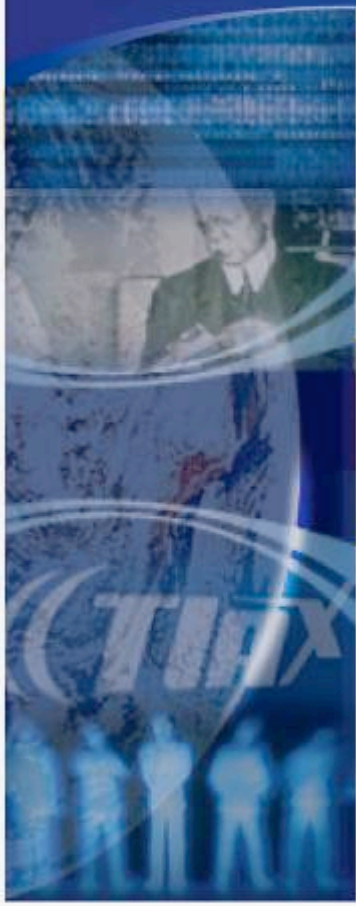
Technologies to Improve Fuel Efficiency of Heavy Duty Trucks



Reducing Greenhouse Gas Emissions from Heavy-Duty Vehicles: Policy options, development, and prospects—International Workshop

European Commission--Climate Action & The International Council on Clean Transportation (ICCT)
Brussels, Belgium
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1. NAS Study
2. Summary of NAS Results
3. Extending Results to Europe
4. Closing Remarks

1 NAS Study

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U.S. National Academy of Sciences Study

Legislative requirements

- US Congress required DOT/ to engage NHTSA engage National Academies to develop a report that evaluates MD and HD vehicle fuel economy (Energy Independence and Security Act of 2007)
- EISA also requested NHTSA to conduct its own study on the fuel efficiency of commercial MD and HD on highway vehicles and work trucks leading to rulemaking.
- Rule making process was a join effort of NHTSA for fuel economy standards and EPA for GHG standards

NAS Committee objectives were to conduct assessment and develop report

- Assessment of technologies and costs to evaluate fuel economy for MD and HD trucks
- Analysis of existing and potential technologies that may be used practically to improve MD and HD fuel economy
- Analysis of how such technologies may be practically integrated into the MD and HD truck manufacturing
- Assessment of how such technologies may be used to meet fuel economy standards
- Associated costs and other impacts on the operation of MD and HD trucks, including congestion

TIAX retained by NAS to provide a comprehensive set of fuel savings technologies, their benefits, and their price

- Developed detailed forecasts of fuel consumption reducing technologies
- Supported evaluation of MD & HD vehicle technologies by researching the technologies and their costs through intensive interviews of manufacturers, fleet owners and others to produce a detailed matrix relating technologies and vehicle types over time.
- Developed a detailed matrix of fuel saving technologies, their fuel consumption benefits, and their costs.
- Focused on ten-year timeframe
- Arranged specific site visits

There are three approaches to reducing fuel consumption from the medium and heavy-duty fleet. TIAX's analysis focuses on characterizing fuel-efficient technologies

Approach	TIAX analysis includes…	TIAX analysis does not include…
Technology Deploy fuel efficient technologies into the vehicle fleet	•Identification of Technologies •Estimate of fuel consumption benefit •Cost estimates (RPE)	•Breakdown of RPE •Analysis of manufacturing processes •Operations & Maintenance (O&M) Costs/Life Cycle Costing
Productivity Increase the use of longer & heavier vehicles	•Estimates of fuel consumption benefit •Identification of enabling technologies	•Cost analysis •Infrastructure analysis •Policy landscape
Operations & Logistics Optimize fleet management	•On-vehicle optimization tools (e.g., driver training, telematic navigation, etc)	•Off-vehicle fleet optimization tools •Optimization of goods movement

Major Sources of Information and Data

- **Site Visits**
  - **Engine/Truck:** Cummins, Daimler/Detroit-Diesel, Navistar, Kenworth, Peterbilt, Volvo
  - **Supplier:** Allison, Arvin Meritor, Azure, Eaton, Great Dane, ISE
  - **End-User:** Wal-Mart
  - **Conferences:** UMTRI LCV Conference
  - **NAS Committee Meetings:** Con-Way, Aluminum Assoc, and others
  - **Testing Organizations:** ARC and TRC
- **Literature Review**: Journal articles and research reports; DOE vehicle technology research reviews; NAS Committee Presentations; 21st Century Truck Partnership; company data sheets, press releases
- **Original Analysis**
  - Extend the results of previous studies to other vehicle classes, adjusting for factors such as duty cycle, vehicle weight, and engine size

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Scope of Analysis & Approach to Data Collection

Vehicle Classes

- Class 8 Tractor-Trailer
- Class 3-6 Straight Box Truck
- Class 3-6 Straight Box Truck
- Class 8 Refuse Hauler
- Urban Transit Bus
- Motor Coach
- Class 2b Pickups & Vans

Technology Categories

- Aerodynamics
- Engines
- Tires & Wheels
- Weight Reduction
- Transmission & Driveline
- Hybrids
- Driver Management & Coaching
- (Overnight) Idle Reduction

Technology Attributes

- Technology description
- Baseline for comparison
- Fuel consumption benefit
- Cost (RPE)
- Year of Introduction
- Effect on technology on weight, coefficient of drag, etc

