Improved Heavy-Duty Vehicle Fuel Efficiency in India: Benefits, Costs and CO₂ Impacts

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The International Council on Clean Transportation

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Project scope of work

- Vehicles included in the analysis: HDVs > 12 tonnes
- Focus on diesel-powered trucks and buses
- Fuel efficiency technologies that can be commercialized over the next 10 years
- Time horizon: 2000 – 2050 (model calibrated against historical data for 2000-2014)

Fuel consumption reduction potential and cost-benefit impacts of various technology deployment scenarios
HDVs in India consume larger share of on-road fuel than in other major markets.

[Image: Bar chart showing share of fuel consumption and CO₂ emissions in 2015 for US, EU, China, Brazil, and India.]

- **US**: Nearly 70% of fuel use and CO₂
- **EU**: Lower share compared to US
- **China**: Moderate share compared to US and EU
- **Brazil**: Similar share to China
- **India**: Lower share than US but higher than China and Brazil

HDVs: nearly 70% of fuel use and CO₂

### HDV characteristics differ across regions

<table>
<thead>
<tr>
<th></th>
<th>Brazil</th>
<th>China</th>
<th>EU</th>
<th>India</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Axle config.</strong></td>
<td>6x2</td>
<td>6x4</td>
<td>4x2</td>
<td>4x2</td>
<td>6x4</td>
</tr>
<tr>
<td><strong>Tractor weight</strong></td>
<td>9.7t</td>
<td>10t</td>
<td>7t</td>
<td>6t</td>
<td>8t</td>
</tr>
<tr>
<td><strong>GVW</strong></td>
<td>35t</td>
<td>33t</td>
<td>40t</td>
<td>40t</td>
<td>36t</td>
</tr>
<tr>
<td><strong>Engine displ.</strong></td>
<td>13 liter</td>
<td>&lt; 11 liter</td>
<td>13 liter</td>
<td>&lt; 6 liter</td>
<td>15 liter</td>
</tr>
<tr>
<td><strong>Engine power</strong></td>
<td>~ 325kW</td>
<td>~ 260kW</td>
<td>~ 325kW</td>
<td>~ 135kW</td>
<td>~ 340kW</td>
</tr>
<tr>
<td><strong>Emission level</strong></td>
<td>Proconve 7</td>
<td>China IV</td>
<td>Euro VI</td>
<td>Bharat III</td>
<td>US EPA 2010</td>
</tr>
</tbody>
</table>

**Heavy-Duty Vehicle Fuel Efficiency in India**
HDV engine size and power are much smaller in India than other major markets

http://www.theicct.org/market-analysis-heavy-duty-vehicles-india
Average speeds are much lower in India than other major markets

* Average speed from surveys of 28 major trucking routes in India
http://www.tcil.com/tcil/study_report.html
Together, engines and tires represent 80% or more of energy losses for Indian HDVs.

Tractor-trailers operating with regionally-specific drive cycles and payloads.

http://www.theicct.org/estimating-fe-tech-potential-hdvs-gfei-wp14
Areas for on-vehicle efficiency improvements

Truck and trailer aerodynamics

- Engine efficiency
- Driver behavior and telematics*
- Transmission and axles
- Auxiliary loads
- Reducing vehicle empty weight
- Rolling resistance

* Not investigated as part of this analysis
Summary of methodology

1 Price Model
Incremental retail price of technology packages

2 Autonomie Model
Fuel efficiency improvements

3 BCA Model
- NPV per vehicle
- Payback period per vehicle

4 Fleet Model
- Fuel savings
- CO₂ emissions reduction
- Fleet level NPV

Heavy-Duty Vehicle Fuel Efficiency in India
Summary of analysis

- Identified HDV baseline and efficiency improving technologies that can be commercial in India within 10 years for 3 vehicle categories over 12 tonnes in GVW
- Full vehicle simulations to estimate fuel efficiency of baseline and technology packages
- Incremental retail price of vehicles fitted with each technology package
- Economic analysis of HDV technology packages – payback period and NPV
- Crude oil, diesel, CO$_2$ implications at the fleet level out to 2050
- Fleet level economic benefits
Per-vehicle fuel efficiency potential and costs: methodology and results
Our analysis to determine fuel-saving technology potential uses simulation modeling

