High Efficiency IC Engines – The Road Ahead

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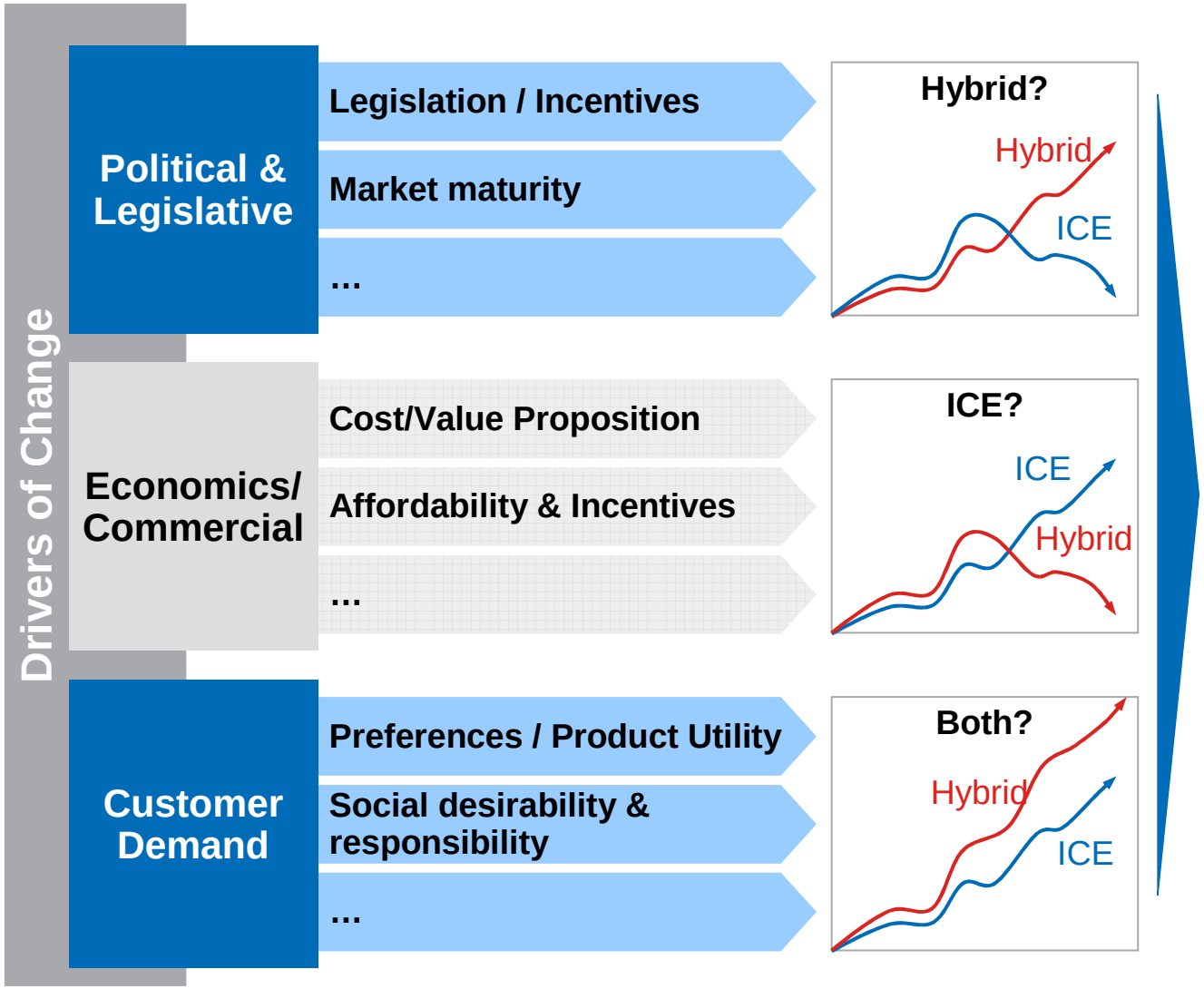
The road will be bumpy!

