HDV Greenhouse Gas Technologies, Costs and Benefits

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

About the ICCT

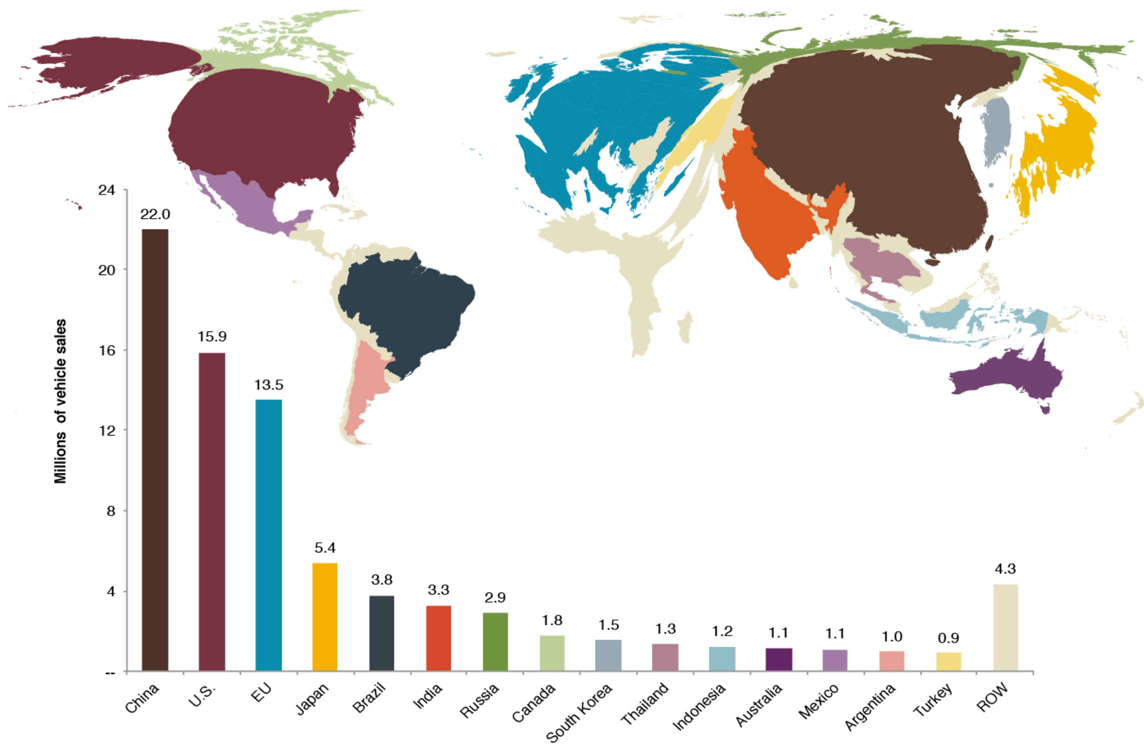
International Council Composed of top government regulators (~25) in major markets founded in 2001.

Non-profit Organization
ICCT incorporated to serve International Council, staff of 35 technical experts on vehicles and fuels, half with background / nationality outside US founded in 2005. Offices in DC, San Francisco and Berlin. China office coming later this year.

Funding
California philanthropies plus government grants and contracts.

Geographic scope: China, US, EU, Japan, Brazil, India, Canada, Korea, Indonesia, Australia, Mexico plus
smaller markets by request.

Top 15 Car and Truck Markets by Sales in 2013



Mission: To dramatically improve environmental performance and efficiency of motor vehicles (cars, trucks, marine, aviation) and fuels by supporting government regulatory agencies in world's top vehicle markets.

Outline

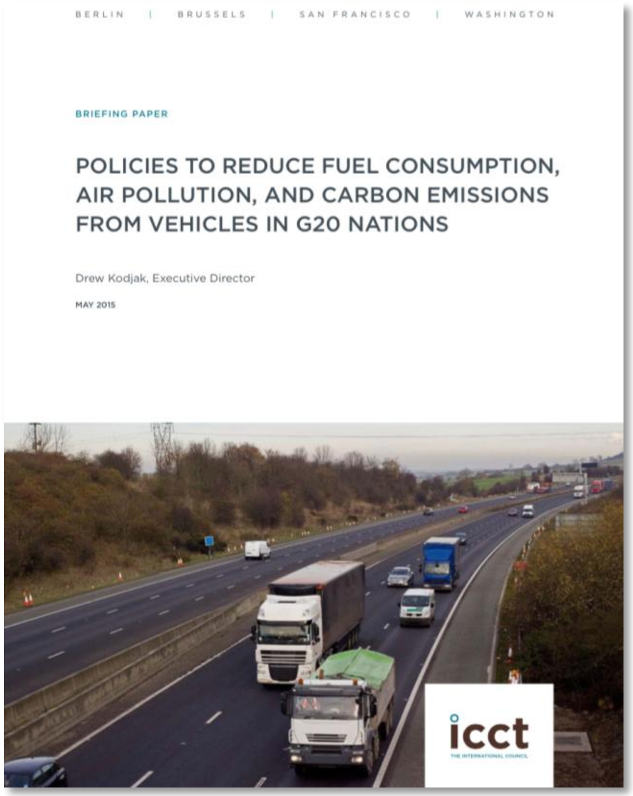
- G20
  - Transport assessment
  - Focus on HDVs
- ICCT research
  - DOE Supertruck program
  - Class 8 technology potential and payback
  - Trailers
- Pickups and Vans (2bs and 3s)
- Observations and conclusions for Mexico

