Strategic Insights Into Engine Downsizing Trends of North American Heavy-duty Truck Manufacturers
A 2% to 3% Reduction in Class 8 Truck Engine Displacement Expected by 2018

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Definition:
Downsizing can be defined as “Reduction of Engine Form Factor (Especially Displacement) With an Aim to Increase Fuel Efficiency and Reduce Emissions.”

2011 Weighted Average Displacement of Class 8 Truck Engines: 13.7–14.1 L

2018 Weighted Average Displacement of Class 8 Truck Engines: 13.3–13.7 L

Potential Key Features:
- 20 percent lower emissions
- 20 percent lower fuel consumption
- 2–3 percent lower displacement
- 6–8 percent higher power density
- Lower engine weight
- Better integration with vehicle

Advanced Engine Technologies:
- Turbocharging
- After-treatment
- Waste heat recovery
- Powertrain optimization
- Powertrain downspeeding
- Hybrid powertrain
- Other advanced technologies

Power Output/Performance

Note: Images are for representation only, and do not hold any qualitative/quantitative inference.

Source: Frost & Sullivan analysis.
Downsizing Definitely a key Solution for Meeting Needs of Tomorrow’s Commercial Vehicle Business Ecosystem

Heavy-duty Truck Engine Market: PESTLE (Political, Economic, Social, Technological, Legislative, and Environmental) Analysis, North America, 2011

- Rising awareness and market adoption for CNG/LNG/hybrid vehicles.
- Growing demand from clients of fleets to provide “green freight transport solutions.”

- GHG 2014-2018 mandate that regulates emission and fuel efficiency levels for HD trucks
  - Regulations expected in the comfort and convenience segment and rising importance for driver comfort.

- Developments in complementary technologies such as turbochargers and after-treatment systems are enabling downsizing.
  - Significant improvements in NG/hybrid technologies are expected to indirectly drive downsizing.

- Federal support for overall fleet efficiency improvement via “SuperTruck” program
  - Growing support for alternate fuel (NG/Bio-fuel) and hybrid technologies

- Fleet operators continue to face liquidity crunch.
  - Reduced profit margins and a consequential need for low TCO products
  - Market opportunity for entry and growth of low-cost trucks

- Likely introduction of mega trucks (GVWR up to 93,000 lb.) expected to negatively impact downsizing.
  - Mega Trends pointing to rising hub and spoke logistics and driving the need for best-in-class fuel efficient HD trucks.

Source: Frost & Sullivan analysis.
Market Trends and Need for Downsizing
Market Realities for Both OEMs and Truck Buyers Indicating Relevance of Engine Downsizing for Sustainable Growth


“While GHG regulation compliance has created the urgency for powertrain downsizing, the benefits of downsizing go far beyond GHG compliance and help us solve some major industry challenges both internally and also for our customers.”

- Director Powertrain, Major HD OEM

Regulatory environment
• GHG 2014-2018 mandate regulating the fuel efficiency and emission levels

Dynamic changes in freight logistics
• Rise in share of regional/short haul vehicles
• Market adoption of NG, hybrid, and electric CVs

Industry dynamics and end-user preferences
• Vertical integration and consequential development of “right-sized” engines
• TCO considered a key purchase criterion

Developments in advanced engine technologies
• Advancements in downspeeding, turbo, after treatment, WHR, and other complementary technologies

Source: Frost & Sullivan analysis.
Greenhouse Gas Regulation is Expected to Usher In Significant Fuel Cost Reduction for Fleets, Especially in a High Diesel Price Environment

**Need**
- In the United States, the transportation sector accounts for 72 percent of total national oil consumption.
- Heavy-duty vehicles account for 17 percent of oil usage within the transportation sector, or 12 percent of total U.S. oil consumption.
- In 2007, an estimated 6 percent of all U.S. greenhouse gas emissions and 20 percent of GHG emission from the transportation sector was attributed to heavy-duty vehicles.

**Solution**
- EPA 2014–2018 mandates all heavy-duty vehicles (heavy-duty pick-up trucks and vans, heavy-duty combination tractors, and heavy-duty vocational trucks) to meet targets for fuel consumption and GHG emissions.
- Specific targets have been laid out for each category.

**Impact**
Impact/Benefits expected over the lifetime of vehicles built for 2014–2018 MY include
- Savings of a projected 530 million barrels of oil.
- Reducing carbon emissions by about 270 million metric tons.
- A semi-truck operator could realize benefits of an estimated $73,000 over the useful life of the truck.

Source: Frost & Sullivan analysis.
Dynamic changes in the heavy-duty industry, which include vertical integration of heavy-duty truck OEMs, tightening emission and fuel efficiency regulations, and market adoption of NG and hybrid/electric vehicles, are driving engine downsizing in North America.

Frost & Sullivan research on the key market drivers and restraints indicates that engine downsizing is gaining interest among all the OEMs and is expected to be a part of their overall freight efficiency improvement roadmap.

