Reducing Heavy-Duty Vehicle CO2 Emissions: Ways and Scope

Impact Assessment on a Strategy for Reducing Heavy-Duty Vehicle (HDV) CO2 Emissions

European Commission--Climate Action
Stakeholders Consultation Meeting
Borschette Centre Room AB-OA
Brussels, Belgium
February 22, 2012

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1. TIAX Study
2. Vehicle Segments
3. Technologies and Possible Impacts
4. Closing Remarks

1	TIAX Study
2	Vehicle Segments
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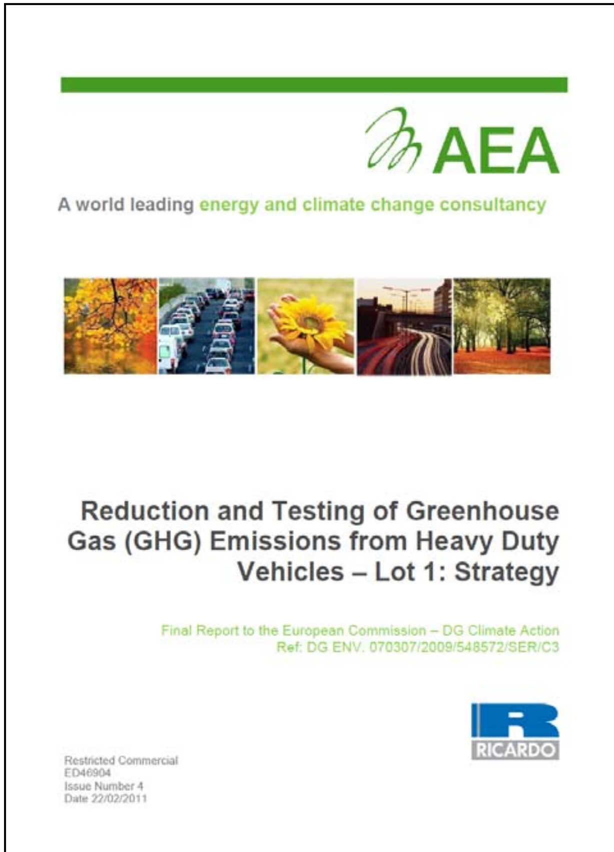
TIAX role to review and compare Lot 1 study to U.S. NRC study results


AEA

A world leading energy and climate change consultancy

Reduction and Testing of Greenhouse Gas (GHG) Emissions from Heavy Duty Vehicles – Lot 1: Strategy

Final Report to the European Commission – DG Climate Action
Ref: DG ENV. 070307/2009/548572/SER/C3

RICARDO

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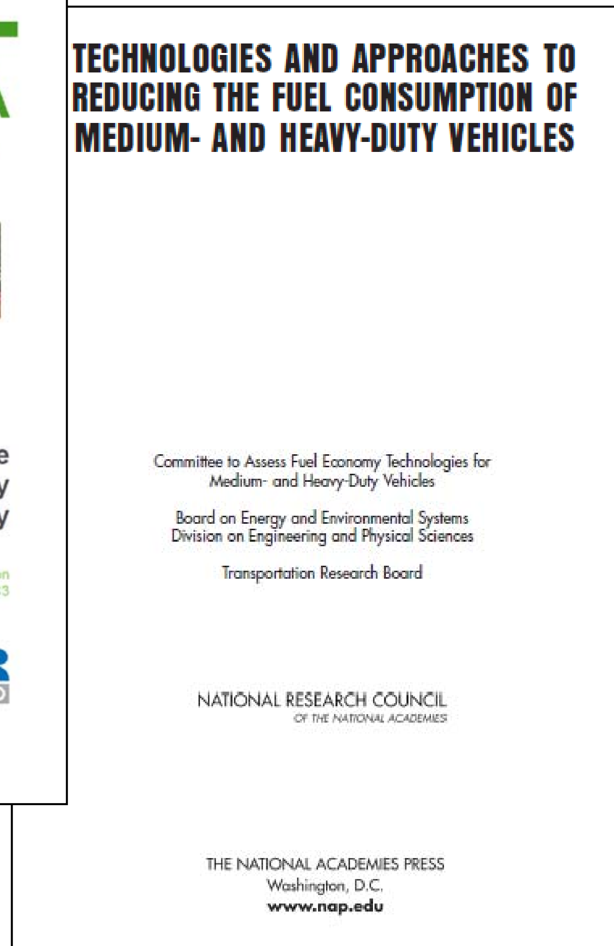
TECHNOLOGIES AND APPROACHES TO REDUCING THE FUEL CONSUMPTION OF MEDIUM- AND HEAVY-DUTY VEHICLES

Committee to Assess Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles

Board on Energy and Environmental Systems
Division on Engineering and Physical Sciences

Transportation Research Board

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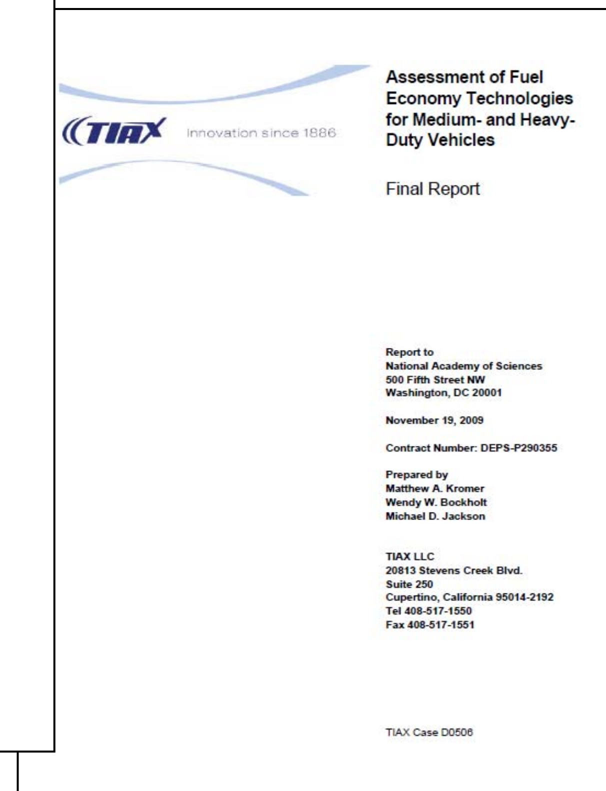
TIAX Innovation since 1886

