(tvfe) Total Vehicle Fuel Economy™

A Systems Approach to Light Duty Vehicle Technologies

ARB Symposium Presentation

Presentation Date: April 21st, 2008

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We all share the goal of maximizing fuel economy and emissions of transportation vehicles

Case Study: EPA CO_2 Impact Study

Program Objectives

- Ricardo work commissioned by the EPA to support future Vehicle GHG Rulemaking
- EPA's desired outcomes:
  - Provide a Peer-Reviewed report that characterizes individual and combined vehicle technology efficiency improvement potentials
  - Use a robust, science-based "full vehicle simulation" analysis to characterize consequences of combining multiple technologies for efficiency gains

Program Approach

- Physical model of total vehicle to accurately simulate EPA specified packages
- Used millisecond-millisecond simulation that satisfies an energy balance and included performance
- Provided accurate input data from our proprietary database and subject matter experts which were peer reviewed by EPA
- Total vehicle system analysis -- ensured compatibility of technologies in a package

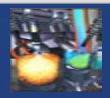
Results and Benefits

- Full vehicle simulation analysis to characterize impacts of 26 technology packages on CO2 and performance estimated for 5 different vehicle classes including
  - How individual technologies and their combinations provide different levels of vehicle efficiency improvement in different vehicle classes
  - Impact of synergies vs. One at a time technologies
- Final report has been issued to the EPA and into the public domain

Total Vehicle Fuel Economy Process

Vehicle Systems Approach

Propulsion System | Ancillaries | Drivetrain | Rolling Resistance | Aero Drag



Scientific Simulation Methodologies

Fuel Economy (MPG)

Vehicle Speed (MPH)

Ricardo was selected because it is one of the world's leading transportation engineering & management consulting firms – with total vehicle and PT capability

Value-Adding Capabilities

- Product Engineering
  - Engine (Gas & Diesel)
  - Transmission & Driveline
  - Controls and Electronics
  - Vehicle Engineering
- Niche Manufacturing
- Strategic Consulting

International Presence

Success Indicators

- Independent and long established (1908)
- Analysis foundation approach
- Core competence in turn-key program delivery
- Significant Investment in people and advanced technology
- Global critical mass with 1800 people and $320 million revenue

Global Client Base

Ricardo has developed a total vehicle fuel economy simulation model that enables full vehicle attribute trade-off's to be assessed

Engine

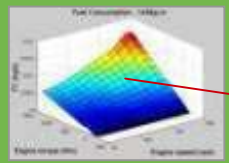
Friction

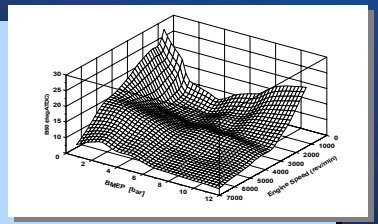
- Crankshaft Friction
- Balancer Drive Friction
- Power Cell Friction
- Camshaft Friction
- Valve train Friction
- Front End Drive Friction
- Oil Pump Friction
- Water Pump Friction
- Accessory Drive Friction
- Other Technology Effects

FAST
Databases
Papers
RS Valdyn, etc…

BSFC maps

Databases
I4, V6, V8, etc…
Diverse fuel,
NA, Turbo

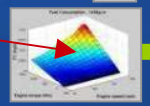




Technology Modifier maps

Coefficient maps to apply to base BSFC map or additional maps to integrate advance technology:
VVT, VVA, Turbocompound, etc…
Database, Papers, WAVE

Look Up Map [FEAD, etc…]



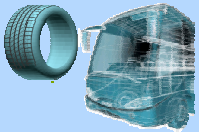
Custom Fuel Maps

Transmission

- Type of gears
- Number/type of seals
- Number/type of bearings
- Number/type of clutches
- Wet/Dry Sump, etc…

Excel/Test:
- MT
- AT
- CVT
- DCT
- etc T…

EASY5 PARAMETERS



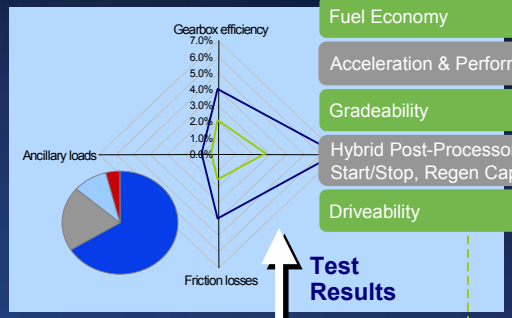
Vehicle

- Tire / Rolling Resistance
- Drag Reduction
- Cooling System
- Interior Feature
- Exterior Features, etc…