Although significant initial capital investment and R&D expenditure is involved, federal support and significant end-user benefits have placed advanced engine technologies (which includes engine downsizing) on the OEMs’ radar.

Within the strongly inter-connected commercial vehicle ecosystem, it is expected that specific Mega Trends such as urbanization, increasing inter-modality, and newer business opportunities will drive engine downsizing in the long term.

Source: Frost & Sullivan analysis.
North America Class 8 Truck Production Split by Engine Type:
A CAGR of At Least 20 Percent Expected for CNG, LNG and Hybrid Engines Within the Class 8 Engine Market; Diesel Engines To Account for 85 Percent of Overall Market by 2020

Heavy-duty Engine Market: Class 8 Truck Production, Split by Engine Type,
North America, 2011–2020

Unit shipments CAGR Data: Diesel=Decline by 1.5 percent, CNG/LNG= Increase by 24.0 percent, Hybrid/Electric= Increase by 20.4 percent

Source: Frost & Sullivan analysis.
Advanced Powertrain Technologies—Benefit versus Barriers
Future Truck Powertrain Will Leverage Multiple Solutions for Fuel Efficiency Enhancement; Downsizing Emerging as a Key Ingredient of an Integrated Solution

**Legend:**
1—advanced in-cylinder improvements; 2—downsizing; 3—downspeeding; 4—hybridization; 5—WHR; 6—turbochargers and boosting technologies; 7—advanced after-treatment; 8—engine prognostics

- Highly inter-dependent technologies with high-end user/industry benefits
- Driven by regulation, after-treatment and downsizing technologies require high capital investment from the OEMs to accomplish desired levels of benefit.
- Expected to continue being key ingredients of the long-term strategy of all HD OEMs

- Downspeeding is emerging as a major focal point for OEMs to enhance fuel efficiency, sometimes in conjunction with and also independent of downsizing.

**Convergence of OEM capabilities and end-user preferences**

- Independent engine technologies capable of delivering significant improvements in engine/vehicle efficiency
- Key focus area for all HD OEMs
- Technological advancements in these areas are easily deployed across product ranges, thereby improving their RoI ratio.

Note: Representation is only for indicative purposes. Mapping is based on primary and secondary research.

Source: Frost & Sullivan analysis.
Advanced Powertrain Technologies—Weighted Average Preference Ranking
OEMs' Preference Ratings for Various Technologies Reveal Downspeeding, Waste Heat Recovery, and Advanced After-treatment as Top Three Most Focused Technologies

Heavy-duty Engine Market: Weighted Average Preference Ranking of Advanced Powertrain Technologies by Key OEMs, North America, 2011

- Downspeeding emerges as top preference across all OEMs.
- WHR is critical due to significant benefits the technology offers.
- All OEMs are expected to focus on after-treatment technologies, owing to regulatory mandates.

Note:
1. Ranking is on a scale of 1 to 10, with 10 being most preferred, and 1 being least preferred.
2. Weighted average ranking used as representative of industry. Individual OEM level rankings are detailed in respective OEM profiles.

Source: Frost & Sullivan analysis.
Analysis of Key Design Parameter Ranges for HD Engine Market, 2011–2018
Powertrain Downsizing Pushing Weighted Average Engine Displacement to Under 14 L in Class 8 Trucks by 2018


<table>
<thead>
<tr>
<th>Year</th>
<th>Displacement (in L)</th>
<th>Power (in bhp)</th>
<th>Torque (in lb. ft.)</th>
<th>Median range</th>
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</thead>
<tbody>
<tr>
<td>2011</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>13.7 L–14.1 L</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>2%–3% reduction</td>
</tr>
<tr>
<td>2018</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>13.4 L–13.7 L</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>400–520 bhp</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>425–540 bhp</td>
</tr>
<tr>
<td></td>
<td>1100</td>
<td>1250</td>
<td>1400</td>
<td>1250–1650 lb. ft.</td>
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<tr>
<td></td>
<td>1550</td>
<td>1700</td>
<td>1850</td>
<td>4%–6% increase</td>
</tr>
</tbody>
</table>

Source: Frost & Sullivan analysis.
Powertrain Downsizing—Key Findings

Heavy-duty Engine Market: Key Takeaways in North America, 2012

1. Weighted average engine displacement is expected to shift from 13.7 to 14.1 liters (L) to 13.4 to 13.7 L, amounting to 2 to 3 percent downsizing. A corresponding shift in power density is expected to be at 6 to 8 percent, increasing from the current level of 36.8 bhp/L to 39.1 bhp/L.
2. Technology advancements are enabling 11 L engines to deliver 380 to 420 horsepower (HP).
3. Key market drivers include changes in freight movement patterns, increasing urbanization, and penetration of natural gas and hybrid commercial vehicles.
4. A strong used truck market and possible introduction of mega-trucks in the long term are expected to be the two major market restraints.
5. Engine downsizing is expected to be higher in the vocational and regional/local haul segments when compared to the line-haul segment.
6. The share of larger engines in the line-haul segment is expected to decrease as a result of the “trucks cubing out before weighing out” trend.
7. All heavy-duty original equipment manufacturers (OEMs) interviewed have shown varying degrees of preference for downsizing, OEMs’ activities are expected to show results from 2014 onwards and will be driven by continued fuel price volatility and rising adoption of CNG/LNG and hybrid heavy-duty trucks.
8. This rising preference for downsizing is indicative of an “OEM push” rather than a “market pull” in the North American heavy-duty engine market.