Variety of Trucks Analyzed

Tractor Trailer

Class 3-6

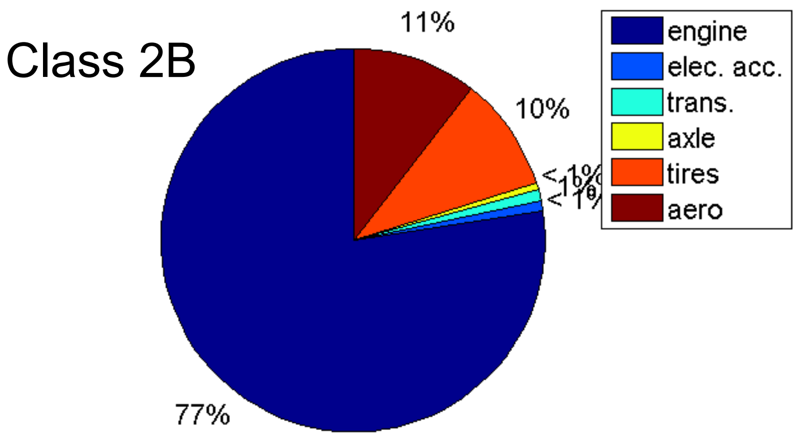
Refuse Hauler

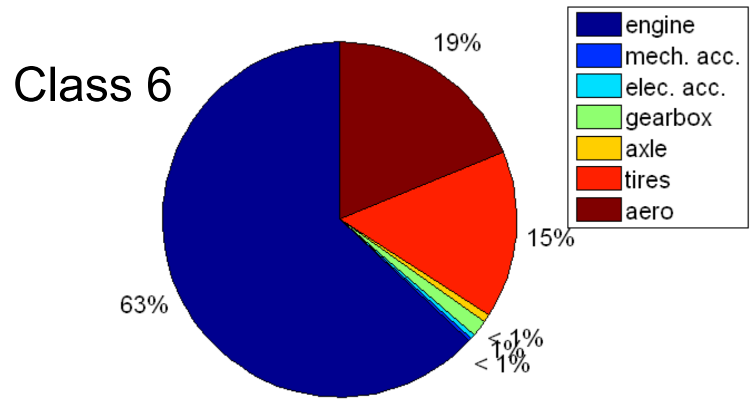
40 ft Transit

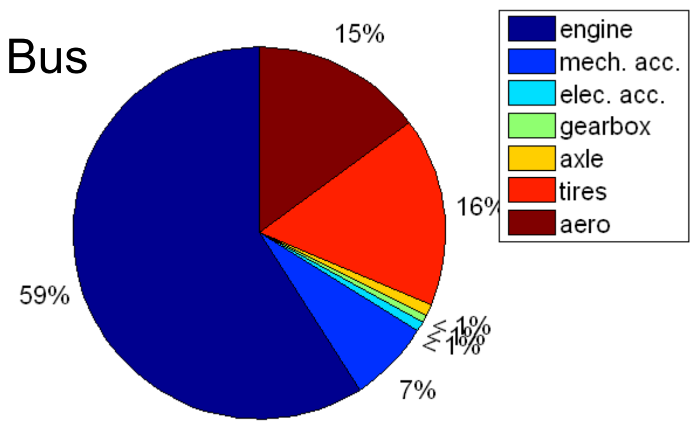
Motor Coach

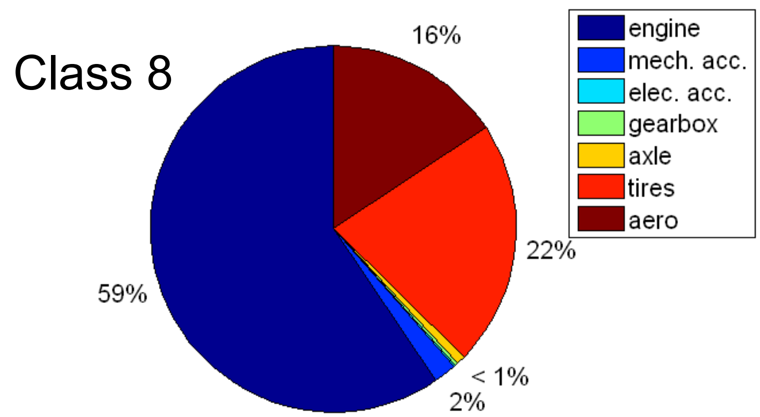
Class 2b

Many opportunities to reduce fuel consumption but energy losses from engine, aerodynamics and tires dominate



