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Presented at the Michelin Bibendum  
Berlin, May 2011

# Heavy Duty Truck Fuel Economy: Technology and Testing

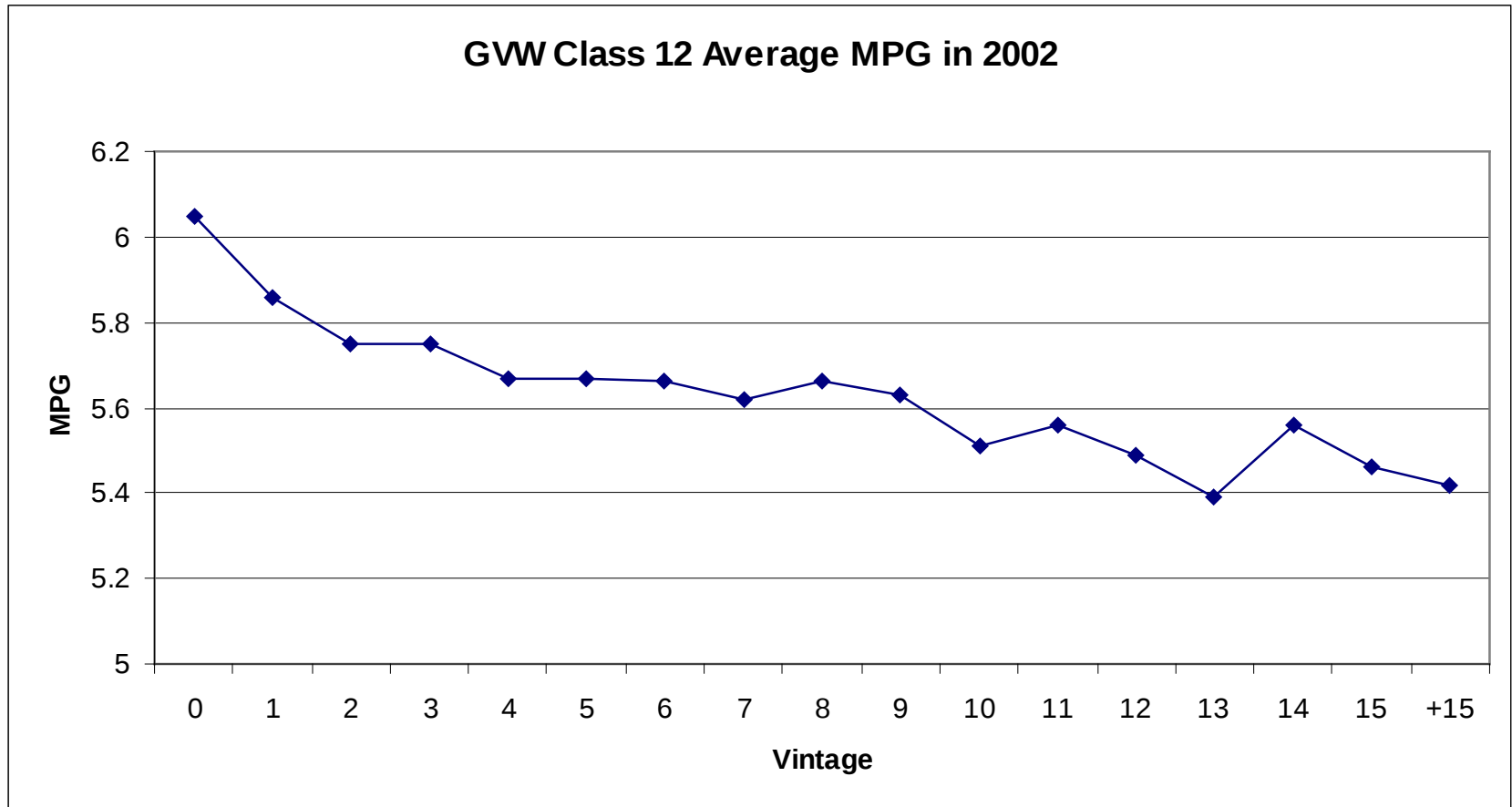
# Background

- Light-duty vehicles have received a lot of attention in the last 10 years and GHG reduction cost is understood. Only a few gaps remain in the analysis.
- A consensus on the cost and benefit for light-duty vehicles is emerging worldwide.
- There are only a few studies on heavy trucks and the cost and benefit of GHG reduction technology.
- Unlike light duty vehicles, significant reduction in FC is possible through retrofit of older trucks, operational improvement and use of larger trucks.
- Study attempts to gauge what can be introduced in the 10 and 20 year time frame and the cost implications,