Source: Frost & Sullivan analysis.
### Heavy-duty Powertrain Configuration—Future Blueprint

Three Percent Reduction in Engine Size Driven by 5 Percent Improvement in Power Density Will Usher Right Sizing of Engines in North American Class 8 Trucks

*Note: All data is proprietary F&S estimates. Weighted average numbers are used, and serve only as representatives of downsizing and related activities in the industry.*

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Engine displacement</td>
<td>13.7 L–14.1 L</td>
<td>13.4 L–13.7 L</td>
<td>2 to 3 percent reduction</td>
</tr>
<tr>
<td>High-end Engine Power</td>
<td>400–520 bhp</td>
<td>425–540 bhp</td>
<td>4 to 6 percent increase</td>
</tr>
<tr>
<td>Engine torque</td>
<td>1250–1650 lb. ft.</td>
<td>1300–1750 lb. ft.</td>
<td>4 to 6 percent increase</td>
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<tr>
<td>Configuration</td>
<td>In-line 6 cylinder</td>
<td>In-line 6 cylinder</td>
<td>Cylinder de-activation being tested for mid- to long-term implementation</td>
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<td>Turbo technology</td>
<td>Predominantly VGT</td>
<td>Predominantly VGT</td>
<td>Electric turbo-compounding expected by 2018</td>
</tr>
<tr>
<td>Transmission</td>
<td>Predominantly manual</td>
<td>Rising penetration of AMT</td>
<td>Increasing market trends toward optimized proprietary engine-transmission-axle offering</td>
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<tr>
<td></td>
<td>Large proportion of third party</td>
<td>OEM proprietary transmission as standard</td>
<td></td>
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<tr>
<td>Brake thermal efficiency</td>
<td>42 percent</td>
<td>50 percent or above</td>
<td>SuperTruck program expected to be a major step toward BTE improvement</td>
</tr>
</tbody>
</table>

Source: Frost & Sullivan analysis.
Voice of Customer Research (Next Five Years)

In 2012, 1 in 5 Fleet Managers of Top-100 Class 6–8 Truck Fleets in the United States Anticipate Spec’ing Downsized Engines; In spite of Being a Small Fraction, This Shows a Noticeable Market Trend

Heavy-duty Engine Market: Fleet Vehicle Purchase Intentions, United States, 2012

Base: All 2012 respondents (n=100).
Q34. Thinking about your fleet's vehicle purchases in the next five years, please select all of those which you anticipate buying. (Multiple response)
### Powertrain Downsizing—Big 5 Predictions

1. Engine downsizing is gaining preference in the North American heavy-duty (HD) truck industry. In conjunction with other advanced technologies, this is expected to drive reduction of fuel consumption and emission by at least 20 percent by 2018. This is also expected to provide flexibility in engine right-sizing for major HD OEMs, which are increasingly adopting platform-based truck production.

2. Weighted average reduction in engine displacement is estimated through OEM/vocation-based analysis to be between two to three percent for the industry. In 2011, the weighted average displacement was 13.7 to 14.1 L, which by 2018 is expected to shift to 13.4 to 13.7 L. Power density for the same period is expected to increase from the current 400 to 520 HP to 425to 540 HP range.

3. Dominance of 15 L engines is expected to continue in the Class 8 long haul segment, although its share within the long haul segment will decline. Driven by factors such as the downsizing of activities of OEMs, growth in the regional/urban haul segment, Cummins Inc.’s larger role in the 12 to 14 L range, vertical integration within the industry, and regulatory pressures, the installation of 12 to 14 L engines is expected to increase and come on par with 14to 15 L engines by 2018.

4. Daimler trucks and Volvo trucks are two participants expected to be the strongest proponents of downsizing in the forecasted period. Navistar Inc. will pursue increased downsizing activities post 2015, owing to its recently adopted SCR-based emission reduction strategy. Cummins Inc. is expected to increase downsizing activities gradually from 2013 until 2018.

5. Key factors such as the rising proliferation of CNG/LNG trucks; the rising utilization of technologies such as downspeeding, advanced turbocharging, waste heat recovery, and in-cylinder improvements; and the rising proliferation of semi-automatic transmissions are expected to bridge the demand-supply gap for downsized engines.

Source: Frost & Sullivan analysis.