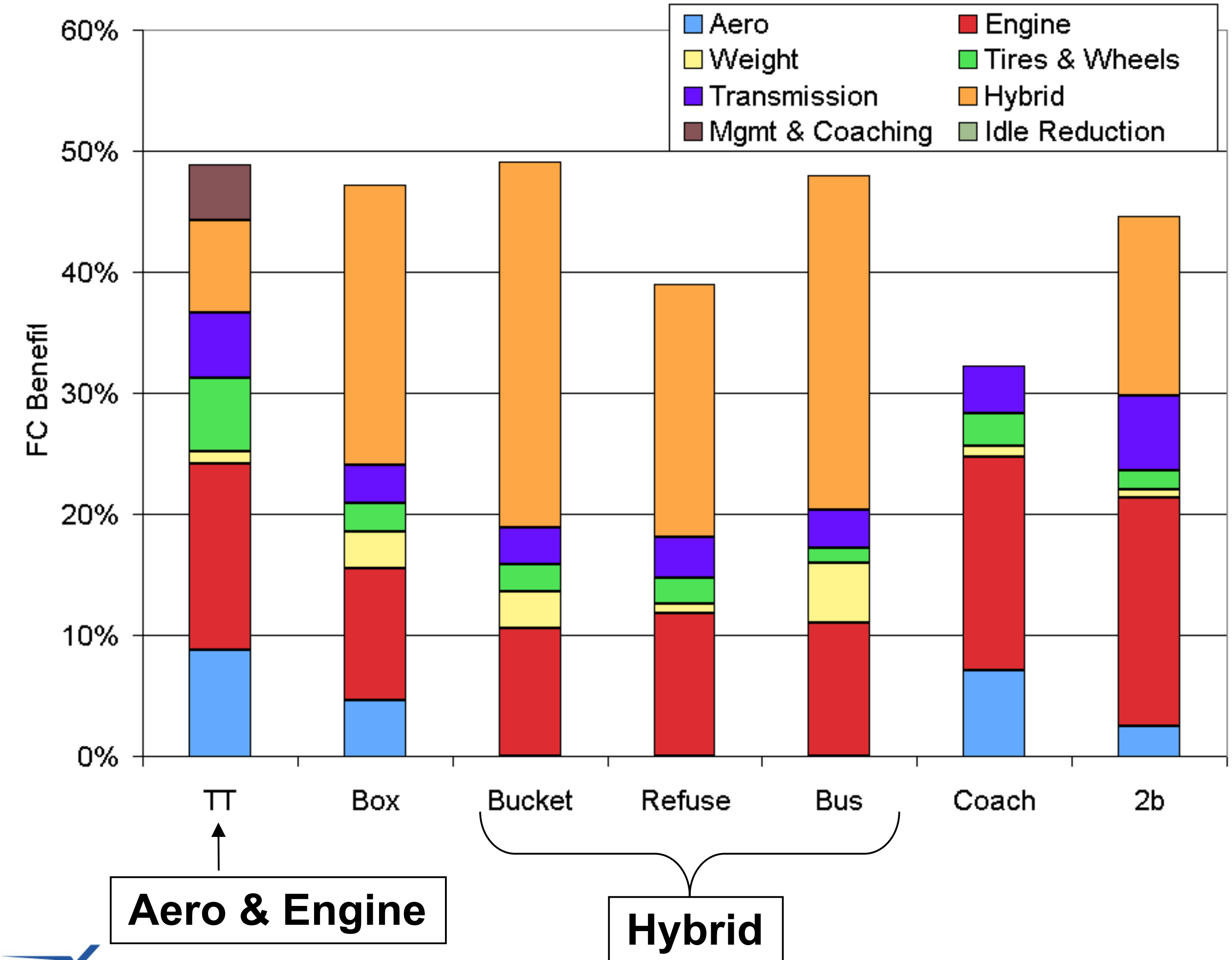




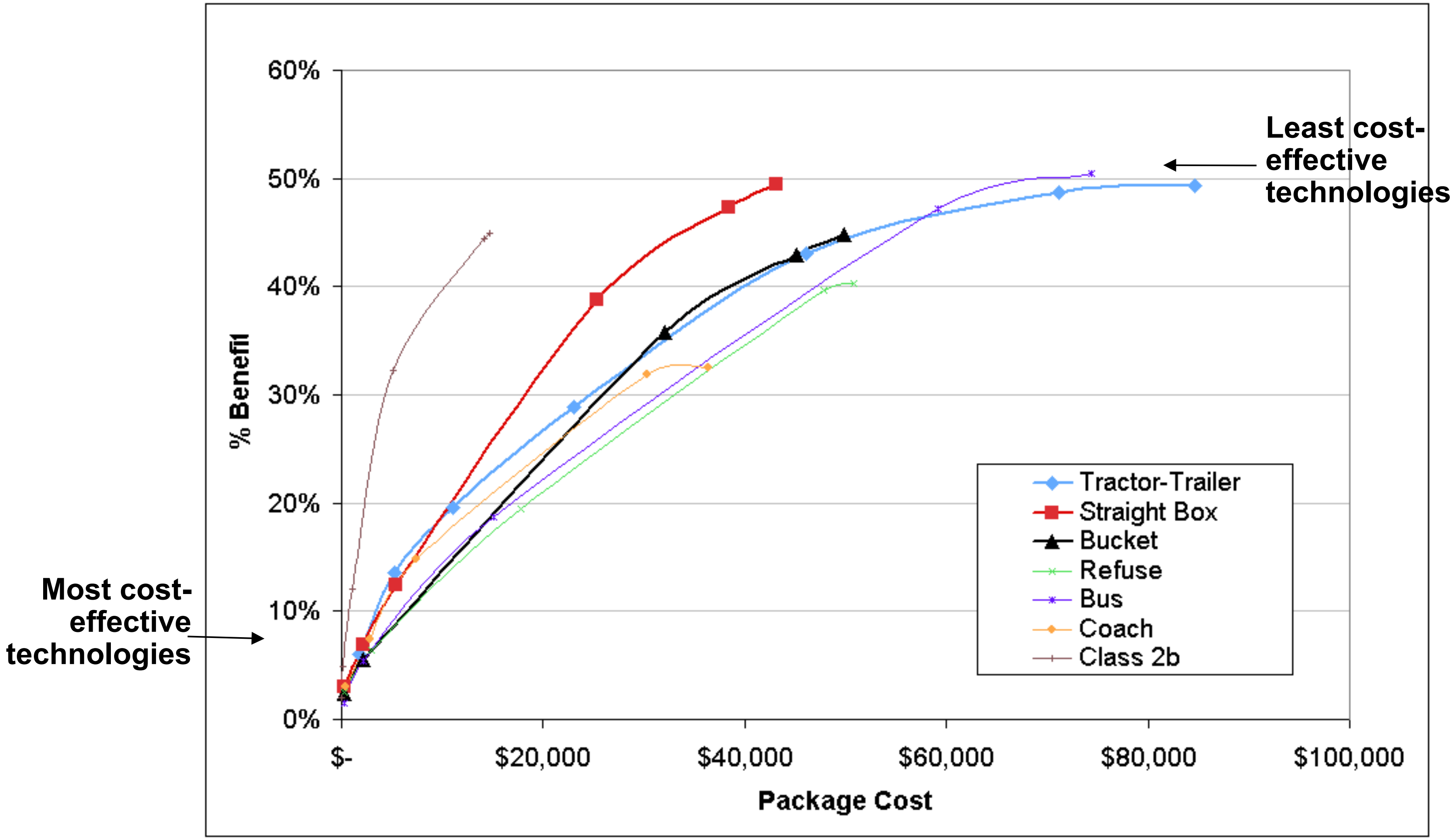


Vehicles at GVWR and 50 mph Steady State Speed

The technologies used to achieve fuel consumption gains varies by market segment



These results were used to develop cost curves for each vehicle class



Aggressively deploying new technologies can reduce fuel consumption by 40 to 50% for most vehicle classes in a 2015 to 2020 time frame

Category	TT	Box	Bucket	Refuse	Bus	Coach	2b
Aero	11.5%	6%	-	-	-	8%	3%
Engine	20%	14%	14%	14%	14%	20%	23%
Wt Reduction	1.3%	4%	4%	1%	6.3%	1.1%	0.8%
Tire	8%	3%	3%	2.50%	1.50%	3%	2%
Transmission	7%	4%	4%	4%	4%	4.5%	7.5%
Hybrid	10%[1]	30%	40%	25%	35%	-	18%
Mgmt & Coaching	6%	-	-	-	-	-	-
Idle Reduction	-[1]	-	-	-	-	-	-
Sub-Total	**49.3%**	**49.4%**	**51.3%**	**40.2%**	**50.4%**	**32.5%**	**43.2%**
Added Wt (lb)	2,500	1,100	1,050	1,500	2,000	1,500	750
Adj. FC[3]	**48.9%**	**47.1%**	**49.6%**	**38.4%**	**47.8%**	**32.0%**	**44.5%**
Cost	**$ 84,600**	**$ 43,120**	**$ 49,870**	**$ 50,800**	**$ 74,400[2]** **$ 250,400**	**$ 36,350**	**$ 14,710**
$/% Benefit	**$ 1,731**	**$ 916**	**$ 1,006**	**$ 1,322**	**$ 1,556**	**$ 1,136**	**$ 331**

[1]The hybrid package includes ~4% credit for overnight idle reduction
[2]The lower cost includes an 80% federal subsidy for Diesel transit bus hybrids