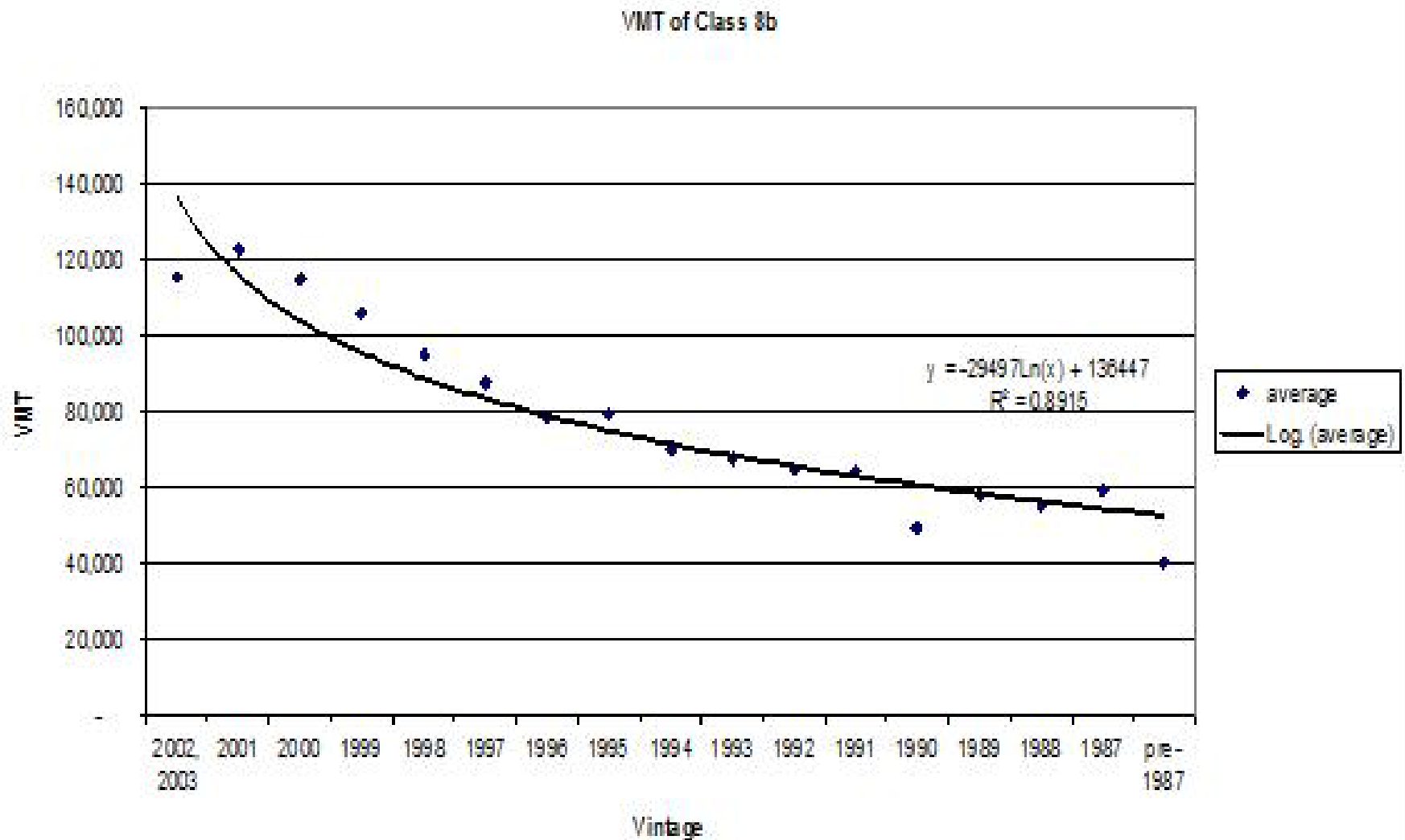
# Overview of HDT Market

- US Market has three major segments by gross vehicle weight class: light (4 to 9 tons), medium (9-25 tons) and heavy (25 to 40 tons)
- Due to high annual mileage and low fuel economy, the heavy segment accounts for about 65% of HDT fuel consumption.
- While preliminary supply curves of fuel consumption reduction have been developed for all segments, focus of this presentation is on heavy segment.
- About 70% of the heavy truck segment are tractor trailers but a significant fraction is used in regional haul as opposed to long haul.

# HDT Segment MPG



# HDT Annual Use



# Driving Cycle Issues

- Customary to evaluate benefits for long haul heavy duty truck at 65 mph (105km/h) constant speed and load for simple analysis.
- This type of analysis is very unrealistic as load and speed vary all the time on the highway due to rolling terrain, traffic, winds, etc.
- Constant speed analysis also suggests no benefit from hybridization as diesel engine is quite efficient at constant speed/load.
- We have used a 48mph average speed cycle with significant speed and gradient change to examine possible real world gains.

