Turbocharged Spark Ignited Direct Injection – A Fuel Economy Solution for The US

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- Solid lines: Actual or projected performance due to adopted regulations
- Dotted lines: Proposed standards

The US Diesel Emissions Challenge

- US Emissions standards much more stringent than European
- Transfer of EU diesel to US will be a major challenge due to US NOx Targets

Source: Delphi Worldwide Emissions Standards Passenger Cars and Light Duty Trucks 2008
• Energy density of current fuels hard to beat
• Electric vehicles still limited by battery capacity & cost
• Battery technologies already mature (other applications)
• Bio-fuels attractive if net energy ratio can be maximized

Energy Density of Current & Future Automotive Energy Carriers
## Market & Technology Trends - Gasoline Engines

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<th>Technology</th>
<th>Micro PC Engines &lt; 1,0 l</th>
<th>Small PC Engines 1,0 - 1,5 l</th>
<th>Medium PC Engines 1,5 - 2,4 l</th>
<th>Large PC Engines &gt; 4 cyl</th>
<th>LDT / MDT Truck</th>
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General Market Trends:
- New / current Mainstream:
Turbocharged SIDI
Low End Torque Vs. Mid / High Speed BSFC
Full Load Potential Of Gasoline Engines
Showing The Potential Of Turbocharged SIDI
AVL- Turbo SIDI Demonstrator

Increased full load performance allows longer final drive ratio for improved fuel economy

*Cost per mile comparisons show best & worst case gasoline vs diesel fuel costs US fuel costs Feb '07 – Jul '09. Red bars for average fuel costs in that period.
Ethanol Turbocharged Direct Injection

Lower Heating Value (MJ/kg)

- Regular Gasoline: 42.5
- Ethanol: 26.8

Heat of Evaporation (kJ/MJ)

- Regular Gasoline: 8.0
- Ethanol: 33.8
Ethanol DI Full Load Benefits - E85 vs. 91 RON (regular gasoline)

Source: Ford/AVL DOE Merit Review Presentation May 2009
EBS Dual Fuel Strategy

- E85 provides significant octane benefit with DI due to high latent heat of vaporization and high octane rating
- Allows knock-free operation at high CR and high BMEP with very high thermal efficiency
  - but…
- Low E85 heating value is a disadvantage

- Dual fuel strategy uses E85 DI only as required to eliminate knock in a high CR gasoline engine.
- Combines high load E85 octane benefit with part load gasoline heating value advantage
- Provides maximum leveraging of available ethanol

Source: Ford/AVL DOE Merit Review Presentation May 2009
Dual Fuel E85 DI % sweep, Full Load, 9.3 CR

Source: Ford/AVL DOE Merit Review Presentation May 2009
Cycle Simulation Results
Dual Fuel Optimized E85 Engine vs. Competitors
Medium Duty Truck

Metro Highway Fuel Economy Improvement (%)

Max Grade in 6th Gear at 65 mph (%)

Heating Value Disadvantage

Downsizing/Downspeeding Benefit

+3 Compression Ratio Increase, Advanced Combustion Phasing Benefits
Gasoline Displaced By E85 At High Load

+ 530 mpg E85
+ 860 mpg Urea

Source: Ford/AVL DOE Merit Review Presentation May 2009
Summary

- Future fuel economy improvements will come from a variety of technologies
- Gasoline engines will be the dominant US powertrain for the foreseeable future
- Turbocharged SIDI is the most promising advanced gasoline technology:
  - Combines existing & proven technologies in a synergistic manner
  - Offers double digit fuel economy benefits
  - Much lower cost than diesel or hybrid
  - Can meet future emissions standards with inexpensive gasoline aftertreatment
  - Can be applied across an OEM’s entire engine portfolio in high volume
  - Provides benefits when operating on E85 in Flex Fuel applications
  - Dual fuel (PFI gas + DI ethanol) concept new benchmark for SI fuel economy