Assessment of Fuel Economy Technologies for Medium- and Heavy-Duty Vehicles

Final Report

Report to
National Academy of Sciences
500 Fifth Street NW
Washington, DC 20001

November 19, 2009

Contract Number: DEPS-P290355

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TIAX Case D0506

Overall objectives and approach

- Examine the data and assumptions used by AEA-Ricardo to estimate GHG reduction potential of heavy duty vehicles in European Union
- Make use of previous U.S. work performed by National Research Council (NRC)/National Academy of Sciences (NAS) on reducing fuel consumption from medium and heavy duty vehicles
- Account for differences in U.S. and EU and then apply fuel savings technologies to specific heavy duty vehicles representative of specific segments
  - Segments defined by AEA-Ricardo but closely match comparable U.S. segments (in most cases)
- Compare TIAX fuel saving technologies by vehicle application to AEA-Ricardo results
- Estimate GHG reductions possible by rolling up on a segment basis new vehicle GHG reductions and compare to AEA-Ricardo fleet methodology
- Study funded by International Council on Clean Transportation (ICCT)
- Results published in "European Union Greenhouse Gas Reduction Potential for Heavy-Duty Vehicles," K. Law, M. Jackson, M. Chan, December 23, 2011

http://ec.europa.eu/clima/policies/transport/vehicles/heavy/docs/icct_ghg_reduction%20_potential_en.pdf

TIAX's approach and analysis focuses on characterizing fuel-efficient technologies and not operations, logistics, or productivity

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
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
Productivity Increase the use of longer & heavier vehicles	•Not included	

Commercial truck sector in EU and U.S. complex

- Service 3.5-7.5 mt
  fuel consumption 28-10 L/100km
- Urban Delivery 7.5->20mt
  fuel consumption 26.6-16.6 L/100km
- Municipal Utility
- Regional Haul 7.5-50 mt
  fuel consumption 36-16.6 L/100km
- Long Haul 16-40+ mt
  fuel consumption 38.3-26.6
- Construction 7.5-40+ mt
  fuel consumption 36-26
- Bus/Coach <15 to > 18 mt
  fuel consumption 94-16 L/100km










Energy Use/GHG emissions similar across EU and US segments

EU Vehicle Segment	EU GHG Emissions by Segment (%)	US % 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

TT Tractor Trailer

Reducing HDV CO_2 Emissions *Vehicle Segments*

Urban Delivery	EU	US
Example	 DAF LF45	 Kenworth T270
Engine displacement (L)	6.7	6.7
Transmission	6-speed manual	6-speed manual
Engine*	Diesel: 190 to 200 bar cylinder pressure, common rail fuel injection (2,000 bar), multiple injections per cycle, electrically actuated variable geometry turbocharger, open-loop emission controls, peak thermal efficiency 42 to 43%	Diesel: 190 to 200 bar cylinder pressure, common rail fuel injection (2,000 bar), multiple injections per cycle, electrically actuated variable geometry turbocharger, open-loop emission controls, peak thermal efficiency 42 to 43%
Emissions control	Euro VI: EGR+DPF+SCR	EPA 2010: EGR+DPF+SCR
Vehicle configuration	Integrated air dam, cab side edge turning vanes	Aerodynamic styled cab including rounded bumper and air dam
Segment Characteristics:		
GVWR (lb)	16,535 to 30,865	16,001 to 26,000
GVWR (kg)	7,500 to 14,000	7,257 to 11,793
Annual activity (mi)	24,855 (average)[†]	20,000 to 75,000[‡]
Annual activity (km)	40,000 (average)[†]	32,187 to 120,701[‡]
Fuel economy (mi/gal)	11.2 (average)[†]	5 to 12[‡]
Fuel consumption (L/100km)	21.0 (average)[†]	20 to 47[‡]

Analysis considered differences in vehicle technologies between EU and U.S. e.g. cabover vs. conventional tractor