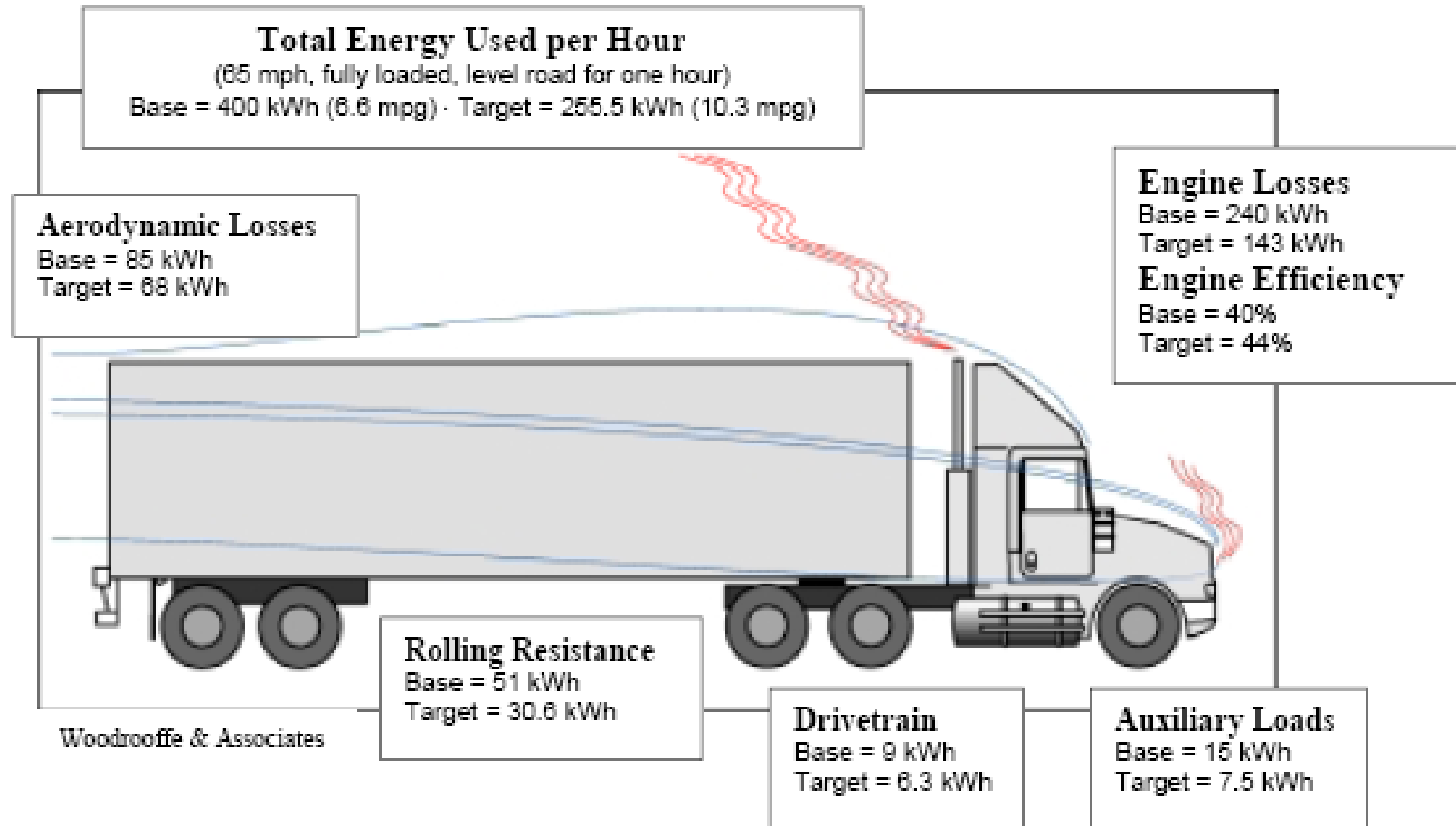
# Market Efficiency

- Broad based belief that commercial truck market is 'efficient' for FE.
- Typically, long-haul truck buyers use the truck intensively for the first 4 to 5 years and then sell to second user who uses it less and on shorter hauls.
- Hence, investment cost payback within 3 years is considered as benchmark for free market adoption.
- Discounted lifetime cost analysis suggests half the savings left on the table due to uncertainty of value of many technologies to second user.
- Our own analysis suggests that only half the claimed benefits for many technologies are actually available!

# Fuel Consumption Reduction

- Major push by DOE for 21<sup>st</sup> Century truck program with a target of doubling fuel economy has been a source for technology data.
- Our study examined specific technologies available to meet DOE targets and the costs and benefits of each technology relative to a 2008 baseline.
- Our study utilized an industry 48 mph driving cycle as a more realistic “average” drive cycle but real world conditions are not well understood.
- Operational and Retrofit Issues are also addressed in this study but is not reported here.

