International HDV efficiency policy and technology potential

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HDV Global vehicle emission standards landscape

- The majority of policy driven technology developments in HDV to date are due to tightening emissions regulations
- Most major markets are on a pathway to Euro VI equivalent emissions standards for HDVs

* US 2007 PM limits are equivalent to Euro VI; there is a Euro V compliance option for buses operatig outside Santiago Metropolitan Region

HDV Global fuel efficiency standards landscape

- Four countries in the world currently have HDV CO2/efficiency standards (10 countries/regions have LDV standards)
- Standards are not harmonized or equivalent (differences include stringency levels, segments covered, technologies covered)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Japan				Phase 1										Phase 2
U.S.			Phase 1					Phase 2						
Canada			Phase 1					Phase 2						
China	Phase 1		Phase 2						Phase 3					
EU						Certification, Monitoring, Reporting								
India									Phase 1					
Mexico									Phase 1					
S.Korea									Phase 1					

Hashed areas represent unconfirmed projections of the ICCT

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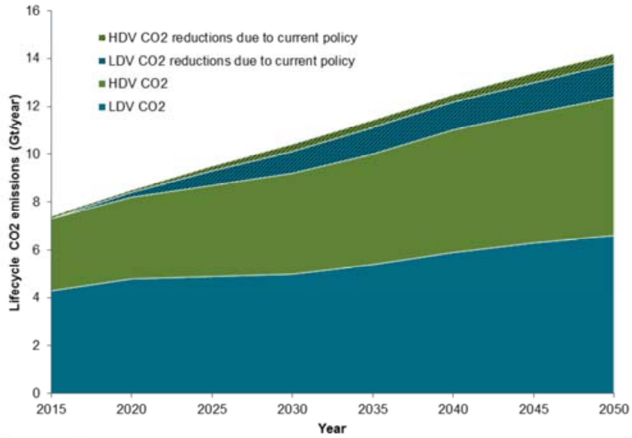
Significance of HDV CO_2 for the on-road sector

- Current global scenarios: HDVs responsible for approximately 45% of on-road CO2 emissions over the next 35 years, HDV standards responsible for less than 25% of CO2 reduction from on road vehicles over the next 35 years
- Current LDV efficiency standards cover over 83% of global sales (47% of sales are covered for HDVs)



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Source: ICCT Roadmap Model

Project methodology

- Objective:
  - Conduct technical analysis to eventually incorporate HDV technology potential into GFEI targets.
- Methodology:
  - **Select representative vehicles.**
    - Five markets: Brazil, China, EU, India, and US.
    - Two segments: tractor-trailer and rigid trucks (these two segments cover the vast majority of on-road freight hauling).
  - **Gather engine and vehicle data to create a baseline.**
    - Engine maps
    - Vehicle parameters (tires, aerodynamics, mass, etc.)
    - Operation (speed profile, grade, payload)
  - **Simulate technology potential of known technologies**
    - "End point" technology packages equivalent to US SuperTruck (advanced technology demonstration project) technology level
    - This analysis does not include "future" zero emissions technology (significant electrification or fuel cell)
  - **Map remaining world markets**
    - To the most appropriate market
    - Use ICCT roadmap model to estimate sales-weighted reductions that are possible.

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Typical tractor-trailer characteristics in each region

	Brazil	China	Europe	India	US
Gross vehicle weight (tonnes)	36	40	40	40	36
Vehicle curb weight (tonnes)	16.7	15	14.5	13	14.7
Maximum payload (tonnes)	19.3	25	25.5	27	21.3
Volume capacity (m^3)	135	84	93	110	112
Axle configuration	6x2	6x4	4x2	4x2	6x4
Trailer axle number	3	3	3	3	2
Engine Displacement (liters)	13	10	12.8	5.9	15
Engine power (kW)	324	250	350	134	340
Transmission type	AMT	MT	AMT	MT	MT
Transmission gears	12	10	12	6	10
Transmission gear ratios	11.32-1	14.8-1	14.9-1	9.19-1	12.8-0.73
Rear axle ratio	4.38	4.11	2.64	6.83	3.7
Tire size	295/80R22.5	12R22.5	315/80R22.5	10R20	295/75R22.5
Engine criteria pollutant emission standard/vehicle fuel efficiency standard	Proconve 7	China IV	Euro VI	Bharat III	EPA 2010
Vehicle fuel efficiency standard	NA	Stage 2	NA	NA	GHG 2014

