Improving Engines and Fuels, Together

Sloan Automotive Laboratory

John B. Heywood
Sun Jae Professor of Engineering, Emeritus
Massachusetts Institute of Technology

11th CONCAWE Symposium
23-24 February 2015, Brussels

Engine and Fuel's Context

My group at MIT has been examining options for improving engine and vehicle technology and fuels. Reports: On the Road in 2035 (2008); On the Road Towards 2050 (2015).

<u>Engines</u>:

1. More efficient alternatives are: turbo gasoline engines (10%) hybrid electric vehicles (30%) plug-in-hybrids (two-thirds kilometers are electric).

2. Propulsion system and vehicle technologies will steadily improve (plausible that fuel consumption reduced by up to 50% by 2050)

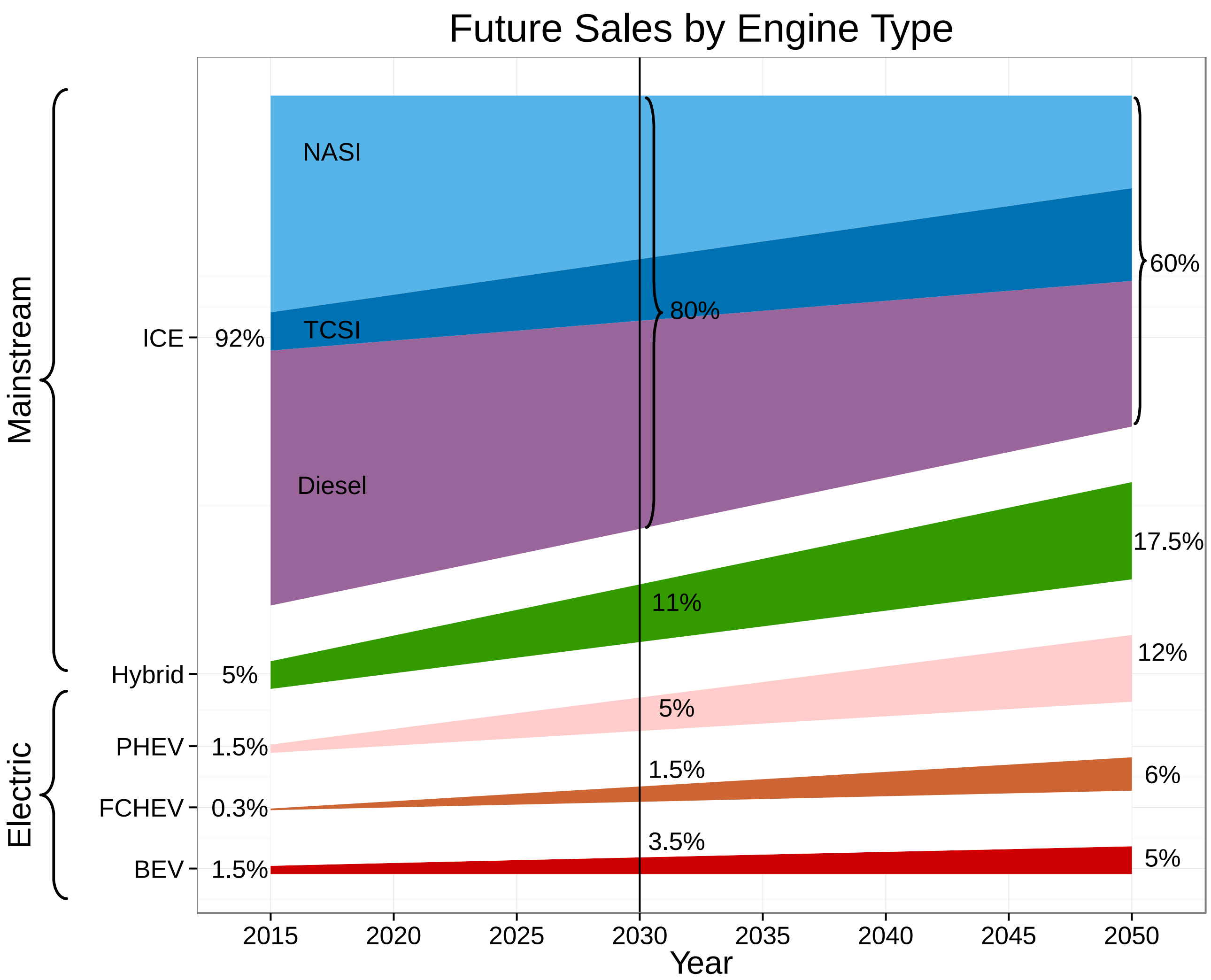
3. Weight reduction (some 20%)—moderate impact: acceleration performance slowly increasing.

Engine and Fuel's Context – continued

Fuels:

1. Development of biomass-based fuels likely limited by land use impacts. Ethanol (high octane) likely to be 10 – 20% of gasoline volume.
2. Cleaner fuels (outside U.S. and Europe) are an important requirement for reducing air pollutant emissions from vehicles.
3. Outside the refining industry, knowledge and information of the aggregate fuel refining and supply system limited.
4. Overall, too much (high octane) gasoline for current market: demand for higher quality diesel is high, and ongoing.