# DOE Technical Targets (at steady state 65 mph/ 105 kmh)



# Steady State Issues

- Use of the 65 mph steady state cycle stresses aerodynamic improvements as 53% of energy is lost to drag, and none to the brakes.
- Real world cycle shows more complex distribution of energy with losses of inertia to the brakes and engine idle and deceleration related fuel consumption losses.
- Aerodynamics are still significant but account for 38% rather than 53% of fuel consumption with industry cycle.
- Inertia and idle/decel. fuel consumption accounts for 17.5% of total fuel consumption

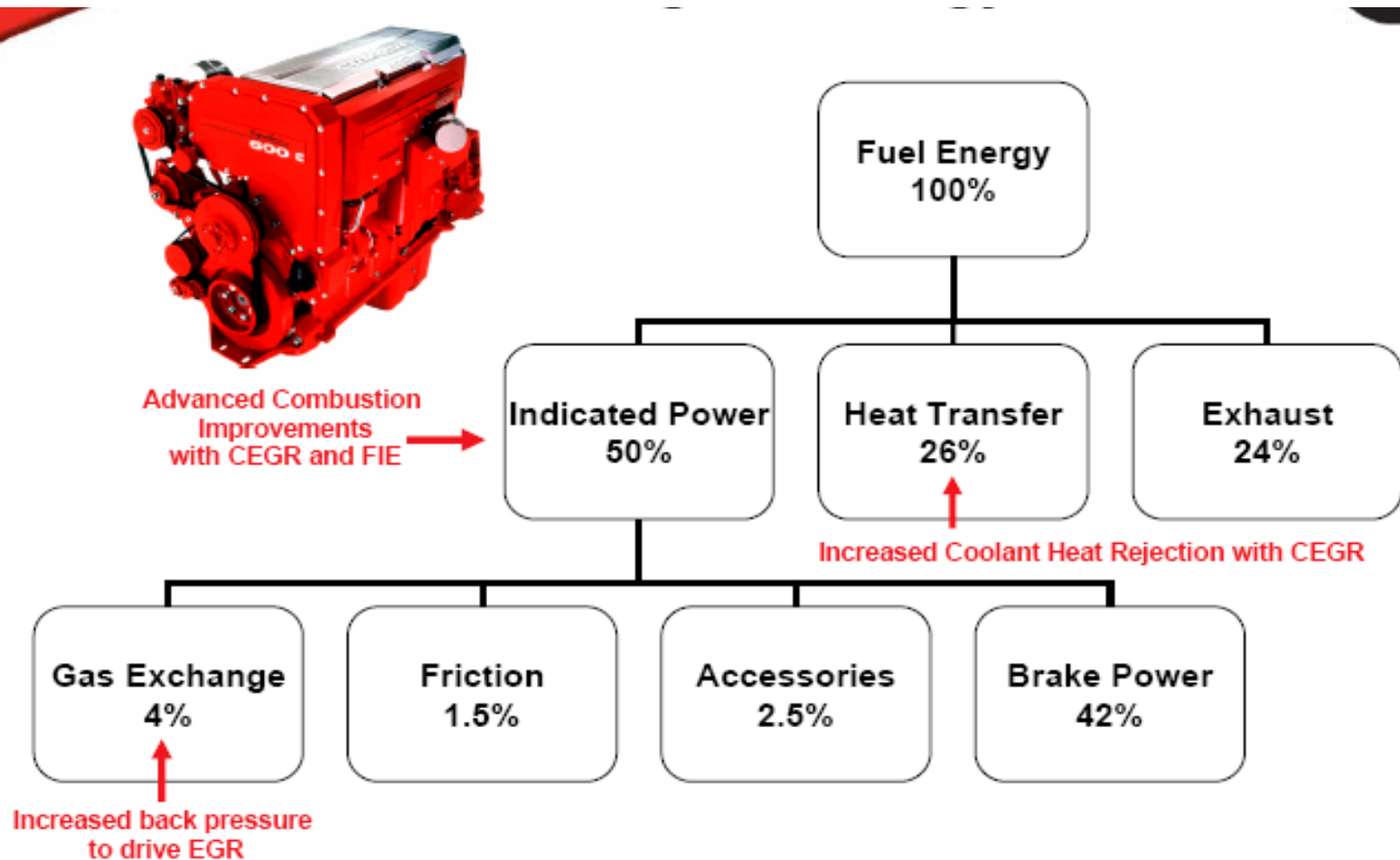
# Fuel Use in Real World Cycles

|                          |  | Line Haul<br>(Manual Trans) | Regional Haul<br>(Manual Trans.) | Urban/ Suburb.<br>(Auto Trans) | Refuse/ Bus (Auto<br>Trans) |
|--------------------------|--|-----------------------------|----------------------------------|--------------------------------|-----------------------------|
| Idle/ Deceleration.      |  | $5 \pm 0.5$                 | $7 \pm 0.5$                      | $8 \pm 0.5$                    | $15 \pm 1$                  |
| Inertia (lost to brakes) |  | $12.5 \pm 1$                | $31.5 \pm 2$                     | $26.5 \pm 2$                   | $32 \pm 2$                  |
| Aerodynamics             |  | $38 \pm 2$                  | $25 \pm 2$                       | $20 \pm 2$                     | $6 \pm 0.5$                 |
| Tire Rolling Resistance  |  | $35 \pm 2$                  | $25 \pm 2$                       | $21.5 \pm 2$                   | $8 \pm 0.5$                 |
| Accessory Drives         |  | $5.5 \pm 0.5$               | $7 \pm 0.5$                      | $9 \pm 0.5$                    | $16 \pm 1$                  |
| Drive-train Loss         |  | $4 \pm 0.5$                 | $5.5 \pm 1$                      | $15 \pm 1$                     | $23 \pm 1$                  |

