An OEM’s Perspective on Fuel Economy Technologies and Future Sustainability

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“Fuel Economy - How Do We Get There?”
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Current Regulations / Requirements
- Fuel economy / CO₂
- Balancing requirements
- Technology costs / Customer value

Sustainability – Well-to-Wheels - Beyond Regulations

Sustainability – Multiple Opportunities
- Vehicle
- Fuel
- Usage

Summary / Conclusions
Compared to 2011, CAFE needs to increase by more than 95% to reach 54.5 MPG by 2025... significant year-over-year improvements are required.

- By 2011, Fuel economy increased ~40% since the beginning of CAFE
- CAFE requires a further 30% uplift by 2016
- The 54.5 mpg target equates to more than a 95% increase over 2011
The current global regulations require aggressive year over year CO₂ reduction requiring a very rapid pace of advanced vehicle technologies development.
Balancing CO$_2$ reduction requirements and increasing customer expectations constrains the feasible solutions zone, requiring an integrated approach.
Though costs are additive, technology benefits are not in most cases, and the costs increase much more rapidly than the fuel economy benefits.
As Fuel Economy improves, customer fuel savings decreases, and the willingness to pay for further incremental increases diminishes...while product costs increase.

* Assuming 15,000 miles are driven annually at $4/gallon
Beyond vehicle-only (Tank-to-Wheels) regulations, stabilization of CO\textsubscript{2} concentrations in the atmosphere at 450ppm will require large reductions in emissions, for all sectors.
Sustainable LDV transportation requires actions on multiple fronts:

**Vehicle**
- Reduce Vehicle Work
  - weight, friction, drag
- Increase Primary Efficiency
  - Engine (GTDI, CR, diesel, fuel cell)
  - Transmission / Driveline
- Increase Average Efficiency
  - HEV

**Usage**
- Reduce Miles Travelled
- Smart Mobility Technologies

**Fuel**
- Properties (Octane, etc.)
- Liquid Fuels
- Gaseous & Liquefied Fuels
- Electricity
- Hydrogen
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**Materials, Manufacturing, End-of-Life**

**Use Phase**
Vehicle technologies continue to be developed to increase the fraction of converted energy available for propulsion, by improving efficiency and reducing system losses.
Body structures, Chassis, and Powertrain provide the most significant opportunities for weight reduction.
Although most of the weight reduction announcements have focused on advanced materials for the vehicle body and chassis...
1.0-liter EcoBoost Concept

Goal:
Target key engine component areas to maximize weight savings and ongoing improvements in EcoBoost power density.

...incorporating innovative ideas with future materials and technologies into the core engine structure can also offer substantial weight reduction opportunity.
Advanced S.I. Engine Technologies

Combustion
- Improved fuel economy
- Reduced NOx emissions
- Advanced direct injection systems required

Fuel Injection
- Piezoelectric Direct Injection
- Multi-Hole Solenoid Direct Injection at Increased Fuel Pressure
- PFI + Solenoid DI

Variable Valvetrain
- Improved breathing efficiency
- Improved transient response
- Variable timing, lift and duration

Boosting Systems
- Improved power density (down sizing)
- Improved transient response (fun to drive)
- Boost Requirements to drive wide range Cooled EGR

Cooled EGR
- Improved combustion efficiency
- Decreased Pumping Work
- Knock Mitigation

Power Cylinder Systems
- Reduction of power cylinder mass and inertia
- Advanced piston skirt coatings
- Low tension ring packs

Advanced technologies will extend the viability of internal combustion engines, addressing the various physical effects (thermal efficiency, pumping, friction, etc.).
Similarly in Diesel engines, key enablers to CO₂ and emissions reductions include technology advances in fuel systems, boosting, variable valve actuation, aftertreatment and controls.
Transmission efficiency improvements also include clutches, gears, bearings, shafts...along with technologies targeting reduced driveline losses.
Thermal Management, Warmup, and Energy Recovery technologies will play a more significant role in helping achieve aggressive future targets, without compromising customer needs.
Opportunities with Lubricants

Near Term
- Gasoline Engine Oil (GF-6)
  - Fuel economy, LSPI Resistance & Hardware Durability
- Diesel Engine Oil (CK-4)
  - Improved fuel economy through lower viscosity without degrading durability

Medium and Longer Term
- Gasoline Engine Oil
  - Lower Viscosity novel base oil / additive chemistry (i.e. polyalkylene glycol, others)
- Diesel Engine Oil
  - Improved turbocharger performance (coking)
- Transmission & Driveline Lubricants
  - Lower viscosity lubricant for improved fuel economy through new formulations

Continued development of powertrain lubricants offer further fuel economy improvements but other attributes, such as durability, cannot be compromised.
Conventional technology capability limits and stringent regulatory requirements will drive higher levels of electrification in order to achieve compliance over time.
Focus is on further optimization of critical systems & technologies for improved performance, increased efficiency and reduced cost.
Electrification technology development applies across a broad range of applications.
Joint OEM development of next generation H2 fuel cell powertrain continues, with a target to transfer fuel cell technology from research to production.

