New Directions in Engines – The Road Ahead

2009 DEER Conference
Aug 4, 2009

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The road ahead
… and some nagging questions

What happened to the widespread introduction of light duty diesel for the US market?

Not a purely technical question

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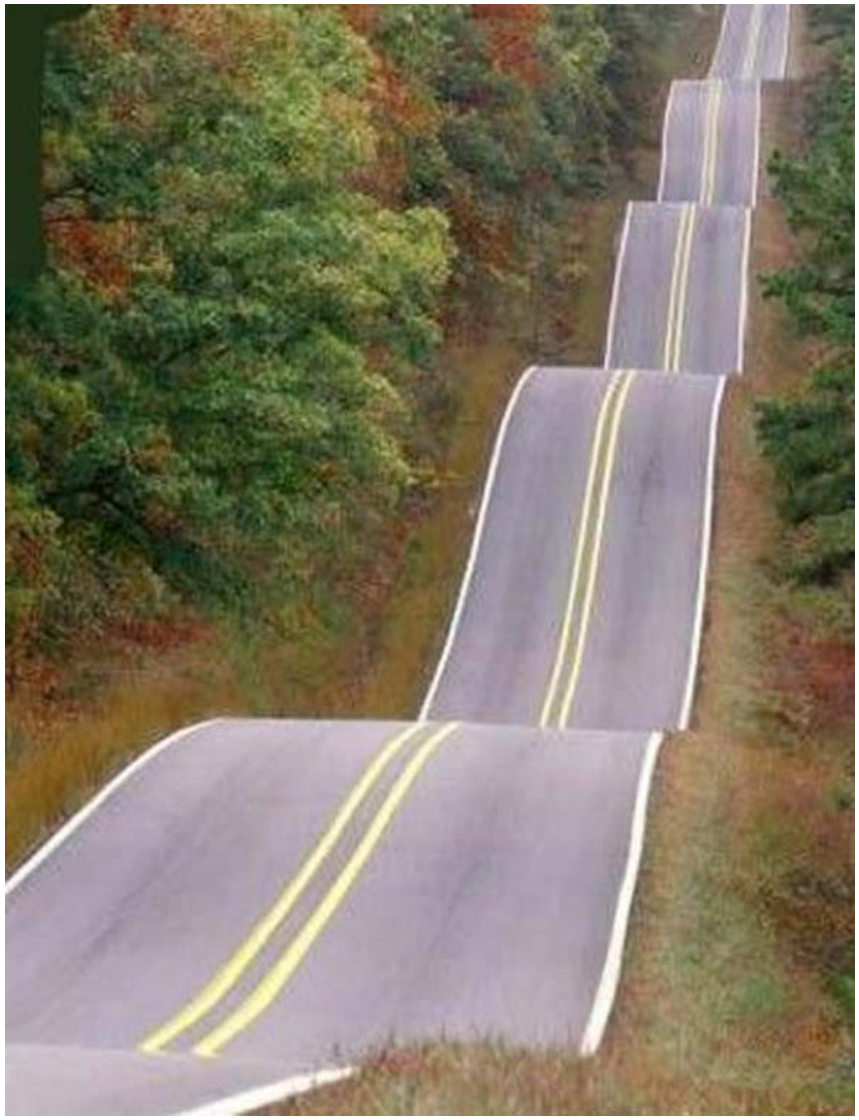
The road has been and will continue to be bumpy!
Factors shaping investments

- Economic volatility
  - Exchange rates
  - Commodity prices
    (Oil Price: *$40 → $140 → $36 in 5 yrs.)*
  - Energy costs
- Sector damage
  - Supply chain damaged by downturn
  - Restricted capital flows
- Disruptive technologies
  - Green technologies
  - Electrification
- Product uncertainty
  - Rapidly shifting consumer preferences
  - Evolving federal and state regulations