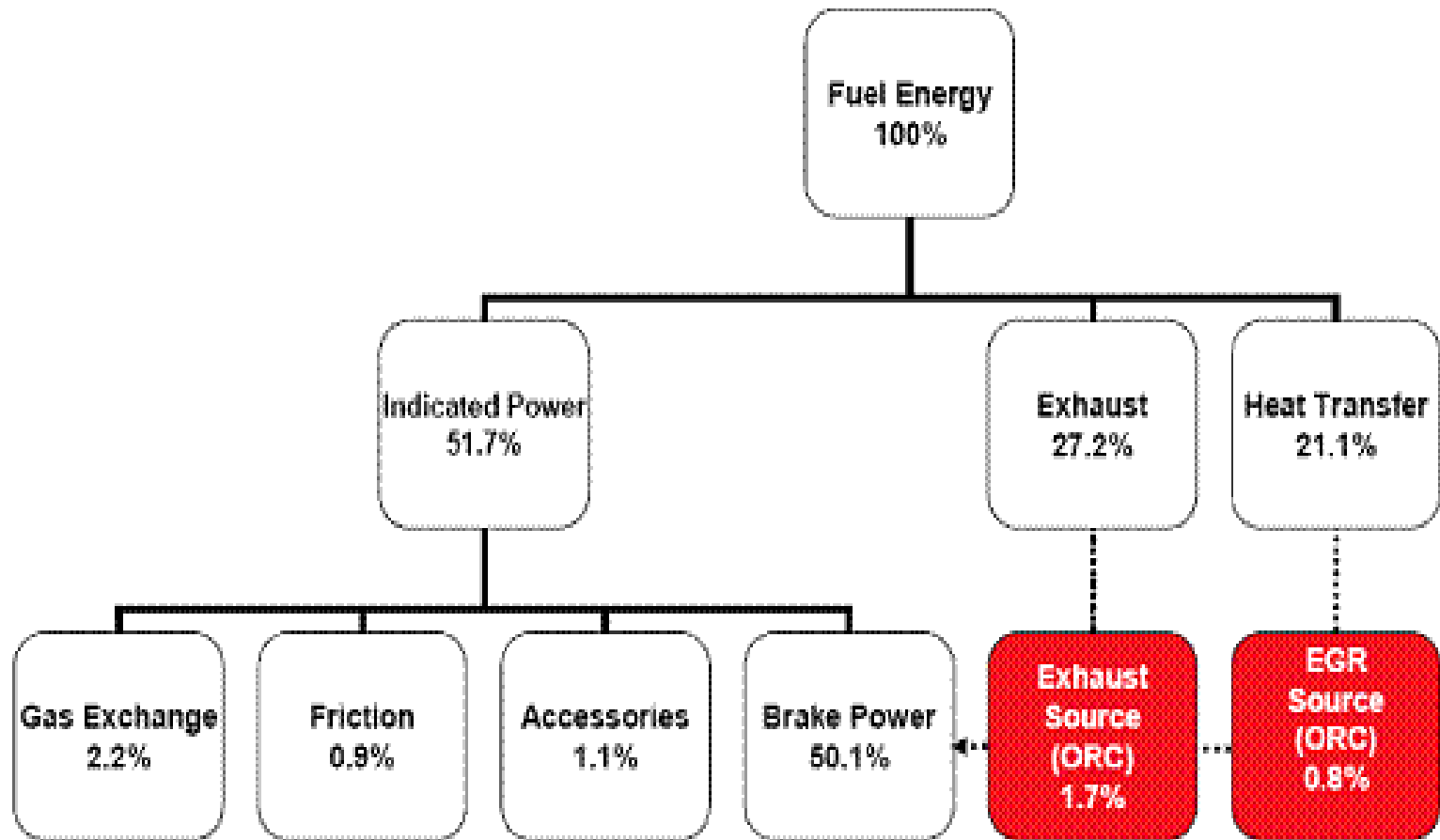
# Engine Technology

- Current HDT engine peak efficiency is about 43% but cycle efficiency is 39 to 40%. Peak efficiency target is 50+%. Cycle efficiency is usually ~3% points lower than peak efficiency.
- Analysis by Cummins and Caterpillar show that efficiencies over 50% possible in 2020 but cost-effectiveness of technologies vary.
- Due to large variation in engine and truck prices, our analysis focuses on payback to owner. Market will adopt technology only if payback is in less than 3 years.

