# CONFIDENCE REPORT: DOWNSPEEDING


## ABSTRACT

This report documents the confidence that North American Class 8 trucking should have in downspeeding for improved fuel efficiency. The study team engaged the entire industry in the data that is presented here. Thanks to all of those who contributed to this important work.


## Trucking Efficiency

Trucking Efficiency is a joint effort between NACFE and the Carbon War Room to double the freight efficiency of North American goods movement through the elimination of market barriers to information, demand and supply.




October 28, 2015

**Acknowledgements:**

**Study Team:**
John Baxter, Baxter TechWrite
Denise Rondini, Rondini Communications
Mike Roeth, NACFE Executive Director

**Study Editor:**
Tessa Lee, Carbon War Room
Denise Rondini, Rondini Communications

**Study Sponsors:**
Cummins
Eaton
Meritor

**NACFE Technical Advisory Committee:**
Ezel Baltali, Ryder System Inc.
Tim Dzojko, Air Products
Randy Cornell, Con-way TL
Bruce Stockton, Kenan Advantage Group
Ken Marko, Frito Lay
Dan Deppeler, Paper Transport
Steve Duley, Schneider National
Dale Spencer, UPS
Steve Phillips, Consultant
Mike Roeth, NACFE Executive Director

Contents

# TRUCKING EFFICIENCY CONFIDENCE REPORT: Downspeeding Executive Summary

**The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. In 2014 diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable.**

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. Unfortunately, multiple barriers have stymied industry adoption of such technologies, including a lack of data about the true performance gains these technologies offer and a lack of confidence in the data that is publicly available today. To overcome these barriers and facilitate the industry's trust in and adoption of the most promising fuel efficiency technologies, the North American Council for Freight Efficiency (NACFE) partnered with Carbon War Room (CWR) to form Trucking Efficiency. The work of Trucking Efficiency has begun by producing a series of Confidence Reports, of which this report on downspeeding technologies is the eighth.

**The goals of this Confidence Report are: (a) to provide fleet leadership with a comprehensive overview of the application of downsped powertrains on over-the-road (OTR) tractors for improved fuel efficiency; (b) to provide an unbiased review of available downspeeding options on the market today; and (c) to increase investment in downspeeding technologies.**

"Downspeeding long-haul trucks is a key strategy for fleets to achieve high mpg and builds upon the use of other key technologies such as electronically controlled transmissions and optimizing engine parameters."

## Methodology

**This report's conclusions were generated through desk research, conversations at a variety of trucking industry events around the country, and a series of structured interviews with fleets, truck, and all of the powertrain manufacturers active in the North American market today.**

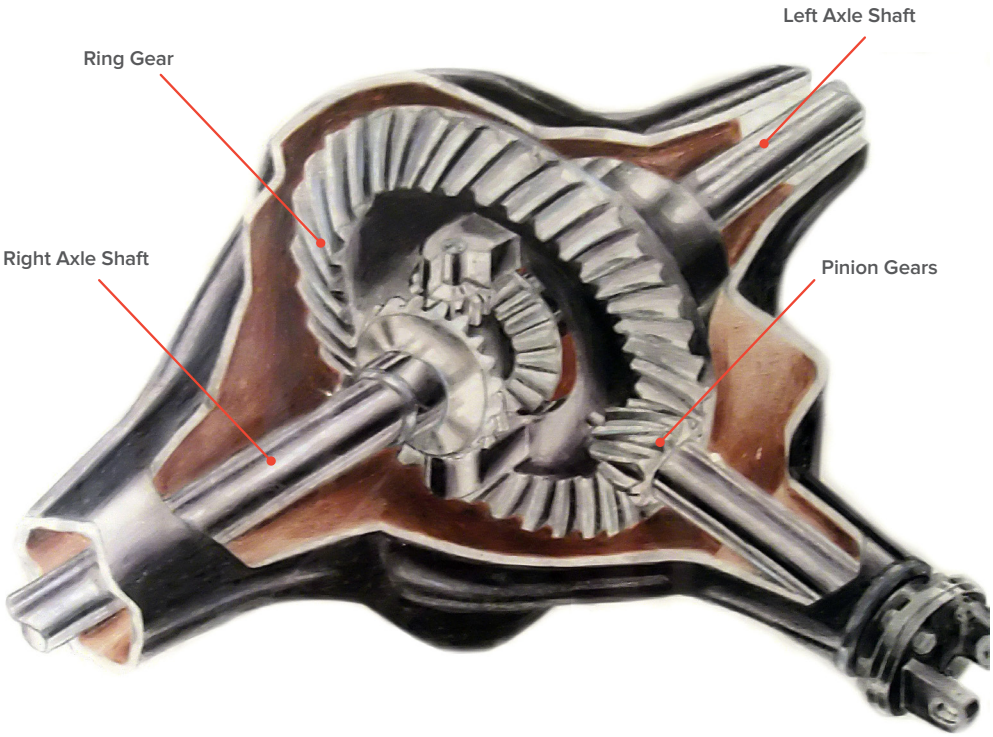
## DOWNSPEEDING AND FAST REAR-GEAR RATIOS

***Downspeeding*** is a term given to the use of fast rear-gear ratios (also called rear-axle ratios), combined with a lowered engine speed, and is one of the primary powertrain-focused strategies for improving the fuel economy of both over-the-road long-haul tractor trailers and of regional-haul daycab trucks whose highway mileage is high and whose infrequent pickups and deliveries allow them to operate at highway speeds much of the time. Downspeeding may be accomplished via one of two powertrain configurations—a fast axle ratio combined with a direct-drive transmission (ideal for true linehaul duty cycles), or a slightly

slower axle ratio (but still faster than traditional powertrains), combined with an overdrive transmission (used for linehaul as well as regional and city applications).

The ***ratio number*** captures the relationship between the output speed of revolutions of the wheel axles and the input speed of revolutions of the driveshafts, which is the same as that of the engine when using a direct-drive transmission. The ratio is determined by the number of teeth on the gears for each. A "faster" ratio will therefore have a lower number, as for every one output revolution, a lower number of input revolutions will be required.

**FIGURE ES1:** COMPONENTS IN A REAR AXLE




## KEY FINDINGS OF THIS REPORT

- When optimally applied, downspeeding will improve fuel efficiency and lower the operating revolutions per minute (rpm) of the engine under cruise conditions, while helping in other areas as well, such as noise reduction and improved drivability.

- Downspeeding alone can **save 2–3% off the fuel bill**. However, specifying a downsped engine without looking at the whole of the powertrain can have negative consequences, such as increased risk of driveline failure or insufficient horsepower.

- Optimal truck design will see downsped powertrains in either of the two configurations spec'd with other technologies, including automated manual transmissions (AMTs), certain rear-axle ratios, modified engine torque levels that may be restricted to certain gears, carefully chosen electronic engine parameters, and reinforced drivelines.

- This package of multiple fuel efficiency technologies results in about 3–6% fuel savings overall and reduces the negatives posed by adopting downspeeding exclusively.

- Downspeeding is at a tipping point, with rear-axle ratios of 2.47:1, and engine rpms of 1,100–1,300 now common offerings among powertrain manufacturers. And "aggressive downspeeding" is just around the corner, with manufacturers poised to offer rear-axle ratios of around 2.08:1, and even lower engine cruise rpms of just 900–1,000.