**MAIN TECHNICAL CHALLENGES**
- Durability
- Cost reduction / commercialization

**CO-OPERATIONS**
- Automotive Fuel Cell Co-operation (AFCC)
- Strategic Agreement with Daimler

**INFRASTRUCTURE AND FUEL CELL VEHICLES**
Development of Fuel Cell vehicles and the supporting hydrogen infrastructure must occur in parallel
From a Well-to-Wheels standpoint, maximum CO₂ reduction based on vehicle-only technology improvements will be limited, irrespective of the pathway chosen.
Even with the significant gains in vehicle operating efficiency, vehicle-only CO₂ reduction will fall short of future long-term needs.
Sustainable LDV transportation requires actions on multiple fronts: Vehicle, Usage, Fuel.
As advanced technologies shift operation to higher load / lower speed to improve efficiency...
...knock risk increases. Improved fuel properties can help address these constraints.
Higher octane rated fuel reduces knock, enabling both higher compression ratio and more optimum spark timing.

- Higher compression ratio (CR) can improve fuel efficiency with higher octane rated fuel.
- At a fixed compression ratio, higher octane rated fuel enables more optimum spark timing.
Though higher-octane fuel and higher compression ratio individually improve M-H cycle efficiency... the best results are achieved by a design-optimized combination of the two.
Fossil fuel pathways supply energy for most of today’s alternative powertrain vehicles.
On a well-to-wheels basis, today’s fuels in HEVs approximate the CO₂ emissions reductions provided by BEVs and FCVs.
A wide variety of alternative fuel pathways have been identified that could provide greatly reduced Well-to-Tank CO₂ emissions.
For any powertrain approach, low-carbon fuels are ultimately required to achieve the extensive Well-to-Wheel CO$_2$ emissions reductions in the future.
From a Well-to-Wheels standpoint, the combination of vehicle technologies and low-carbon fuel dramatically extends the CO₂ reduction potential.

Along with vehicle CO₂ reductions, achieving long-term CO₂ glide path targets will require renewable / low-carbon fuels.
Sustainable LDV transportation requires actions on multiple fronts:

**Vehicle**

- Materials, Manufacturing, End-of-Life

**Usage**

- Use Phase
- Reduce Miles Travelled
- Smart Mobility Technologies

**Fuel**
Beyond regulatory mandates, changing Societal Trends will shape the future of our industry, and will transform the way we view innovation and mobility.
Mission: Leverage actionable insights across connectivity, autonomy, and full-service mobility solutions to provide innovative experiences loved by customers, enabling a better world.

Vision

*Changing how the world moves...again.*
Gaining a better understanding of how customers use their vehicles will enable development of products, services and experiences that excite and delight, as well as enhance sustainability.
Smart Mobility key strategic areas: flexible use & ownership of vehicles, and multi-modal transportation.
The transition from Driver Assist Technologies toward Autonomous driving is progressing rapidly.
Beyond the Consumer Experiences, understanding how this additional degree of freedom known as “Usage” can impact long-term sustainability is a key question for industry.
A collaborative approach to address these goals is required.

- Environmental Sustainability (e.g. Well-to-Wheels CO₂)
- Economic Sustainability
- Investment in supporting Energy and Transportation Infrastructure
Fuel economy and CO₂ regulations continue to drive rapid vehicle technology development.

Customer savings from improved fuel economy alone will not offset growing technology costs.

Long-term sustainable LDV transportation requires a Well-to-Wheels perspective and actions on multiple fronts, including: Vehicle, Fuel and Usage.

There is extensive work on the full spectrum of vehicle technologies that can substantially improve fuel economy and CO₂ in the future.

Higher octane rated fuel combined with today’s advanced engine technology has even further efficiency potential by improving knock limit.

From a Well-to-Wheels standpoint, multiple alternative pathways exist which can support achieving significant CO₂ reduction.

Vehicle efficiency improvements will continue to play an important role, but achieving long-term CO₂ glide path targets will require low-carbon fuels.

Understanding how customers will use vehicles in the future can enable development of products that address societal trends and enhance long-term sustainability.

A collaborative approach among all major stakeholders is required to address overall sustainability goals, both environmental and economic.