MAN TGX

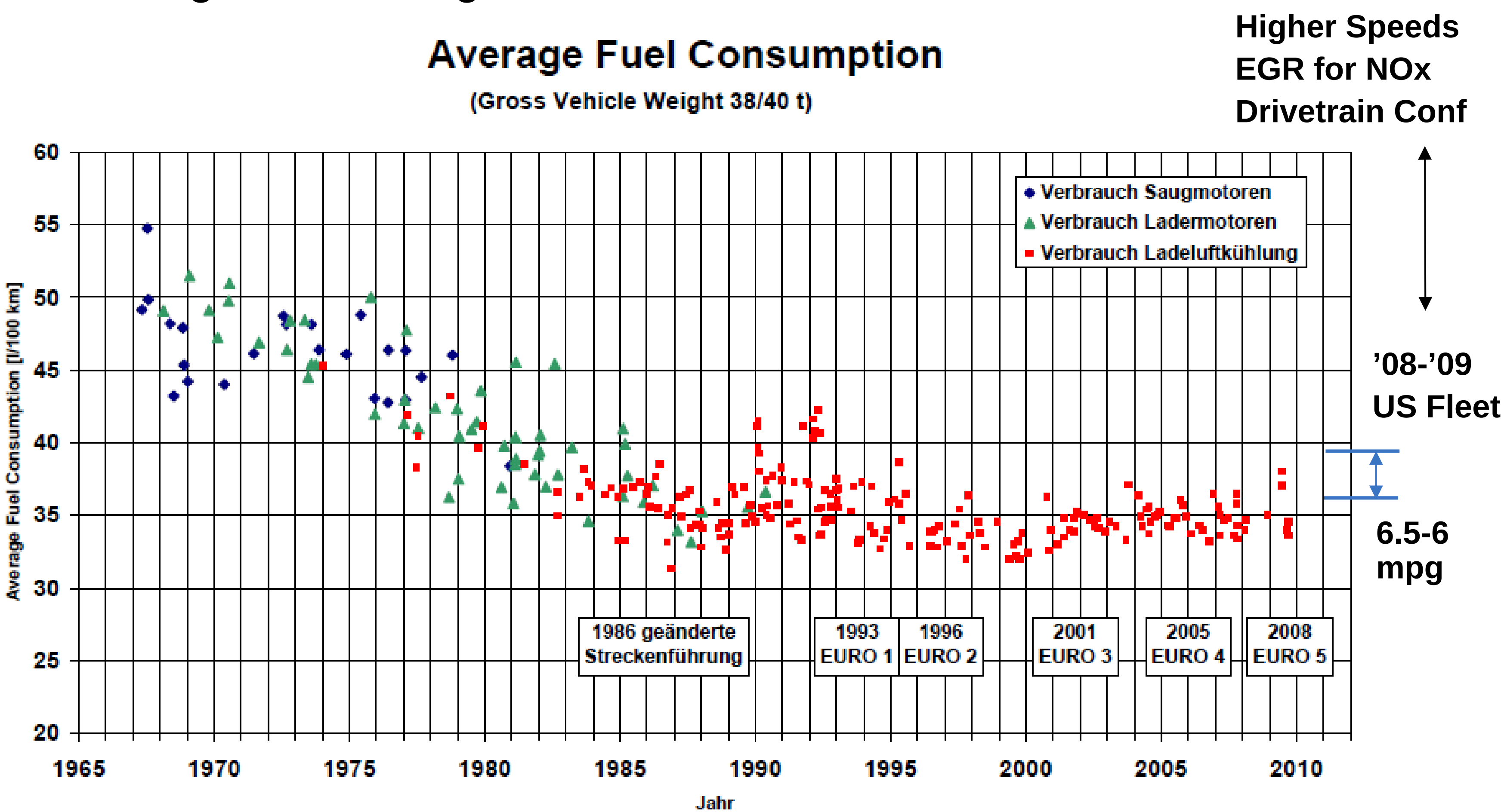
Peterbilt 386

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

Other important factors affecting fuel consumption

Parameter	EU	US
C_d (aero drag coefficient)	~US	0.62-0.64
Trailer	13.6 m	53' Std Box (16.2 m)
Engine	11-15L	11-15L
Transmission	Automated manual	10 speed manual
Governed speed	90 kph	75 mph (120kph)
GVW (gross vehicle weight)	40-44 mt	80,000 lb (36 mt)
Fuel consumption (L/100km)	30-35 L/100km	6-6.5 mpg (36-39 L/100km)
Fuel Price	1.3 €/L	$3.90/gal (0.75 €/L)

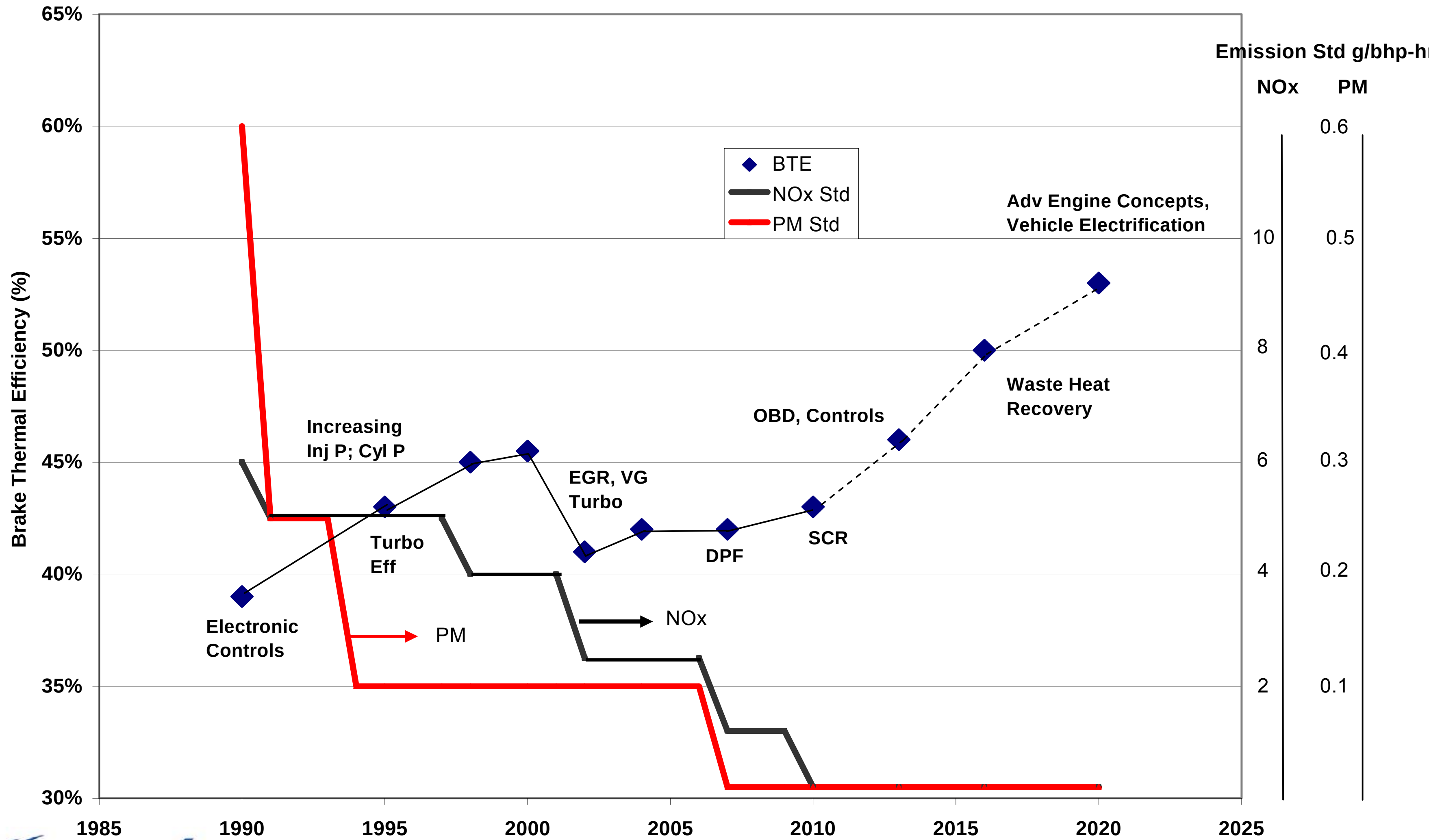
Long haul fuel economy has improved and held relatively constant with increasing emission regulations