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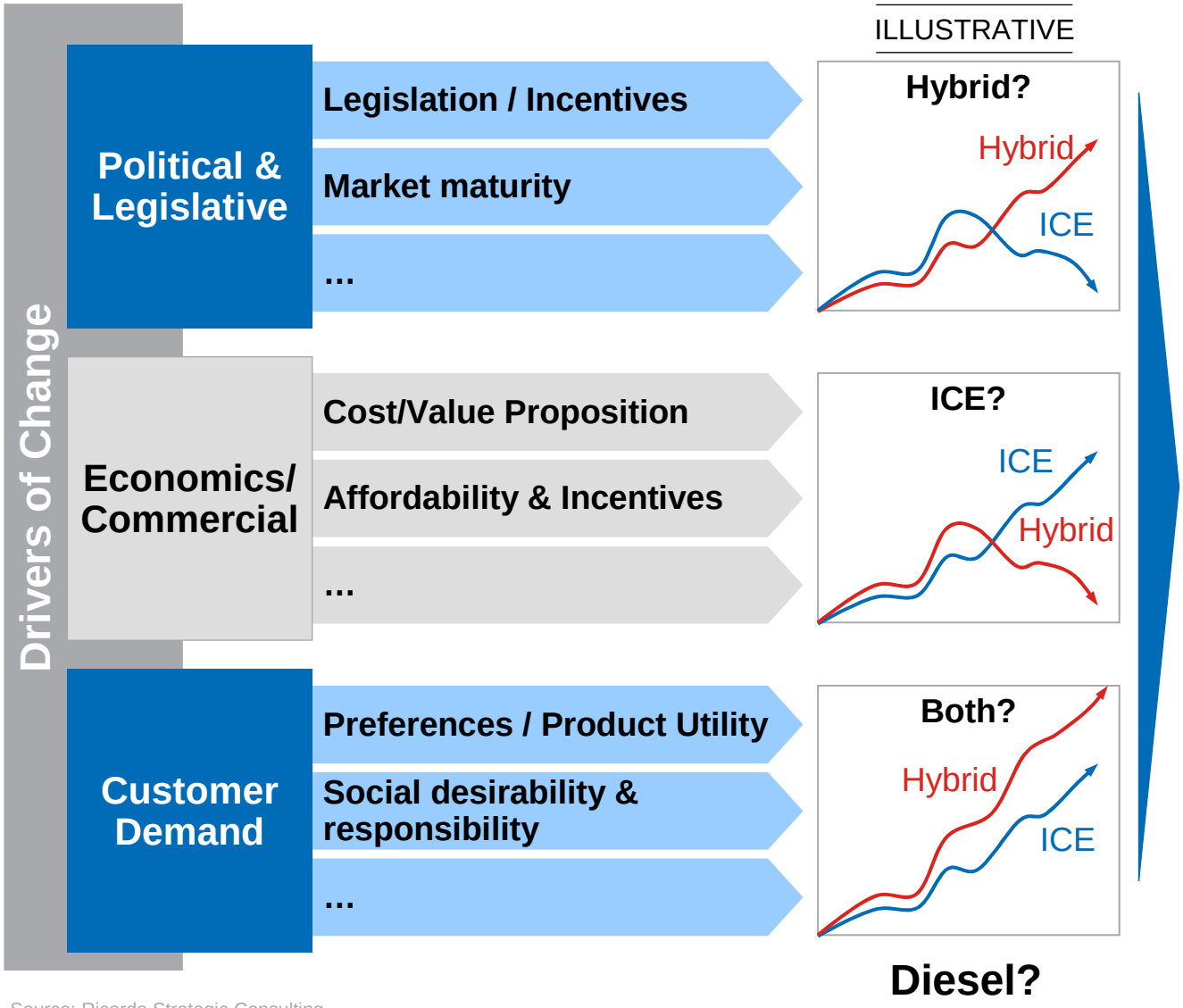
Government policy and customer preference can be conflicting drivers of change – both are impacted by changing economics