Database
Simulation [AMESim, Flowmaster]
Papers

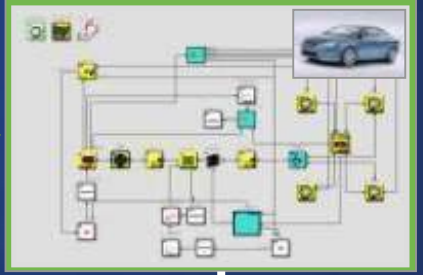
Trade Off Analysis

- Fuel Economy
- Acceleration & Performance
- Gradeability
- Hybrid Post-Processor Start/Stop, Regen Capacity…
- Driveability

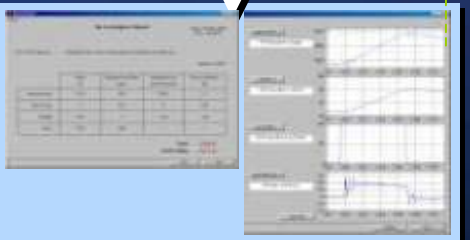


Test Results

Core Vehicle Model

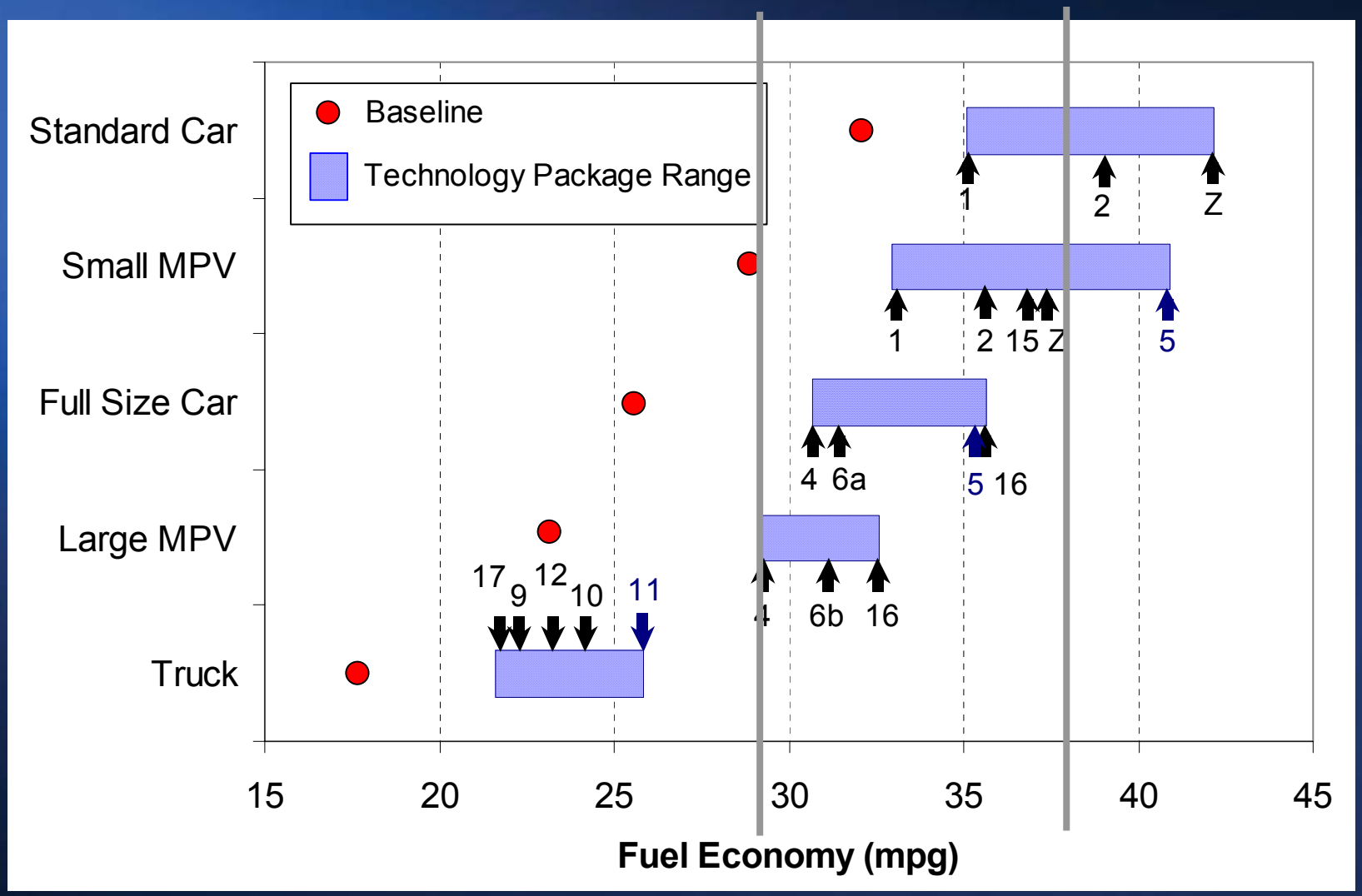


Test Results



Driveability Assessment and Rating Tool

Fuel Economy ranges of high readiness (0-5yr) technology packages



- Report shows that up to 27% ("car") - 34% ("truck") fuel economy improvement is possible using this subset of "conventional" or "nearer-term" technologies, without altering weight

Recommendations for further study

- Study CAFE impact with more/ different vehicle classifications
- Evaluate more technologies, particularly Hybrids and emerging Tier 1 technologies
- Define and evaluate weight saving technologies and weight impact of PT technologies
- Critically examine non-powertrain assumptions (aero, rolling resistance, friction)
- Simulate Performance vs Fuel Economy tradeoffs
- Integrated cost and technology impact study

Report available on www.totalvehiclefueleconomy.com