## DOWNSPEEDING SPECIFICS

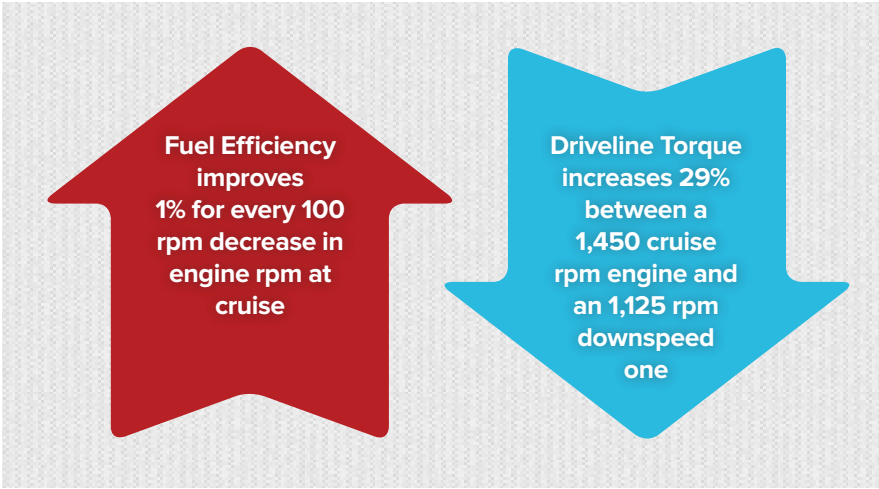
In trucking, downspeeding specifically entails reducing the 65-mph cruise engine rpm (also known as the engine's speed) from 1,600 rpm or higher to less than 1,200 rpm, corresponding to a reduction in rear-axle ratios from over 4.00:1, to around 2.47:1 common today. Recent product announcements and new product launches are even more aggressive with downspeeding, offering ratios as low as 2.28:1 and even 2.08:1.

Downspeeding can be adopted in one of two configurations:

- A direct-drive transmission combined with a very fast axle ratio (between 2.64:1 and 2.47:1)

- An overdrive transmission and somewhat slower rear axles (approximately 3.36:1 and faster)

**FIGURE ES2:** KEY BENEFIT AND CHALLENGE WITH DOWNSPEEDING




For example, one common specification combines a transmission with an overdrive ratio of 0.80:1 with 2.64:1 ratio axles, which gives a cruise rpm near 1,150 at 65 mph. The fast axle ratio plus direct drive specification offers the very greatest reductions in both friction and fuel consumption, but is really only appropriate for true linehaul applications where the highest torque conditions occur infrequently. The somewhat slower axle ratio of an overdrive transmission spec subjects the transmission output, driveshafts, and axles to far less torque overall. This makes it appropriate for both linehaul and regional and city delivery applications, as frequent starts and maneuvers in the yard subject the drivetrain to considerably more high-torque situations. Therefore, for the vast majority of Class 8 OTR trucks, the direct drive option is recommended, as it offers the greatest fuel savings.

## FUEL SAVINGS OF DOWNSPEEDING

These changes to the powertrain reduce fuel consumption 2–3%, as downspeeding allows the engine to operate at the most-fuel-efficient rpm when generating only the minimal horsepower required under cruise conditions. Trucks need much less cruise horsepower today than in years past thanks to other efficiency advances in aerodynamics, tires, lightweighting, and more.

Besides imposing a subtle, but very definite, limit on available power, turning the engine more slowly saves fuel by:

- Reducing friction and parasitic losses in the engine;
- Reducing the effort required to ingest air and expel exhaust, as there is more time for air and exhaust flow; and
- Creating a higher fuel/air ratio in the cylinder resulting in higher peak temperatures and pressures, because the amount of fuel injected during each power stroke is greater. This also increases turbo boost.

As recently as 2011, the most common rear-axle ratios were in the range of 3.21:1 to 3.9:1. By 2015, rear-axle ratios in the 2.64:1 to 2.47:1 range have become much more common, especially for long-haul duty cycles, achieving the highest fuel savings when coupled with direct-drive AMTs.

## ADDITIONAL MOTIVATIONS FOR DOWNSPEEDING

Along with the fuel savings, a downsped truck equipped with an electronically controlled transmission is easier and more pleasurable to drive. Trucking today faces a major problem finding and retaining drivers; fleets recognize that investment in driver comfort and amenities is critical. In a downsped truck, the most notable difference to the driver will be the switch from a manual to an electronically controlled transmission, most likely an AMT. In fact, the need to attract large numbers of new drivers to the industry has already resulted in a major uptake in the

> "Downspeeding is a key to our high-mpg approach. These trucks, when properly set up, are snappy, with great torque, yet are very quiet and a real pleasure to drive."
> MAJOR FLEET EXECUTIVE

adoption of AMTs, which many drivers now prefer. Downspeeding works best when spec'd along with an AMT, thus drivers, particularly newer ones, have a positive opinion of downsped trucks overall. Another reason that drivers find downsped trucks to be nicer to drive is simply that their engines are much quieter.

## CHALLENGES OF DOWNSPEEDING

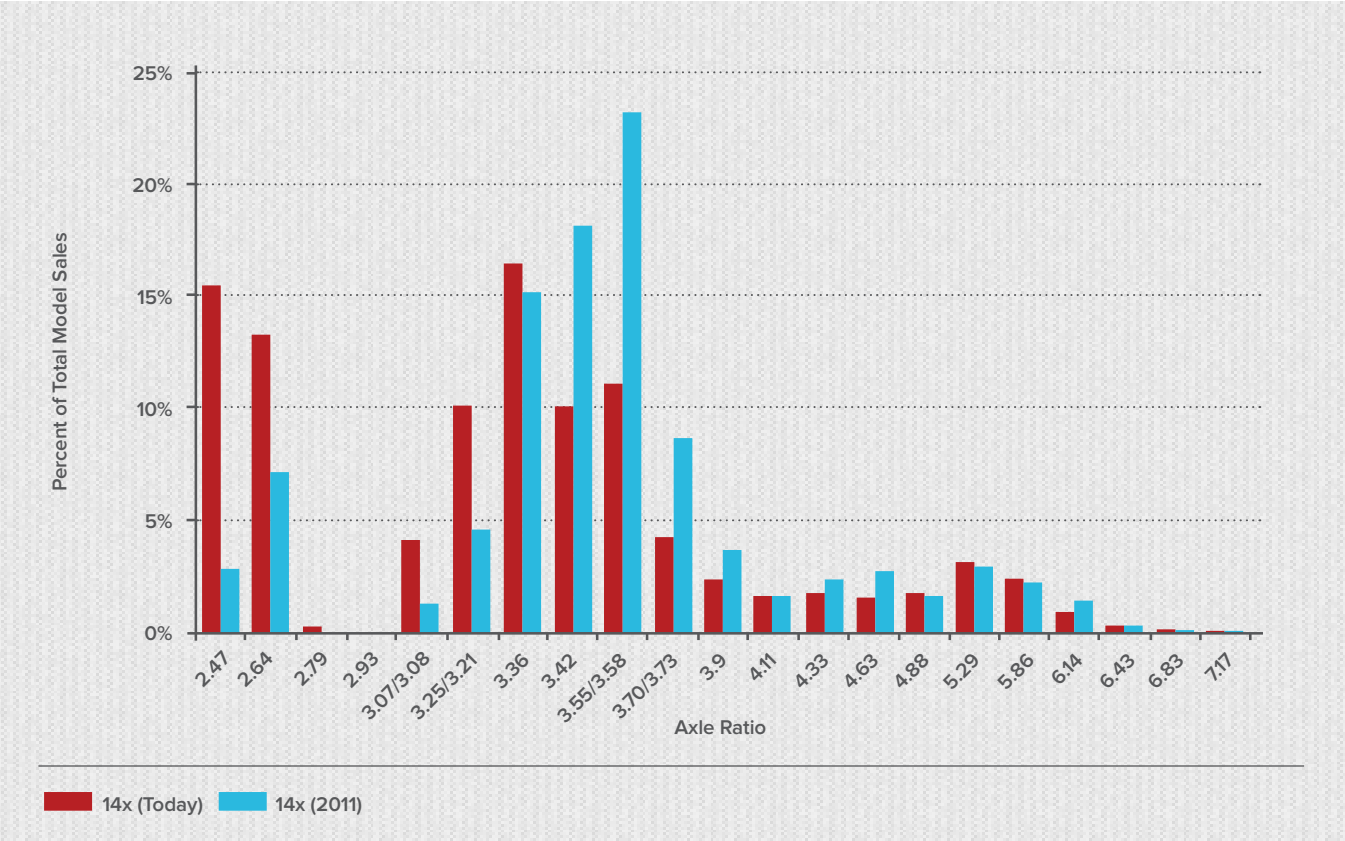
Downspeeding faces two major challenges to adoption: the greater potential for driveline failure if improperly spec'd, and the higher upfront costs of the needed components for an optimally downsped truck.