Source: Lastauto Omnibus
Testreports 1967 - 2009

Status: 10/2009

Future engine improvements will focus on better fuel economy



TIAX

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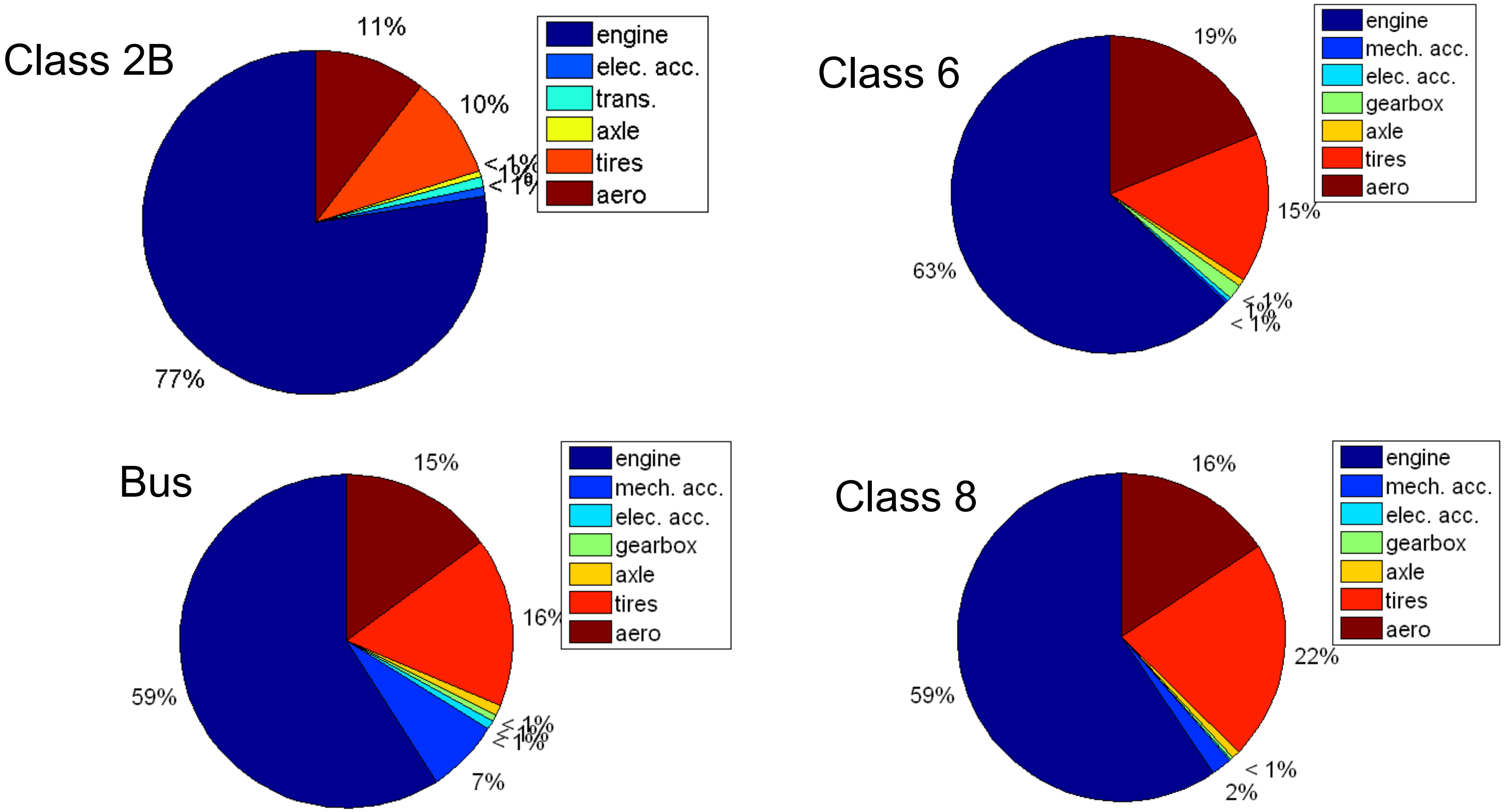
Major Sources of Information and Data for TIAX NAS Study

- **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:** University of Michigan Transportation Research Institute (UMTRI) LCV Conference
  - **NAS Committee Meetings:** Con-Way, Aluminum Assoc, and others
  - **Testing Organizations:** Auto Research Center and Transportation Research Center
- **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

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



Vehicles at GVWR and 50 mph Steady State Speed

AEA-Ricardo and TIAX analyses included wide range of possible fuel efficiency improvements

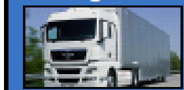
Technology Category	TIAX	AEA-Ricardo
Aerodynamics	Streamlining for service segment and only trailer aerodynamics considered for tractor-trailer combinations*	Streamlining, trailer aerodynamics, and spray reduction mud flaps considered
Lightweighting	Material substitution to achieve certain levels of weight reductions	Level of weight reduction not necessarily specified
Tires and wheels	Low rolling resistance tires, wide-base tires, and automatic tire pressure adjustment considered	Low rolling resistance tires, wide-base tires, and automatic tire pressure adjustment considered
Transmission and driveline	Technologies applied to automatic, manual, and automated manual transmission baselines	All baselines assumed to use manual transmissions
Engine efficiency	Engine improvement packages considered, with higher cylinder and fuel injection pressures, advanced turbocharger geometries, improved controls, heat recovery, electrification of accessories, and higher peak thermal efficiencies	Controllable air compressor, electrical turbocompound, and heat recovery considered; all other engine improvements captured as natural powertrain improvements over time (separate from specific technology options)
Hybridization	Electric and hydraulic hybridization considered	Electric, hydraulic, pneumatic booster, and flywheel hybridization considered
Management	Predictive cruise control and driver aids (route management, training and feedback) considered	Predictive cruise control and driver aids considered

