High Efficiency IC Engines – The Road Ahead

2009 ERC Symposium
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11 June 2009, University of Wisconsin - Madison
The road will be bumpy!

- Economic volatility
  - Exchange rates
  - Commodity prices
  - Energy costs
- Sector damage
  - Supply chain severely damaged by downturn
  - Restricted capital flows
- Disruptive technologies
  - Green technologies
  - Electrification
- Product uncertainty
  - Rapidly shifting consumer preferences
  - Evolving federal and state regulations
Government policy and customer preference can be conflicting drivers of change – both are impacted by changing economics.

Drivers are hard to predict:
- Surveys & market research do not always reflect what legislators and customers actually do.
- Economic shifts such as oil price can rapidly change consumer behavior and policy.
- There are significant regional variations.

Source: Ricardo Strategic Consulting
Growing disconnect between development and market cycle times, adds risk to new vehicle development costs

**Automotive Development is a High Investment and Long Lead Time**

- Average program cost
  - MY Update (~5% of content): ~$10M
  - Mid-Cycle Enhancement/Minor Upgrade (~20%): ~$120M
  - Major Upgrade (~50%): ~$200M
  - New Vehicle (~90%): $500M+

- Average Development time
  - Model Year Update: 9 to 12 months
  - Mid-Cycle Enhancement/Minor Upgrade: 12 to 18 months
  - Major Upgrade: 18 to 24 months
  - New Vehicle: 36 to 60 months

**In 2008 10.8 M vehicles were recalled at a cost of $24B**

**Shifts in Market Drivers Can Occur Very Quickly!**

**Average Crude Oil Price/Barrel (2001–present)**

During development, oil price/barrel went from $40 to $140, and back to $36!

Source: Warranty Week, Autoloan Daily, Japan Times, EIA, Ricardo Analysis
Powertrain improvements generally most cost-effective

- Cost of weight reduction higher than powertrain improvements for a given vehicle
- Improvements in gasoline technology will close gap with diesel
- Most hybrid systems are still expensive

**Cost/Benefit Ratio for CO₂ Reduction**

- Powertrain
- Other Improvements
- Weight Reduction

**Cost vs. CO₂ Reduction for Powertrain Technologies**

- Hybrid
- Diesel
- Improved Gasoline

Source: Ricardo Internal data
Powertrain Technologies for Efficiency (a subset)

- Full hybrid (+30% DS)
- Full hybrid
- Mild hybrid (+20% DS)
- Mild hybrid (42v no DS)
- Micro hybrid (12V BSG)
- Stop-start
- Diesel (E6)
- Diesel (E5) w/DPF
- Diesel (E4) no DPF
- US Diesel
- Lean Boosted DI
- US Diesel
- Boosted DI
- Homo DI + Variable Valve
- Micro Hybrid (12V BSG)
- Twin Phaser VVT
- Stop-start
- Gasoline (E4/E5)

CO₂ Improvement over Base Gasoline Engine vs Cost Increase over Base Gasoline Engine

Reduce Engine Out NOx & Aftertreatment
No one winning technology to address future EU and US fuel economy/CO₂ regulations – plus market diversity

Ricardo 2020 Studies – Conclusions

- **Dieselisation**
  - Requires market penetration of >70%
  - Requires >40% vehicles with hybrid functionality in addition to 38% stop / start systems
  - Lower impact due to greater penetration of diesel in EU

- **Hybridisation**
  - Requires market penetration of >60% – 600 times more than 2007(!)
  - Requires ~85% of vehicles with hybrid functionality
  - Requires ~70% of market 2nd generation advanced gasoline

- **Advanced Gasoline**
  - Persuading 20% of consumers to d'size → 1% reduction in fleet average CO₂
  - Persuading 50% of consumers to d’size → 3.4% reduction in fleet average CO₂

- **Customer Vehicle Segment Downsizing**
  - Persuading 20% of consumers to d’size → 1.8% FE improvement
  - Persuading 50% of consumers to d'size → 4.5% FE improvement

**No single solution is able to achieve either EU or US targets – combined utilisation of multiple technologies required**

Source: Ricardo Analysis, Department for Transport, NHTSA
What technologies would be required to improved the US LD fleet fuel consumption by 35%?

- A system optimization approach is necessary
- The optimum cost/benefit solution is application specific

Costs will be staggering!
The Road Ahead

SHORT TERM: ~2015
Evolution of ICE

- Good news – improved current Internal Combustion Engine technology will offer “best value” solutions
- New alternatives will enter the mix as an impact of regulation

MEDIUM TERM: ~2025
Electrification & Bio Fuels

- Technology will be more diverse to satisfy sector- & region-specific applications, but evolved current technology will still play a strong role
- Conventional energy chain will be supplemented by Bio fuels and Electricity

LONG TERM: ~2050
New Energy Vectors

- New energy vectors drive the need for new powertrain technologies
- Roles for Electricity (and Hydrogen) alongside sustainable Liquid fuels

The internal combustion engine will be with us for a long time!