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Where does the remaining 25% come from? Fuel economy improvements must be accomplished with minimum tradeoffs

Consumer

+ Purchase Drivers

Environment

+ Energy Security

- CO2

+ MPG

- No silver bullet
- Multiple technologies
- OEMs have limited capital & engineering resources

- Achieving maximum fuel efficiency at minimum cost requires a holistic, total vehicle approach including all powertrain and vehicle systems

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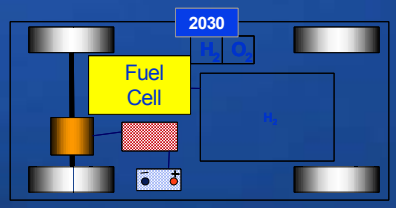
Ricardo's R&D portfolio is focused on advanced technology for fuel economy, emissions & vehicle electrification

Technology Portfolio	Example Ricardo Solutions
Hybrids & Fuel Cells	
Advanced Gasoline Engines	
Clean Diesels	
Efficient Transmissions	
Controls and Electronics	
Alternative Fuels	

Pass Car T2B2 Diesel Adv Tech Demo Vehicle

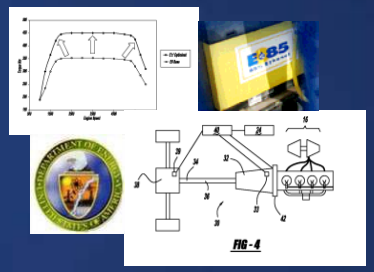
2-Stroke/ 4-Stroke Engine

Ethanol Boosted DI Engine "EBDI"



Hydrogen-Powered Vehicle Concept

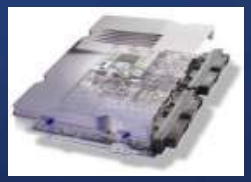
Torque Vectoring - Active Steer with Safety Critical Software