G20

Transport assessment
Focus on HDVs

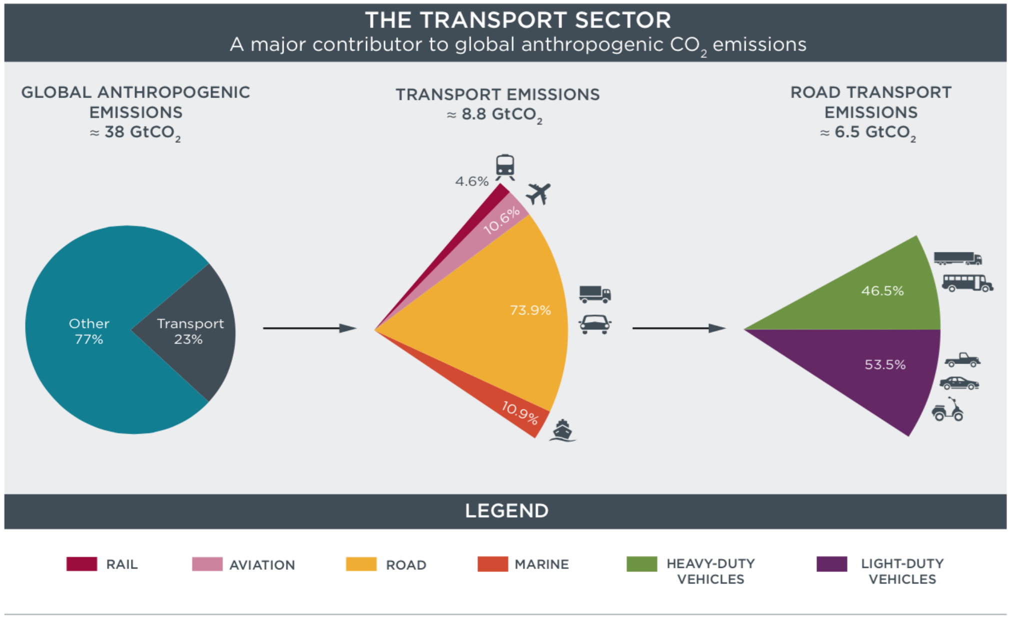
Efforts in the G20 to address transport

- Participating economies:
  - AU, BR, CA, EU, FR, GE, IT, JP, MX, RU, UK, US
- Steering Committee:
  - US, EU, IT, MX
- Implementing Organizations:
  - ICCT
  - Global Fuel Economy Initiative (GFEI)
- Shared goal: Reduce the energy and environmental impacts of motor vehicles in all G20 countries
- Foundational Policy Brief (May 2015)
- Assesses rationale, status, and opportunities for action in G20 nations on clean fuels and vehicles



Emissions from the transport sector are significant…especially from heavy-duty vehicles

- The transport sector, in particular heavy-duty vehicles, are significant contributors to global CO_2 emissions and local air pollutant emissions.



- Worldwide, heavy-duty vehicles (trucks and buses) represent just 11% of motor vehicles, but they are responsible for almost half of vehicle CO_2 emissions and over two-thirds of vehicle particulate emissions.

Solutions are cost effective

- G20 experience shows that fuel economy and CO_2 emission standards pay back to the consumer in 1 to 5 years.
- Heavy-duty vehicle fuel economy standards (in red) are particularly cost effective with a payback in 1 – 2 years due to high fuel use.

Rule	Per-Vehicle Cost	Payback Period
US LDV 2017-2025[1]	$1,800	3.5 years
US LDV 2012-2016[2]	$950	3 years
US HDV Phase 1 2014 – 2017[3]	$378-$6,215	1-2 years
California Advanced Clean Cars Program 2017 – 2025[4]	$1,340-$1,840	3 years
Canada LDV 2017-2025[5]	$2,095	2 to 5 years
Canada LDV 2011-2016[6]	$1,195	1.5 years
European 95g CO_2/km Standard 2020[7]	€1,300	4-5 years
India LDV 2020[8]	$400 to $600	2-3 years

ICCT research

Background

Trailers

Engines

DOE Supertruck

Overall scope: Tractor-trailer assessment

- Project components
  - **Trailer** technology and cost assessment (July 2013-Feb 2014)
    - *http://www.theicct.org/trailer-technologies-increased-hdv-efficiency*
    - *http://www.theicct.org/costs-and-adoption-rates-fuel-saving-trailer-technologies*
  - Analysis of **SuperTruck** technologies (June 2014)
    - *http://www.theicct.org/us-supertruck-program-expediting-development-advanced-hdv-efficiency-technologies*
  - Stakeholder workshop to solicit leading **industry technology input** (Aug 2014)
    - *http://www.theicct.org/stakeholder-workshop-report-tractor-trailer-efficiency-technology-2015-2030*
  - Assess **regulatory design** and test procedures (Oct 2014)
    - *http://www.theicct.org/us-phase2-hdv-regulation-design-options*
  - **Engine energy audit** from laboratory data collection (Nov 2014)
    - *http://www.theicct.org/heavy-duty-vehicle-diesel-engine-efficiency-evaluation-and-energy-audit*
  - Tractor-trailer **simulation modeling of** technology potential (April 2015)
    - *http://www.theicct.org/us-tractor-trailer-efficiency-technology*
  - Tractor-trailer technology cost and **payback period assessment** (April 2015)
    - *http://www.theicct.org/us-tractor-trailer-tech-cost-effectiveness*

Background: Tractor-trailer efficiency

- Combinations tractor-trailers are a key focus focus area in the US
  - Tractor-trailers are ~2% of all on-road vehicles, but consume 20% of vehicles' energy use and greenhouse gas emissions
  - Tractor-trailers represent two-thirds of heavy-duty fuel use and carbon emissions
  - Tractor-trailers have averaged about 6 miles per gallon for two decades
  - There are many available and emerging efficiency technologies

Tractor
- Tires
- Aerodynamics
- Engine idle-off
- Lightweighting

Engine
- Friction, load reduction
- Aftertreatment
- Advanced control, injection
- Turbo, air handling improvements
- Turbocompounding, clutch
- Waste heat recovery

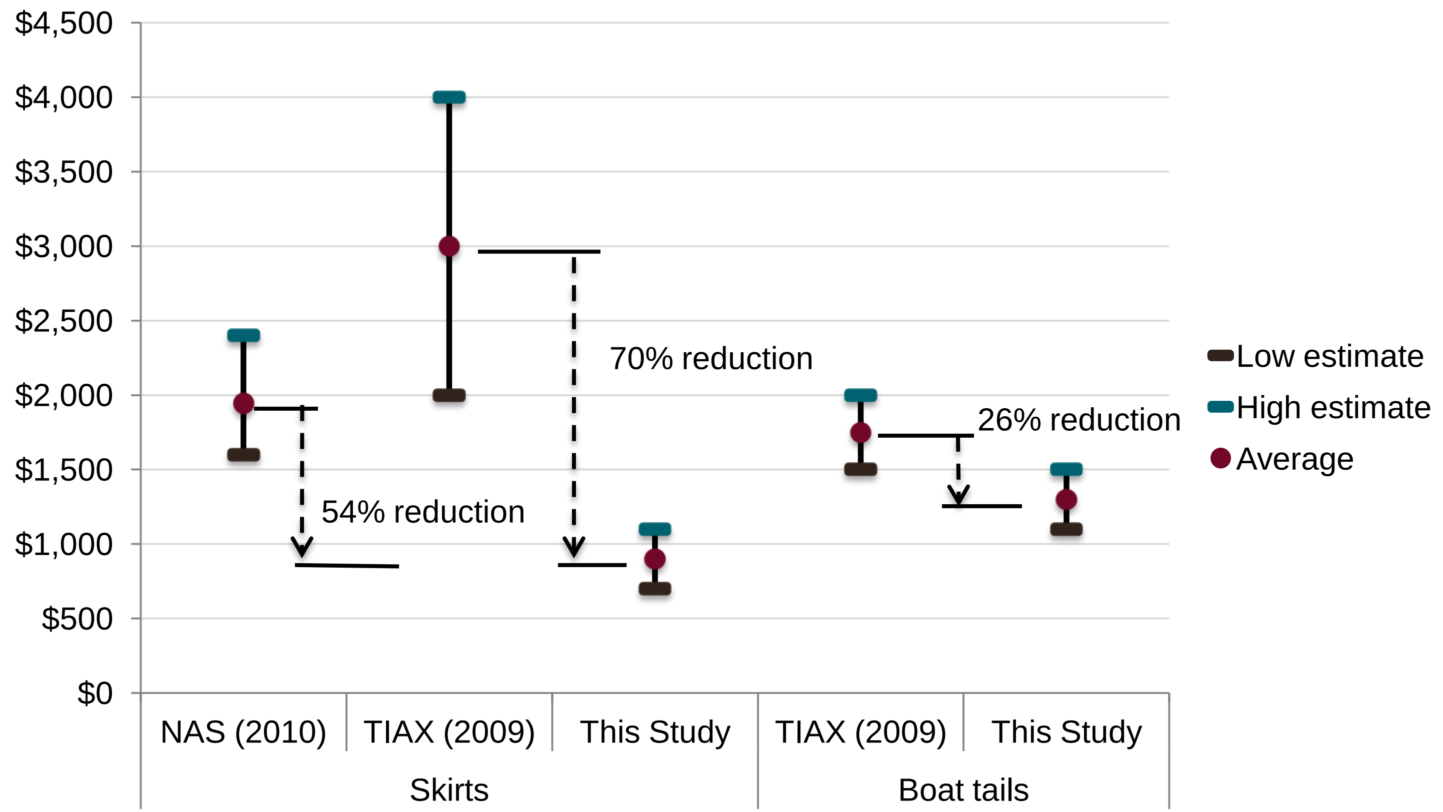
Transmission
- Optimal gearing
- Direct, single drive
- Friction reduction
- Automated manual
- Dual clutch
- Hybridization