- 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



ILLUSTRATIVE

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

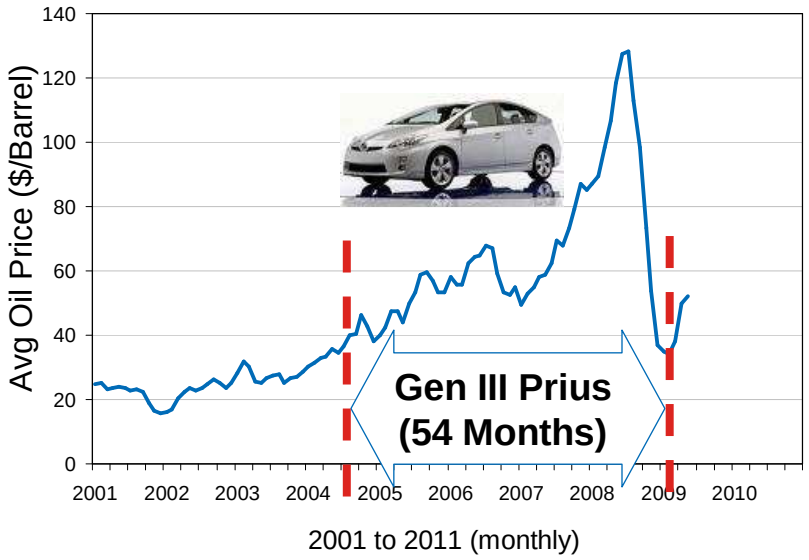
Automotive Development is a High Investment and Long Lead Time

- 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)

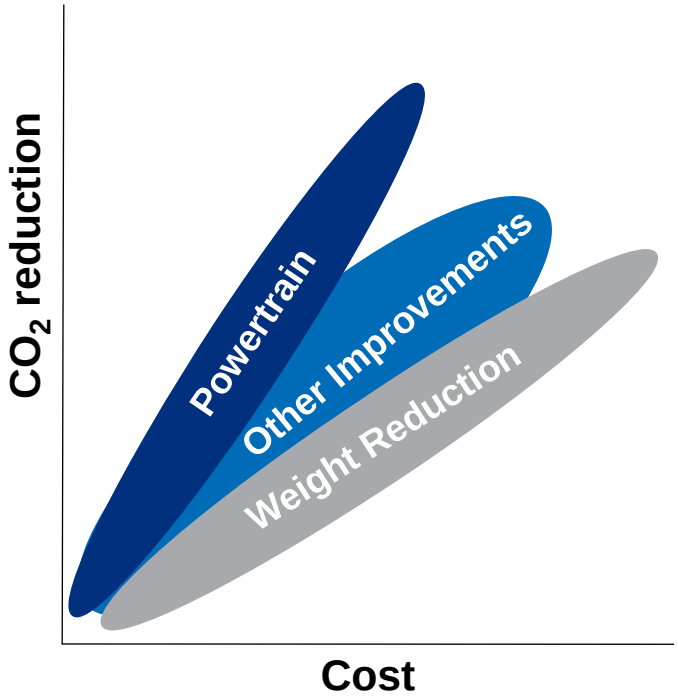


During development, oil price/barrel went from $40 to $140, and back to $36!