Optimized E85 Powertrain

Hybrid Transmission Design

Vehicle-to-Vehicle or Infrastructure Communication



Advanced electronic controllers

WAVE-RT for Full Model Based Control in ECU

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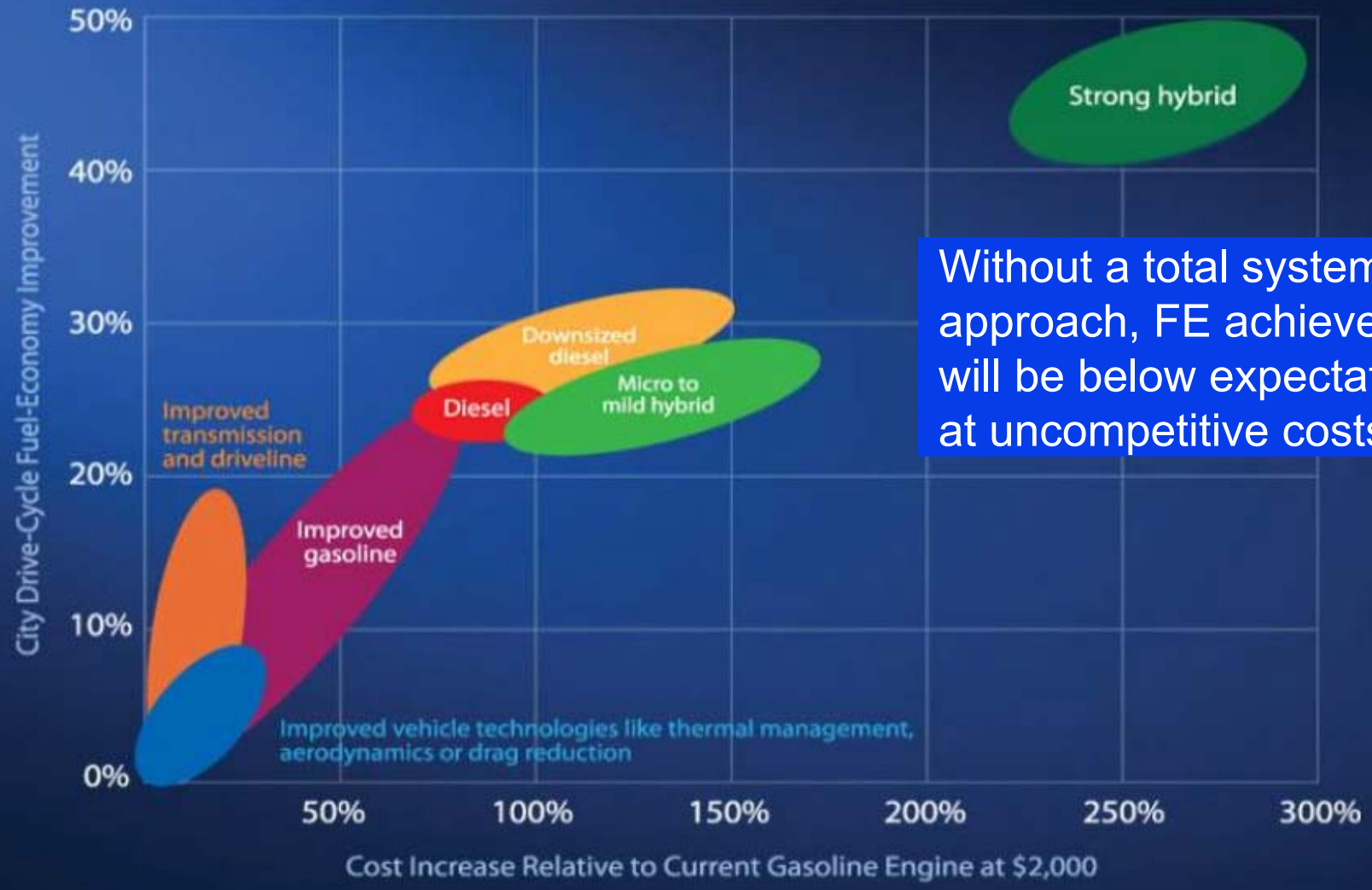
The Key Question:

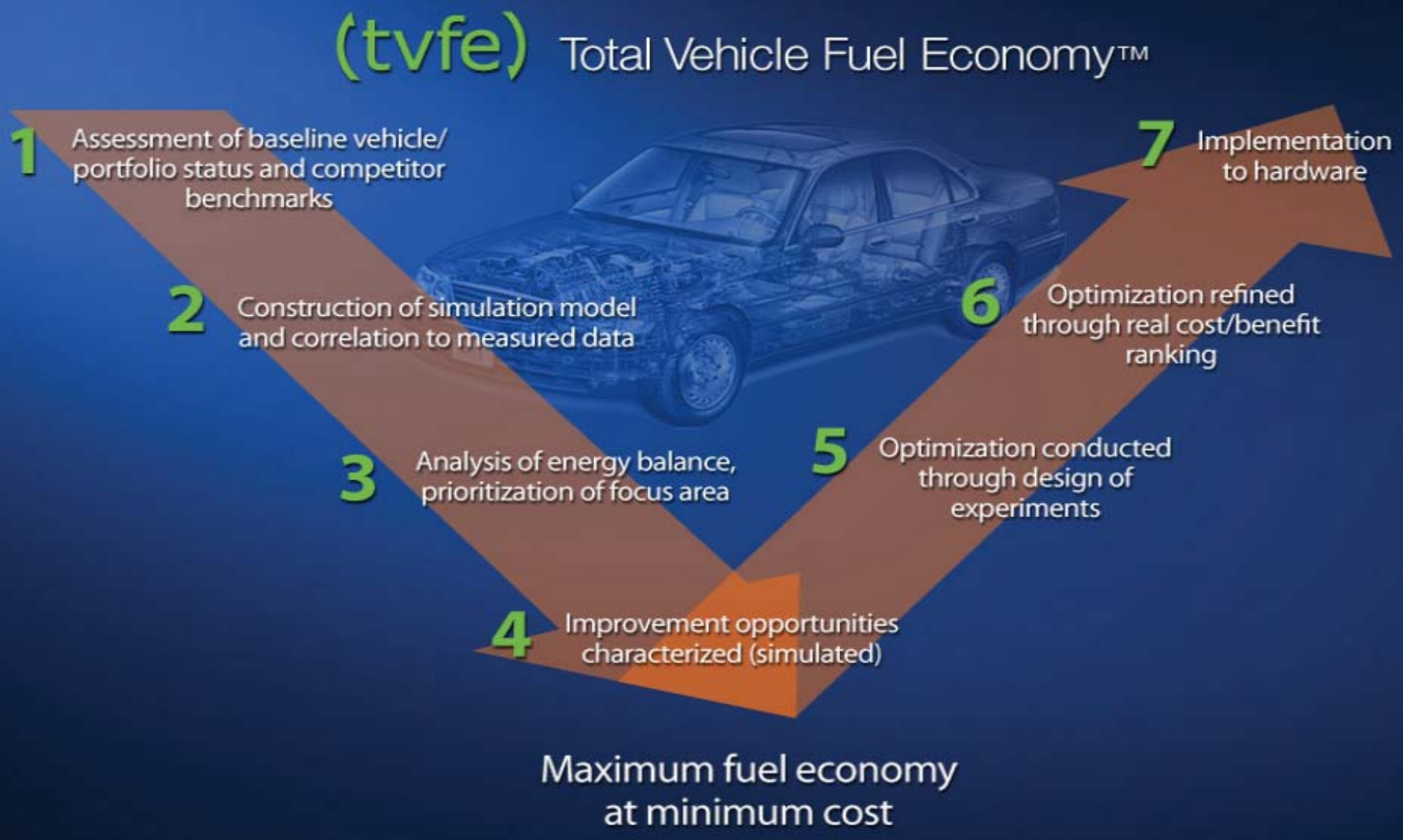
How will you implement the right combinations of discrete technologies to increase vehicle efficiency in the most cost-effective manner?

A traditional view of FE roadmaps will lead to very expensive solutions



Without a total systems approach, FE achievements will be below expectations or at uncompetitive costs

Ricardo has a proven process and analytical tools to solve vehicle fuel economy challenges



TVFE is applicable to optimization of portfolios of vehicles and individual vehicles

Optimized Portfolio

Optimized Vehicles

Propulsion System

Parasitic Loads

Drivetrain

Vehicle Systems

Exterior/Other

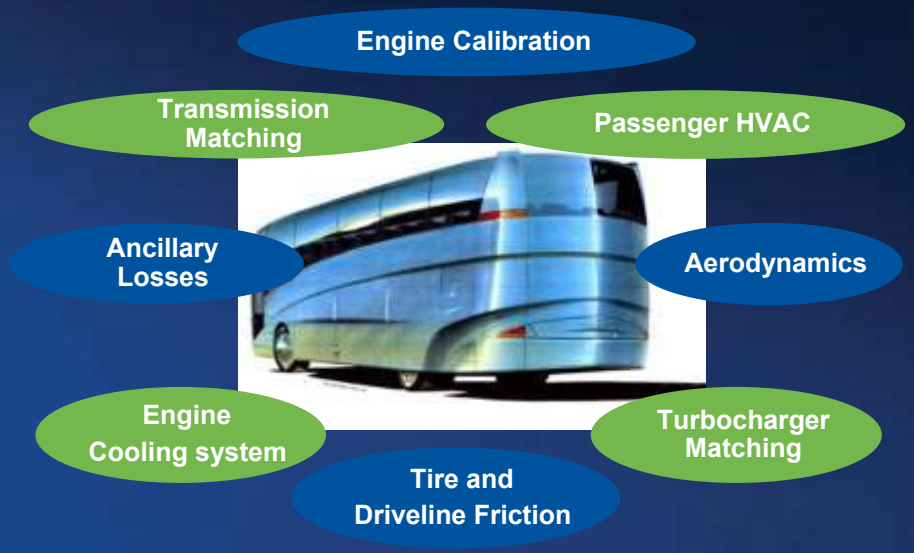
For an Asian vehicle manufacturer, Ricardo was responsible for identifying and validating a real world fuel economy improvement of 13% on their highway bus project