Trailer
- Tires/wheels
- Aero skirt
- Aero gap
- Aero tail

Some improvements you can see on the road

Trailer technology cost reductions in recent years (2013-2014 study)

- Nearly half of all new box trailers are sold with side skirts
- Costs of trailer aerodynamic technologies—particularly side skirts— have decreased substantially in the past 3-5 years



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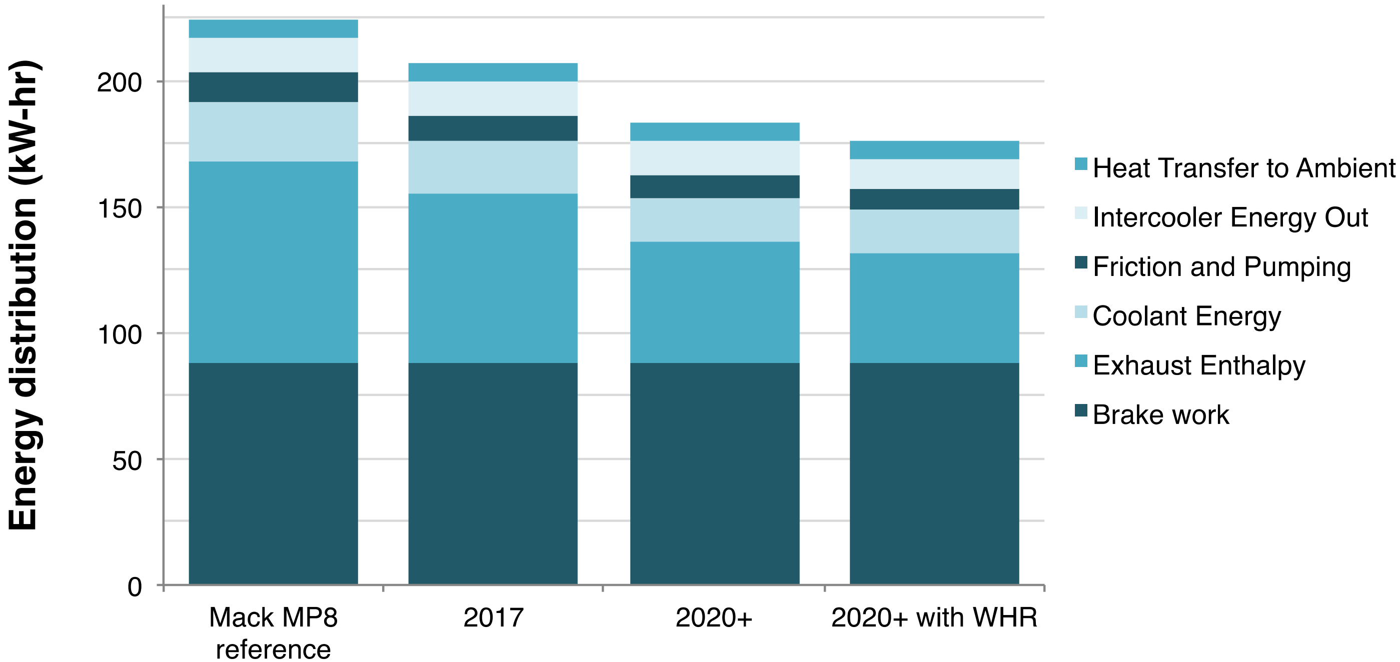
Sharpe and Roeth (2014). Costs and adoption rates of fuel-saving trailer technologies
http://www.theicct.org/costs-and-adoption-rates-fuel-saving-trailer-technologies