Drivetrain vulnerability is a critical concern for fleets, and faster axle ratios increase the potential for damage. This is primarily because lower rpm means more torque overall, and also means that torque spikes are applied to the driveline parts at a lower frequency, which can translate into gear chatter or wear issues.

However, our findings indicate that vehicle and component manufacturers are actively addressing this torque issue by developing heavier-duty components like driveshafts and axle housings, bearings, and gears that can handle the increased torque produced when engines turn at reduced rpm. Manufacturers augment these changes with more subtle but critically important elements of electronic control that soften engine response during clutch engagement, and less extensive mechanical enhancements to such parts as the torsional dampers used in the clutches fitted to downsped drivetrains.

Another reason for the increased risk of driveline failure is the better engine responsiveness that post-2010 engines have at low rpms, which puts more stress on the driveline. Finally, the stronger components used in downsped axles are much more sensitive to sudden shocks than those used in traditional axles, simply because they are less flexible. Overall though, the risk of failure from such sudden shocks is lower than the risk from components that are unable to

**FIGURE ES3:** MERITOR HIGHWAY TANDEM AXLE SALES BY RATIO - CURRENT vs. 2011



> "Downspeeding as a concept has been around for decades, but with high fuel costs, it is now being aggressively pursued with rear-axle ratios as low as 2.08:1."
>
> JOHN BAXTER, NACFE STUDY MANAGER

handle the higher torques, as the shocks are a rare occurrence.

Overcoming the challenge of increased driveline failures requires that fleets manage their downsped truck purchases with an unprecedented level of attention to the drivetrain. It will not be enough to simply fortify individual parts—it will be necessary to integrate the entire system of both mechanical parts and electronic engine tuning to ensure strength and durability. It also requires that fleets take a careful look at how they will be using the vehicle and discuss that very precisely with their OEMs; many trucks see mixed use as fleets use them in linehaul service during the day, and much different applications at night.

**The Confidence Report ultimately finds that** it remains to be seen just how reliable downsped drivetrains will be, and it is too early to predict failure percentages of various configurations, especially in the more demanding pickup-and-delivery type of operation where the truck may spend time off the highway negotiating heavy traffic and making frequent stops.

The other challenge to the adoption of downspeeding is that the upfront cost of a fully optimized downsped power train will be slightly higher than that of a "regular" truck—by about $500. Trucks are not priced by gear ratios, so downspeeding itself is essentially free. Instead, costs will be increased by the need to spec an electronically controlled transmission with a higher output torque capability, a certain clutch with a higher capacity damper, and higher torque driveshafts and rear axles. But for the majority of Class 8 long-haul trucks, the 2–3% fuel savings offered by downspeeding in the direct drive configuration with rear-axle ratios of 2.64:1 or lower will far exceed any added costs.

## CURRENT INDUSTRY TRENDS

Downspeeding as a concept has been around for decades, but recent complementary technologies have made it much more attractive. Above all, the increased adoption of electronically controlled transmissions is greatly facilitating investment into downspeeding for two reasons: First, a downsped powertrain will require much more frequent downshifting under highway conditions. This is because the engine operates much closer to its torque peak, which means a shift to a more powerful transmission gear ratio will be required after only a minimal drop in vehicle speed to ensure adequate hill climbing performance and cruise speed maintenance. Such frequent shifting would be objectionable to most drivers. Second, electronically controlled transmissions control clutch engagement very precisely by allowing the engine and transmission to communicate, thus ensuring shock-free engagement of the clutch.

Regulations are also incentivizing fleets to adopt downspeeding technologies at present. Phase 1 greenhouse gas emission standards, which focus on tractors, launched in 2014 and will take full effect in 2017. Phase 2 of these regulations will add a focus on trailers in 2018. Overall these standards will require truck, engine, and other suppliers to continue to develop, integrate, and sell features for improved freight and fuel efficiency, of which downspeeding is a strong option.

As of this report, all North American manufacturers offer downsped powertrains, and all are working intimately with engine, transmission, driveline, and rear-axle manufacturers to optimize their various combinations of products for the industry.

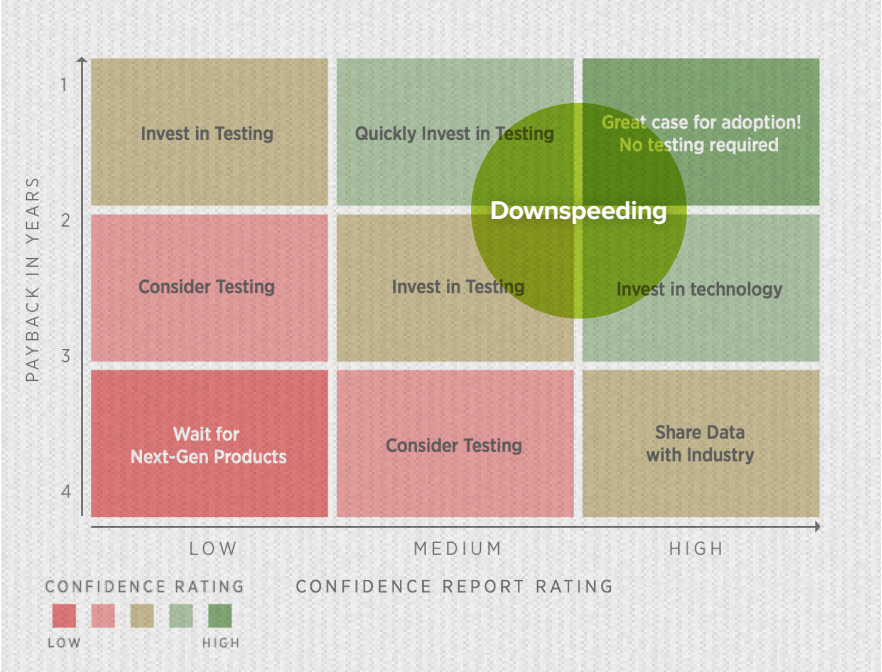
Looking ahead, Trucking Efficiency finds that over the next 5–10 years, "aggressive" downspeeding options will become widely available, with rear-axle ratios of 2.28:1 or lower. This Confidence Report is therefore timely, as it gives fleets insights into the current situation of downspeeding, with ratios of 2.47:1 or higher, and allows them to prepare for the additional pending advances.

## RECOMMENDATIONS

Three key recommendations emerged from this research:

- Fleets in long-haul duty cycles should strongly consider downspeeding their powertrains with direct drive and incorporating a complementary suite of other technologies, in order to obtain significant improvements in fuel efficiency, as well as increased driver satisfaction.
  - Optimally, downspeeding will include an electronically controlled transmission; an axle and driveshaft system specifically engineered for downsped engines, including robust tandem axles that offer the fast ratios required to fully leverage the efficiency offered by downspeeding; and driveshafts that can withstand higher torques—both in the short and long term.
- Fleets should work with their tractor and driveline suppliers to appropriately specify all of the components for their specific duty cycle, avoiding driveline failures.
  - It is critical for fleets to make sure their OEM knows exactly how they are going to use the vehicle, and how its usage could change in the future.
- Fleets must also ensure they allow their OEM to specify the necessary premium components—downspeeding is not a place for upfront cost-cutting, given the risk of those savings being erased by failed parts and downtime.
  - Manufacturers should continue to advance their downspeeding product offerings, and to work with fleets to appropriately specify components for their specific use.

**FIGURE ES4:** CONFIDENCE MATRIX FOR DOWNSPEEDING




## CONFIDENCE RATING

The confidence matrix (Figure ES4) illustrates the Trucking Efficiency study team's confidence in the investment case for downspeeding technologies adopted alone.

This Confidence Rating indicates that fleets should look to invest in downspeeding, as overall it offers significant gains in fuel efficiency. Certain duty cycles will be better served by downspeeding than others, and each fleet will have to make its own assessment of the potential trade-offs, in order to decide which configuration of downspeeding and complementary technologies will be best for them. Trucking Efficiency hopes that this report will catalyze significant additional interest in the package of fuel efficiency technologies that together offer an optimized downsped powertrain and up to 6% fuel savings.

Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share your own experiences with downspeeding technologies.

"Fleets in long-haul duty cycles should strongly consider downspeeding their powertrains and incorporating complementary technologies, ensuring the components are appropriate for their duty cycle and business practices."

MIKE ROETH, OPERATION LEAD, TRUCKING EFFICIENCY

# TRUCKING EFFICIENCY

Trucking Efficiency is a joint effort between NACFE and Carbon War Room to double the freight efficiency of North American goods movement by eliminating barriers associated with information, demand, and supply.

Worldwide, heavy-duty freight trucks emit 1.6 gigatons of $CO_2$ emissions annually—5.5% of society's total greenhouse gas emissions—due to the trucking sector's dependence on petroleum-based fuels. With fuel prices still commanding nearly 40% of the cost of trucking, the adoption of efficiency technologies by all classes of trucks and fleets offers significant cost savings to the sector while reducing emissions. These technologies are relatively cheap to implement and widely available on the market today.

Trucking Efficiency provides detailed information on cost-effective efficiency technologies, including data from across a variety of fleets and best practices for adoption. This Confidence Report series from Trucking Efficiency aims to serve as a credible and independent source of information on fuel efficiency technologies and their applications.

In order to generate confidence on the performance claims of efficiency technologies, Trucking Efficiency, via these reports, gathers and centralizes the multitude of existing sources of data about the performance results of different technology options when employed in a variety of vehicle models and duty cycles, and makes all of that data openly accessible and more easily comparable. Furthermore, we assess the credibility of the available data, and provide an industry-standardized ranking of confidence in performance results, including ROI and efficiency gains.

www.truckingefficiency.org

Trucking Efficiency welcomes outside views and new partners in our efforts to help accelerate the uptake of profitable, emission-reducing trucking technologies.

## CARBON WAR ROOM

Carbon War Room (CWR) was founded in 2009 as a global nonprofit by Sir Richard Branson and a group of likeminded entrepreneurs. It intervenes in markets to accelerate the adoption of business solutions that reduce carbon emissions at gigaton scale and advance the low-carbon economy. CWR merged with Rocky Mountain Institute (RMI) in 2014 and now operates as an RMI business unit. The combined organization engages businesses, communities, institutions, and entrepreneurs to transform global energy use to create a clean, prosperous, and secure future. The combined organization has offices in Snowmass and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.carbonwarroom.com

## NACFE

The North American Council for Freight Efficiency works to drive the development and adoption of efficiency-enhancing, environmentally-beneficial, and cost-effective technologies, services, and methodologies in the North American freight industry by establishing and communicating credible and performance-based benefits. The Council is an effort of fleets, manufacturers, vehicle builders, and other government and non-governmental organizations coming together to improve North American goods movement.

www.nacfe.org

# 1 Introduction

This Confidence Report forms part of the continued work of Trucking Efficiency, a joint initiative from the North American Council for Freight Efficiency (NACFE) and Carbon War Room (CWR) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 70 available technologies can be found at www.truckingefficiency.org.

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade. In 2014 diesel fuel costs were $0.58 per mile, costing the industry as much per annum as the costs of drivers' wages and benefits combined. Despite recent fuel cost decreases, all indications are that fuel price volatility will continue, forcing the industry to find solutions that increase its fuel efficiency in order to stay profitable.


*Figure 1: US Diesel Fuel Prices*

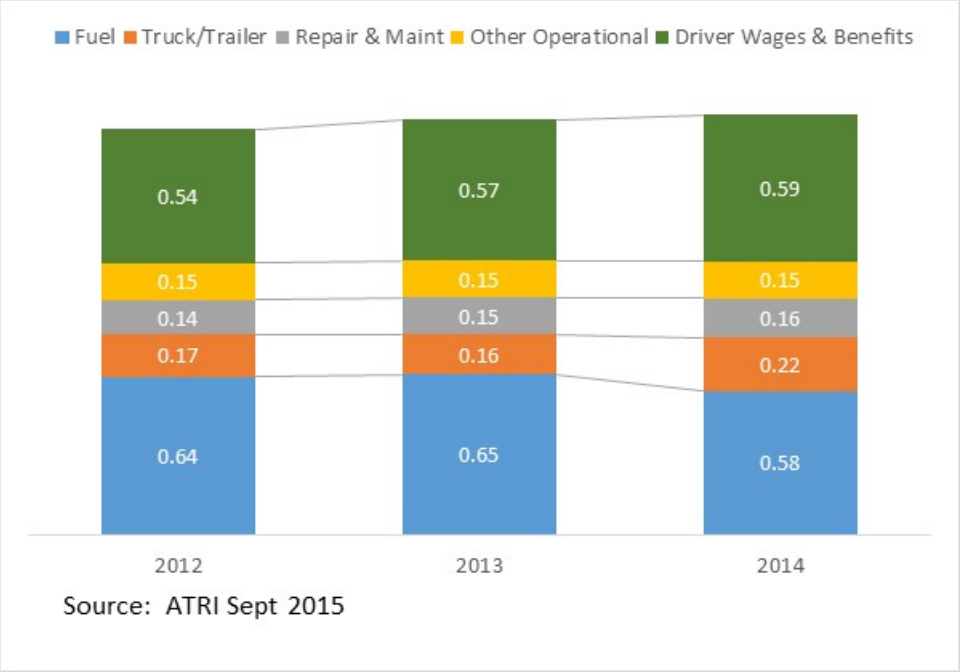



*Figure 2: Trucking Operational Cost*

Investment into proven technologies and practices that allow a truck or fleet to increase their fuel efficiency – meaning that they can do the same amount of business while spending less on fuel – is a hugely promising option for the industry in light of this trend.

To understand, and thereby better facilitate, the uptake of such technologies, NACFE conducts an annual review, the "Fleet Fuel Study," of the industry-wide adoption rates of nearly 70 fuel efficiency technologies currently available for Class 8 tractors and trailers. This work, available on the www.nacfe.org website, has been called "the most comprehensive study of Class 8 fuel efficiency adoption ever conducted." (Truck News, 2012)

*Figure 3: Fleet Fuel Study Participants*

The overriding take-away from the most recent Fleet Fuel Study, completed in 2015, is that fleets are enjoying dramatic improvements in their fuel efficiency by adopting combinations of the various technologies surveyed — savings of about $9,000 per tractor per year compared to a fleet that has not invested in any efficiency technologies. It found that these fleets have fleet-wide fuel economy of just under 7.0 mpg, while the USA average, for the approximately 1.5 million tractors in over-the-road goods movement, is 5.9 mpg. This finding was drawn from research into the use of fuel efficiency products and practices by 14 of the largest, most data-driven fleets (Figure 3). Those fleets represent both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boast a combined inventory of 53,000 tractors and 160,000 trailers. The 2015 study reviewed twelve years of adoption decisions by these ten fleets, and describes their specific experience with the nearly 70 technologies. Each fleet shared the percentage of their new purchases of tractors and trailers that included any of the technologies. They also shared twelve years' worth of annual fuel economy data for the trucks in their fleet. With these two pieces of information, which will be updated every year, NACFE is able to generate insights into the following aspects of the industry:

- Adoption curves for each of the technologies, indicating which technologies have the steepest adoption rates, which are being adopted steadily but slowly, and which are not being purchased at all. These curves also show how uniformly (or not) fleets are acting in their adoption patterns.
- Identification among the various fleets of the innovators, early-majority, late-majority, and even laggards, in new technology adoption.
- Comparison of technology adoption rates to overall fuel efficiency.
- Identification of three key insights: that the adoption of automated manual transmission has reached high levels, that aerodynamics are now available for natural gas tractors, and that the optimization of engine parameters is being pursued more widely as a fuel-saving strategy by large, medium, and small fleets.

