Low Emissions Diesel Engines from International
Our Approach for Modern Transportation and Environmental Benefits

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International’s legacy

• Major diesel engine manufacturer
• Main product focus: medium displacement (6-10 l)
• Currently expanding product line
  Small displacement  HS  2.5 l; 2.8 l
  NGD 3l
  Medium displacement  V6 4.5 l; V8 6.0 l
  I 6  7.6 l; 9.3 l
  Large displacement  11 l -13 l
International’s Commitment to Low Emission Diesels

- In 1989 demonstrated 1994 Compliant Smokeless Diesel
- In 1996 demonstrated 2004 Compliant Diesel

- In 1999 demonstrated Green Diesel School Bus with lower PM and HC emissions than CNG

- In 2001 certified GDT Diesel Engine at 2010 PM and HC levels

- In 2003 made technology path decisions for 2007
Progress In Reducing HD Truck PM Emissions

Year | Particulates (g/bhp-hr)
--- | ---
1988 | 1.0
1991 | 0.6
1994 | 0.4
Urban Bus 1996 | 0.2
2007 | 0.0
Progress In Reducing HD Truck NOx Emissions

Industry Reductions

<table>
<thead>
<tr>
<th>Model Year</th>
<th>NOx (g/bhp-hr)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>15 NOx</td>
<td>BASE</td>
</tr>
<tr>
<td>1990</td>
<td>6 NOx</td>
<td>60%</td>
</tr>
<tr>
<td>1991</td>
<td>5 NOx</td>
<td>67%</td>
</tr>
<tr>
<td>1998</td>
<td>4 NOx</td>
<td>73%</td>
</tr>
<tr>
<td>2004</td>
<td>2 NOx</td>
<td>87%</td>
</tr>
<tr>
<td>2007</td>
<td>0.2 NOx</td>
<td>99%</td>
</tr>
</tbody>
</table>
Diesel Technology: An Evolutionary Path to Near Zero Emissions

- 2002
  - Advanced Injection System
  - Advanced Turbocharging
  - Advanced Combustion
  - Advanced Electronics
  - Particulate Filter

- 2004
  - 4 Valve Head
  - Vertical Injector
  - G2 Injection System
    - Electronic Pilot
    - Electronic Trim
    - Higher Peak Pressure
  - Advanced Turbo
  - Cooled EGR
  - Oxidation Catalyst

- 2007
  - Advanced NOx Adsorber
  - Advanced Particulate Trap

- 2010
  - Advanced NOx Adsorber
  - Advanced Particulate Trap
Current Technology Path

The 2004 emission standards were pulled ahead in October 2002

- Additional stringencies
  - Compliance ranges widened
  - NTE limits (flatter emission maps)

- Preferred technology includes use of EGR and continued enhancements of basic combustion processes
Challenges Ahead – 2007 Standards

• Significant emission reduction (NOx and PM)
• Requires System Approach
  – Engine/ exhaust system/ fuel
• Use of 2007 technology requires ultra-low-sulfur fuel
Challenges Ahead – 2007 Standards

• Approach: EGR, DPF, DOC
• Technology can be applied to all engines:
  – Heavy-duty trucks, buses
  – Light-duty vehicles
• 2007 technology is an evolution of the 2004 technology
• Some 2007 technology is available today
Fuel Issues-Commercial Transportation

• Fuel issues - global economy implications
  – New technology introduction worldwide
  - Globalization of environmental emission standards
  - Fuel characteristics harmonization

• World Wide Fuel Charter- a framework for fuel evolution and harmonization; developed jointly by:
  – Alliance, EMA
  – ACEA
  – JAMA
World Wide Fuel Charter

• Recognizes technological differences worldwide
  – Four categories of diesel fuels: I;II;III;IV

• Provides a road map for strategic fuel development
  – (critical elements)
    • Sulfur, cetane number, alternative blends

• It is a living document; it faces challenges
Diesel Fuel Quality - What have we achieved?

- **ULSF** - the “technology enabler” for 2007 emission standards – on its way!
  - By June 2006, over 80% of on-road diesel fuel will have less than 15 ppm Sulfur!
  - By 2010, all on-road diesel fuel will be ULS
  - In 2010-2014, off-road diesel fuel will be ULS

- Performance of catalytic systems will be maximized (new technology)

- Particulate reduction benefits for all vehicles (new and old)
Lubricity?