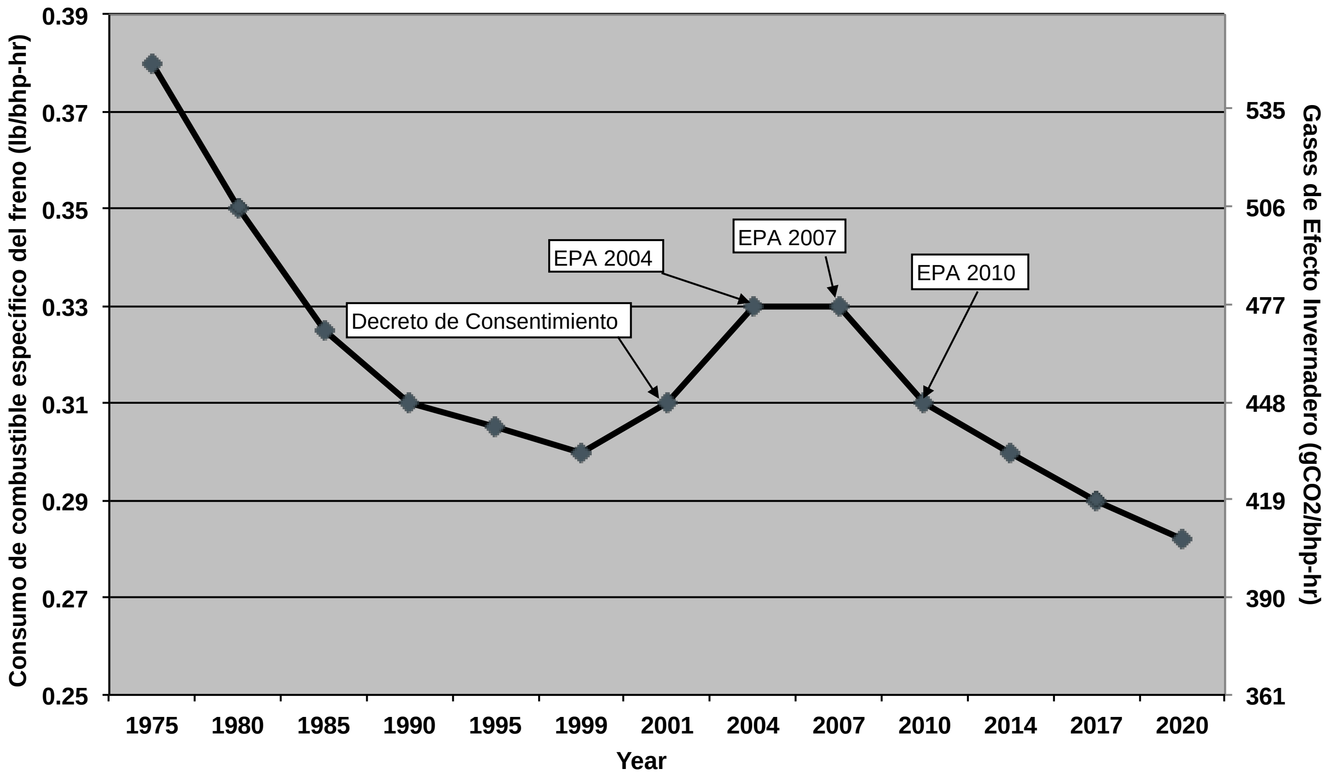
Tractor-trailer engine data

- In collaboration with West Virginia University
- Data collection for engine compliant with US EPA 2010 regulations
  - Engine fuel consumption map (fuel use vs torque, rpm)
  - Energy audit: breakdown of engine loss characteristics



Supplemental Emissions Test (SET) cycle. From Thiruvengadam et al (2014).
http://www.theicct.org/heavy-duty-vehicle-diesel-engine-efficiency-evaluation-and-energy-audit

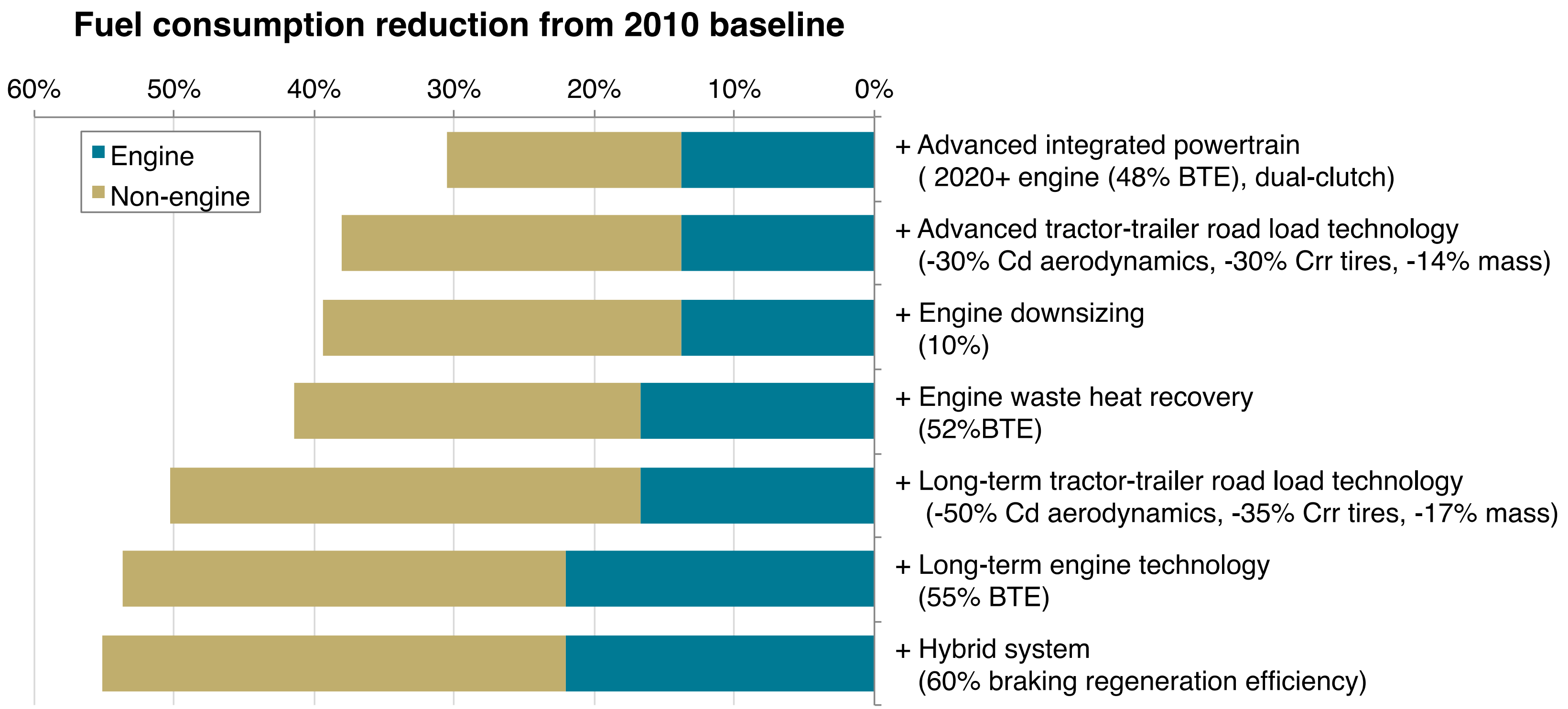
Past efficiency has been related to emissions