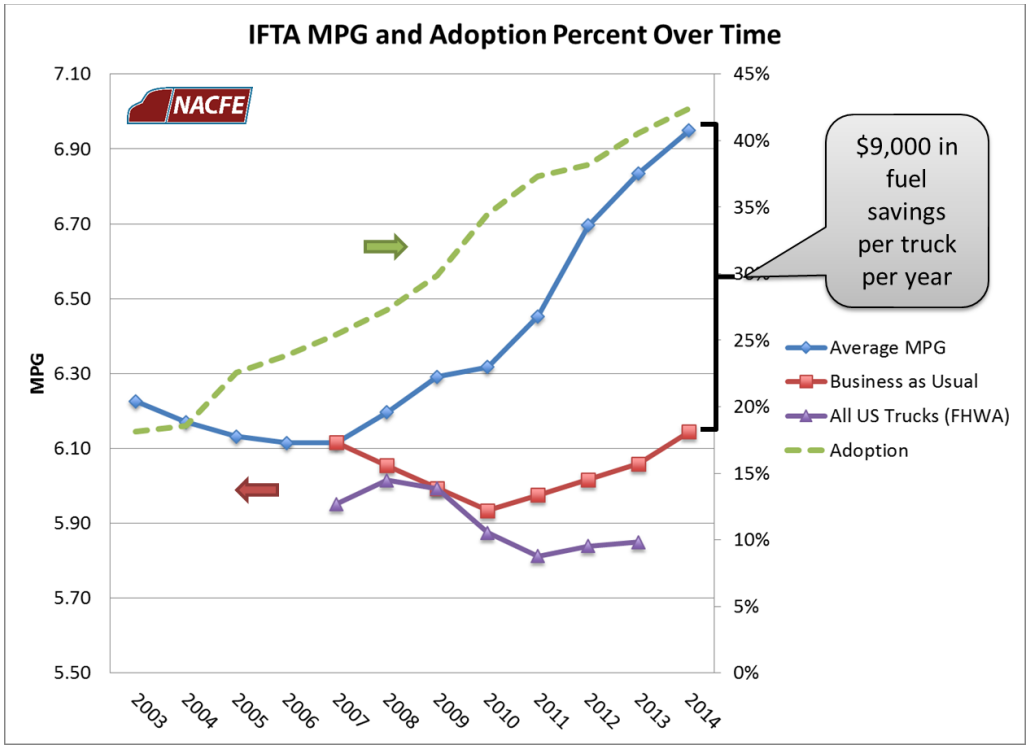



*Figure 4: Savings in Fuel per Truck*

## 1.1 Trucking Efficiency's Confidence Reports

NACFE's Fleet Fuel Studies provide useful insights into adoption trends in the industry, as well as into the specific practices of different major fleets. NACFE hopes that this information could alone spur additional investment, particularly by fleets that may be lagging behind the overall industry when it comes to certain widely-adopted technologies. However, in the course of conducting the studies, it became clear that some technologies are still only being adopted by the most progressive or innovative of fleets in spite of their showing strong potential for achieving cost-effective gains in fuel efficiency. In order to facilitate the wider industry's trust in and adoption of such technologies, NACFE and CWR formed Trucking Efficiency and began this series of reports, called "Confidence Reports," which will take an in-depth look at those most-promising but least-adopted technologies one-by-one.

Confidence Reports provide a concise introduction to a promising category of fuel efficiency technologies, covering key details of their applications, benefits, and variables. The reports are produced via a data mining process that both combs public information and collects otherwise-private information (which is shared with Trucking Efficiency for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

Downspeeding is a term given to the use of fast rear-gear ratios (also called rear-axle ratios), combined with a lowered engine speed, and is one of the primary powertrain-focused strategies for improving the fuel economy of both over the road long-haul tractor trailers and also of regional-haul daycab trucks whose highway mileage is high and whose infrequent pickups and deliveries allow them to operate at highway speeds much of the time. Downspeeding may be accomplished via one of two

powertrain configurations—a fast axle ratio combined with a direct-drive transmission (ideal for true linehaul duty cycles) or a slightly slower axle ratio but still faster than traditional powertrains combined with an overdrive transmission (used for linehaul as well as regional and city applications).

The core objective of this Confidence Report is to provide the leadership of fleets with a comprehensive overview of the application of downsped powertrains on over-the-road (OTR) tractors for improved fuel efficiency. Visit www.truckingefficiency.org to view this and other completed reports on tire pressure systems, 6x2 axles, idle reduction, electronically controlled transmissions, engine parameters, low rolling resistance tires, and lightweighting options, as well as information on many other freight efficiency technologies.

## 1.2 Methodology

Trucking Efficiency's Confidence Reports are researched by an unbiased team of trucking industry experts. For this downspeeding report the core study team included: John Baxter, Baxter TechWrite, Denise Rondini, Rondini Communications and Mike Roeth, NACFE Executive Director and CWR Trucking Efficiency Lead.

In February 2015, this study team began assessing the current state of downspeeding in Class 8 tractor-trailers. The team used a "360 degree" technique to gather existing data on downspeeding in order to uncover any points of industry-wide agreement or areas of confusion. The study team started this research by meeting with heavy-duty powertrain suppliers, tractor builders, and fleets over the course of several months.

The team met with or used phone interviews to speak with all of the truck and powertrain builders as well as many large and small fleets with experience in downspeeding. They also used the spring 2015 truck shows; the Technology and Maintenance Council meetings in Nashville, MidAmerican Trucking Show in Louisville, the National Private Truck Council event in Cincinnati and the Alternative Clean Transportation Conference in Dallas, to learn and meet with many of the key industry stakeholders for downsped powertrains.

### 1.2.1 Preliminary study questions used in study team interviews

Sample Questions:

- To your mind, what is meant by downspeeding? What is the history and current state of the technology?
- To what level is the strategy currently being adopted?
- What are the benefits of downspeeding?
- What are the challenges or consequences?
- Are there any best practices that can be learned from early adopters?
- What options or alternatives are emerging with respect to this?
- Are there specific duty cycles that are most appropriate for downspeeding?
- Any situations where the technology should be avoided?

- What is the upfront cost and total cost of ownership?
- Are there issues with resale value, should a fleet want to sell their trucks earlier in their overall useful life?
- How far might downspeeding go in the future?

# 2 Overview of Downspeeding

Perennially high fuel costs, as well as the Greenhouse Gas Emissions (GHG) reduction rules for on-road medium and heavy-duty vehicles, have together forced the industry to make many changes in heavy trucks that improve fuel economy. One big opportunity has been the introduction of downspeeding, which ensued when the engine and drivetrain component makers were induced to carry the "gear-fast-run-slow" concept one step further, reducing 65-mph cruise engine rpm (also known as engine "speed") to less than 1,200 rpm. Basically, the configuration change is to decrease the rear-axle ratio, making it run faster in order to slow down the engine speed, which makes it run more efficiently. Sometimes this has been called operating the engine in its "sweet spot". Generally meaning at a lower speed which uses less fuel due to lower pumping losses, to be explained further, later.

The result is a fuel consumption reduction of about 1% for every 100 rpms of lower engine speed. For most fleets, the change results in about a reduction of 200-300 rpm or at least a fuel expense improvement of 2% - 3%. These savings are generated by a number of forces, which relate to operating the engine at the most fuel efficient rpm while generating the minimal horsepower required to maintain a 65-mph cruise with modern aerodynamics, tires, and drivetrains.