Evolving New LDV Market (Europe)
Percent Sales by Powertrain out to 2050

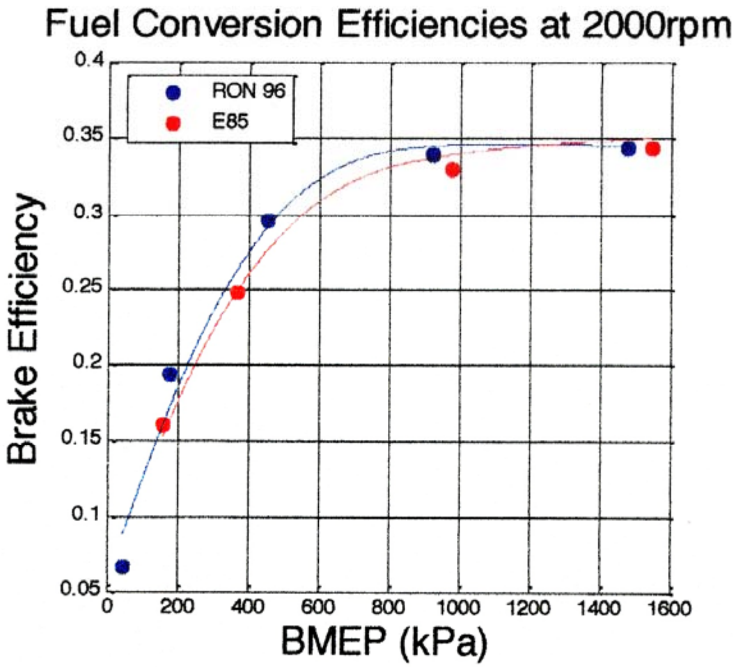


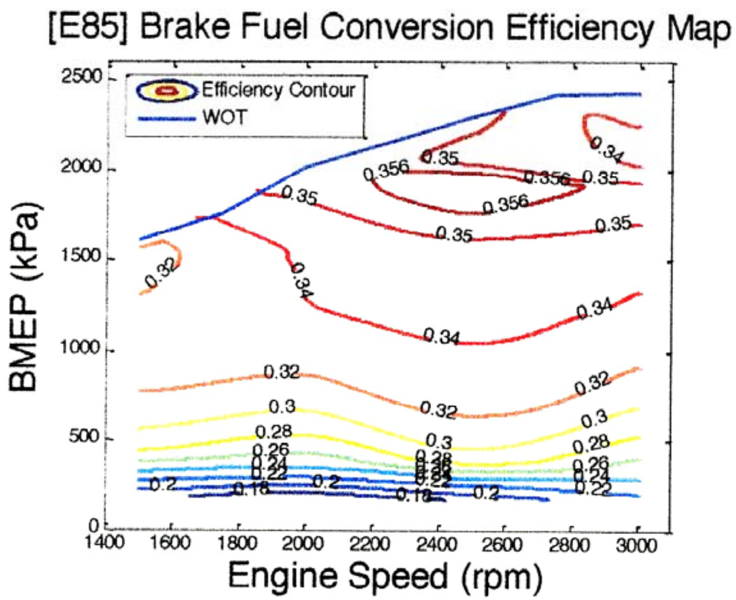
Source: Heywood et al. On the Road towards 2050

Some of the Engine/Fuels Opportunities

1. Higher gasoline resistance to knock (in actual use): fuel sensitivity; optimum use of ethanol; tighter matching of engines and fuels.
2. Using the "right octane" gasoline over full engine performance map.
3. Air pollution—engine particulate emissions: combustion system, fuel composition, diesel and DI gasoline.
4. Alternative IC engines to the diesel: knock-free gasoline engine, reaction-controlled compression-ignition engine?
5. Lubricants for reduced friction and particulates.

Turbocharged Gasoline Engine Performance Map: Brake Efficiency Data



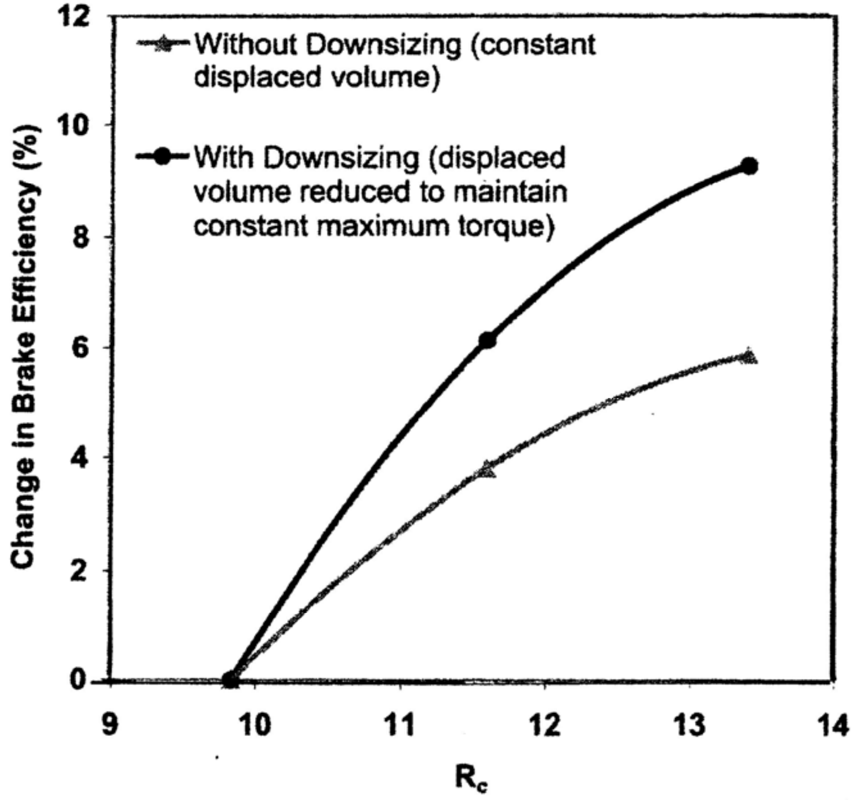


Right: Turbocharged gasoline engine performance map: efficiency constant over top half of map.

Left: Fuel conversion efficiency as function of engine load at 2000 rev/min for this TC engine. Shows increasing role of friction at light load.