Duty cycles, payloads, and other assumptions

- Payloads and duty cycles listed below (kept constant throughout years of analysis)
- Assume no significant change to vehicle configuration, engine size
- Assume no significant change to logistics, infrastructure, etc

		Duty cycle	Average speed (km/h)	Maximum Payload (tonnes)	Representative Payload (tonnes)
Tractor-trailer	Brazil	Brazil - WHVC	76.3	19.5	19.5
	China	China - WHVC	72.7	25	25
	Europe	ACEA Long Haul	77.3	25.5	19.3
	India	India - WHVC	32.9	27.2	27.2
	US	US Phase 2 cycles	99.1	21.3	17.2
Rigid trucks	Brazil	US Vocational Multipurpose	36	6.5	3.2
	China	WHVC-China	51.3	6.2	3.1
	Europe	ACEA Urban / Regional	49	5.5	2.7
	India	ARB Transient	24.6	8	4
	US	US Vocational Multipurpose	36	5.3	2.6

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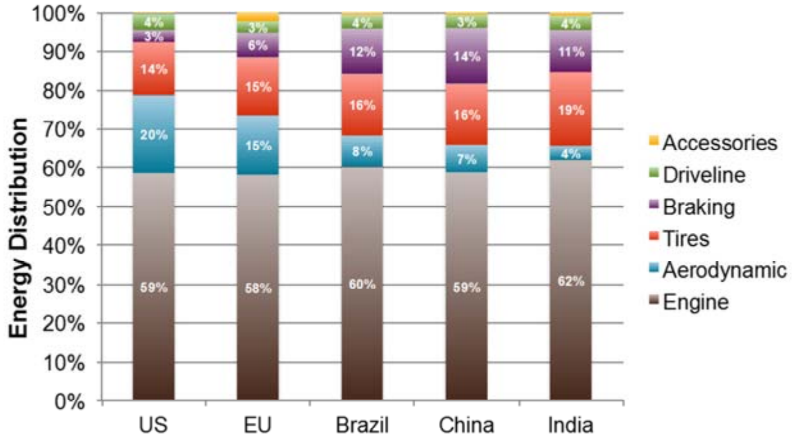
Tractor-trailer energy audits over representative duty cycles and payloads

- Energy audit gives an indication of the relative impact of different technologies
  - Engine and tire improvements are important for all markets
  - Aerodynamic improvements are more important in the markets with higher speeds



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Technology potential assumptions for tractor-trailers

	Technology	Step 1 (US Phase 2 technology)	Step 2 (EPA best / SuperTruck) Technology End Point
Vehicle parameters	Engine (BTE)	~47%	~50%
	Tractor aerodynamics (CdA)	5.3 m^2	5.1 m^2
	Trailer aerodynamics (delta CdA)	1.1 m^2	1.6 m^2
	Tire rolling resistance (RRC)	5.6N/kN (Steer) 5.9N/kN (Drive) 4.8N/kN (Trailer)	4.3N/kN (Steer) 4.5N/kN (Drive) 4.3N/kN (Trailer)
	Transmission type	AMT	AMT/DCT
	Axle configuration	6x2	6x2
	Rear axle ratio	3.2	2.3
	Weight reduction	-	Up to 2,800 pounds
Technology effectiveness	Transmission benefit	1.80%	2.00%
	Axle configuration benefit	1.50%	2.50%
	Downspeeding	1.80%	1.80%
	Axle lubricant	0.20%	0.50%
	Predictive cruise	0.80%	2.00%
	Accessories improvement	0.30%	1.00%
	A/C improvement	0.20%	0.50%
	Automatic inflation systems	0.40%	1.00%
	ATIS (trailer)	1.40%	1.50%
	Direct drive	1.00%	2.00%
	Idle reduction	3.00%	5% APU / 7% other

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Technology potential assumptions for rigid trucks

	Technology	Step 1 (US Phase 2 technology)	Step 2 (EPA best set) Technology End Point
Vehicle parameters	Tire rolling resistance	6.4N/kN (Steer) 7.0N/kN (Drive)	2.20%
	Weight reduction	10 lbs	400 lbs (2.5%)
Technology effectiveness	Two more gears (over 5-speed)	0.10%	1.70%
	DCT or AMT (over AT)	0.20%	3.40%
	Strong Hybrid	4.10%	22.90%
	Deep driveline integration	4.40%	6.20%
	Axle lubricant	0.40%	0.50%
	Neutral idle	0.70%	2.30%
	Stop-start	2.70%	3.80%