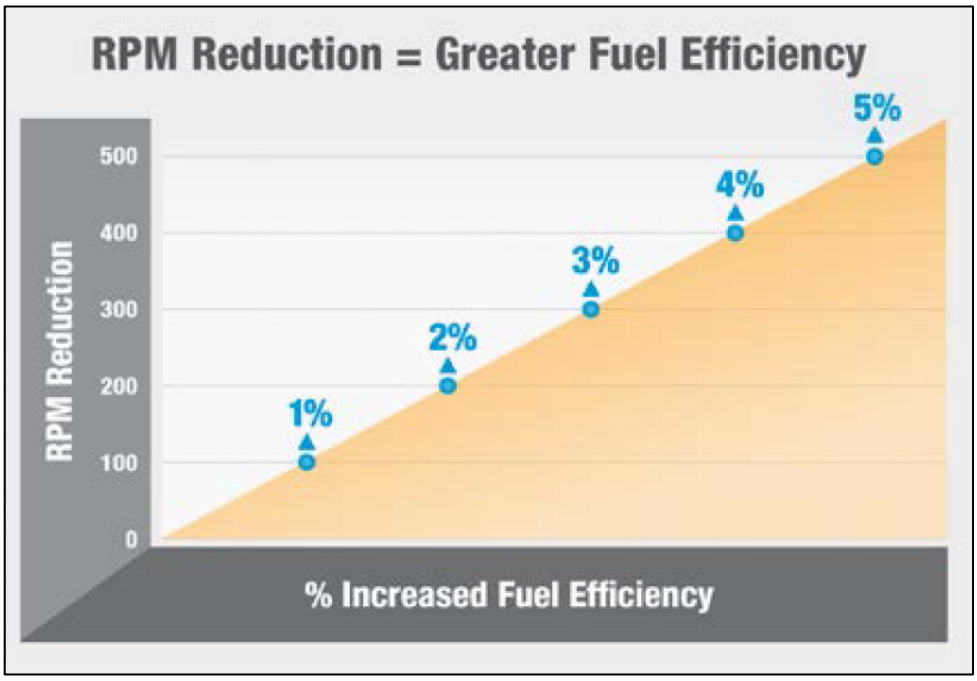



*Figure 5: Fuel Economy at Lower Engine Speeds (Source: Dana)*

There is little doubt that downspeeding saves fuel under highway cruise conditions. But having the engine turn so slowly can also potentially result in poor performance. Most engines as configured prior to downspeeding would produce significantly less power at the lower rpm, and would quickly reach the bottom of their peak torque range. The driver would then experience an unacceptable drop-off in power as speed drops when climbing hills or slowing with traffic. The faster axle speed would also quickly bring the engine to a point where it would be turning too slowly to deliver responsive performance. Further, faster axles create a considerable increase in torque, and this leads to increased drivetrain stress and delivers torsional spikes at a lower frequency, a situation that can cause severe drivetrain issues.

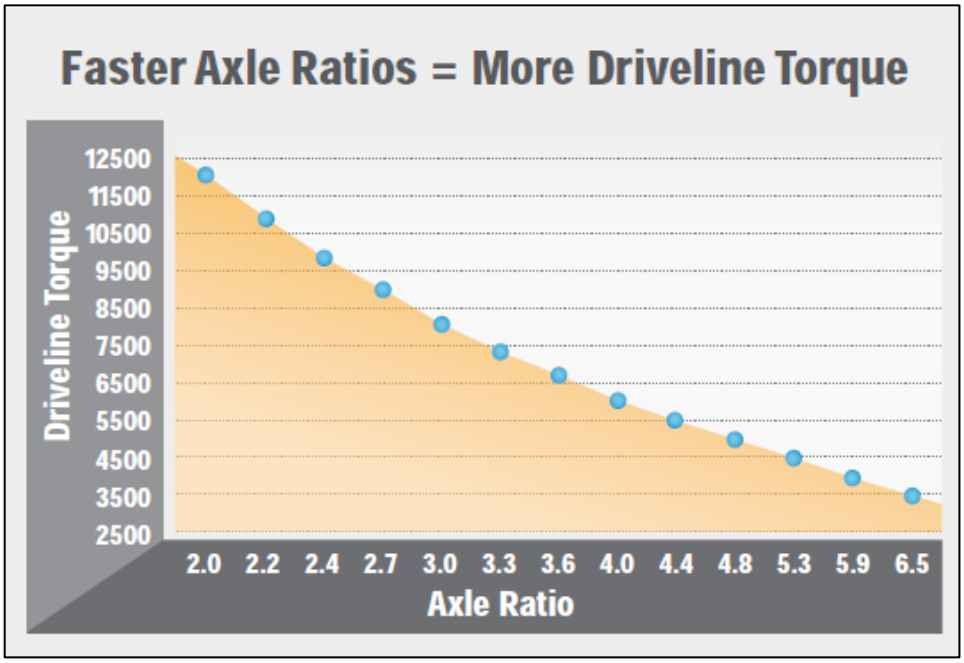



*Figure 6: Driveline Torque at Lower Engine Speeds (Source: Dana)*

Downspeeding has been evolving over the past decades with rear-axle ratios coming down from over 4.00 to levels around 2.47 by 2014. Recent product announcements and new product launches are occurring with ratios as low as 2.28 and 2.08, in order to be even more aggressive with this downspeeding practice. A key enabler for this movement has been the adoption of electronically controlled transmissions, most often automated manual transmissions. See Confidence Report on transmissions at www.truckingefficiency.org. Downspeeding creates more shift events and as AMTs have become more of the norm, downspeeding becomes a much more practical solution.

This higher speed rear-axles and faster turning drivelines, between the transmission and the rear-axle, cause increased torque that the driveline must endure. This is not such an issue with long-haul over the road operation, but has shown to be an issue in the more demanding Pickup-and-Delivery type of operation where the truck may spend time off the highway negotiating heavy traffic and making frequent stops. Occasional problems have already shown up in various situations, especially in "zero-

speed events," that is, when the driver needs to start the truck from rest in 1st, 2nd, or reverse gear. This will be discussed in more detail later.

Most fleets integrating a downspeeding strategy are doing so with the main intent to save fuel, so they are also optimizing engine parameters, training and incentivizing drivers and implementing automated manual direct-drive transmissions, 6x2 axles and low rolling resistance tires. All of which can co-exist with the right change management practices.

Direct-drive is an alternate means of saving fuel that allows manual shifting and conventional gear-splits to continue to be used. It's a cousin of downspeeding because it also requires faster axles, and many consider it to be a viable alternative. But, direct-drive requires even faster axles than downspeeding. Karl Mayer Director, Product Strategy – Axles at Meritor said 28% of their drive axles have ratios between 2.47:1 and 2.64:1, with direct-drive transmissions. When direct-drive is used, torque will increase in direct proportion to the reduction in axle ratio, just as with downspeeding. Thus, in going from a .74 overdrive to 1:1, even with the same cruise rpm, a 26% increase in torque must be expected. The driveline torque will increase even where a traditional cruise rpm is maintained.

## 2.1 Two Downspeeding Alternatives

The study team found two alternatives emerging with downspeeding, one with direct-drive transmissions and a fast axle ratio and others with overdrive transmissions and somewhat slower rear gears. The fast axle ratio direct-drive transmission specification is optimal in terms of friction and fuel consumption reduction, but given the potential for driveline failure, some manufacturers only approve it for true linehaul applications where the highest torque conditions occur only infrequently. The somewhat slower axle ratio of an overdrive transmission spec subjects the transmission output, driveshafts, and axles to far less torque. It therefore has the significant advantage of being approved for both linehaul and regional and city delivery applications, as frequent starts and maneuvers in the yard subject the drivetrain to considerably more high-torque situations.

For fleets looking to specify a durable, downsped drivetrain, the key best practice is to make sure that your OEM knows exactly how you are going to use the vehicle, and even how its usage could change in the future. Fleets must also make sure that they allow their OEM to specify the premium components that are needed – downspeeding is not a place for upfront cost-cutting, given the risk of those savings being erased by failed parts and downtime.

It is also best practice to specify an electronically controlled transmission (either an automated manual or fully automatic transmission) on any downsped engine. Great care must be used if manual transmissions are selected, in order to ensure that the engine's torque response during clutch engagement is specifically tailored to the drivetrain.

## Efficiency Trend Spotlight: Downspeeding

**Downspeeding is used for fuel efficiency gains and greenhouse gas emissions reduction. Similar results may be accomplished in two ways.**

**1**

**FAST AXLE RATIO + DIRECT DRIVE TRANSMISSION**

This should be used only for true linehaul applications.