<table>
<thead>
<tr>
<th>Engine</th>
<th>Tractor-trailer</th>
<th>Rigid truck</th>
<th>Transit bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bharat Stage IV, 5.9 liter, 134 kW</td>
<td>6 speed manual (9.2, 5, 3, 1.9, 1.4, 1)</td>
<td>6 speed manual (9.2, 5, 3, 1.9, 1.4, 1)</td>
<td>6 speed manual (6.6, 3.8, 2.3, 1.5, 1, 0.8)</td>
</tr>
<tr>
<td>Transmission (gear ratios: 1st, 2nd,..., 6th)</td>
<td>6 speed manual (9.2, 5, 3, 1.9, 1.4, 1)</td>
<td>6 speed manual (9.2, 5, 3, 1.9, 1.4, 1)</td>
<td>6 speed manual (6.6, 3.8, 2.3, 1.5, 1, 0.8)</td>
</tr>
<tr>
<td>Payload</td>
<td>13,615 kg</td>
<td>9,245 kg</td>
<td>1,837 kg</td>
</tr>
<tr>
<td>Gross vehicle weight</td>
<td>40,200 kg</td>
<td>25,000 kg</td>
<td>16,200 kg</td>
</tr>
<tr>
<td>Aerodynamic drag coefficient</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal area</td>
<td>7.2 m²</td>
<td>6.8 m²</td>
<td>7.5 m²</td>
</tr>
<tr>
<td>Coefficient of rolling resistance</td>
<td></td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Final drive ratio</td>
<td>6.8</td>
<td>6.1</td>
<td>6.1</td>
</tr>
</tbody>
</table>

http://www.autonomie.net

Heavy-Duty Vehicle Fuel Efficiency in India
WHVC-India cycle created to better represent HDV driving in India

Weighting factors for each ‘mini cycle’

- **Urban**
  - 10% Weighting
  - 40% Weighting
  - 85% Weighting

- **Rural**
  - 10% Weighting
  - 30% Weighting
  - 15% Weighting

- **Motorway**
  - 80% Weighting
  - 30% Weighting
  - 0% Weighting

Heavy-Duty Vehicle Fuel Efficiency in India
Engine and tire rolling resistance losses dominate in cycles with low average speeds.

Energy balance for a tractor-trailer over the WHVC-India cycle and 27,200 kg payload:

- **Engine:** 62%
- **Aerodynamics:** 2%
- **Transmission and axles:** 3%
- **Rolling resistance:** 19%
- **Braking:** 11%
- **Accessories:** 3%

Source: Sharpe and Delgado (2016)
http://www.theicct.org/engine-and-tire-tech-hdvs-india-201602
Choosing technology packages

- Baseline and efficient technologies determined based on our expert understanding of global markets and discussions with Indian industry and government
- Commercial in India within 10 years
  - Most technologies we chose will be feasible much sooner
- We know India is different
  - Price sensitive market
  - Much smaller capacity engines
### Technology packages (TPs): tractor-trailer

#### Baseline
- **Engine**: BS IV (EGR)
- **Transmission**: Manual 6-speed
- **Tires**: Bias
- **Aerodynamics**: No aero drag (Cd)
- **Weight reduction**: No weight reduction

#### Increasingly efficient technologies, moving left to right

<table>
<thead>
<tr>
<th>Engine</th>
<th>Transmission</th>
<th>Tires</th>
<th>Aerodynamics</th>
<th>Weight reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS IV (EGR)</td>
<td>Manual 6-speed</td>
<td>Bias</td>
<td>No aero drag (Cd)</td>
<td>No weight reduction</td>
</tr>
<tr>
<td>5% more efficient</td>
<td>AMT 8-speed</td>
<td>Radial</td>
<td>10% red. In Cd</td>
<td>1% WR</td>
</tr>
<tr>
<td>10% more efficient</td>
<td>Improved AMT</td>
<td>Low rolling resistance (LRR)</td>
<td>20% red. In Cd</td>
<td>2.5% WR</td>
</tr>
<tr>
<td>12.5% more efficient</td>
<td>Advanced AMT</td>
<td>Advanced LRR</td>
<td>30% red. In Cd</td>
<td>5% WR</td>
</tr>
<tr>
<td>15% more efficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TP1</th>
<th>TP2</th>
<th>TP3</th>
<th>TP4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Transmission</td>
<td>Tires</td>
<td>Aerodynamics</td>
</tr>
<tr>
<td>BS IV (EGR)</td>
<td>Manual 6-speed</td>
<td>Bias</td>
<td>No aero drag (Cd)</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TP5</th>
<th>TP6</th>
<th>TP7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Transmission</td>
<td>Tires</td>
</tr>
<tr>
<td>BS IV (EGR)</td>
<td>Manual 6-speed</td>
<td>Bias</td>
</tr>
<tr>
<td>5% more efficient</td>
<td>AMT 8-speed</td>
<td>Radial</td>
</tr>
<tr>
<td>10% more efficient</td>
<td>Improved AMT</td>
<td>Low rolling resistance (LRR)</td>
</tr>
<tr>
<td>12.5% more efficient</td>
<td>Advanced AMT</td>
<td>Advanced LRR</td>
</tr>
<tr>
<td>15% more efficient</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Heavy-Duty Vehicle Fuel Efficiency in India
Technology packages (TPs): rigid truck