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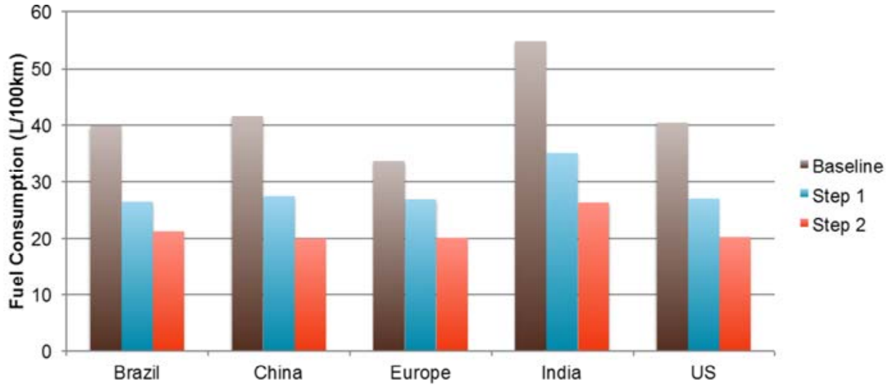
Fuel consumption reduction with technology packages (tractor-trailers) (preliminary data)

- Baseline and potential numbers take into account
  - Baseline technology level
  - Duty cycle
  - Payload
- Data is not reflective of how vehicles would perform in other markets



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Country mapping for global scenario (preliminary data)

- Mapping procedure
  - First check if the fleet similar to one of the 5 assessed markets
  - If not then map to a market where the estimated potential is similar

Region	Assessment of Technology Potential	Technology Potential	
		Rigid truck	Tractor
United States	Assessed individually	31%	50%
Canada	Technology potential of US	31%	50%
Mexico	Technology potential of US with a lag of 5 years	31%	50%
Brazil	Assessed individually	33%	47%
Other Latin America	Technology potential similar to Brazil	34%	49%
EU-28	Assessed individually	30%	40%
Russia	Technology potential of US with a lag of 5 years	31%	50%
Other Europe	Technology potential of EU with a lag of 5 years	30%	40%
China	Assessed individually	33%	52%
Japan	Technology potential of US	31%	50%
India	Assessed individually	36%	52%
South Korea	Technology potential of EU	30%	40%
Australia	Technology potential of EU with a lag of 5 years	30%	40%
Other Asia-Pacific	Technology potential similar to Brazil	34%	49%
Middle East	Technology potential similar to Brazil	34%	49%
Africa	Technology potential similar to Brazil	34%	49%

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Rigid truck and tractor-trailer annualized efficiency improvements by scenario and region

- **Current Policies:** No progress beyond HDV policies currently in place
- **Moderate:** markets reach their efficiency potential between 2035 and 2045.
- **Advanced:** markets reach their efficiency potential between 2030 and 2040.
- **World Class:** markets reach their efficiency potential between 2030 and 2035.

[For reference: Annual improvement rates for US Phase 1+2: tractor-trailer improvement ~2.5%/year, rigid truck improvement ~1-1.5%/year]

Rigid trucks	MODERATE						ADVANCED						WORLD CLASS					
Region	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**
Brazil		1.2%	1.2%	1.6%	2.5%			1.7%	2.1%	2.5%			1.7%	2.1%	2.5%			
China	1.2%	1.2%	1.6%	2.5%			1.7%	2.1%	2.5%				1.7%	2.1%	2.5%			
EU-28	1.0%	1.2%	1.4%	2.3%			1.6%	1.9%	2.3%				1.6%	1.9%	2.3%			
India		1.4%	1.2%	1.9%	2.5%			1.9%	2.5%	2.5%			1.9%	2.5%	2.5%			
US & Canada	1.4%	1.4%	1.0%	2.3%			1.4%	1.4%	3.2%				1.4%	1.4%	3.2%			
Japan	1.4%	1.4%	1.0%	2.3%			1.4%	1.4%	3.2%				1.4%	1.4%	3.2%			
Mexico		1.4%	1.4%	1.0%	2.3%			1.4%	1.4%	3.2%				1.4%	1.4%	3.2%		
Other Europe & Australia		1.0%	1.2%	1.4%	2.3%			1.6%	1.9%	2.3%				1.6%	1.9%	2.3%		
Other Regions			1.2%	1.2%	1.7%	2.5%			1.7%	2.3%	2.5%		1.7%	2.3%	2.5%			
Russia		1.4%	1.4%	1.0%	2.3%			1.4%	1.4%	3.2%				1.4%	1.4%	3.2%		
South Korea	1.0%	1.2%	1.4%	2.3%			1.6%	1.9%	2.3%				1.6%	1.9%	2.3%			