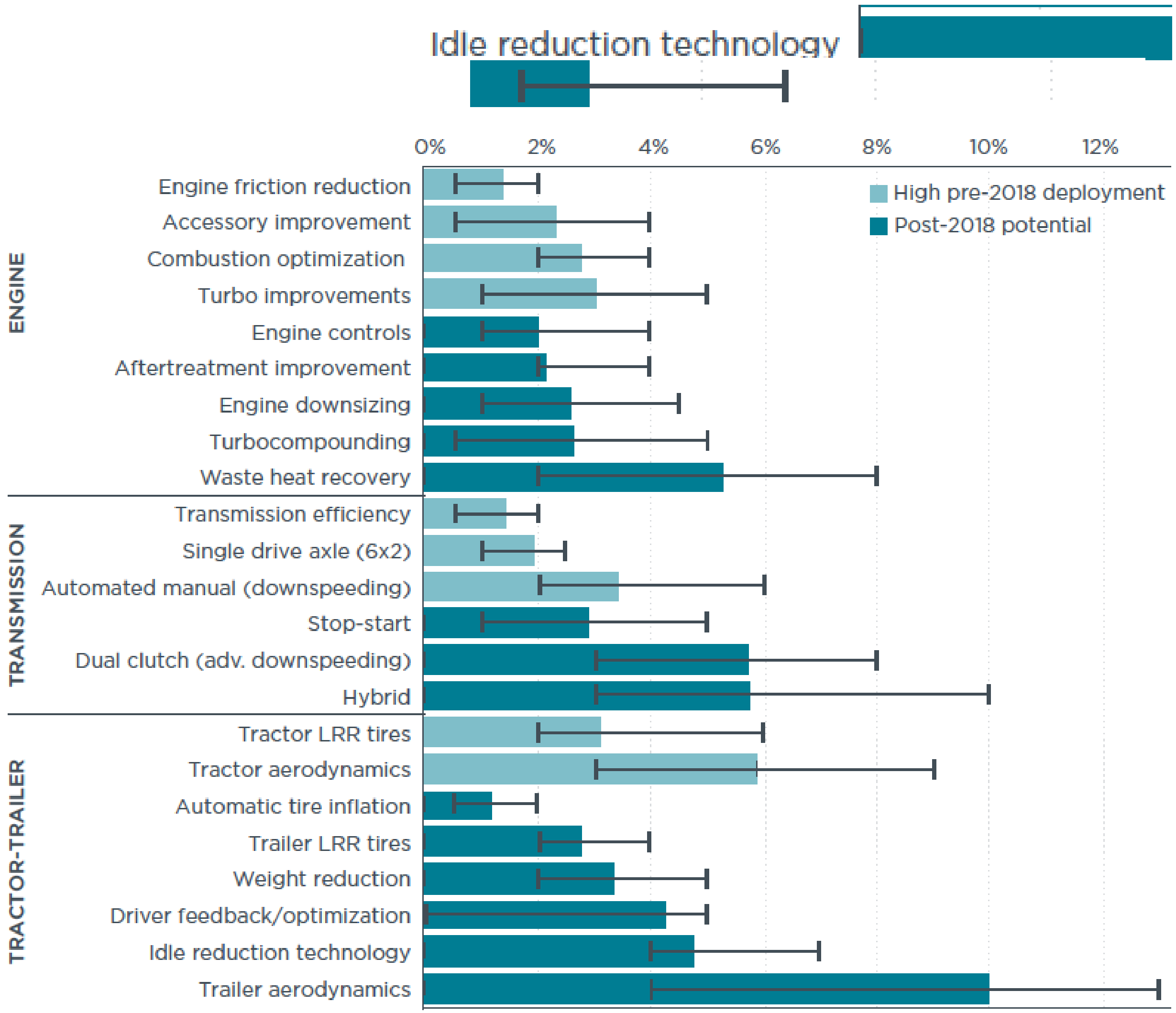
- Immediate benefits expected with finalization of NOM 044
- These clean engines are the for future efficiency improvements

Results: Engine contribution to advanced efficiency packages

- Engine efficiency amounts to about 1/3 to almost 1/2 of all potential fuel consumption benefits from 2020-2030 technology packages



Tractor-trailer efficiency technologies



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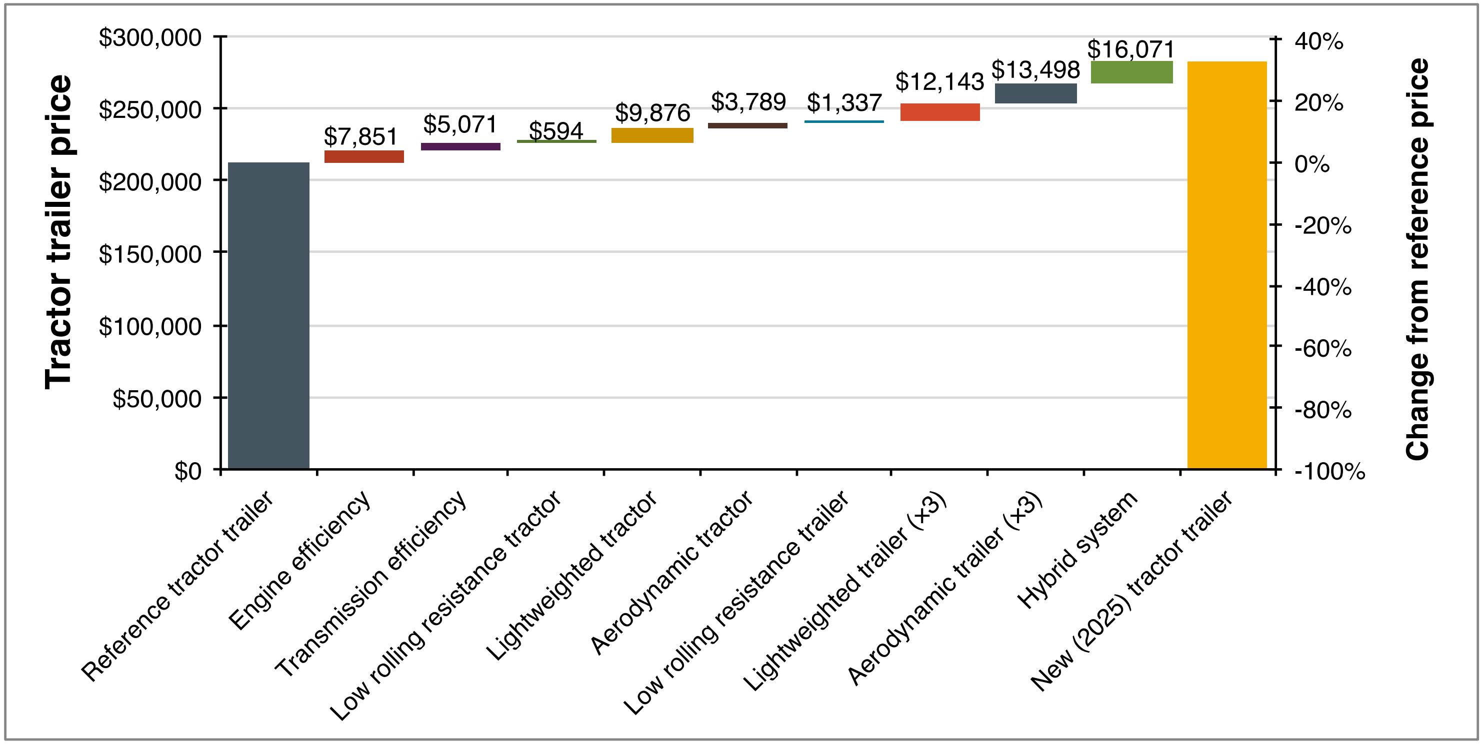
From July 22, 2014 HDV stakeholder workshop with OEMs, suppliers, research groups, NGOs, government agencies. Lutsey et al (2014). http://www.theicct.org/stakeholder-workshop-report-tractor-trailer-efficiency-technology-2015-2030