Source: Jo, Lewis,Bromberg, Heywood, SAE 2014-01-1206

Effect of Compression Ratio on Efficiency with Engine Downsizing

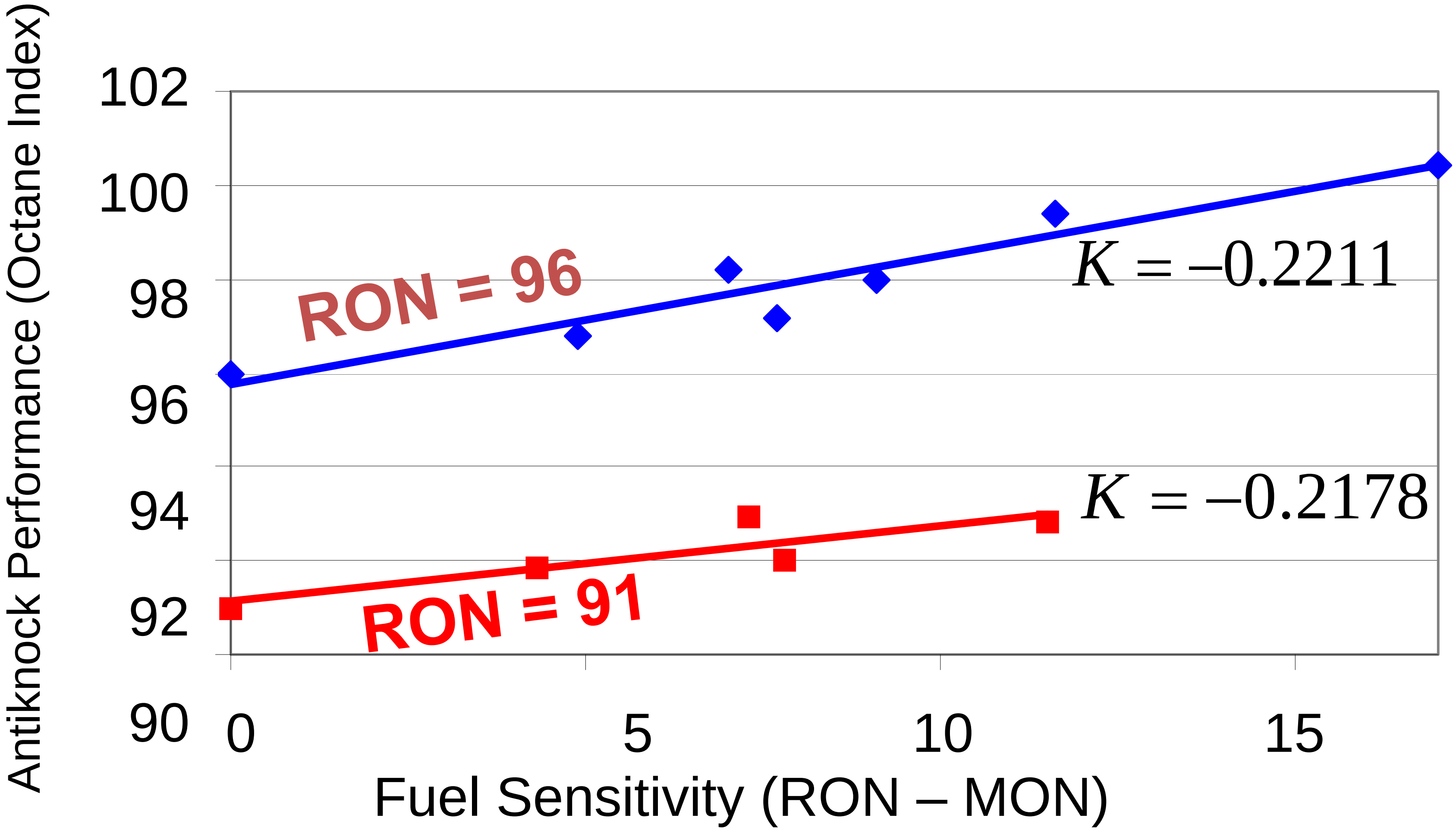


Efficiency change:

1. At constant displaced volume (487 cm^3/cyl.)
   6 percent
2. At constant torque (downsized by 9 percent)
   9 percent
3. With downsizing, 50 percent larger benefit

Source: Gerty and Heywood. SAE 2006-01-0228.