# Engine Loss Analysis – 2008 Base (source: Cummins)



# Possible 2020 Efficiency Improvements (source: Cummins)



# Engine Technology Findings

- The US 2010 emission standards have forced upgrades to the fuel injection systems, and the introduction of urea/SCR catalysts.
- The urea/SCR systems have allowed an increase in engine-out emissions which in turn has allowed a one-time FE improvement of 4 to 5%.
- A detailed analysis of available engine technology suggests that by 2016, a 13 to 15% improvement is possible, while by 2025, a 23 to 27 % improvement is possible on the long haul cycle.
- Only about half this improvement will be cost effective in the 3 year payback period while the remainder will need a 6 year+ payback.

# Engine Related Technology

| Technology                                                      |  | 2009 -2017      |                 | 2009 – 2025     |                 |
|-----------------------------------------------------------------|--|-----------------|-----------------|-----------------|-----------------|
|                                                                 |  | Highway         | Regional        | Highway         | Regional        |
| Urea SCR                                                        |  | 3.0*            | 2.0*            | 5.0             | 4.0             |
| Closed loop combustion control                                  |  | 1.5             | 1.0             | 3.0             | 2.0             |
| 2500/3000 bar fuel injection                                    |  | 0*              | 0*              | 1.0             | 1.0             |
| Sequential turbo/ down-sizing                                   |  | 0*              | 0*              | 0.5             | 0.8             |
| Cooled EGR                                                      |  | 1.0             | 1.0             | 1.5             | 1.5             |
| Friction reduction                                              |  | 1.0             | 1.5             | 1.5             | 2.2             |
| Improved accessories                                            |  | 0.5             | 0.8             | 0.7             | 1.0             |
| Variable valve actuation                                        |  | -               |                 | 1.0             | 1.0             |
| Mechanical turbo-compound                                       |  | 2.5             | 1.3             | 3.0             | 1.5             |
| Electric turbo-compound                                         |  | 5.0             | 2.5             | 6.5             | 3.3             |
| Organic Rankine cycle                                           |  | -               |                 | 6.5             | 3.3             |
| Electric accessory drive<br>(oil/water/steering/air compressor) |  | 2.0             | 3.0             | 2.0             | 3.0             |
| <b>Maximum Engine total</b>                                     |  | <b>13 to 15</b> | <b>12 to 14</b> | <b>23 to 27</b> | <b>21 to 23</b> |

# Hybrid Technology

- Hybrid technology under active consideration for both heavy and medium/light-heavy duty vehicles, especially in Europe.
- Even for long haul trucks, potential to improve FE by 6 to 7% with payback in 5 to 7 years. Even on highway driving, rolling hills and congested highways yield significant regenerative energy recapture.
- System can be relatively simple with an electric motor in the 25 to 50 kW range and a battery not much larger than one in a hybrid car.
- Urban and suburban hybrid trucks have 25 to 35% FE improvement but payback period is similar due to much lower annual VMT