Source: Warranty Week, Autoloan Daily, Japan Times, EIA, Ricardo Analysis

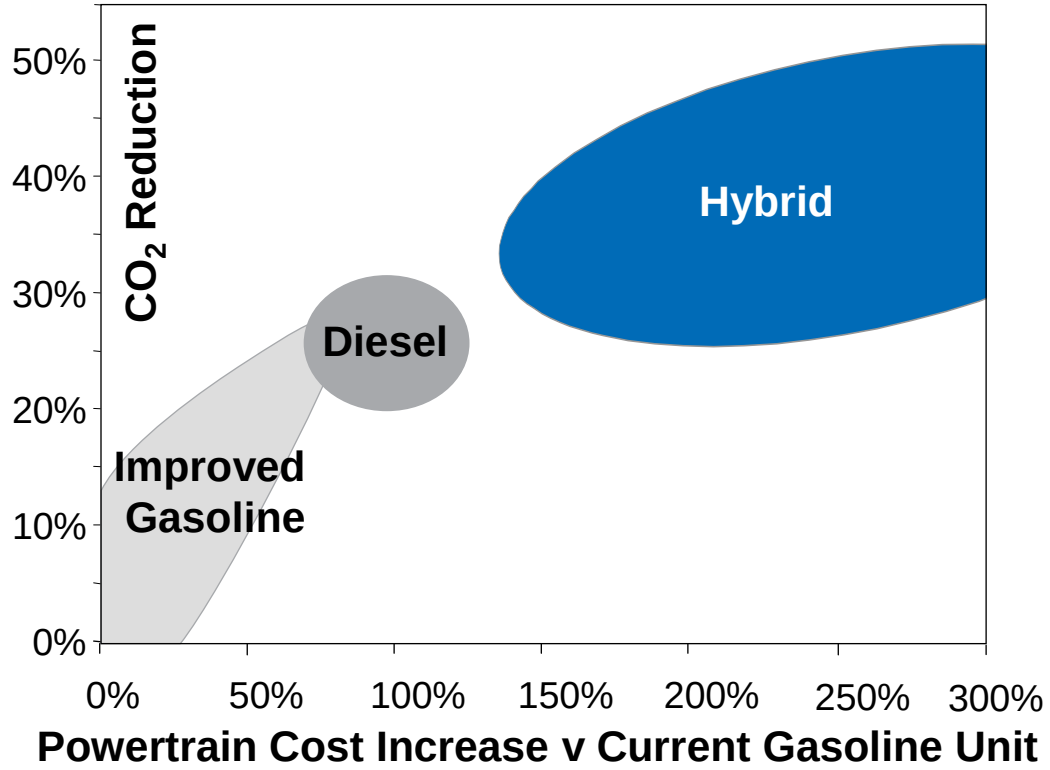
Powertrain improvements generally most cost-effective

Cost/Benefit Ratio for CO_2 Reduction



- Cost of weight reduction higher than powertrain improvements for a given vehicle

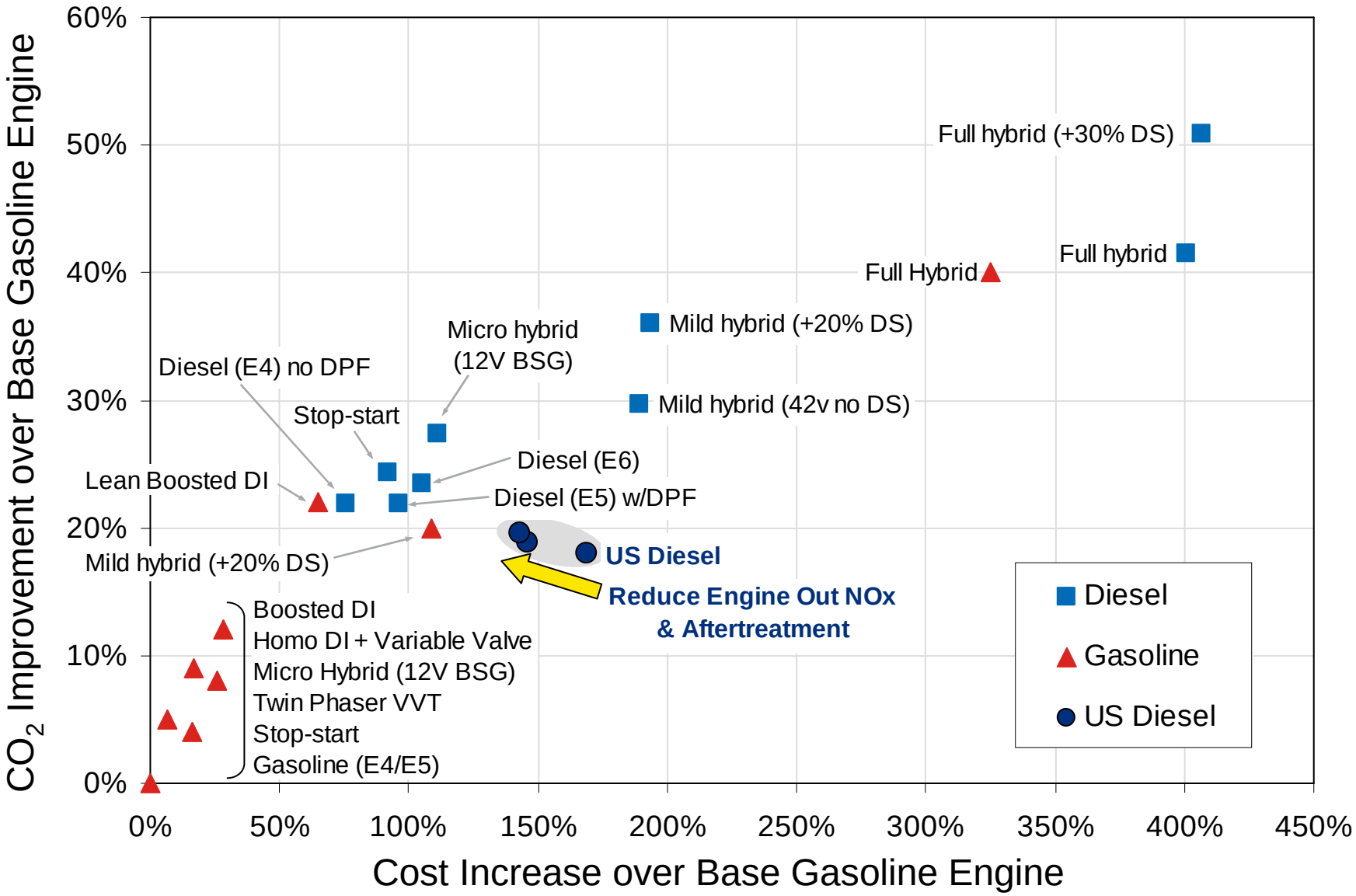
Cost vs. CO_2 Reduction for Powertrain Technologies