• Lubricity has become a requirement for diesel fuel (included in standard)
• Is the current specification good enough for 2007 Advanced Fuel Injection System?
• Will ULSF have adequate lubricity?
  – Some concerns with early ULSF in the market
Trend of Diesel Fuel Lubricity

Source: Infineum Worldwide Winter Diesel Fuel Quality Survey 2002
Diesel Fuel Quality- Where do we fall short?

• Performance and Sociability Characteristics of Diesel Engine:
  – ease of start; noise,
  – white smoke; odor

• Influenced by diesel fuel properties:
  – Cetane Number
  – Low Temperature Operability

• Affect all diesels but especially, buses, diesel cars, pickup trucks, SUVs
Cetane Number- CN

• ASTM D 975 specifies CN of 40 min.
• This value has not changed since first standard issue!
• Diesel engine technology has changed!
• Market surveys show that average CN is higher!
• Isn’t it time to change CN?
Worldwide Trend of Cetane Number

Average Cetane Number Split by Region

Source: Infineum Worldwide Winter Diesel Fuel Quality Survey 2002
Premium Diesel Fuel

  – Cetane Number (47 minimum)
  – Low Temperature Operability
  – Thermal Stability
  – Lubricity (520 HFRR)
• This specification would give customers a choice for a better diesel fuel
• Would enhance the performance of new diesel vehicles in the market and demonstrate the real potential of advanced diesel technology.
Other Diesel Fuel Issues

• Low temperature operability

• Stability (as sulfur is removed)

• Energy content

• Cleanliness (water and impurities)
Lubricants Issues

• New generation of lubricants - PC-10 Category is under very active development in US
  – Compatible with the 2007 engine technology

• Industry-wide effort that includes:
  – Trade associations
  – Independent test laboratories
  – Corporate laboratories

• Complex process development with large participation, cost sharing and aggressive test schedule, to provide timely introduction of PC-10 lubricants by mid-2006
Lubricants Issues-(cont’d)

• **Challenges:**
  – Provide equal or better performance of oils, while protecting after treatment systems
  – Maintain or improve oil drain intervals

• **Chemical limits for :**
  – Sulfated ash (1.0% max)
  – Phosphorus (0.12% max)
  – Sulfur (0.4% max)

• **Development of new additives**
Alternative Fuels

• Biodiesel
• Natural Gas
• Synthetic Diesel (FT fuel/GTL fuel)
• Alcohols (methanol, ethanol)
• Dimethylether (DME)
• Blends (diesel/water, diesel/alcohol)
Alternative Fuels - Relevance

• Driving forces
  – Lower emissions (some pollutants)
  – Domestic resources, less dependence on imports
  – Long term potential when crude oil is depleted
Alternative Fuels- Challenges

- Availability,
- Infrastructure
- Technology maturity
- Cost
- Fuel quality, specifications
- Emissions?
Future Engines; their Fuel Requirements

- Hybrid (IC/Electric) powertrain
  - Increased performance and efficiency
  - Lower emissions
  - Same fuel requirements

- Hybrid combustion (HCCI)
  - Fuel Characteristics?

- Fuel Cells
  - Hydrogen fuel energy system
    - Fuel production and distribution
    - On-board storage
    - Fuel usage (engines, cells, etc.)
    - Applications
Conclusions

• Fuels and compatible lubricants are an “enabling technology” for the development of low emissions engines:
  (both traditional and new concepts)
Conclusions

• Fuels and lubricants formulations will maximize the potential of high performance engines with benefits in:
  – Environmental impact (emissions and greenhouse gases)
  – Fuel efficiency (better use of resources)
  – Customer acceptance

• The conventional fuels will continue to support transportation (as long as they can be produced economically from existing resources)
Low-Emitting Diesel Engines from International

- Equivalent or better emissions than gasoline or alternative fuels
- Still more fuel efficient with lower greenhouse gas emissions
- Performance and reliability that customers depend on
Conclusion

• Diesels from International will continue to be an environmental solution

• 2007 diesels will change the way people see diesel engines