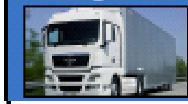
Improved tractor and trailer aerodynamics

Technologies identified and applied in each market segment to estimate fuel consumption savings and costs

- Apply technologies to vehicle type most representative of vehicle segment (simplifying assumption)
- Compared our assumptions on fuel consumption benefit and technology costs by vehicle to those of AEA-Ricardo. Our benefits scaled back for lower EU speeds
- Following shows example for tractor trailer vehicle configuration. Report shows technology comparisons for the other vehicle applications:
  - Service
  - Urban Delivery
  - Municipal Utility
  - Regional delivery
  - Construction
  - Bus
  - Coach

Reducing HDV CO2 Emissions *Technologies and Possible Impacts*

Long Haul 	Technology	Fuel Consumption Benefit (%)	Cost (2010€)	Added Weight	Included in AEA-Ricardo Combined Package?	Source
Aerodynamics	Boat tail	2 to 4	1,345	—	—	TIAX/NAS
	Full gap fairing	1 to 2	961	—	—	TIAX/NAS
	Full skirts	2 to 3	2,306	—	—	TIAX/NAS
	Aerodynamic trailers	*11*	*3,500*	—	*Yes*	*AEA-Ricardo*
	Aerodynamic fairings	*0.4*	*1,180*	—	*Yes*	*AEA-Ricardo*
	Spray reduction mud flaps	*3.5*	*14*	—	*Yes*	*AEA-Ricardo*
Lightweighting	Material substitution – 990 lb (450 kg)	2.2	2,283	-990 lb (-450 kg)	—	TIAX/NAS
	Lightweighting	*2.2*	*1,600*	—	*Yes*	*AEA-Ricardo*
Tires and wheels	Next generation low rolling resistance wide-base single tires with aluminum wheels (2)	9 to 12	346	-200 lb (-91 kg)	—	TIAX/NAS
	Automatic tire inflation on trailer	0.6	269	—	—	TIAX/NAS
	Automatic tire inflation on tractor	0.6	3,459	—	—	TIAX/NAS
	Low rolling resistance tires	*5*	*350*	—	*Yes*	*AEA-Ricardo*
	Single wide tires	*5*	*1,300*	—	*Yes*	*AEA-Ricardo*
	Automatic tire pressure adjustment	*3*	*11,790*	—	*Yes*	*AEA-Ricardo*
Transmission and driveline	Transmission friction reduction	1 to 1.5	192	—	—	TIAX/NAS
	Automated manual	*1.5*	*4,716*	—	*No*	*AEA-Ricardo*
Engine efficiency	Advanced 11-15L engine (240 bar cylinder pressure, 4,000 bar super-critical atomization fuel injection, electrically boosted variable geome-try turbocharger, improved closed-loop engine controls, bottoming cycle, electric accessories, peak thermal efficiency 51 to 53%)*	14.6 to 17.9	10,415	250 lb (113 kg)	—	TIAX/NAS
	Controllable air compressor	*1.5*	*190*	—	*Yes*	*AEA-Ricardo*
	Electrical turbocompound	*3*	*7,000*	—	*Yes*	*AEA-Ricardo*
	Heat recovery	*5*	*11,570*	—	*Yes*	*AEA-Ricardo*
	Powertrain natural improvement	*6.2*	—	—	*Yes*	*AEA-Ricardo*