- Improvements in gasoline technology will close gap with diesel
- Most hybrid systems are still expensive

Source: Ricardo Internal data

Powertrain Technologies for Efficiency (a subset)



No one winning technology to address future EU and US fuel economy/CO_2 regulations – plus market diversity

Ricardo 2020 Studies – Conclusions

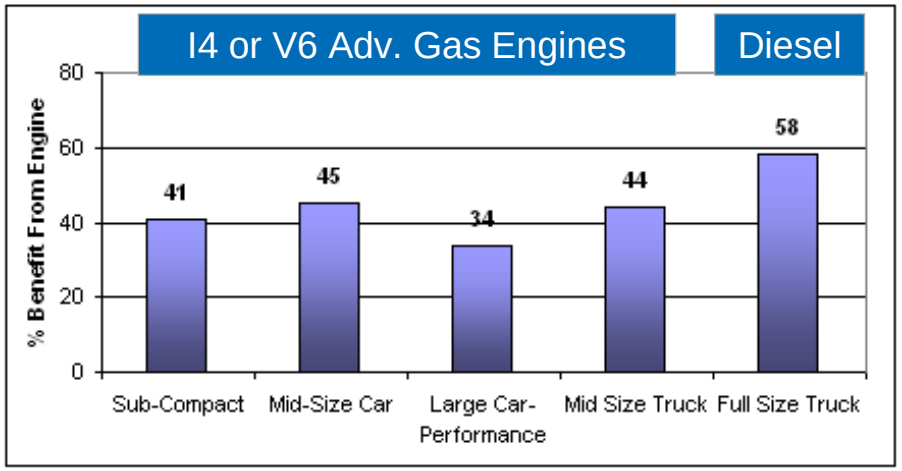
Dieselisation	• Requires market penetration of >70%	• Requires market penetration of >60% – 600 times more than 2007(!)
Hybridisation	• Requires >40% vehicles with hybrid functionality in addition to 38% stop / start systems	• Requires ~85% of vehicles with hybrid functionality
Advanced Gasoline	• Lower impact due to greater penetration of diesel in EU	• Requires ~70% of market 2nd generation advanced gasoline
Customer Vehicle Segment Downsizing	• Persuading 20% of consumers to d'size → 1% reduction in fleet average CO_2 • Persuading 50% of consumers to d'size → 3.4% reduction in fleet average CO_2	• Persuading 20% of consumers to d'size → 1.8% FE improvement • Persuading 50% of consumers to d'size → 4.5% FE improvement