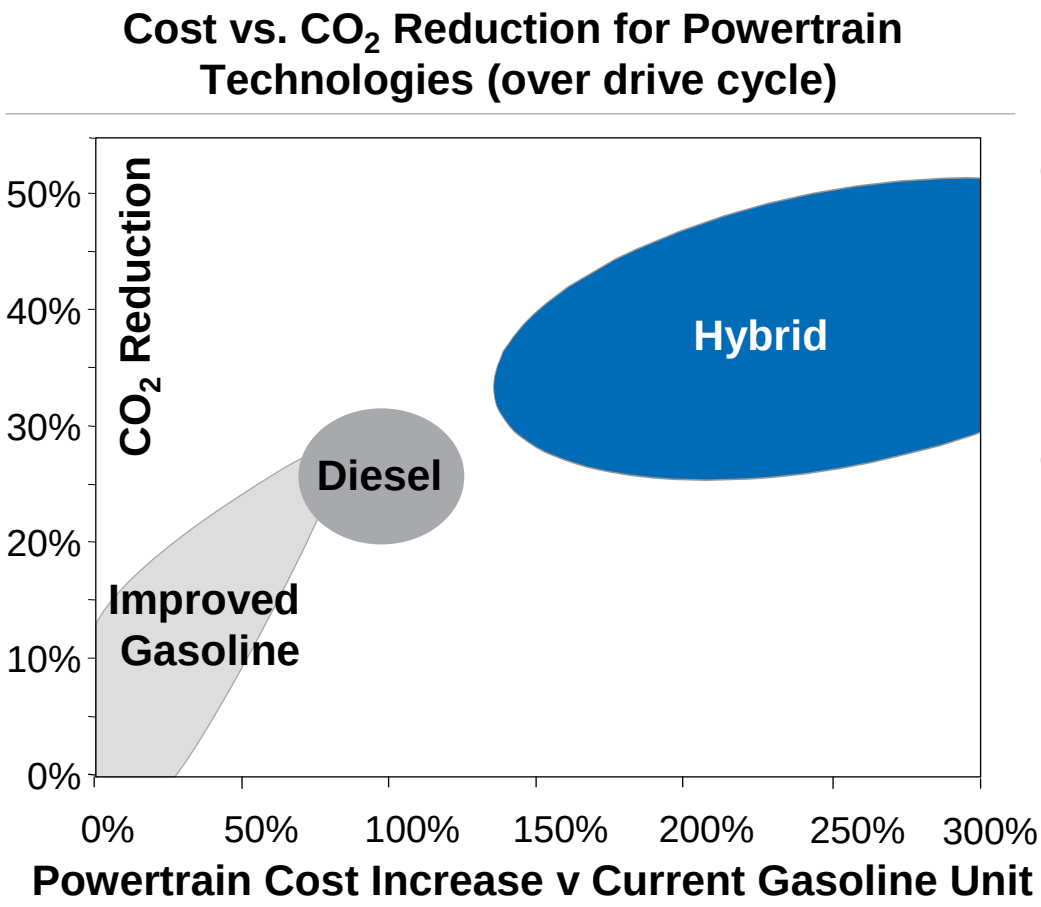


Drivers are hard to predict:

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

Source: Ricardo Strategic Consulting

Piece cost: tough love for our favorite technologies



- Improvements in gasoline technology are closing the gap with today's US light-duty diesel*
- Aside: Gaps remain in what will be economically achievable with today's hybrid technology

Stay tuned …lots of innovation is just around the corner

* Real world fuel economy of diesels can be significantly better for highway or towing applications

Source: Ricardo Internal data

Looking to the medium and heavy duty world

- Diesel engines will remain the power-plant of choice for most applications
  - Technology advances will continue to reduce the impact of emissions compliance
  - Efficiency will continue to rise as combustion and waste energy recovery technology improves
- However, advanced spark-ignited engines have the potential to penetrate selected medium-duty commercial truck and off-road segments, including agricultural and construction vehicles
  - Cost sensitive applications
  - Packaging constrained applications
  - Lightly loaded, low usage applications