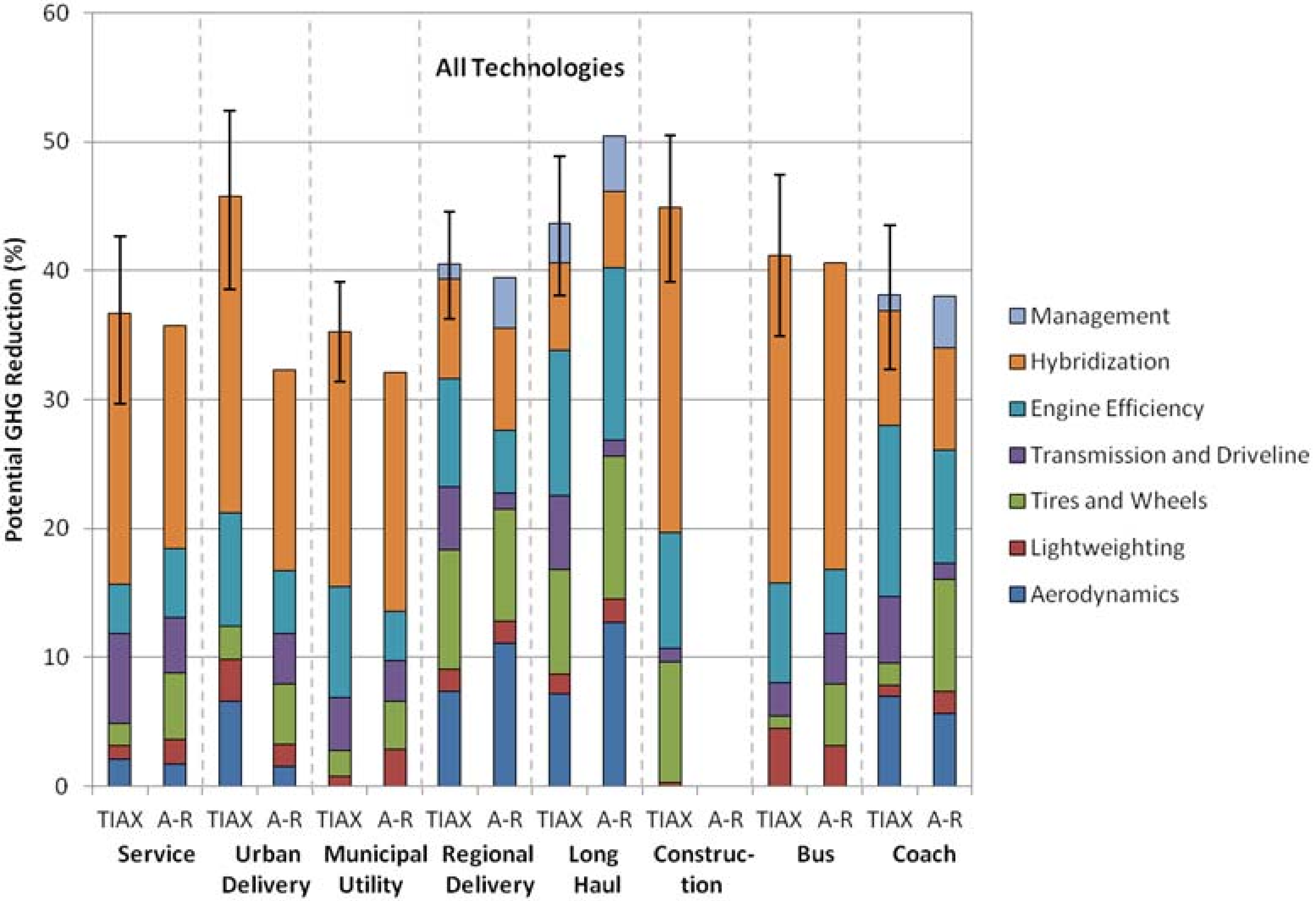
Long Haul 	Technology	Fuel Consumption Benefit (%)	Cost (2010€)	Added Weight	Included in AEA-Ricardo Combined Package?	Source
Hybridization	Gen II dual hybrid with all electric capability, electrified accessories, overnight hotel loads, engine-off at idle	8 to 12	21,137	750 lb (340 kg)	—	TIAX/NAS
	Pneumatic booster, air hybrid	*3.5*	*800*	—	*No*	*AEA-Ricardo*
	Stop/start system	*1*	*940*	—	*No*	*AEA-Ricardo*
	Full hybrid (electric)	*7*	*24,000*	—	*Yes*	*AEA-Ricardo*
	Flywheel hybrid	*5*	*5,900*	—	*No*	*AEA-Ricardo*
	Alternative fuel bodies	*15*	*14,000*	—	*No*	*AEA-Ricardo*
Management	Predictive cruise control	1 to 2	77	—	—	TIAX/NAS
	Route management	0 to 1	461	—	—	TIAX/NAS
	Training and feedback	1 to 4	615	—	—	TIAX/NAS
	Predictive cruise control	*5*	*1,400*	—	*Yes*	*AEA-Ricardo*
	Vehicle improvements using driver aids	*10*	—	—	*Yes*	*AEA-Ricardo*
Fuel efficiency improvements between 2010 and 2014 (baseline)		10	—	—	—	TIAX/NAS
	Total combined package, TIAX**	**47 (41 to 52)**	**43,866**			
	Total combined package, AEA-Ricardo**	***50***	***63,894***			

Baseline 2010 fuel economy assumptions for each average vehicle

Vehicle Segment		2010 EU Fuel Economy	2014 EU Fuel Economy	% Improvement
Service	mi/gal		14.7	
	L/100 km	16.4	16	2.5% *
Urban Delivery	mi/gal		11.2	
	L/100 km	21	21	0.0%
Municipal Utility	mi/gal		4.3	
	L/100 km	56.6	55.2	2.5% *
Regional Delivery	mi/gal		9.3	
	L/100 km	27.2	25.3	6.9% **
Long Haul	mi/gal		7.7	
	L/100 km	34	30.6	10% **
Construction	mi/gal		8.8	
	L/100 km	26.8	26.8	0%
Bus	mi/gal		6.5	
	L/100 km	36.9	36	2.5% *
Coach	mi/gal		8.5	
	L/100 km	29.8	27.7	7% **

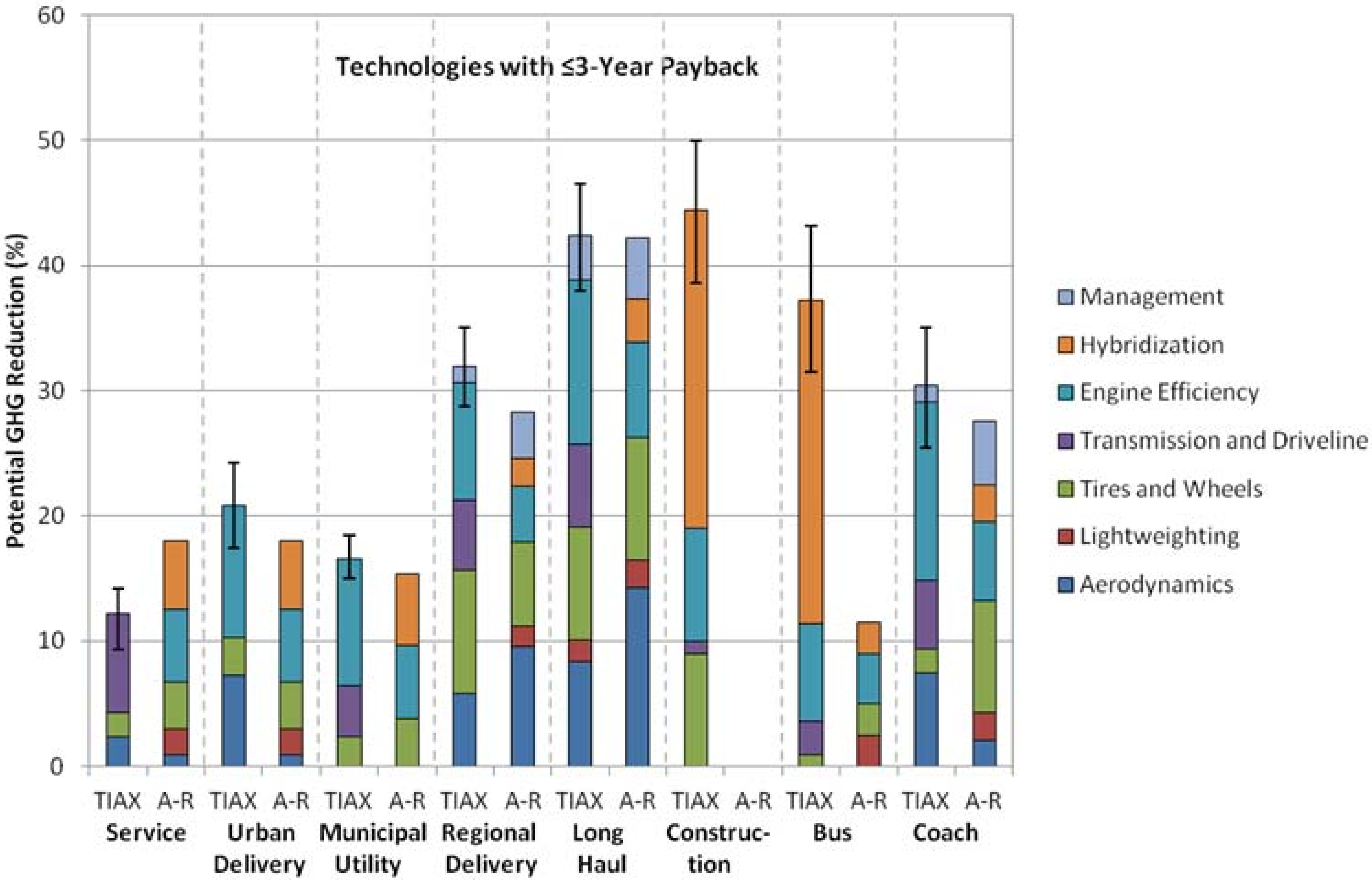
2014 engines meet Euro VI standards
***automatic transmission**
****automatic manual transmission and aerodynamics**