<table>
<thead>
<tr>
<th>Engine</th>
<th>Transmission</th>
<th>Tires</th>
<th>Aerodynamics</th>
<th>Weight reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS IV (EGR)</td>
<td>Manual 6-speed</td>
<td>Bias Radial</td>
<td>No aero drag (Cd) red.</td>
<td>No weight red. (WR)</td>
</tr>
<tr>
<td>5% more efficient (BS VI)</td>
<td>AMT 8-speed</td>
<td>Low rolling resistance (LRR)</td>
<td>10% red. In Cd</td>
<td>1% WR</td>
</tr>
<tr>
<td>10% more efficient</td>
<td>Improved AMT</td>
<td>Advanced LRR</td>
<td>20% red. In Cd</td>
<td>2.5% WR</td>
</tr>
<tr>
<td>12.5% more efficient</td>
<td>Hybrid-electric</td>
<td></td>
<td></td>
<td>5% WR</td>
</tr>
<tr>
<td>15% more efficient</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Baseline

TP1

TP2

TP3

TP4

TP5

TP6

TP7

Increasingly efficient technologies, moving left to right

Heavy-Duty Vehicle Fuel Efficiency in India
## Technology packages (TPs): transit bus

<table>
<thead>
<tr>
<th>Engine</th>
<th>Transmission</th>
<th>Tires</th>
<th>Aerodynamics</th>
<th>Weight reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS IV (EGR)</td>
<td>Manual 6-speed</td>
<td>Bias</td>
<td>Low rolling resistance (LRR)</td>
<td>No weight red. (WR)</td>
</tr>
<tr>
<td>5% more efficient</td>
<td>AMT 8-speed</td>
<td>Radial</td>
<td>Advanced LRR</td>
<td>1% WR</td>
</tr>
<tr>
<td>10% more efficient</td>
<td>Improved AMT</td>
<td></td>
<td></td>
<td>2.5% WR</td>
</tr>
<tr>
<td>12.5% more efficient</td>
<td>Hybrid-electric</td>
<td></td>
<td></td>
<td>5% WR</td>
</tr>
<tr>
<td>15% more efficient</td>
<td></td>
<td></td>
<td></td>
<td>7.5% WR</td>
</tr>
</tbody>
</table>

### Increasingly efficient technologies, moving left to right

- **Baseline**
- **TP1**
- **TP2**
- **TP3**
- **TP4**
- **TP5**
- **TP6**
- **TP7**

**We assume no aerodynamic improvements for the transit bus**

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Heavy-Duty Vehicle Fuel Efficiency in India
Engine, transmission, and tire technologies represent the large majority of total fuel savings.
Cost breakdown for each technology package

Costs, including taxes and markup (Rs in Lakh)

Technology package number

Tractor-trailer | Rigid truck | Transit bus

Weight reduction | Aerodynamics | Tires | Trans. and axles | Engine

Hybrid system

Heavy-Duty Vehicle Fuel Efficiency in India
Incremental retail price versus fuel consumption reduction

Reduction in fuel consumption versus the Baseline

Note: Incremental retail price includes manufacturing cost, tax, and markup.
Economic, oil, and greenhouse gas impacts: methodology and results
Payback period is within 2 years for nearly all of the technology packages.