**2**

**SLOW AXLE RATIO + OVERDRIVE TRANSMISSION**

This can be used for linehaul as well as regional and city delivery applications.

| EXAMPLE | Axle Ratio | | Transmission Ratio | | Overall Ratio in Top Gear |
|---|---|---|---|---|---|
| 1 | 2.47 | x | 1.00 (DD) | = | 2.47 |
| 2 | 3.36 | x | 0.74 (OD) | = | 2.48 |

**Meritor delivers product solutions for both downspeeding methods. More on Downspeeding in Meritor booth.**

6

*Figure 7: Two Scenarios for Downspeeding (Source: Meritor)*

# 3 History of Downspeeding

Mack Trucks, Inc. in the early 1960s explored an approach similar to today's downspeeding with its Maxidyne concept. A Mack vice president named Walter May modified a Bosch injection pump so that peak torque was generated at 1,100 rpm. A properly matched turbo would prevent smoke at the torque peak even though the engine was lugging by previous standards. The result of this new phenomenon called "torque rise" was that the truck could run with a 5-speed transmission. However, traditional cruise RPMs were still being employed at highway cruising speeds and the Maxidyne 5-speed transmission was never widely adopted by the industry.

The next innovation in downspeeding was more widely embraced. In the early 1970s, truck diesels were run "on the governor," which meant that the vehicle speed was limited by the 2,100 rpm engine governor which kept the engine cruising at just below 2,100 rpm. Then, a maintenance manager named Bob Deal at Signal Delivery, a subsidiary of Leaseway Transportation, theorized that the 6-71

Detroit Diesel engines in their fleet would be much more efficient if their vehicles were equipped with faster axles, and some other means were used to put a cap on vehicle speed, like driver discipline or an additional road-speed governor. Deal worked with the company Eaton to develop a 3.33:1 drive axle, and with a Detroit Diesel engineer and former associate named Bob Rosenthal to create vehicles that would cruise at 1,600 rpm. Rosenthal developed special governor springs that would actually increase the amount of fuel injected per power stroke as engine rpm dropped below 2,100, allowing the engine to perform well at the lower rpm. Deal dubbed the concept "gear-fast-run-slow" and the industry has never been the same since.

While earlier engines had actually performed at their best when running at the governed rpm, injection and combustion systems had been improved by this time to the point where turning the engines more slowly saved a lot of fuel. The new powertrains were a success in spite of worries that the lower engine rpm might clog injectors or cause other problems. Torque peaks dropped down as the years went by, with Detroit Diesel's Series 60 having a 1,200 rpm torque peak at its introduction in 1987, and Cummins following suit with the N14 in 1991. Stating in 2002, NOx restrictions became stricter and stricter, causing injection timing to retard and the engine's sweet spot to occur at a lower and lower rpm.

As a result of all this, wider-ratio nine-speed transmissions have replaced both close-ratio 10-speeds and even the most popular transmission on the market to date, the 13-speed, in many applications; Spicer went further and began to offer a 7-speed fleet transmission. The Caterpillar ACERT engines that came out in 2003 typically ran with 3.25:1 rear-axle ratios and overdrive transmissions.

But even more recently, gearing and cruise rpms were being designed to minimize the need for the driver to downshift under highway cruise conditions. Most trucks were cruising at 1,350 rpm or higher, which allowed vehicle speed to drop to about 50-mph before a significant loss in hill climbing ability would be noticed.

Downspeeding returned to center stage in 2011, when Volvo introduced its new XE, "Exceptional Energy" package with a new concept they dubbed "downspeeding." It allowed the engine to cruise at 1,150 rpm at 65-mph, 200 rpm lower than average at the time. The system combined a Volvo D13 engine rated at 425 horsepower (hp) and 1,750 lb ft of torque with an overdrive transmission (0.78:1 top gear) and axle ratios in the range of 2.65:1, and it required an I-shift automated manual transmission. This system is a 12-speed gearbox, with 28% steps between gears, as compared with the typical 38% steps of a standard 10-speed, and the engine's peak torque range had been extended downward to about 1,050 rpm. The combination of more torque below the cruise rpm, the slightly shorter step, and software that ensured a downshift after the vehicle lost only about seven mph guaranteed good highway performance. Volvo claimed a 3% fuel savings versus an overdrive transmission and 1.5% even when compared with direct-drive.

Mack, Volvo's sister company soon followed suit and introduced its Super-Econodyne downspeeding concept. Allison had been working on a similar drivetrain arrangement with its TC-10 TS transmission prior to the Volvo introduction. Eaton and Cummins introduced their SmartAdvantage drivetrain in 2013 at the TMC Annual Meeting. That system combined the new, more efficient Eaton Advantage 10-

speed transmission with an unusually short gear-step between the top two gears. Its drive-shafts and axles were somewhat similar to those used with the XE powertrain, since Volvo's approach was to use domestic components behind their unusual European 12-speed. Finally, Detroit introduced its downsped powertrain in conjunction with its DD12 12-speed transmission and proprietary drive axles in 2014.

As of this report, all manufacturers offer "downsped" powertrains and are working intimately with engine, transmission, driveline, and rear-axle manufacturers to optimize the various combinations of products for the industry.

# 4 Downspeeding Product Offerings Today

Downspeeding today is one of the primary powertrain-focused strategies for improving the fuel economy of both over-the-road long-haul tractor trailers and also regional-haul daycab trucks, whose highway mileage is high and whose infrequent pickups and deliveries allow them to operate at highway speeds much of the time. Rear-axle ratios in the 2.64 to 2.47 range are becoming common when direct-drive is used and define the current state of downspeeding in 2015.

The study team concluded that downspeeding is proving successful for fleets and that leading fleets will be even more aggressive in its implementation. In a Meritor white paper, the four authors stated that, "The trend to downsped engines will continue as a way to improve fuel efficiency and lower emissions. The new engines will be combined with rear-axles having ratios as low as 2.19 or less and direct-drive transmissions."

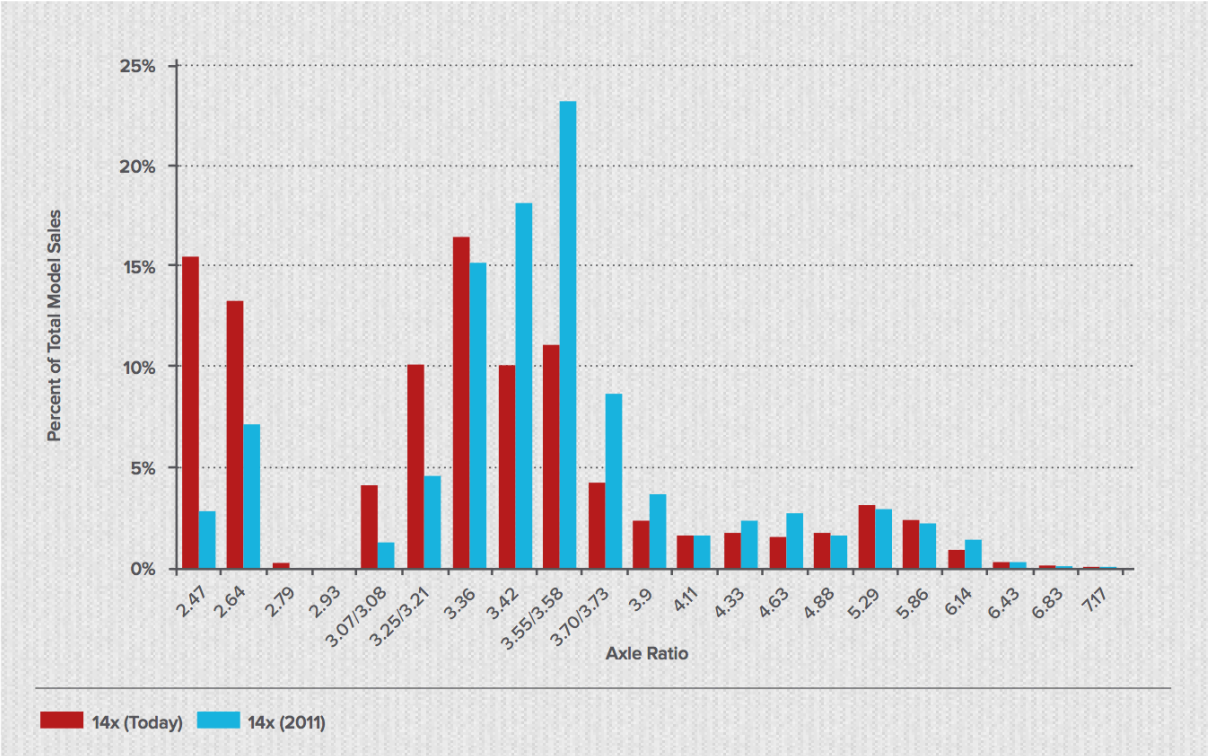



*Figure 8: Increased Use of Faster Rear-axle Ratios (Source: Meritor)*

In a white paper called "The right solution for downsped engines" Dana Commercial Vehicle Technology's Andy Nieman, said, "The trend toward engine downspeeding will continue to gain momentum as OEMs look for ways to further improve fuel economy." Nieman's paper also concluded, "The proper driveshaft designed for longevity can improve life by 57% at the 1125 rpm typical of today's low-speed engines, and by 77% for the 900-rpm engines on the immediate horizon."