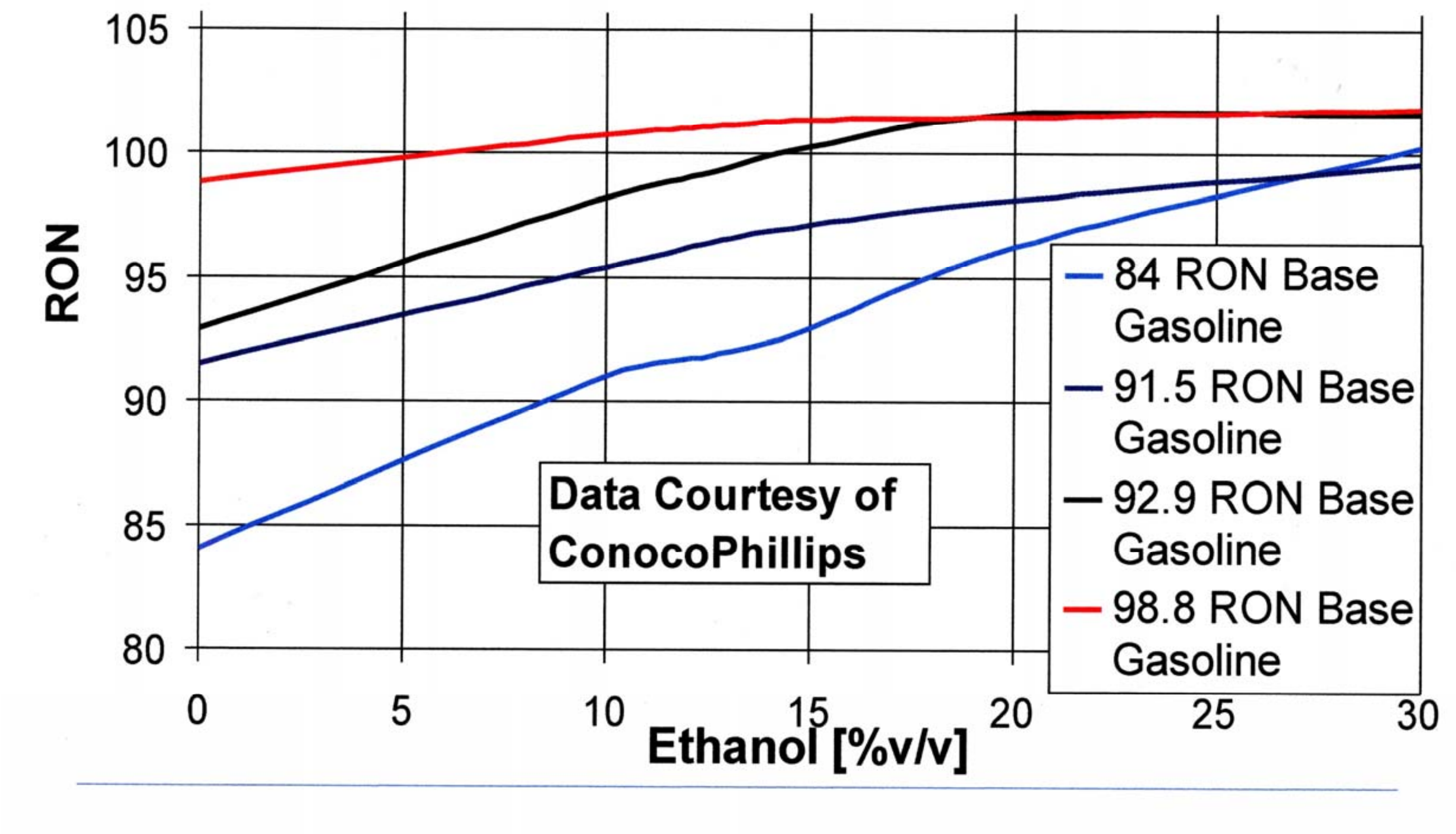
Octane Index vs Fuel Sensitivity at Base Test Condition



Operating Conditions: 1500 RPM, WOT, λ = 1, T_{intake} = 25° C, varying spark

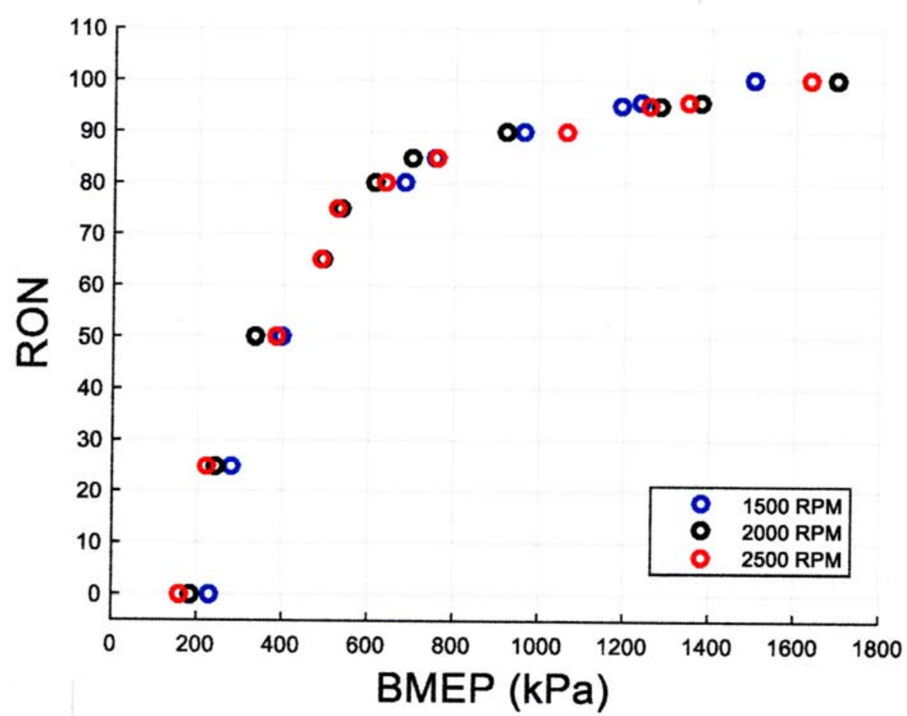
Increasing sensitivity increases Octane Index. Source: Mittal and Heywood. SAE 2010-01-0617.

Blending Ethanol with Gasoline to Improve Octane



10-15% ethanol increases gasoline RON 5-8 numbers
Kasseris and Heywood, SAE 2012-01-1275 and 2012-01-1284.

Turbocharged Engine Octane Requirement as as a Function of Load



Octane Requirements of the Turbocharged Engine versus BMEP

1. 2-liter, 4-cylinder turbocharged engine
2. Octane requirement (RON) to avoid knock over full load range
3. With typical driving, average RON to avoid knock is 50

Source: Young Suk Jo, DOE High Compression Ratio… project, 2014.