[3]Fuel consumption benefit, adjusted for the added weight

Major conclusions of TIAX assessment

- 50% reduction in fuel consumption possible in 2017 timeframe
  - MY2008-2009 diesel vehicles and MY2008-2009 gasoline vehicles
  - 2007 emissions compliant
  - But at relatively high costs (our estimates)
- Idle emissions could be eliminated in future
  - technology exists today and electrification will further enable eliminating idle emissions on all vehicles
- National maximum speed limit should be "hardwired" in all new trucks
  - Technology exists
  - Unifies at least one of the variables on truck specification

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Many similarities between EU and US truck market/users

EU Vehicle Segment	GHG Emissions by Segment (%)	% of MD/HD Fuel Consumed	US Vehicle Segment
Service	13	13	Class 2b
Urban Delivery	4	8	Class 3-6
Municipal Utility	5	5	Refuse/Service /Utility
Regional Delivery	15	61	TT
Long Haul	36		TT
Construction	11	5	Dump Trucks
Bus	9	1.4	Bus
Coach	7	0.5	Coach

Cabover design dominates in Europe vs. US

MAN TGX

Peterbilt 386

Tractor Characteristics	EU	US
Width (m)	2.55	2.6
Height (m)	4 (max)	4.09
Length (m)	~4.5-5.3	7.9
Frontal area (m2)	<10	10
No of axles	2	3
No of tires	6(dual)	10(dual)
Driveline conf	4x2	6x4
Weight (mt)	7	8.6