Substantial GHG reductions possible across all end use sectors



greater benefits from hybridization, engine efficiency, and transmission and driveline improvements that were estimated in this study

For 3 yr payback or less, GHG reductions decrease in vehicle segments that use less fuel or have relatively higher cost technologies



Both TIAX and AEA-Ricardo estimated the GHG emissions reductions possible in 2030

- Several scenarios where consider by TIAX and AEA-Ricardo
  - AEA-Ricardo: challenging, cost effective
  - TIAX: all technologies, 3 year payback
- Key to these estimates are assumptions regarding
  - Technology uptake (either market or regulation driven)
  - Vehicle turnover rate
  - Vehicle populations and future growth
- TIAX made the following assumptions
  - All technologies required in all new vehicles starting in 2020 or only technologies meeting 3 year payback are adopted in all new vehicles starting in 2020
  - GHG emission reductions in 2030 limited by vehicle turnover in each segment

Segment penetration of new vehicle technologies limited by vehicle turnover as estimated by fraction of vehicle kilometers traveled by 2030

Vehicle Segment	Fraction of Total VKT in 2030 from Vehicles with Advanced Technology Packages (%)*
Service	75%
Urban Delivery	75%
Municipal Utility	75%
Regional Delivery	80%
Long Haul	80%
Construction	75%
Bus	75%
Coach	80%

Summary of TIAX 2030 GHG emission reductions with all technologies

Vehicle Segment	2010*		2030, Projected*		2030 Emissions Reduction, Assuming All Applicable Technologies (million tonnes)	2030 Emissions Relative to 2030 BAU Levels, Assuming All Applicable Technologies (%)
	Population (million vehicles)	**CO_2e Emissions** (million tonnes)	**Population** (million vehicles)	**BAU CO_2e Emissions** (million tonnes)		
Service	1.90	35	2.60	48	11	76%
Urban Delivery	0.45	12	0.55	15	4	71%
Municipal Utility	0.40	15	0.60	23	5	79%
Regional Delivery	1.20	40	1.75	58	15	74%
Long Haul	2.00	100	2.60	130	39	70%
Construction	1.00	30	1.25	38	12	67%
Bus	0.45	25	0.44	24	6	75%
Coach	0.40	18	0.30	14	3	75%
All Segments	**7.80**	**275**	**10.09**	**349**	**96**	**72%** (28% reduction)

AEA-Ricardo used a fleet model to estimate 2030 GHG emissions

- AEA-Ricardo approach consisted of
  - Estimating “organic” improvements in vehicle/engine technology
  - Estimating negative effects of implementing vehicle/engine standards
  - Estimating technology adoption roll in percentages based on technology costs/payback period
  - Technology adoption started immediately

	TIAX	AEA-Ricardo
Fuel economy projections	• No underlying fuel economy changes over time (i.e., all fuel economy increases result directly from application of specific technologies)	• Natural powertrain improvements ranging from 0 to 0.5% from previous year • Fuel consumption improvements ranging from 0 to 0.5% from previous year • Fuel consumption penalties ranging from 0 to 3% from previous year
Market uptake model	• Application of technology packages to all new vehicles starting in 2020 • No uptake percentages specified, uptake in 2030 depends on vehicle turnover within each segment, as defined by average vehicle lifetime	• Application of individual technologies to vehicles at specified uptake rates • Uptake percentages by year for new vehicles and HDV fleet, ranging from 0 to 80% in 2010 and 0 to 100% in 2030 across segments