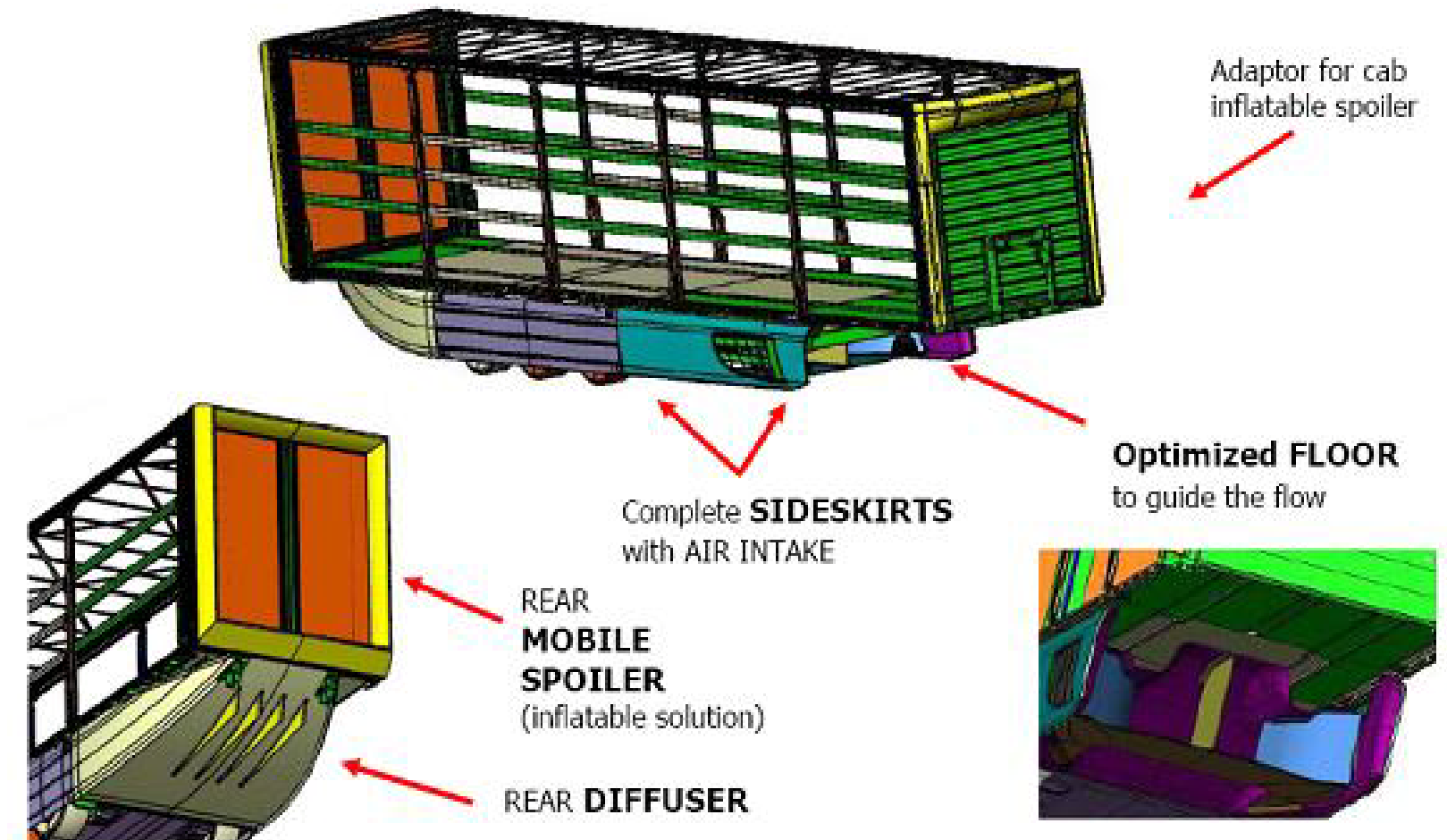
# Truck and Trailer Aerodynamics

- Aerodynamic improvements to the tractor and trailer have occurred continuously since the late 1970s. Most trucks have roof fairings and an aerodynamic cab, while about 50% of new 2008 tractor trailers had the full aero package.
- The drag co-efficient has come down from  $\sim 0.73$  in the early 1980s to 0.55 for a 2008 truck with the aero package, which is a 25% decrease in drag.
- Future gains will have to come from the trailer and better tractor-trailer integration but this is more difficult as there are 4 or more trailers for every tractor.
- With trailer side skirts, tractor-trailer gap seals and a smooth trailer underbody drag can be reduced by another 20%.

# Modern vs. Classic Tractor



# Trailer Aerodynamics



# Issues with Aero Devices

- Even though many trailer related devices such as gap seals and side skirts have been commercially available for many years, few trucks use them.
- Fleet owners claim that most aero devices they have purchased get **half the benefit** that device manufacturers claim or advertise.
- Some of this is due to unrealistic testing cycles (like constant speed 65 mph) but it may also be due to the fact that trucks are often in the wake of other vehicles on the highway, which shield them from aerodynamic forces.
- Trailers also may not have the same owner as the tractor, and the trailer owner may see no monetary benefit.