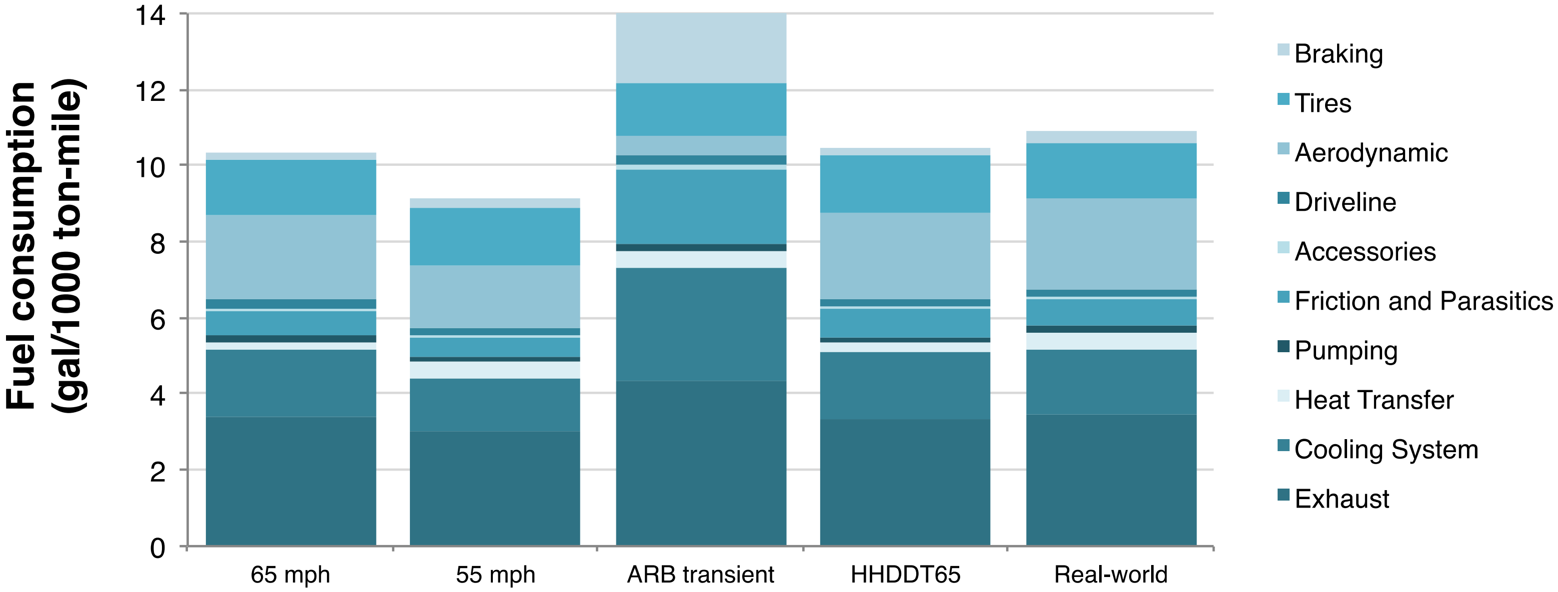
Price impact of 2025 technology package

- Price effect (2014$) of full technology package in 2025 with all engine, transmission, lightweighting, aerodynamic, tire, and hybridization technologies
  - Assumes mid point between Low and High cost estimate and 3 trailers per tractor
  - Technology package could result in tractor-trailer cost increase of about 28-39%

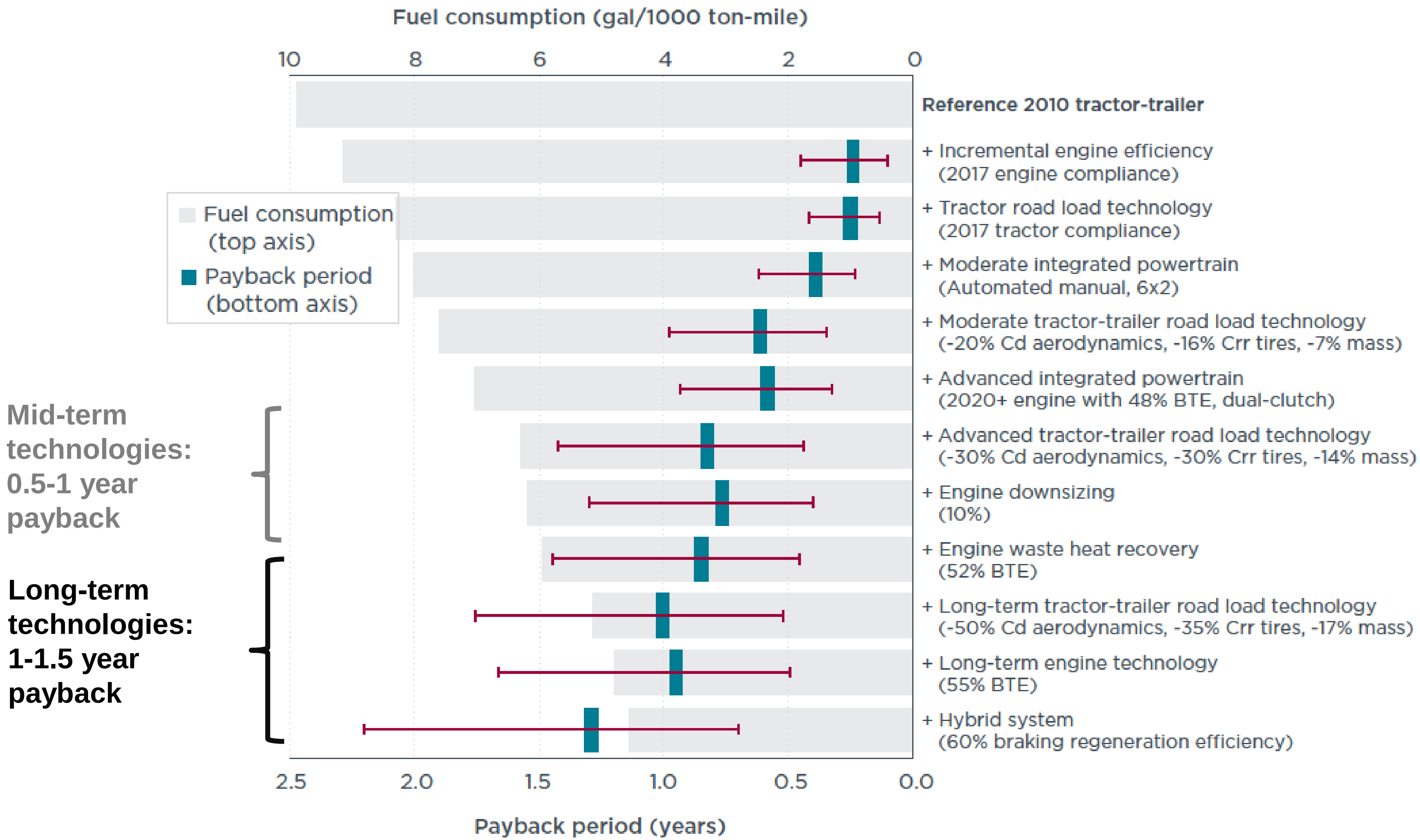


Tractor-trailer modeling

- Simulation modeling of tractor-trailer fuel consumption
  - Incorporate interactions between the technologies
    - Engine, transmission, aerodynamics, tire, mass reduction, etc
  - Modeled in US DOE Autonomie framework
  - Evaluate energy loads and losses over various drive cycles across



Results: Technology payback period



Meszler et al (2015). http://www.theicct.org/us-tractor-trailer-tech-cost-effectiveness ;