Examples of Opportunities

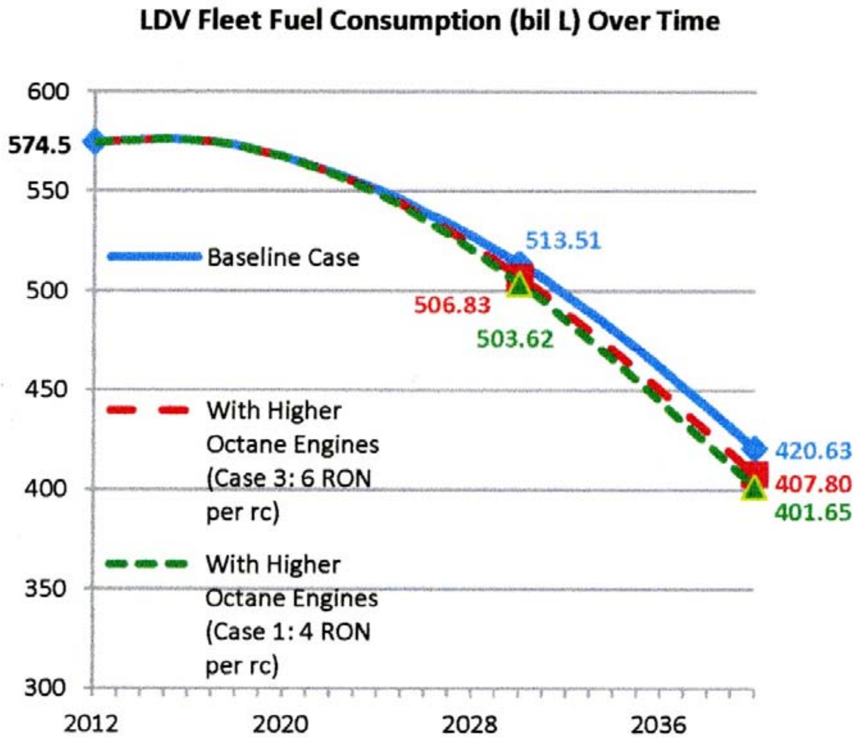
1. Raise octane rating of gasoline (MIT US study: standard fuel from RON 91 to RON 98)
2. Match fuel octane to engine need as a function of load and speed: (a) extra tank with knock-suppressing fuel; (b) on-board fuel separation into high and low octane stream.
3. Can we implement a new engine combustion mode?
    a. Auto-ignite gasoline in a diesel engine
    b. New combustion mode (Reaction-Controlled Compression Ignition) and new fuel

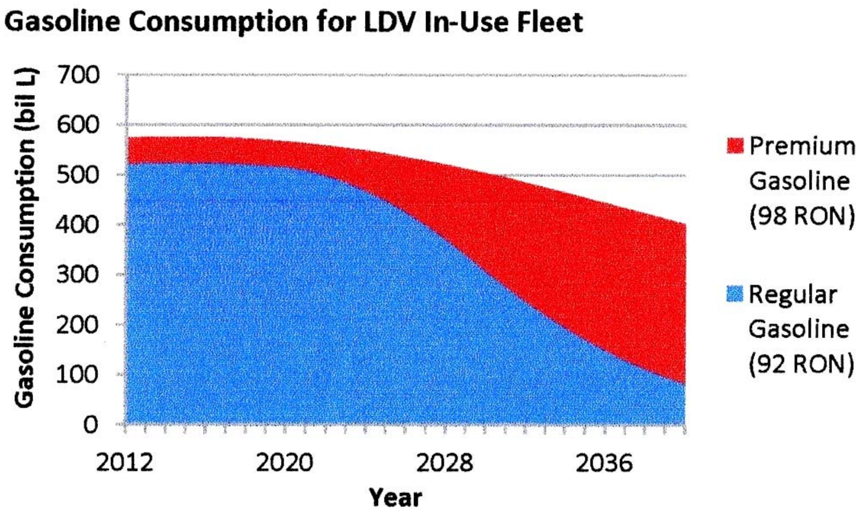
Fleet Model

- Incorporates:
  - Estimated projections for engine and vehicle technological improvements over time
  - Estimated timeline for introducing engines designed for higher octane (higher compression ratio and boost levels) to the market

- **2013** — Current day
- **2016** — Policy passed to increase RON
- **2020** — Automobile manufacturers introduce engines redesigned for higher octane to the market
- **2030** — 100% of the vehicle sales of each powertrain will be the higher octane version