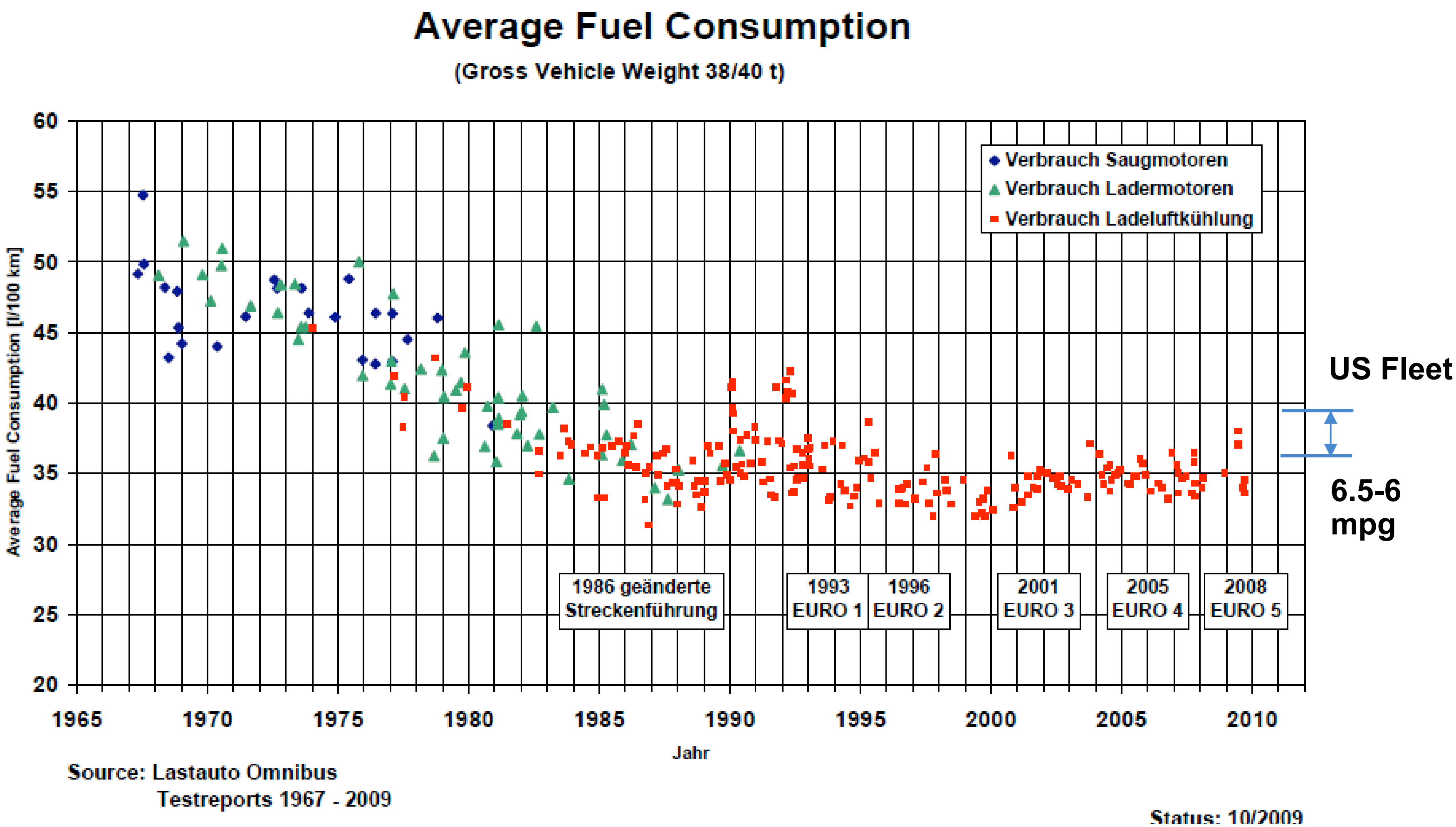
Trailers and total vehicle length limited in EU compared to US

Trailer/Vehicle Characteristics	EU	US
Width (m)	2.55	2.6
Height (m)	4 (max)	4.09
Length (m)	13.62	15.15
Tractor trailer gap (m)	0.87	1.02
Typical king pin distance (m)	1.668	0.914
No of axles	3	2
No of tires	6(single)	8(dual)
Tare weight (kg)	5650	6124
Payload (kg)	same	17240
Total vehicle GVW (mt)	40	36.3
Total vehicle Length (m)	16.5	21.3-22.9