# Hedonic Costs of Aero Devices

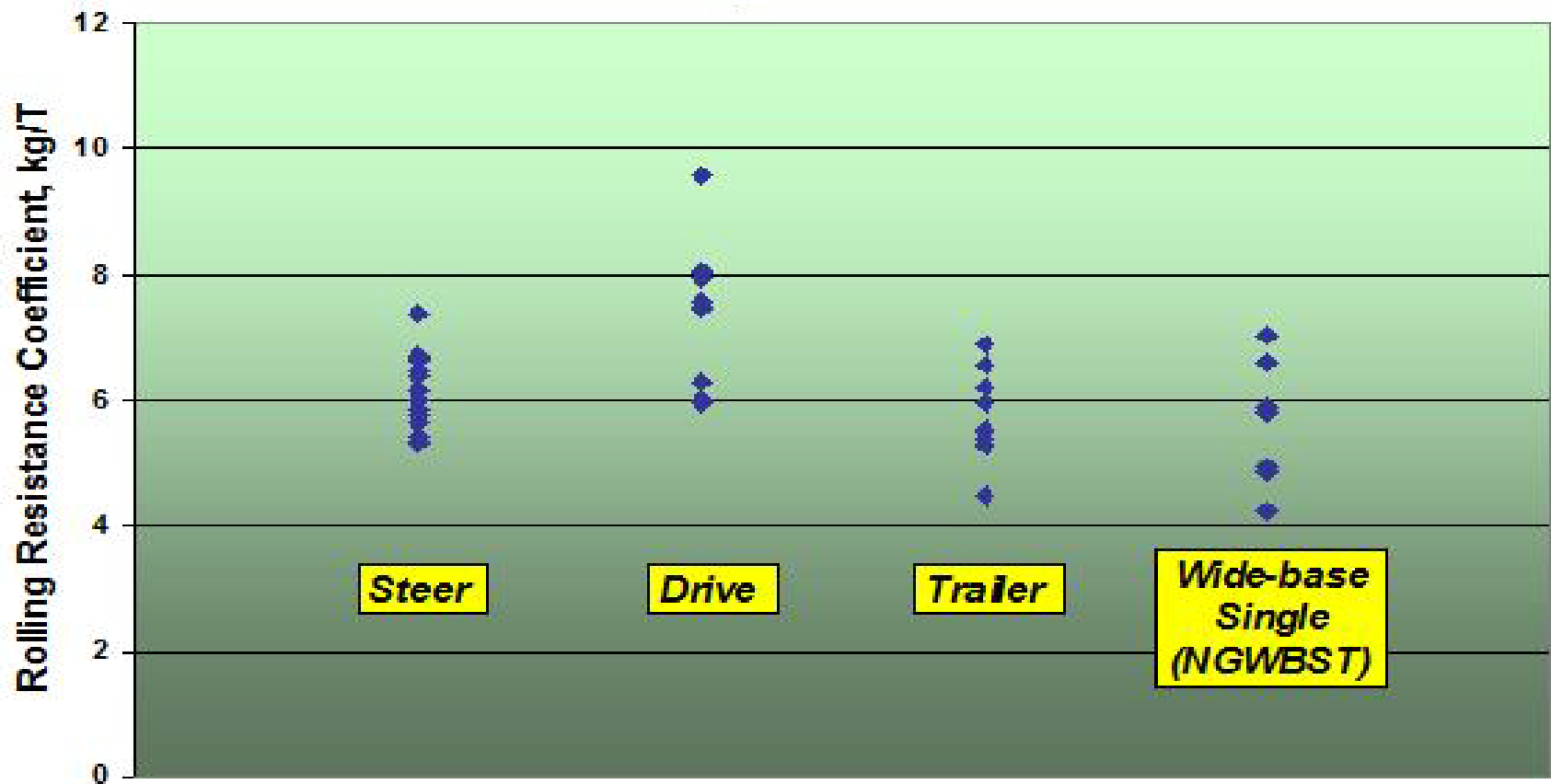
- Cost effectiveness calculations even with real world benefits show payback in less than 3 years for many trailer aero devices.
- The low market penetration is thought to be due to other hedonic costs and potential safety issues
- Example- side skirts may cause brake cooling problems and are reputed to pick up snow, increasing truck weight. In addition, tire changes and underbody access is more difficult.
- Gap seals make trailer connections more difficult, and truckers often use the gap space to store tarpaulins or chains

# Tires

- Tire improvements to reduce rolling resistance occur constantly, and reduction of rolling resistance co-efficient occurs at about 0.7% rate per year.
- In the current market, there are a number of tire makes with a wide range of rolling resistance.
- The US EPA has instituted a program to certify tires with low rolling resistance, and this has led to increases in market share.
- Michelin has had a “wide base single” tire that replaces 2 tires and has 20% lower rolling resistance

# Rolling Resistance of Current Tires

Example Range of Rolling Resistance Coefficients  
for Heavy Truck Tires



# Tire Issues

- Even though low RRC tires have been shown to be very cost effective, market penetration is still relatively low.
- There may be perceived or real trade off with other parameters such as traction or durability.
- The Michelin Super Single tire and rim actually costs less than 2 tires and rims, but market penetration is still low.
- In this case, fear of truck disablement with tire failure may be a major reason, since dual tires allows a limp home mode.
- In many rough duty applications, bias ply tires with much higher rolling resistance are still used due to better resistance to sidewall damage than radial tires.

# Other Technologies

- Accessory drives consume a large fraction of power and improved accessory efficiency is possible with the cooling fan, alternator, power steering pump and air compressor.
- Electrification of accessory drives can improve efficiency by allowing need based operations but power requirements are high. It may be most effective when combined with hybridization that provides high voltage electric power.
- Transmissions with direct drive in top gear can provide small improvements in efficiency and are already in widespread use in Europe.
- Automated manual transmissions are more efficient than conventional automatic transmissions but this is a bigger issue for medium duty trucks

# Total Potential Improvements

- For the long haul van body tractor trailer, or analysis finds a maximum potential reduction in fuel consumption of 40% by 2025 starting from a 2008 baseline.
  - 5% has occurred already due to urea/SCR introduction
  - 18% appears cost effective within a 3 year payback period
  - 12% is cost effective within a 6/7 year payback
  - 5% is high cost and technology cost reduction is required
- Hedonic costs of many technologies not fully considered in above analysis and more work is needed
- Surprisingly, other body types and medium trucks have similar reduction potential, but with increasing dependence on hybrid technology for lower speed cycles, with much longer payback periods.

# Regulatory Issues

- Setting regulations based on cost effectiveness is difficult in this market due to the many hedonic values of some technologies.
- The selection of the reference test cycle is important as it influences technology selection ,costs and benefits
  - Higher and more constant speeds lead to emphasis on aero dynamic and tire technology
  - Lower and more variable speeds lead to more emphasis on engine and hybrid technology
- Attention is needed to understand why many highly “cost-effective” technologies have failed in the market, and how market barriers can be overcome.