Tractor-trailers	MODERATE						ADVANCED						WORLD CLASS					
Region	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**
Brazil		1.9%	1.6%	3.0%	2.5%			2.7%	3.7%	2.5%			2.7%	3.7%	2.5%			
China	1.9%	1.6%	3.0%	3.4%			2.7%	3.7%	3.4%				2.7%	3.7%	3.4%			
EU-28	1.2%	1.2%	1.6%	3.7%			1.7%	2.1%	3.7%				1.7%	2.1%	3.7%			
India		1.9%	1.7%	3.2%	3.0%			2.8%	3.9%	3.0%			2.8%	3.9%	3.0%			
US & Canada	2.3%	1.9%	2.1%	3.2%			2.3%	1.9%	5.1%				2.3%	1.9%	5.1%			
Japan	2.3%	1.9%	2.1%	3.2%			2.3%	1.9%	5.1%				2.3%	1.9%	5.1%			
Mexico		2.3%	1.9%	2.1%	3.2%			2.3%	1.9%	5.1%				2.3%	1.9%	5.1%		
Other Europe & Australia		1.2%	1.2%	1.6%	3.7%			1.7%	2.1%	3.7%				1.7%	2.1%	3.7%		
Other Regions			1.9%	1.6%	3.2%	2.7%			2.7%	3.9%	2.7%		2.7%	3.9%	2.7%			
Russia		2.3%	1.9%	2.1%	3.2%			2.3%	1.9%	5.1%				2.3%	1.9%	5.1%		
South Korea	1.2%	1.2%	1.6%	3.7%			1.7%	2.1%	3.7%				1.7%	2.1%	3.7%			

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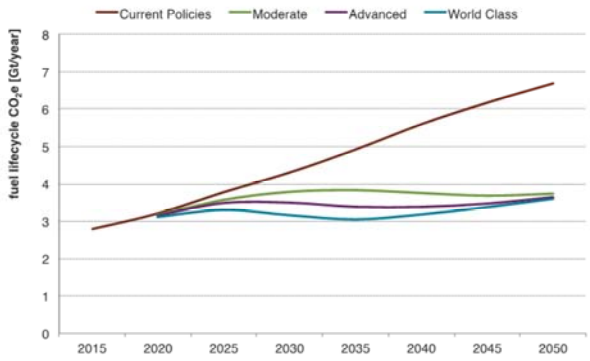
GHG emissions from tractor-trailers and rigid trucks worldwide by efficiency scenario, 2015-2050

- End point converges in 2050
- Compared to Current Policies, the Moderate efficiency scenario could prevent the cumulative release of more than 27 Gt from 2015-2050
- Advanced and World Class pathways could increase the cumulative emissions benefit by 5 and 8 Gt, respectively, compared to the Moderate scenario.



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Source: ICCT Roadmap Model

Summary/Conclusions

- HDV sector is behind LDV sector in implementation efficiency standards
  - Significant technology potential exists to improve the global HDV fleet
  - Technology forcing standards will be needed in the major markets in order to drive technology adoption
- Europe is currently the largest market without standards. As EU is very influential in global HDV policy and vehicle/engine market – it is key for EU to come online with a commitment for standards in the very near future
- "Tier 1" markets would ideally start developing now a stronger vision/roadmap for zero emissions technology, like electrification and fuel cell technology. Current pathway is not well defined and while there is still significant potential from incremental technology, the "end point" could start to be reached by 2030.
- Strong compliance programs required
  - Conformity of production and in-use verification requirements are needed to ensure that regulatory requirements translate to real-world improvement and to avoid the real-world "gap" that is well documented for LDVs.

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thank you

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