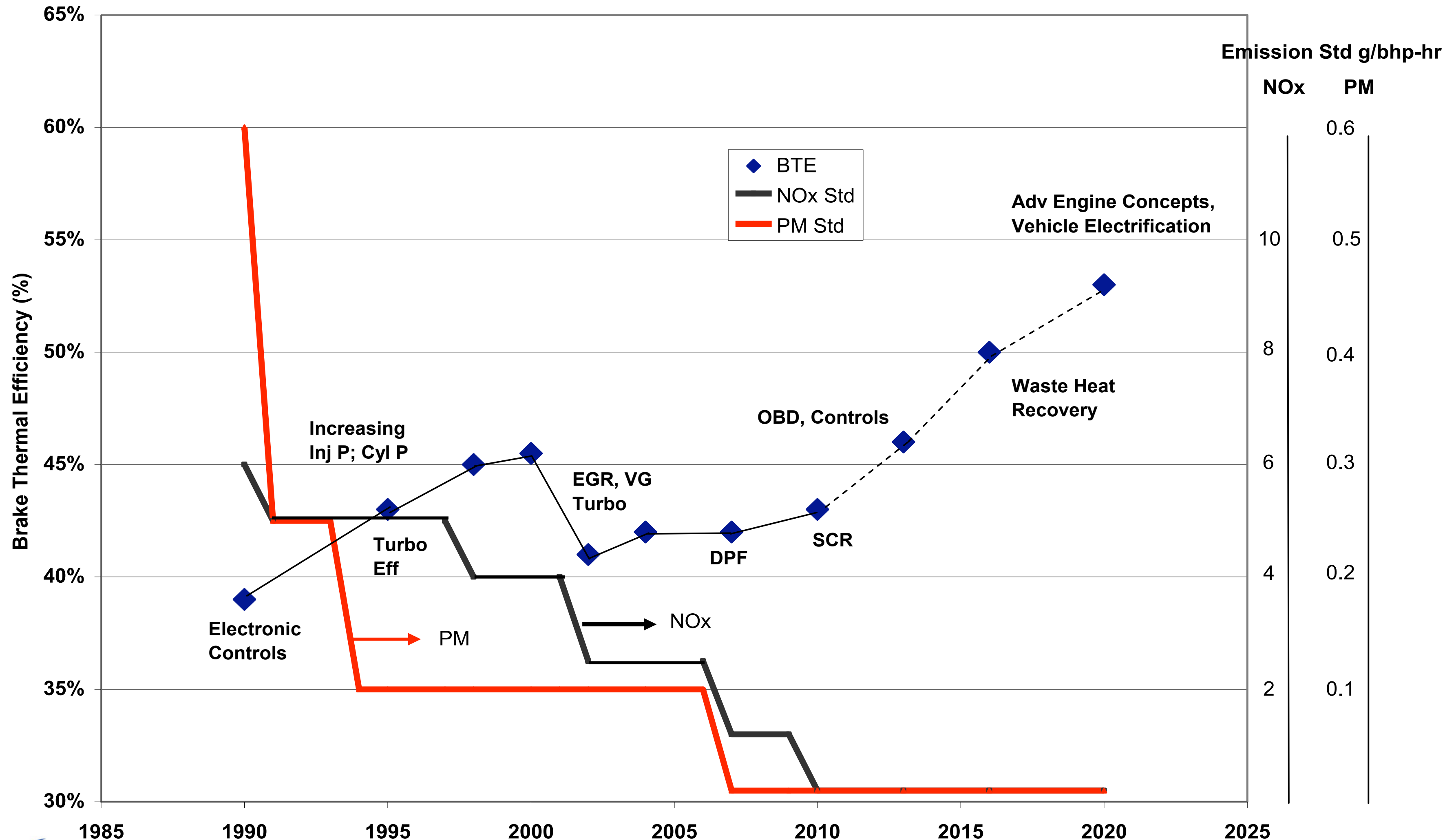
Other important factors affecting fuel consumption

Parameter	EU	US
C_d	<US	0.62-0.64
Trailer	13,6 m	53’ Std Box
Engine	11-15L	11-15L
Transmission	Automated manual	10 speed manual
Governed speed	90 kph	75 mph
GVW	40-44 mt	80,000 lb
Fuel consumption (L/100km)	30-35 L/100km	6.5 mpg (36 L/100km)
Fuel Price	1.3 €/L	$3.90/gal (0.75 €/L)

Long haul fuel economy has improved and held relatively constant with increasing emission regulations



US Fuel Economy Suffered with EGR Engines in 2000’s



Apply Fuel Savings Technologies to European Market Segments

Technology		Vehicle Segment							
		Service	Urban Delivery	Municipal Utility	Regional Delivery	Long Haul	Construction	Bus	Coach
Aerodynamics	Aft box taper		✓						
	Boat tail				✓	✓			
	Box skirts		✓						
	Cab side extension or cab/box gap fairings		✓						
	Full gap fairing				✓	✓			
	Full skirts				✓	✓			
	Roof deflector		✓						
	Streamlining	✓							✓
Lightweighting	Material substitution	✓	✓	✓	✓	✓	✓	✓	✓
Tires and Wheels	Automatic tire inflation on vehicle/tractor				✓	✓	✓		✓
	Automatic tire inflation on trailer				✓	✓			
	Low rolling resistance tires	✓		✓				✓	✓
	Low rolling resistance wide-base single tires		✓		✓	✓	✓		
Transmission and Driveline	Aggressive shift logic and early lockup	✓		✓				✓	
	Increased transmission gears	✓		✓				✓	
	Transmission friction reduction	✓		✓	✓	✓	✓	✓	✓
Engine Efficiency	Improved diesel engine	✓	✓	✓	✓	✓	✓	✓	✓
Hybridization	Dual-mode hybrid	✓			✓	✓			
	Parallel hybrid		✓				✓		✓
	Parallel hydraulic hybrid			✓					
	Series hybrid							✓	
Management	Predictive cruise control				✓	✓			