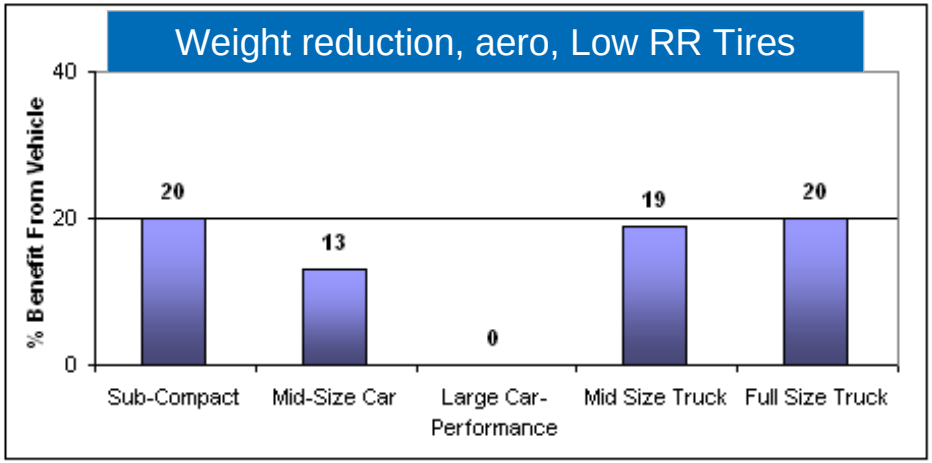
No single solution is able to achieve either EU or US targets – combined utilisation of multiple technologies required

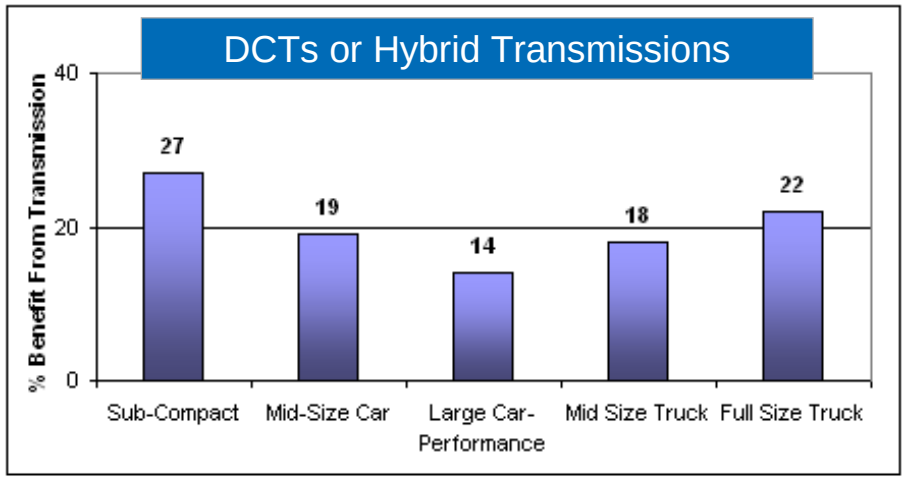
Source: Ricardo Analysis, Department for Transport, NHTSA

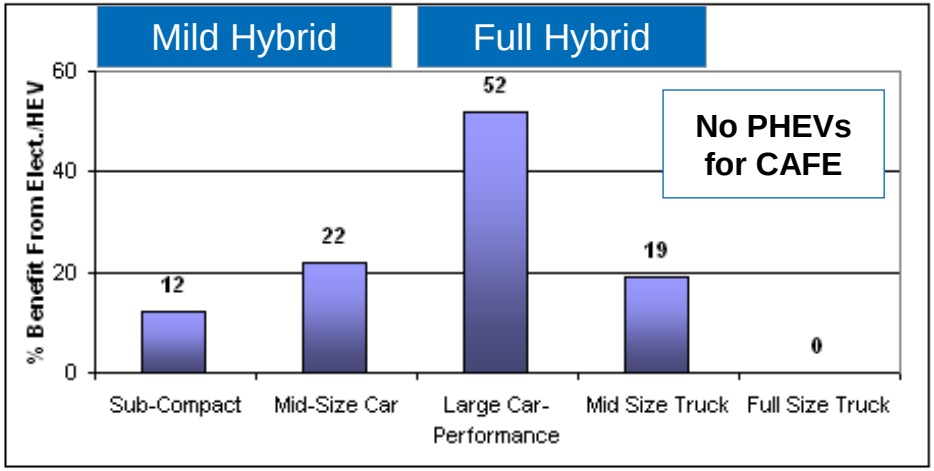
What technologies would be required to improved the US LD fleet fuel consumption by 35%?

(tvfe) Total Vehicle Fuel Economy™









- 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!

Source: Ricardo Technology Roadmaps, Ricardo Analysis