Comparison of TIAX and AEA-Ricardo 2030 GHG emission reductions

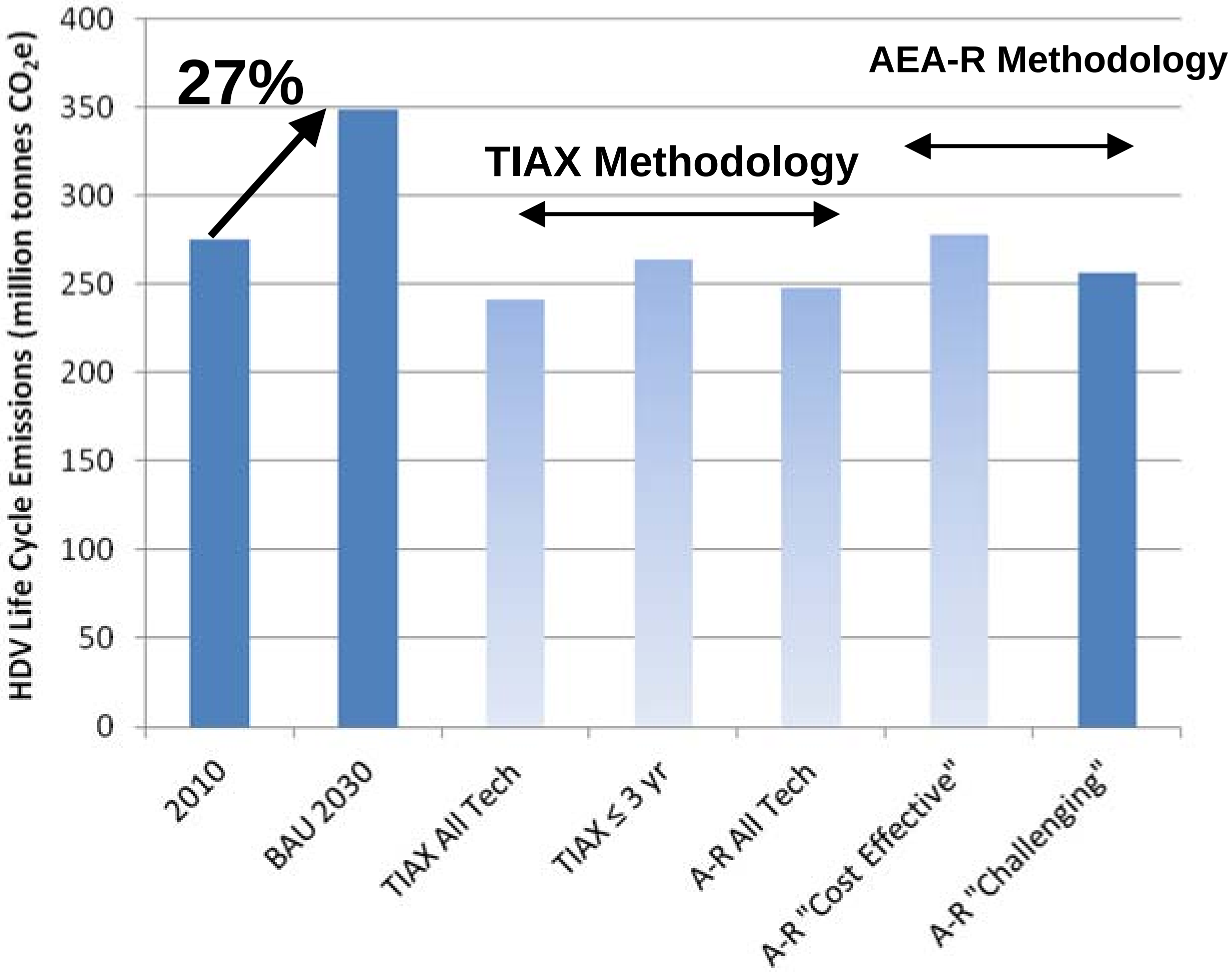
Vehicle Segment	2010 Population (million vehicles)	2010 CO_2e Emissions (million tonnes)	Projected 2030 Population (million vehicles)	2030 BAU CO_2e Emissions (million tonnes)	2030 Emissions Reduction, Assuming All Applicable Technologies (million tonnes)		2030 Emissions Relative to 2030 BAU, Assuming All Applicable Technologies (%)		2030 Emissions Reduction, Assuming Only Technologies with ≤3 Year Payback (million tonnes)		2030 Emissions Relative to 2030 BAU, Assuming Only Technologies with ≤3 Year Payback (%)	
					TIAX	A-R	TIAX	A-R	TIAX	A-R	TIAX	A-R
Service	1.90	35	2.60	48	11	11	76%	77%	4	6	92%	88%
Urban Delivery	0.45	12	0.55	15	4	3	71%	80%	2	2	87%	89%
Municipal Utility	0.40	15	0.60	23	5	4	79%	81%	2	2	90%	91%
Regional Delivery	1.20	40	1.75	58	15	15	74%	75%	12	11	80%	82%
Long Haul	2.00	100	2.60	130	39	45	70%	65%	35	38	73%	71%
Construction	1.00	30	1.25	38	12	Unknown	67%	Unknown	12	Unknown	68%	Unknown
Bus	0.45	25	0.44	24	6	6	75%	76%	5	2	78%	93%
Coach	0.40	18	0.30	14	3	3	75%	75%	3	2	80%	82%
All Segments	**7.80**	**275**	**10.09**	**349**	**96**	**88**	**72%**	**75%**	**75**	**62**	**78%**	**82%**

A-R: AEA-Ricardo BAU Business as usual

261 vs. 256

287 vs. 278

Large GHG emission reductions from HDV are possible in 2030 timeframe



Several observations regarding 2030 GHG estimates

- AEA-Ricardo estimates 1.2% annual growth in HDV fuel consumption and GHG emissions
- Not much difference in results of either TIAX or AEA-Ricardo analyses even thought methodologies quite different. Also not much difference in reductions from the cost effective/≤ 3 yr payback and challenging/all technology scenarios
- Both AEA-Ricardo and TIAX analysis focused on fuel efficiency technologies and not fuel technologies. Additional reductions possible with alternative fuels such as natural gas, biodiesel, and electricity
- Technology costs may still be too high for adoption, but some reasons for optimism with many of the advanced technologies starting to enter the light duty vehicle market. This will provide learning and scale. Also, world demand for diesel fuel is only going to increase resulting in continuing upward price pressure

- 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

GHG emission reductions needs to account for the large diversity of vehicles and end use applications

Vehicle Segment	GHG Emissions by Segment (%)
Service	13
Urban Delivery	4
Municipal Utility	5
Regional Delivery	15
Long Haul	36
Construction	11
Bus	9
Coach	7

- Vehicle and engine technologies grouped around like duty cycles/work performed and like vehicle configurations

GHG emission reductions will depend on a number of factors

- Availability and cost effectiveness of technologies
- Start of regulation and vehicle segments covered
- Fleet turn over
  - Normal
  - Accelerated
- Technology trajectory especially for hybridization
  - Full vs. partial systems
- Include fuel and vehicle technologies
  - Low carbon conventional fuels
  - Alternative fuels

Thank you for your attention

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