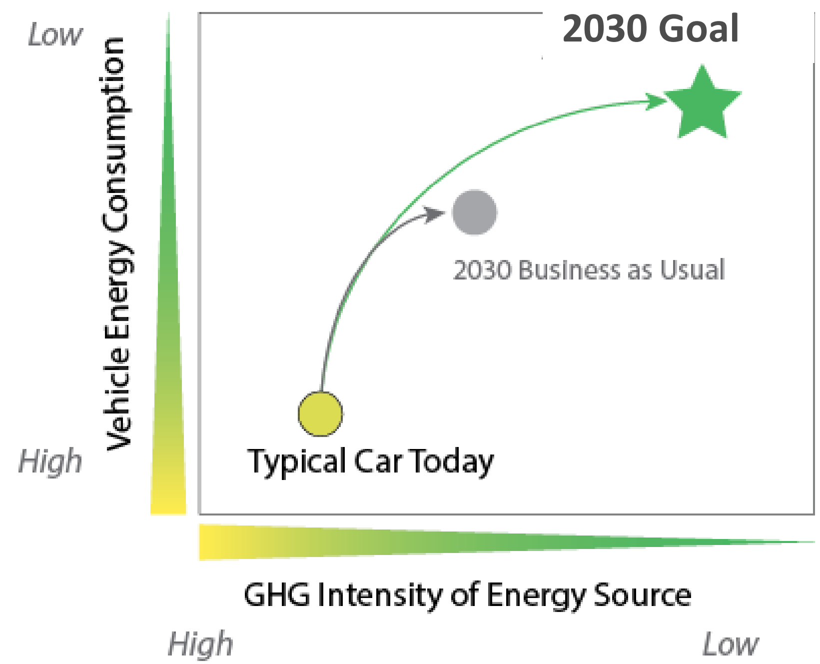
- Synergistic development of advanced CI combustion strategies and fuel properties for further reductions in GHG emissions
- Broad landscape of possibilities with different opportunities and challenges
- Builds upon significant fundamental and applied fuels/engines research across DOE



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

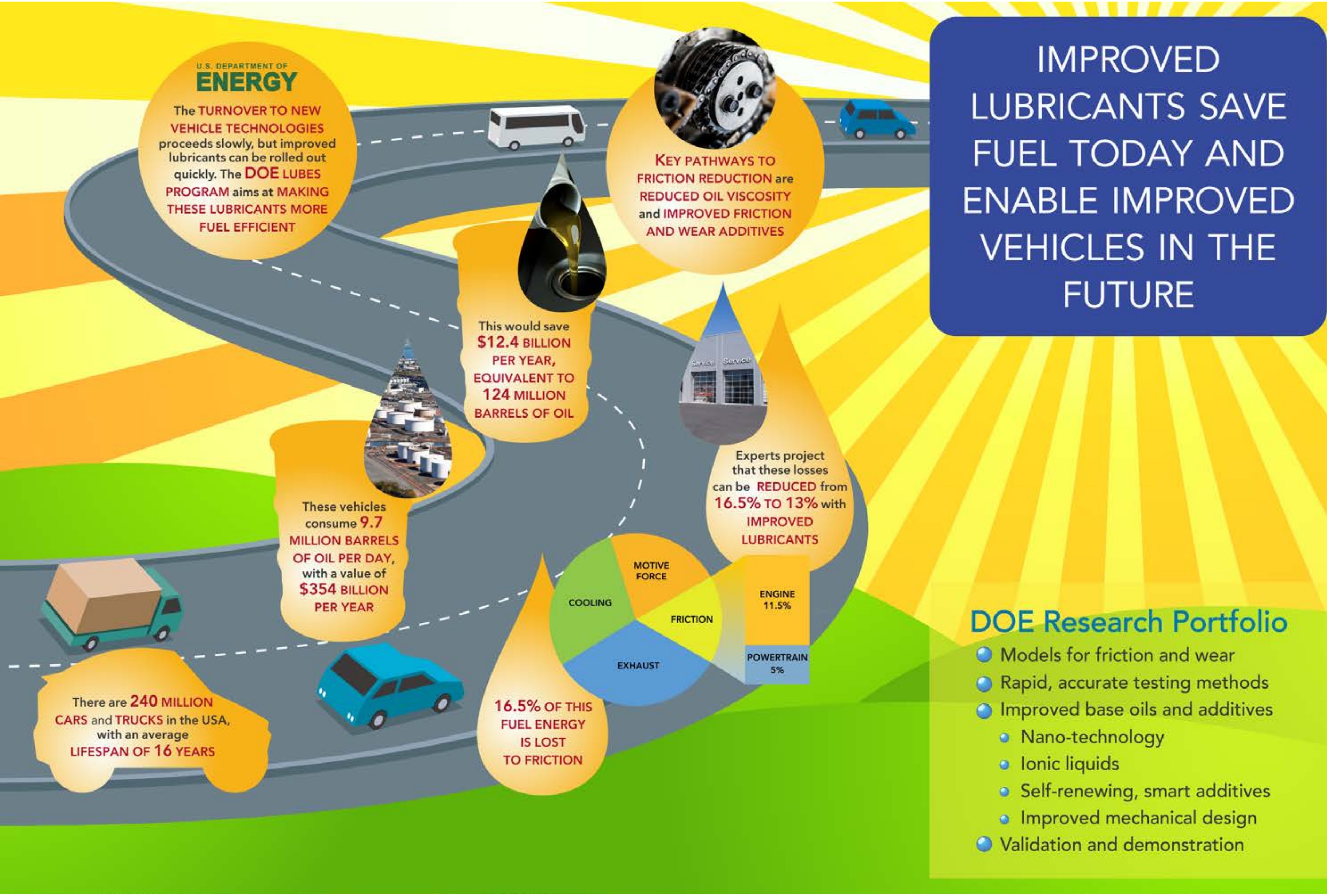
Big Idea: Optima

- 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


IMPROVED LUBRICANTS SAVE FUEL TODAY AND ENABLE IMPROVED VEHICLES IN THE FUTURE
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
Experts project that these losses can be REDUCED from 16.5% TO 13% with IMPROVED LUBRICANTS
MOTIVE FORCE
COOLING
FRICTION
EXHAUST
ENGINE 11.5%
POWERTRAIN 5%
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
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 **x** 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

Contact Information

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