Situation and Objective

- Desire to improve fuel consumption competitiveness of their Highway Bus product
- System approach with combined development of engine, transmission and vehicle systems required
- Targeting fuel consumption improvement over real-world customer drive cycle

Ricardo Responsibilities

- On-site support for vehicle data acquisition
- Engine test bed development of calibration maps and turbocharger matching
- Simulation of vehicle over selected drive cycles
- Energy analysis to define Fuel Consumption critical components / systems. Confirm effect of system developments
- Engineering of development specifications
- Implementation support of developed systems and vehicle confirmation testing



Results and Benefits

- 13% fuel consumption improvement identified:
  - 2.0% from engine re-calibration
  - 2.5% from transmission and driveline
  - 8.5% from cooling system and thermal management strategy
- Cost/benefit analysis completed to enable the OEM to make an informed decision on what changes to implement in production

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A systems approach identifies and integrates opportunities across the entire vehicle – selected Ricardo favorites

Propulsion System	Parasitic Loads	Drivetrain	Vehicle Systems	Exterior/ Other
• T2B2 diesel solutions (SULEV) enabling reduced NOx aftertreatment • Ethanol Boosted Direct Injection for extreme downsizing • EGR Boost for downsizing with full flex fuel capability	• Electrified accessories • Reduced alternator loads through optimization • PT Cooling Strategy & optimization • EPAS	• Advanced transmissions • Optimized PT matching & shifting strategies • Gear Ratio's • Drivetrain Efficiency	• Calibration optimization • Tire Technology • PT & Vehicle thermal optimization • Vehicle Weight • Hybrid Systems • Intelligent Transportation Systems (ITS)	• Exterior Design (e.g. Styling) • Underbody Aerodynamics • Impact of Drive Cycle(s) • Real time controls

- **The race for improved technologies that address the long-term efficiency challenge must be met with fully integrated solutions that bring multiple systems together efficiently**

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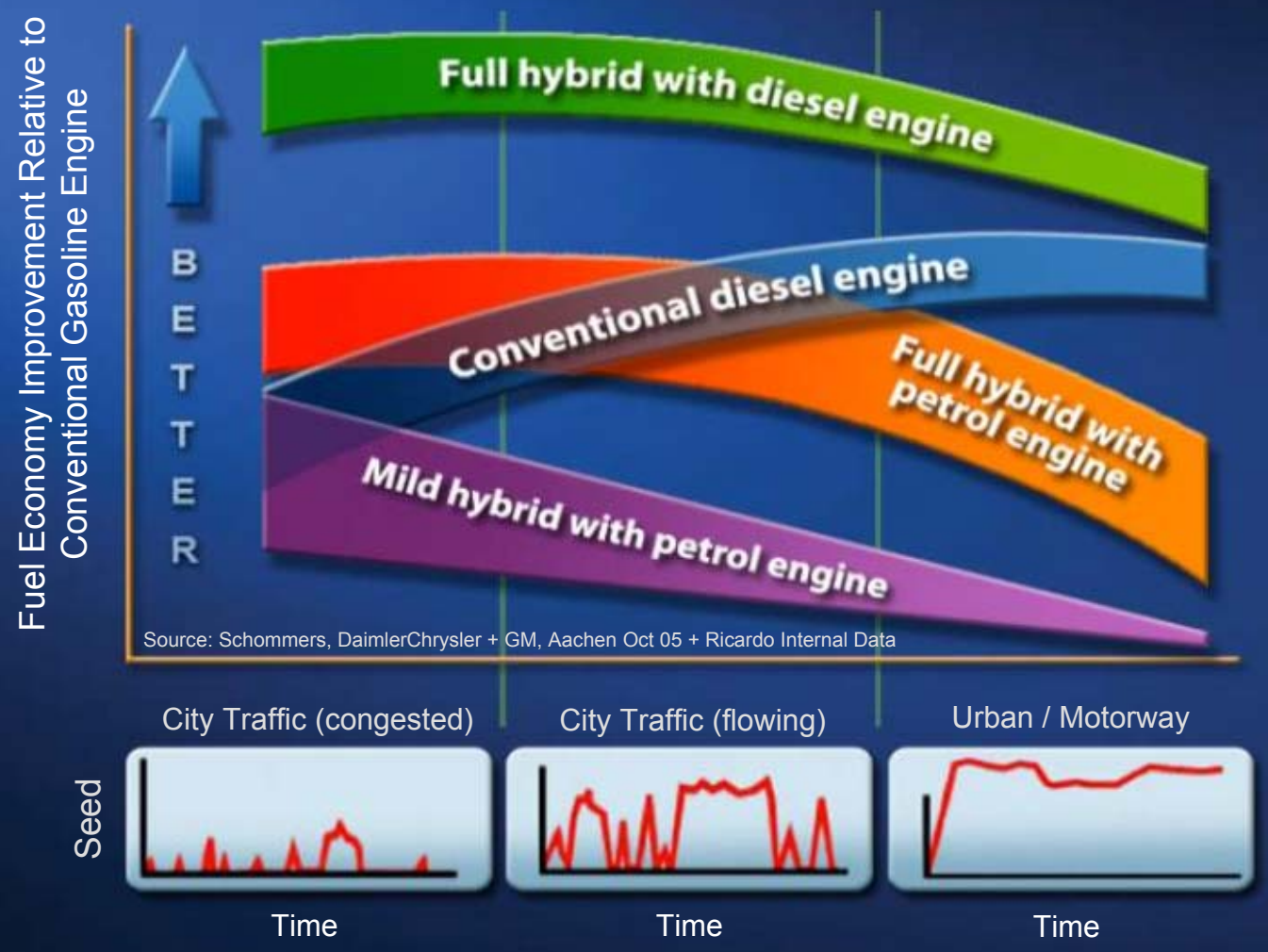
Optimizing the fuel economy requires a careful analysis of the dominant drive cycles