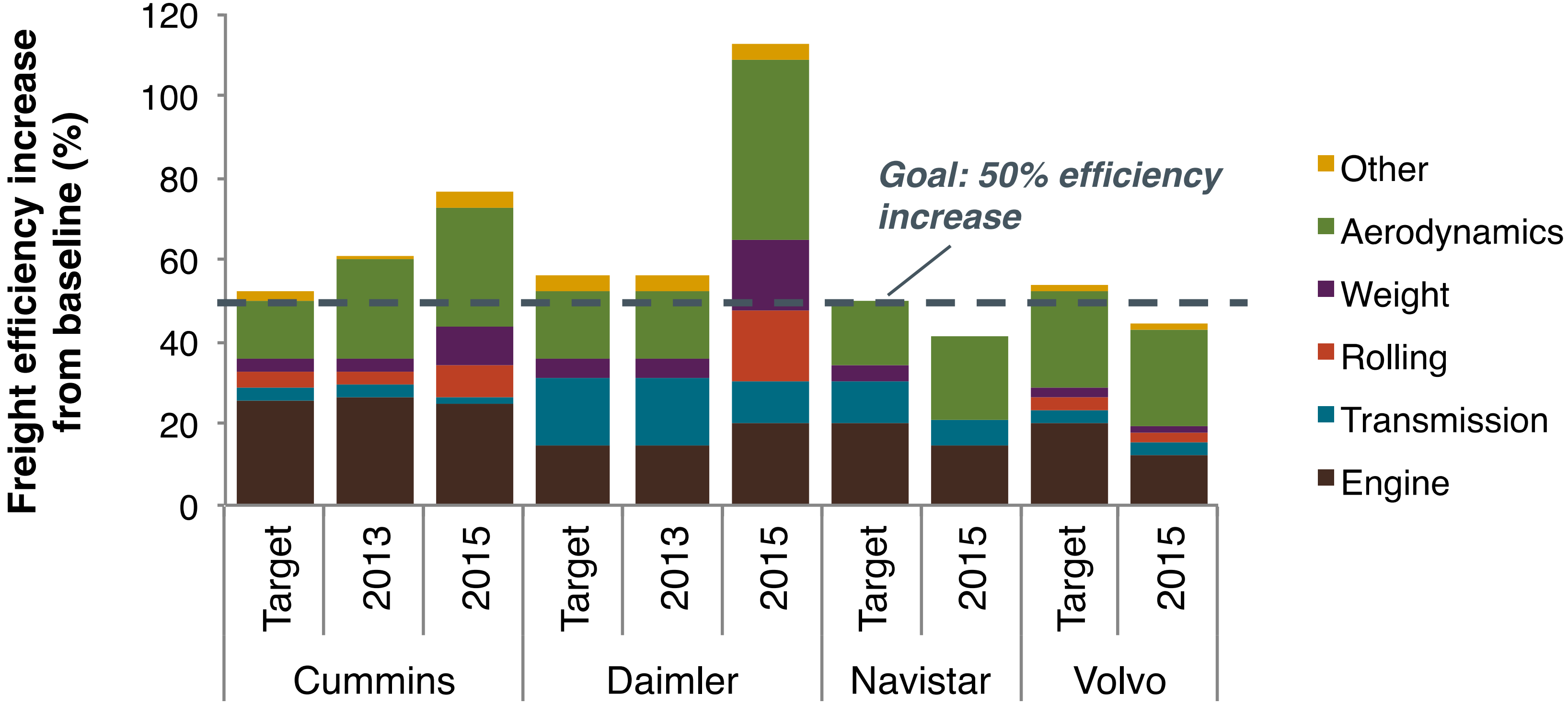
Notes: "Error" bars reflect range in tech cost, fuel price ($3.10-$5.40 /gal), discount rates (3%-10%)

Delgado and Lutsey (2015). http://www.theicct.org/us-tractor-trailer-efficiency-technology

Notes: "real-world" highway cycle with grade, 38,000 lb payload for all packages

SuperTruck 2015 update: Freight efficiency progress

- Goal: Demonstrate 50% increase in freight efficiency (e.g., ton-mi/gal)
  - For a given payload, this would approximately result in 10 mpg tractor-trailers (from 6-7 mpg baseline)
- Progress to date:



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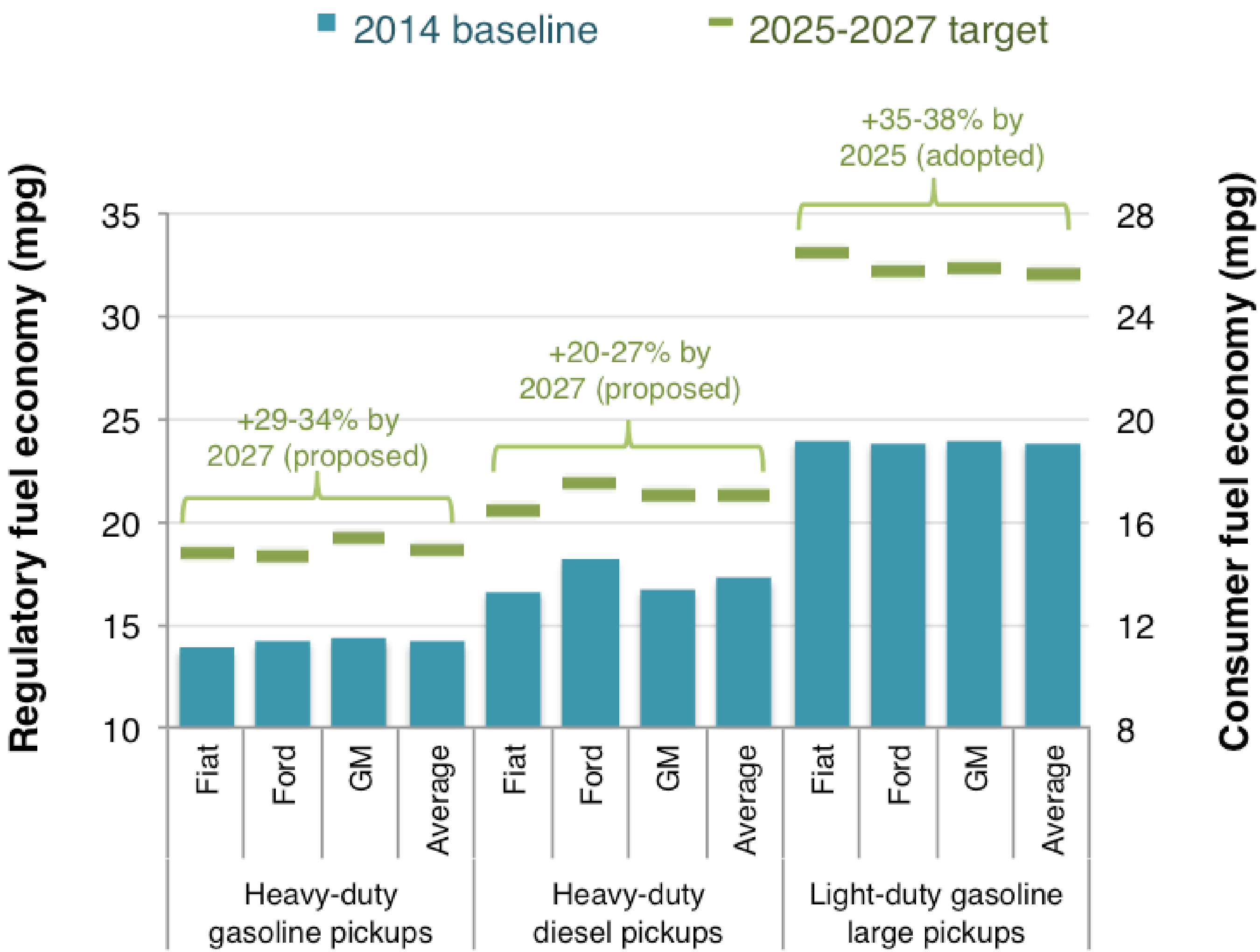
Energy category breakdown is based on US DOE Annual Merit Review reports; Freight efficiency of Cummins and Daimler are based on representative real-world routes and include weight reduction and increased payload