11 to 15L Engines

<table>
<tr><th>Engine Technology</th><th>2007 Baseline</th><th>2010 Engine</th><th>2013 Engine</th><th>2015 Engine</th><th>2015 to 2020 Package</th></tr>
<tr><td>Cylinder Pressure</td><td>190-210 Bar</td><td colspan="4">Increasing Cylinder pressure</td></tr>
<tr><td>Fuel system</td><td>1,800 to 2,200 Bar Common rail or 33K psi Unit Injector</td><td colspan="4">Common rail, multiple injections per cycle, Higher injection pressure</td></tr>
<tr><td>Emissions Control</td><td>Med-rate EGR, DPF w/ active regen</td><td>SCR, low-rate cooled EGR, DPF w/passive regen</td><td colspan="3">Improved cat conversion efficiency, advanced EGR</td></tr>
<tr><td>Aspiration</td><td>VG Turbocharger</td><td colspan="2">Improved VG Turbocharger</td><td colspan="2">E-Turbo</td></tr>
<tr><td>Engine Controls</td><td colspan="2">Open-loop</td><td>Closed-loop</td><td colspan="2">Improved Closed-loop</td></tr>
<tr><td>Waste-heat recovery</td><td colspan="2">None</td><td>Mech. Turbo-compound</td><td>Mech or Electric turbo-compound</td><td>Bottoming cycle</td></tr>
<tr><td>Accessories</td><td colspan="3">Belt-driven mech.</td><td>Var disp pumps -or- elec acc</td><td>Electric accessories</td></tr>
<tr><td>Weight</td><td>2,200 to 3,100 lbs</td><td>+400 lbs</td><td>+450 lbs</td><td>Similar to 2013</td><td>+750 lbs</td></tr>
<tr><td>Peak Efficiency</td><td>41 to 42 %</td><td>43.2 to 44.2%</td><td>45.5 to 47.5%</td><td>47.9 to 51.4%</td><td>50.6 to 53.5%</td></tr>
<tr><td>Package Cost</td><td>-</td><td>$10K</td><td>$14K</td><td>$16.5K</td><td>$23.5K</td></tr>
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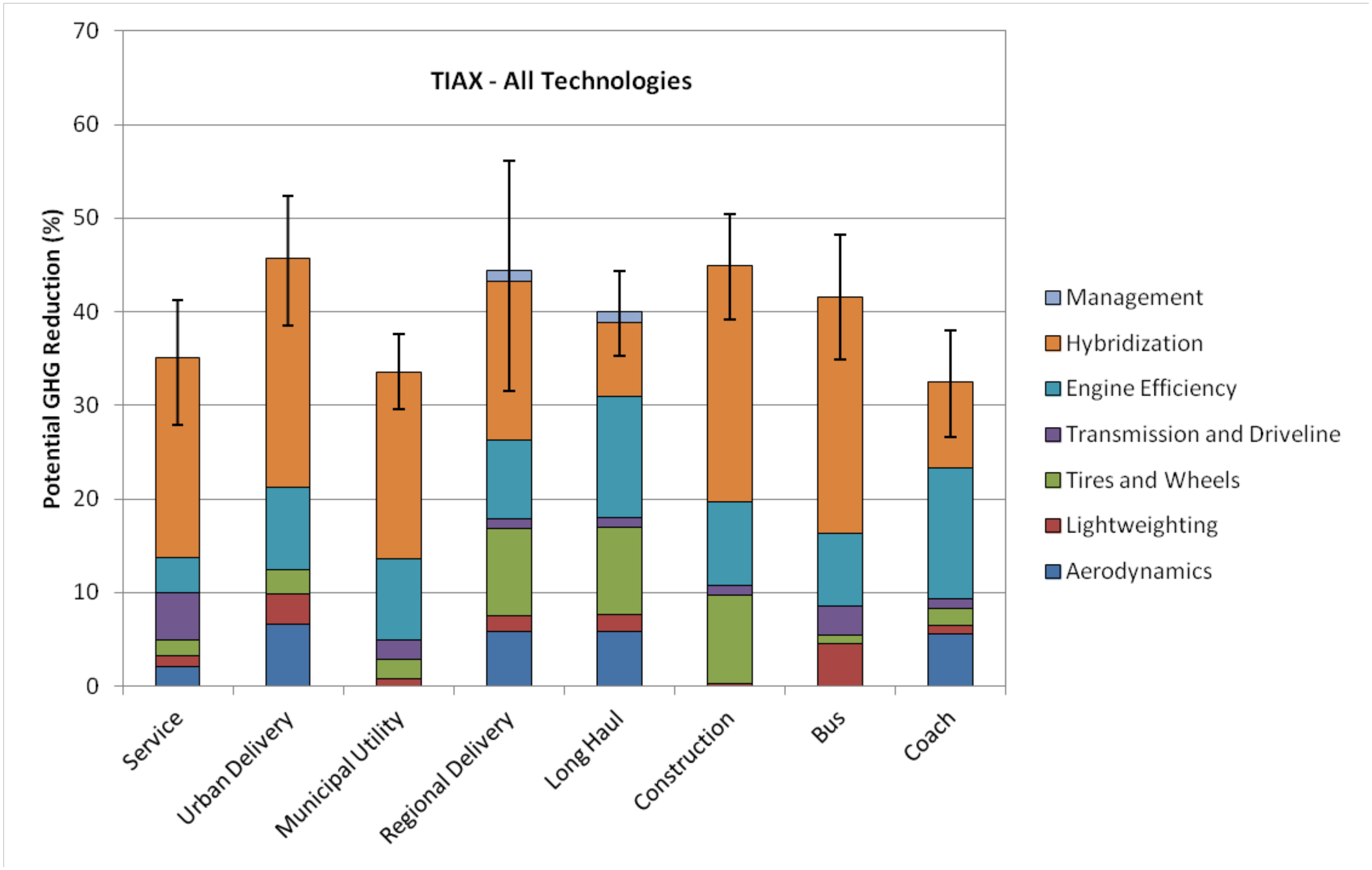
Improved tractor and trailer aerodynamics