Both diesel and gasoline powerplants are evolving rapidly

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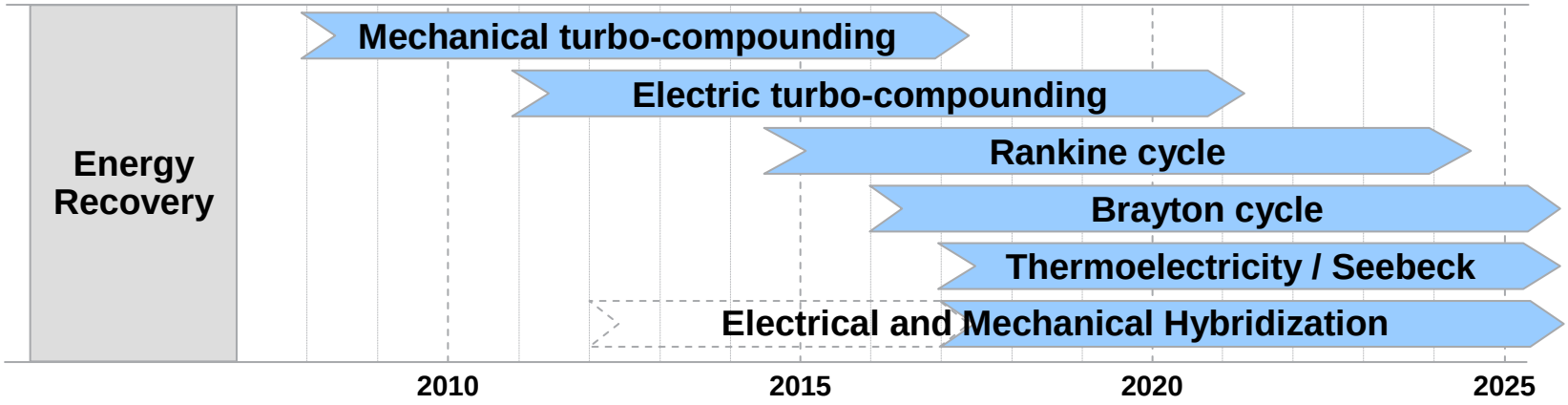
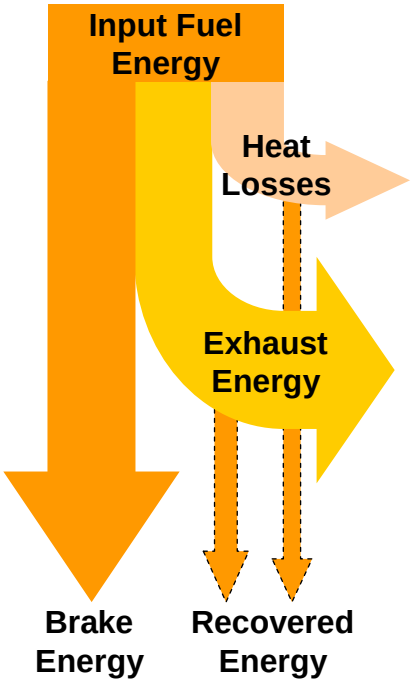
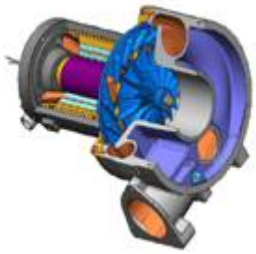
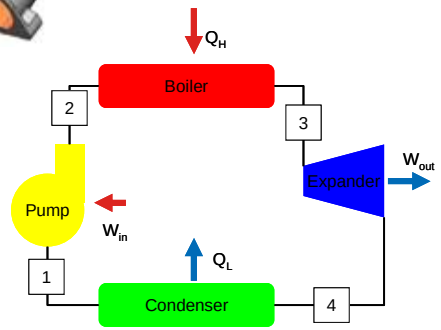
Waste heat recovery for heavy duty applications









Low efficiencies on large heat sources = big savings (6 - 8%)

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The road ahead

SHORT TERM: ~2015

Evolution of ICE

- Improved ICE technology will offers the “best value” solutions
- ICEs will undergo significant evolution
- New alternatives will enter the mix as an impact of regulation

MEDIUM TERM: ~2025

Bio Fuels & Electrification

- Technology will be more diverse to satisfy sector- & region-specific needs
- Evolved ICE technology will continue to offer “best value” solutions
- 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

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