Other themes

Pickups and Vans

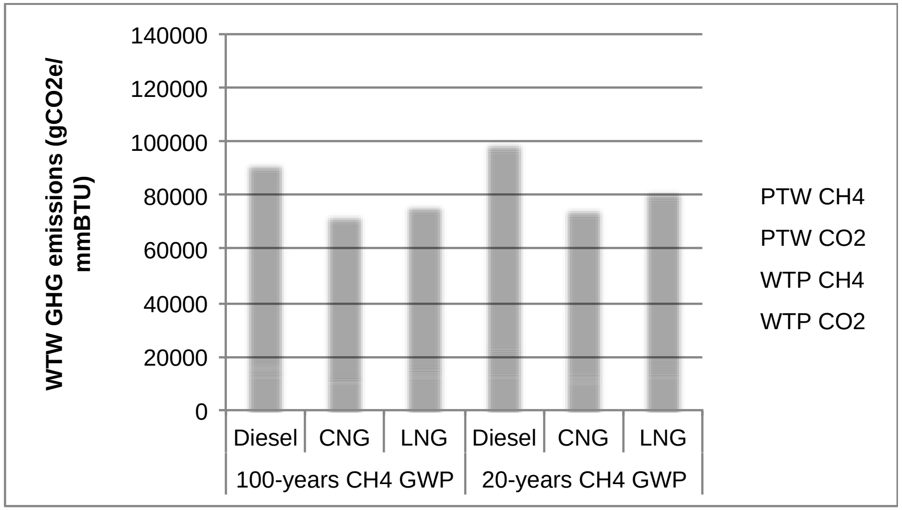
Natural gas

Pickups and Vans (2bs and 3)



GREET: Well-to-wheel GHG emissions

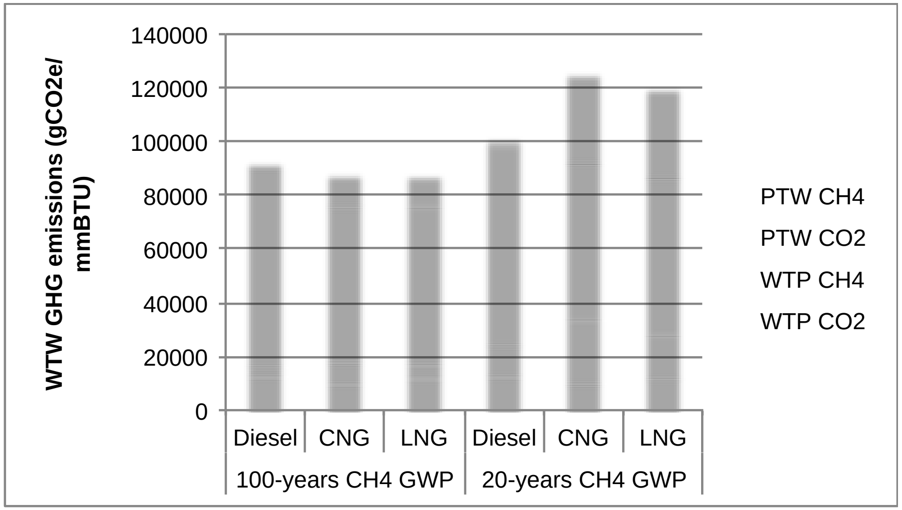
Ideal Case



Upstream leakage: ~0%
NG efficiency gap: 0%
NG CH4 tailpipe: 1x of diesel

17% - 21% benefit (100-y)
18% - 25% benefit (20-y)

Realistic Case



Upstream leakage: 1.1%
NG efficiency gap: 10%
NG CH4 tailpipe: 10x

4% - 5% benefit (100-y)
19% - 24% disbenefit (20-y)

Conclusions for Mexico

ICCT technical analyses

- Mid-term potential
  - Reduce fuel use per ton-mile by 39% (2010 baseline) and 27% (2017)
- Long-term potential
  - 50% reduction (2010) in the 2025-2030 timeframe
- Diverse technology approaches
  - Offer similar efficiency results for different drive cycles and needs
- Robust payback
  - 0.5-1.5 years for mid-term potential
  - 1.4-2.2 years for long-term potential
- First-user benefits
  - Fuel savings greatly exceed upfront technology costs. Mid-term potential offers $100,000-$194,000 in fuel savings, 3-9 times greater benefits than cost over five years

Sources:
Delgado and Lutsey (2015). http://www.theicct.org/us-tractor-trailer-efficiency-technology
Meszler et al (2015). http://www.theicct.org/us-tractor-trailer-tech-cost-effectiveness

Modeling for Mexico could take into account

- Baseline engine efficiency
- Duty cycles
  - Average speeds and use patterns
- Typical vehicle characteristics
  - Frontal area, coefficient of drag (Cd), coefficient of rolling resistance (CRR), and mass
- Fleet composition

Conclusions

- Regulatory design improvements
  - Allow for more tailored approach, including consideration of grade, average speed, etc
  - More complete technology package includes transmission and powertrain
- Tremendous potential for Mexican fleet
  - Engine efficiency gains account for 1/3 to 1/2 of all packages
  - Payback of aerodynamic and other technology packages will depend on Mexican duty cycles
  - Medium-duty vehicles have a lot of potential for efficiency gains
- Finalizing NOM 044 is a critical step
  - Will have tremendous benefits for the environment and climate
  - Will have immediate and long-term benefits for fuel economy

¡Gracias!

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Trailer costing methodology and data sources

- Cost estimation methods
  - Review existing cost data (ICF, NAS, AEA, Ricardo, TIAX, etc) for each technology
  - Assemble best estimate low and high costs for the various technologies
  - Cost methodology matched to that used by EPA/NHTSA
    - Include direct and indirect manufacturing costs for each technology
    - Include time- and volume-based learning based on technology maturity
- Key assumptions
  - Three fuel prices: $3.10, $4.10, $5.40 per gal (US EIA AEO 2014, average 2020-2030)
  - Discount rates: 3%, 7%, 10%
  - Vehicle miles traveled by age from EPA/NHTSA RIA
  - Vehicle miles traveled elasticity = -0.05. Based on EPA/NHTSA RIA
  - Operating cost breakdown from EPA/NHTSA RIA
  - Baseline tractor/trailer prices from public market data
  - Fuel efficiency data from simulation “real-world” cycle results (include transients, grade)
  - Three trailers assumed per tractor

RIA = Regulatory Impact Analysis. *http://www.epa.gov/oms/climate/documents/420r11901.pdf*