(U.S.): Standard Gasoline Increased to 98 RON





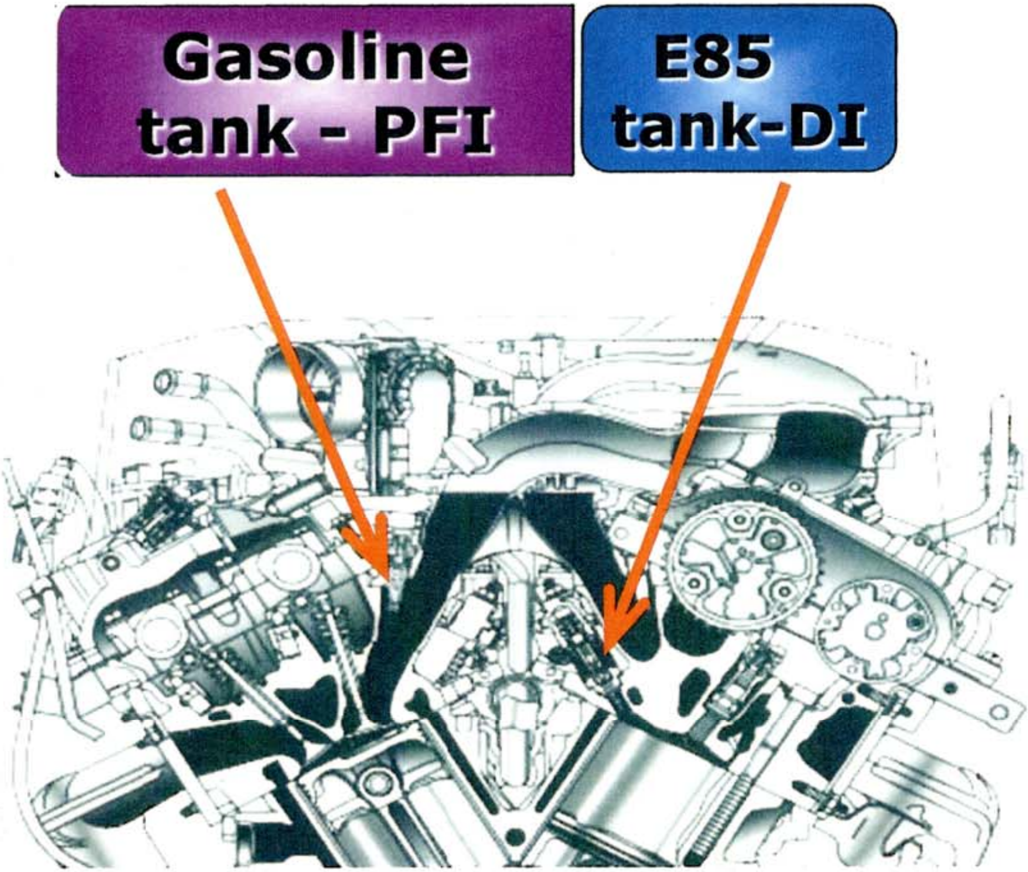
Projected U.S. in-use fleet fuel consumption reduction of up to 5% by 2040. 80% of fuel is then 98 RON. Benefit is 7 – 8 % by 2050.

Source: Chow and Heywood, SAE paper 2014-01-1961. Speth, Chow et al., Environ. Sci. Technol., Vol. 48, 2014.

Findings

1. Fleet analysis indicates a 4-5% reduction in in-use LD vehicle fuel consumption in 2040 (when annual consumption is down by 30%), and 6% in 2050.
2. By 2040 almost 80% of the gasoline is 98 RON: Higher octane vehicles are then 70% of in-use fleet vehicles.
3. With 98 RON standard gasoline, the refinery energy consumption (and GHG) does not significantly change, so net benefit is essentially the in-use fleet benefit.
4. Challenge: requires coordinated changes in petroleum and automotive industries.