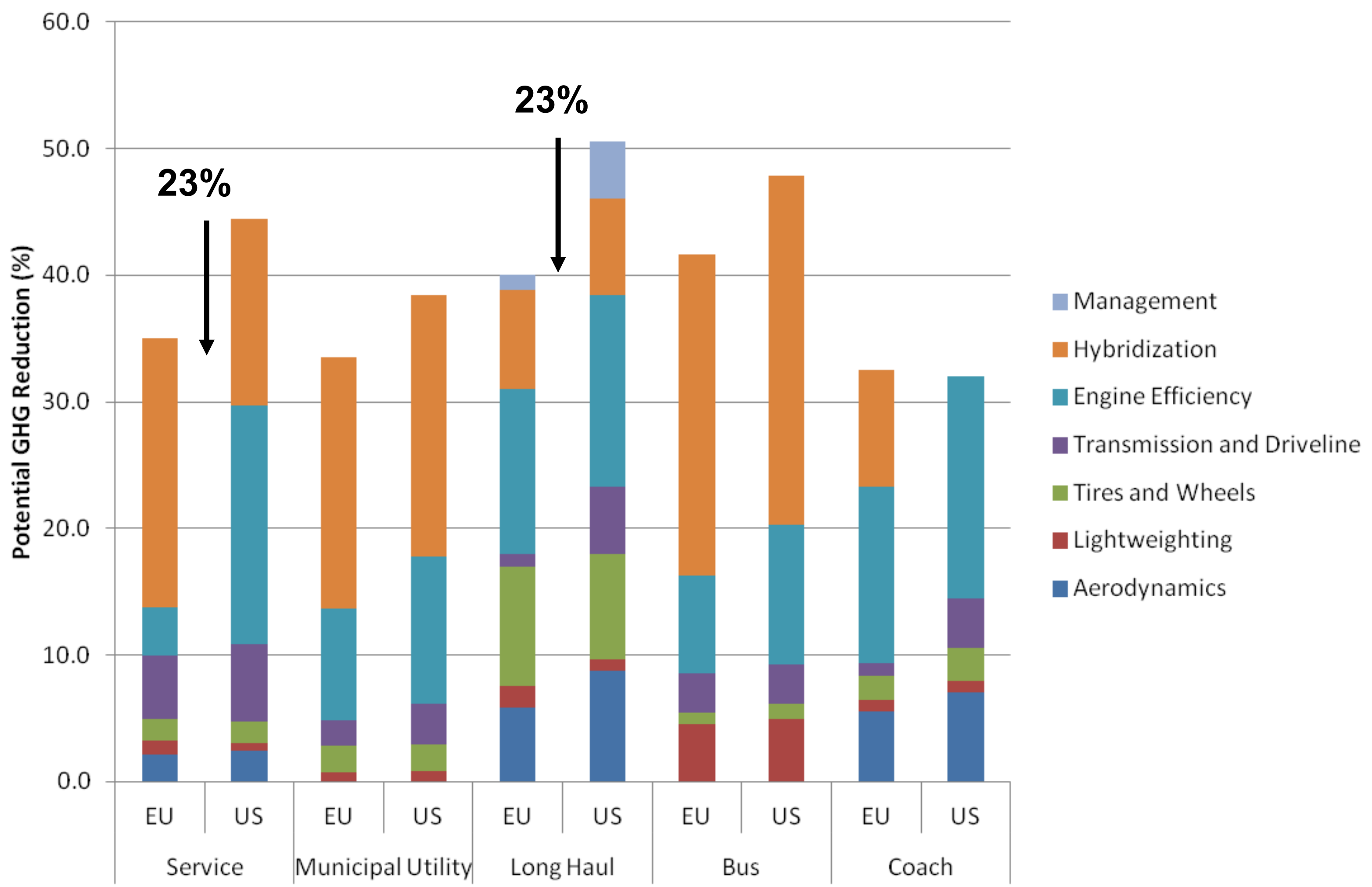
Substantial GHG reductions possible across all EU market segments



Comparison of EU results to NAS results

- Assume Long Haul EU technologies compared to NAS baseline TT
  - Aerodynamics Lower Speeds
    - Reduced from 105 to 90 kph; -0.3% fuel savings/kph
    - Fuel savings of 5%
  - Engine aftertreatment EGR and DPF (without SCR)
    - Fuel savings of 6%
  - Transmission and driveline
    - 4x2 tractor configuration and AMT
    - Fuel savings of 7%
  - Tractor and Trailer wheels and tires
    - Fuel savings of 3%
  - Total estimated EU Long haul vs. NAS TT fuel savings 19%
- Assumed service segment EU technology compared to NAS baseline
  - Replace gasoline with diesel engine
  - Fuel savings 19-24%

Estimated EU GHG reductions lower due to market penetration of fuel savings technology



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- Like the U.S. the EU has the potential to substantially reduce GHG emissions from heavy-duty vehicles
  - Off the shelf diesel technology exists with reasonable economics
  - Use of alternative fuels can also contribute to lower GHG emissions
- For most HDV segments powertrain improvements proves significant savings
  - Engine improvements
  - Hybridization for vocational or stop and go duty cycles
- Aerodynamics of entire vehicle important for long haul and duty cycles that have extended high speed driving
  - Need to improve both tractor and trailer
- The long haul, regional delivery, service, and bus/coach segments account for 83% of total HDV fuel consumption and therefore have the largest leverage
  - Segments also have common vehicle configurations
- Even at high fuel prices in Europe, GHG reductions will require regulations to move fuel savings technologies into the market

Thank you for your attention

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