Heavy-Duty Vehicle Fuel Efficiency in India
Assuming a 5-year loan, payback time is even more attractive.
Cumulative benefit for tractor-trailer with TP1, assuming one-time upfront payment

Discount rate: 7.75%

Investment pays back in less than 1 year
Cumulative benefit for tractor-trailer with TP7, assuming one-time upfront payment

Discount rate: 7.75%

Cumulative benefit (Rs in Lakh)

Investment pays back within 2 years
Cumulative benefit for *rigid truck with TP2*, assuming one-time upfront payment

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative benefit (Rs in Lakh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>10.0</td>
</tr>
<tr>
<td>4</td>
<td>15.0</td>
</tr>
<tr>
<td>5</td>
<td>20.0</td>
</tr>
<tr>
<td>6</td>
<td>25.0</td>
</tr>
<tr>
<td>7</td>
<td>30.0</td>
</tr>
</tbody>
</table>

Discount rate: 7.75%

Investment pays back in less than 1 year.
Cumulative benefit for *rigid truck with TP6*, assuming one-time upfront payment

Discount rate: 7.75%

Investment pays back within 2 years
Cumulative benefit for *transit bus with TP2*, assuming one-time upfront payment

Discount rate: 7.75%

- Investment pays back in less than 1 year

Year

Cumulative benefit (Rs in Lakh)

- ₹0
- ₹5
- ₹10
- ₹15
- ₹20
- ₹25
Cumulative benefit for *transit bus with TP6*, assuming one-time upfront payment

Discount rate: 7.75%

Heavy-Duty Vehicle Fuel Efficiency in India
Net present value (NPV), assuming one-time upfront payment

Heavy-Duty Vehicle Fuel Efficiency in India
Net present value (NPV), assuming 5-year loan
HDV stock growth model results

Note: GDP growth is based on the World Bank forecasts.
Penetration of technology packages

Share in total HDV (>12t) stock

- Conventional rigid trucks
- Rigid trucks with technology packages
- Conventional tractor-trailers
- Tractor-trailers with technology packages
- Conventional transit buses
- Transit buses with technology packages

Years:
- 2020
- 2025
- 2030
- 2035
- 2040
- 2045
- 2050
Baseline HDV diesel consumption

HDV (> 12t) diesel consumption (MTOE)

- 2015
- 2020 BAU
- 2030 BAU
- 2040 BAU
- 2050 BAU

Heavy-Duty Vehicle Fuel Efficiency in India
Technology packages provide substantial diesel and CO$_2$ savings.
HDV fleet diesel consumption in 2030

Heavy-Duty Vehicle Fuel Efficiency in India
HDV fleet diesel consumption in 2050

HDV (> 12t) diesel consumption (MTOE)

2050 Baseline

Total Savings

<table>
<thead>
<tr>
<th>TP</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP1</td>
<td>14.7</td>
</tr>
<tr>
<td>TP2</td>
<td>16.1</td>
</tr>
<tr>
<td>TP3</td>
<td>23.9</td>
</tr>
<tr>
<td>TP4</td>
<td>24.4</td>
</tr>
<tr>
<td>TP5</td>
<td>27.6</td>
</tr>
<tr>
<td>TP6</td>
<td>31.0</td>
</tr>
<tr>
<td>TP7</td>
<td>48.0</td>
</tr>
</tbody>
</table>

Heavy-Duty Vehicle Fuel Efficiency in India
Total national diesel and oil consumption

![Graph showing diesel consumption (MTOE) and crude oil consumption (million barrels) for 2015, 2030 IEA, and 2040 IEA.]

2030 HDV diesel savings relative to total Indian consumption; more savings needed

Baseline

India diesel consumption (Mtoe)

2015
2030 IEA
2030 PACKAGES

TP1 = 4.0%
TP2 = 4.4%
TP3 = 6.5%
TP4 = 6.7%
TP5 = 7.6%
TP6 = 8.5%
TP7 = 13.4%

Total Savings

Savings in technology packages

-4.0%
-0.4%
-2.1%
-0.2%
-0.9%
-0.9%
-4.7%

Heavy-Duty Vehicle Fuel Efficiency in India
CO$_2$ emissions savings

Heavy-Duty Vehicle Fuel Efficiency in India
Total fleet NPV for tractor-trailer fleet

Heavy-Duty Vehicle Fuel Efficiency in India
Total fleet NPV for rigid truck fleet

NPV (Rs in Lakh)

- TP2
- TP6

Heavy-Duty Vehicle Fuel Efficiency in India
Total fleet NPV for transit bus fleet

- NPV (Rs in Lakh)
  - ₹0
  - ₹50,000
  - ₹100,000
  - ₹150,000
  - ₹200,000
  - ₹250,000
  - ₹300,000

- Years:
  - 2020
  - 2025
  - 2030
  - 2035
  - 2040

- Lines:
  - TP2
  - TP6

Heavy-Duty Vehicle Fuel Efficiency in India
Download Full Report here:
http://eetd.lbl.gov/node/62069

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