Removing Knock Limit On Engine Torque and Power Density

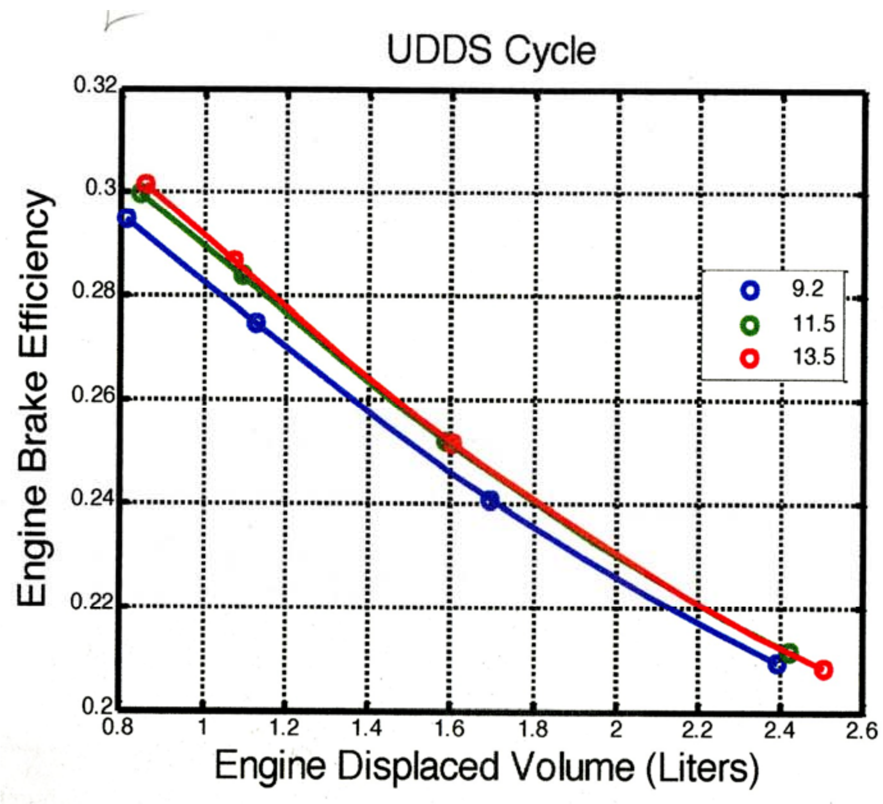


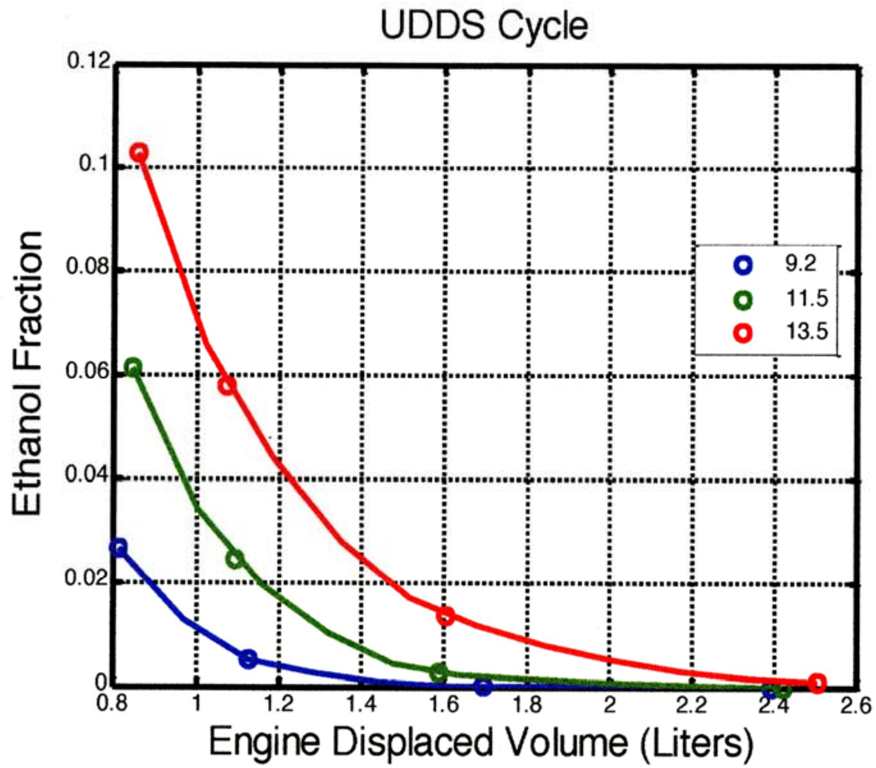
Single split tank or two tanks

Variable Direct Injection of E85 suppresses knock

Highly turbocharged, high compression ratio engine (up to 3 X more torque)

Engine in Vehicle Simulation - Results





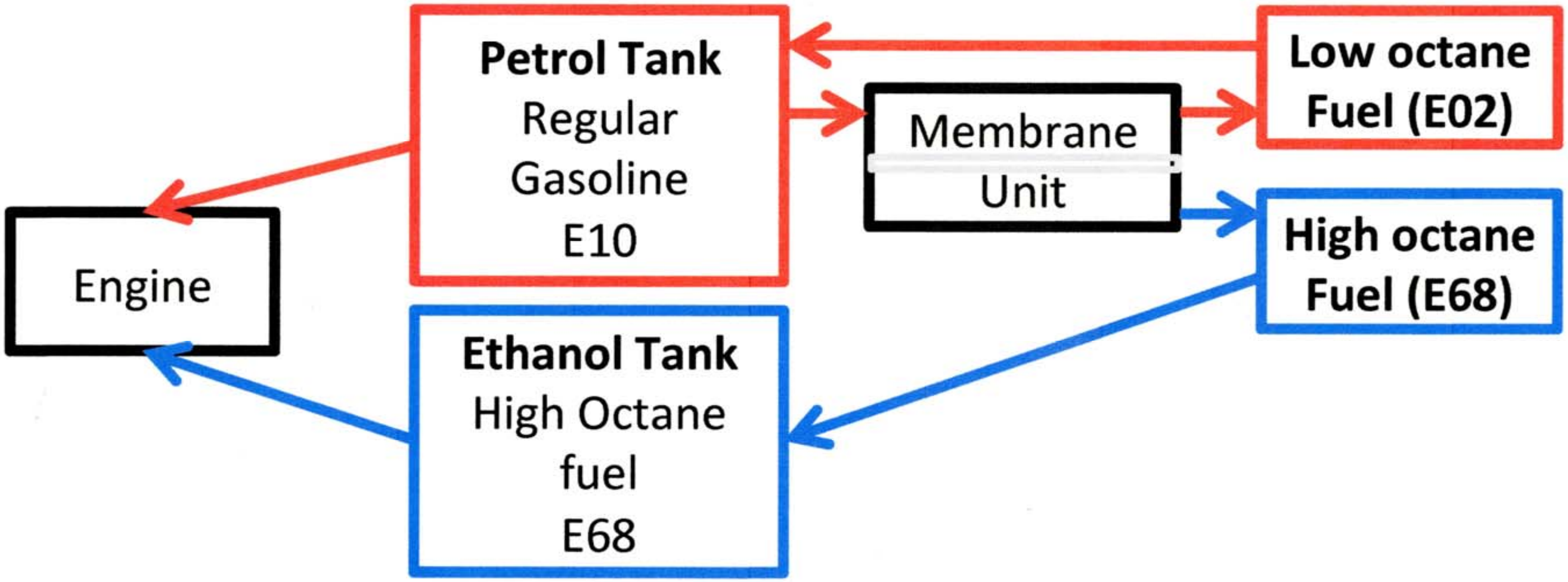
- Effect of engine downsizing is large in this urban driving cycle: improvement in average engine efficiency 33% with downsizing from 2.4 (NA) to 1.2 (TC) liter engine
- Impact of increased compression above 12 is small: up to 10 deg. spark retard employed before ethanol injected