- Relative merits of Diesel or Hybrid depend on application and drive pattern
- Stop/start and low speed driving favors Hybrid configuration
- Higher speed operation requires high efficiency combustion and transmission

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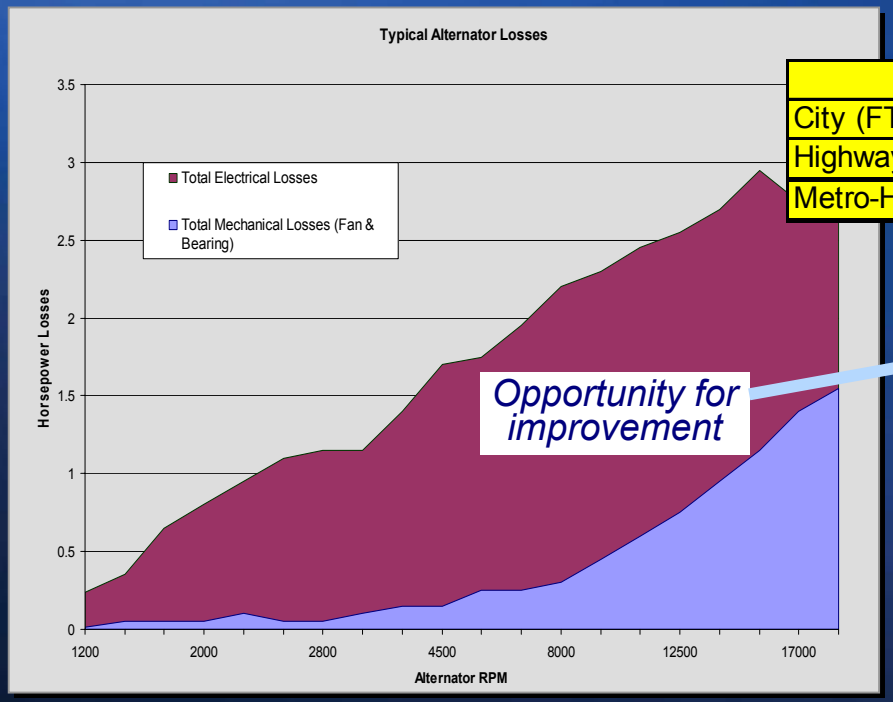
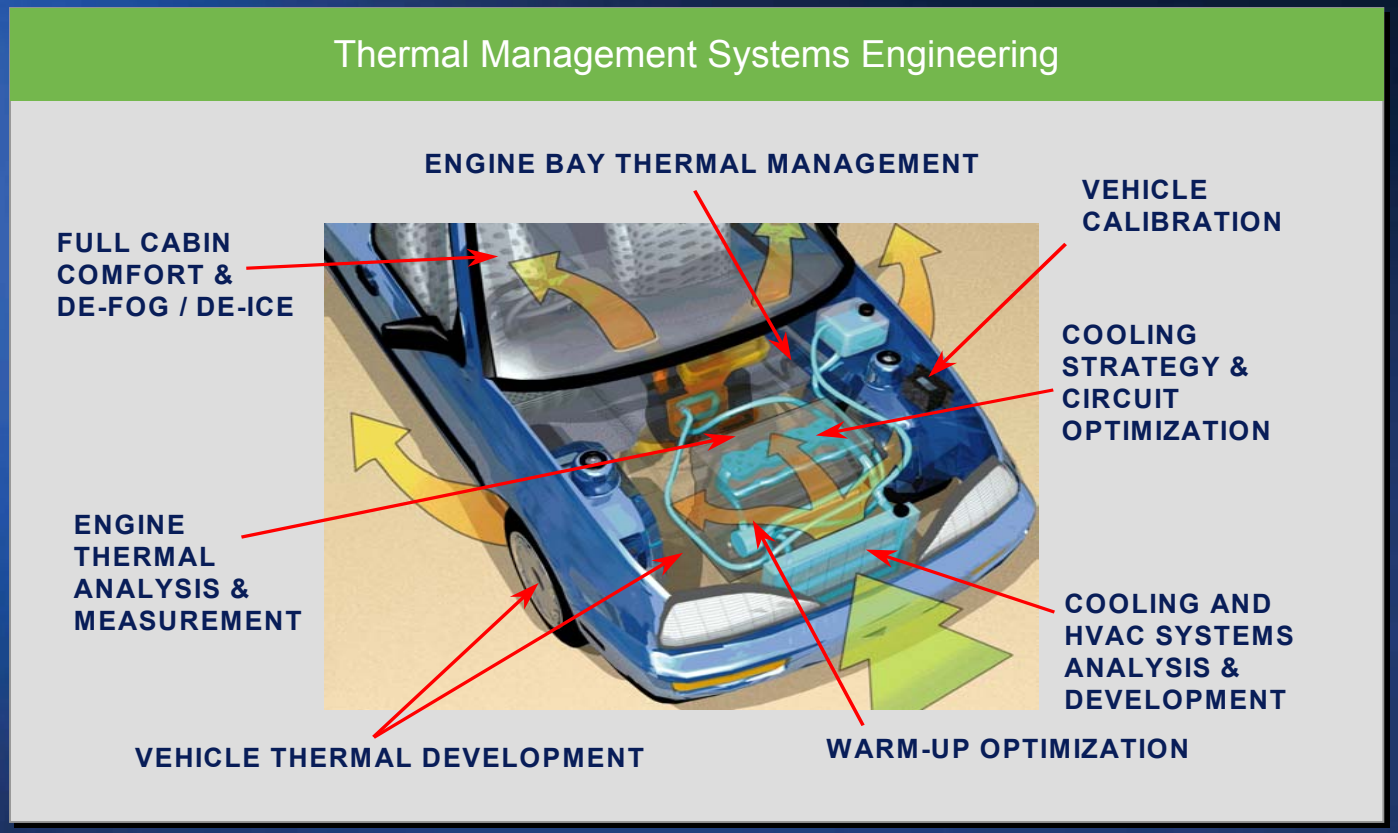
Electrical Load Optimization and Control → Low cost fuel economy improvement

- Many stand alone systems have shown promise to reduce electrical loads (e.g Smart Alternator and Smart Power Distribution Boxes) but have not been fully integrated.
- A full system approach can yield significant fuel economy benefits through optimized control of the these devices and therefore **at minimal cost.**
- Ricardo is developing a vehicle electrical control system aimed at real world fuel economy gains in conventional powertrain vehicles.



Drive Cycle	Baseline	Results	% Improve
City (FTP75)	21.79	22.21	**1.93%**
Highway (HWFET)	32.56	33.23	**2.06%**
Metro-Highway (Combined)	**26.64**	**27.17**	**2.00%**

Vehicle & PT Thermal Management



- Co-simulation between cooling system, HVAC and engine performance models to predict system performance, fuel economy and emissions
- Improved system design through holistic vehicle approach leads to reduced cost and significant fuel economy benefits

Summary

- Ricardo report shows that at current volumes, 27-34% of the 40% improvement can be achieved with “conventional technologies”
- Remaining 25% of the gap is turning into a space race for technology
- Technology must be accomplished at the minimum cost
- Occurs only with a systems approach, otherwise results will be too costly
- Ricardo launched TVFE to make such an approach available in a stand alone offering for all customers

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