Octane On Demand

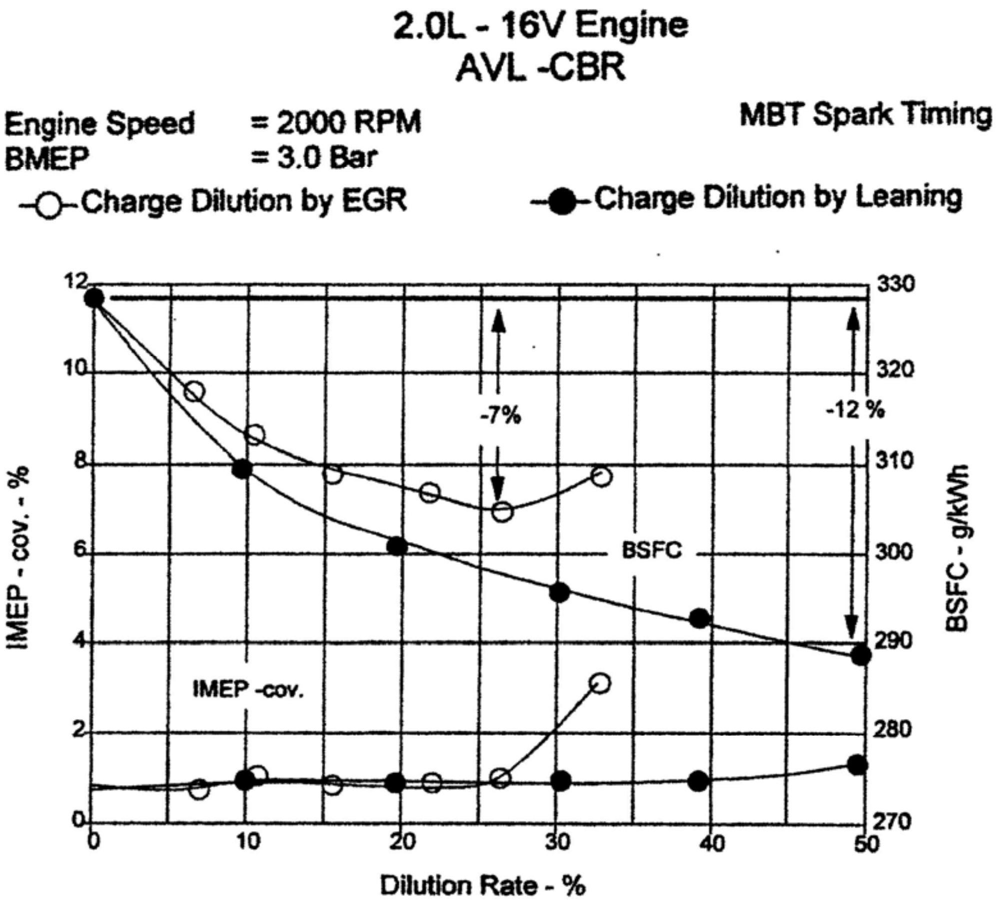
Honda System

Dual Fuel Octane On Demand

- Provide the optimal octane fuel when the engine needs it
- Effectively using fuel octane to achieve maximum efficiency



Potential for Charge Dilution: Air and EGR



Dilution with air and EGR improves part-load fuel consumption:

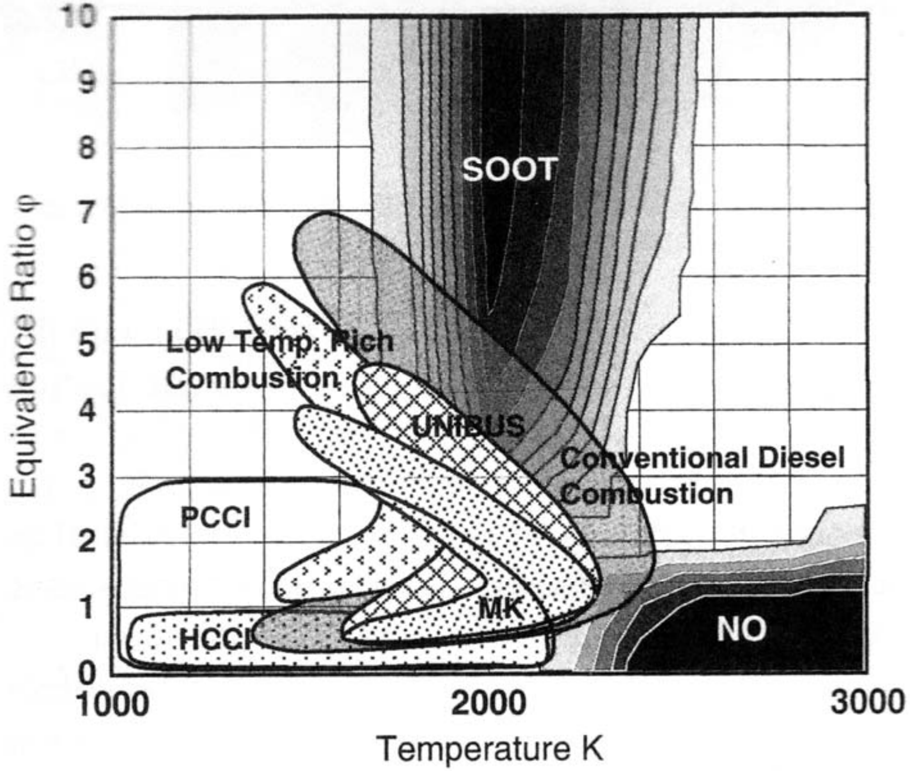
Lean: 12% plus, reduction

EGR: 7% reduction

(At combustion stability limit)

Source: AVL

Potential for Charge Dilution: Air and EGR



Source: Ohsawa and Kamimoto, Combustion in Reciprocating Engines, Eds. Arcoumanis, and Kamimoto, 2009

1. RCCI is a new auto-ignited engine combustion process (light to mid load)
2. Reduces diesel's NO_x and particulate problem
3. Several options:
   (a) Use in SI engines
   (b) Use in diesels
   (c) Use low-octane gasoline in diesel
4. Likely requires changes in both engine, fuel, and strategy

Overall Potential

1. Matching gasoline octane to engine needs is "untidy," and far from optimized.

2. The fuel supply and the vehicle engine supply systems are both massive in scale and hard to change.

3. The energy industry, the auto industry, and government would need to coordinate their actions if the types of changes discussed here are to occur.

4. Several approaches: e.g., updated fuel requirements, higher octane standard gasoline, duel fuel for knock suppression (two tanks), on-board fuel separation, have potential. Approaches with greater impact are more challenging and have higher cost.

5. The potential reductions in (light-duty) vehicle energy consumption are in the 5 – 25 percent range: a significant impact.