Below, in alphabetical order, are descriptions of the current offerings of the manufacturers of powertrains for the North American market:

## 4.1 Allison

The Allison TC-10 10-speed automatic was designed from the beginning for downspeeding. Its use of a torque converter allows a relatively fast first gear ratio of only 7.4:1. This ensures the system is still able to produce a powerful start even on steep grades, because the converter not only multiplies torque by as much as 1.76x, it allows the engine to rev faster than normal clutch engagement torque with no abnormal wear or stress. In turn, this set-up also allows for a gathered step approach in the top gears; specifically, the top three shifts have 28%, 24%, and 17% steps, respectively. Ultimately, this means that the engine can be kept in a narrow range of low rpms while traveling at a wide range of highway speeds. The transmission will normally downshift right away at conservative cruise speeds when full throttle is applied, enhancing performance. As of publication, the TC-10 is offered only by International.

## 4.2 Dana

The Spicer® AdvanTEK® 40 Tandem Axle is designed for Class 8 linehaul fleets and features what the company calls "AdvanTEK gearing". It offers increased power density and efficiency in a smaller package than competing axles. The wide gear face improves gearing strength, tapered roller bearings increase fuel efficiency by reducing friction in the axle, and the overall design is optimized for best-in-class noise, vibration, and harshness (NVH) performance. Spicer claims a 30% reduction in failures, and reduced inertia and torsional vibration levels, which contribute to the reduction in failures.

Dana's SPL-350 main driveshaft and mating SPL-250 inter-axle shaft are specifically designed to supply greater torque capacity, durability, and savings for severe-duty vocational applications, as well as low-emission, high-efficiency trucks. The company says they are ideal for use when specifications include slowing down the engine and selecting faster axle ratios. Available in standard service and extra heavy-duty versions, these additions to the Spicer line of heavy-duty driveshafts and U-joints extend the expected life of the drivetrain and eliminate application restrictions on engine power in today's Class 8 linehaul and vocational vehicles.

## 4.3 Detroit/Daimler

Daimler Trucks provides downsped Detroit powertrains that use the 12-speed DD12 transmission and Detroit proprietary drive axles.

Detroit's own direct-drive downspeeding option is currently limited to a 1,200 rpm cruise and 2.85:1 rears. Although a 15-L downspeeding drivetrain was originally presented as well, the DT12 is now the only offering. Detriot claims that "the unique torque management of the DT12 has proved to be very effective" and that it does not cause "the kind of driveline issues that the industry is experiencing with manuals and 2.47s." Detroit shared with the study team that they planning to introduce this option with RPL35 axles with 2.28 ratios in the fall of 2015."

Detroit's Scott Keubler said, "Our testing shows approximately 1% for every 75 rpm reduction at cruise speed." With the 200-rpm reduction typically provided, that equates to just over 2.6%.

## 4.4 Eaton / Cummins

Eaton rolled out its first downsped drivetrain offering in an integrated solution with Cummins; the system is called SmartAdvantage. It combines Eaton's Advantage transmission and Cummins' ISX engines with various driveshaft and axle choices.

The Advantage transmission incorporates aluminum components and a lube pump, called Precision Lubrication, which lowers fluid level and eliminates churning by the gears, thus making the cooler unnecessary and saving weight. It also has a short, 26% step between 9$^{th}$ and 10$^{th}$ gears, so the engine can be kept within the sweet spot during all highway cruising.

The overall SmartAdvantage system also includes SmartTorque 2 technology, which limits maximum torque to the top two gears, and vehicle acceleration management (VAM), which both limits torque and adjusts it to conditions of weight, grade, and needed acceleration.

Eaton's claim's that the SmartAdvantage package can deliver 3-6% improvements in fuel economy over a comparable package of an Eaton UltraShift PLUS LAS transmission paired with a Cummins ISX 15L engine.

Eaton also offers another integrated downsped package, the Fuller Advantage Automated, which it claims will deliver 2-4% improvements in fuel economy when paired with the Cummins MX-13 engine, and up to a 5% improvement when paired with the ISX engine.

For its part, Cummins shared with the study team its claims that "the ISX15 400-450hp ratings have been optimized for downspeeding since 2010, in terms of hardware and calibration to operate efficiently at lower rpms, 200rpms lower than previous product, with no impact to engine durability." Furthermore, they stated that they "have not needed to implement any specific new hardware changes to accommodate downspeeding," as they "Can leverage the 15L displacement on the ISX15 engine with the highest compression ratio in order to produce higher and prolonged peak torque at lower operating rpms and deliver the necessary horsepower. Despite the high compression ratio, the ISX15 operates at lower peak cylinder pressure and lower brake mean effective horsepower when compared to 12/13L engines, which places less overall stress on the engine when it operates at low rpms with high peak torque."

Finally, Cummins stated that they have been "evaluating and testing downspeeding for many years, and thanks to the capability of modern AMTs and optimized integration of aftertreatment, we can operate the engine where it is most efficient without detriment to drivability or driver comfort."

## 4.5 Mack

Mack's downsped drivetrain is called the Super-Econodyne. It integrates the Mack® MP® engine, the Mack *m*DRIVE12-speed ™ automated manual transmission, and a heavy-duty driveshaft as standard equipment. Various driveshaft and rear-axle options are available, including Mack's own 125/126 Mack axles in an appropriate range of ratios, with the standard ratio being 2.66:1.

Mack claims that their integrated powertrain enables a lower cruise RPM to save fuel, without impacting power or performance, and that their customers report fuel efficiency savings of up to 3% percent with Super Econodyne, and even more when paired with their proprietary axles. "One of the most common comments about Super Econodyne-equipped trucks is how quiet they are."

## 4.6 Meritor

Meritor's 14X tandem drive axle includes a more robust inter-axle differential that is 20% larger than the one in its predecessor, the Meritor RT-40-145, and has fewer parts while also being able to handle up to 2,050 lb ft of torque in some applications. And, if features a new inter-axle differential bearing

system for reduced heat and wear, which improves reliability. It also features premium Meritor Amboid gearing design for what is described as "smooth and efficient performance." Fast ratios are offered for the most efficient direct-drive drivetrain. The Amboid gearing also allows parallel positioning between the forward and rear drive axles for improved driveline angles, reduced vibration, and longer overall component life. What is described as "an industry-leading" breather, designed for use with extended-drain synthetic lubes is another feature.

The Meritor RPL Driveline (RPL-35 driveshaft and RPL-25 inter-axle driveshaft) offers a bearing package with a large diameter, precision-tolerance needle bearing for optimum bearing alignment and maximized performance. The RPL is permanently lubricated with a proprietary specially formulated wear- and temperature-resistant grease. Steel straps ensure bearing cups are located to precise dimensions. A two-piece U-joint thrust washer prevents bearing end-galling and absorbs loads for minimized wear and an extended life cycle. And the driveline is retained with four patch lock bolts for simplified installation and ease of service.

## 4.7 Navistar

Navistar's International N13 downsped engines have an Eaton clutch and Advantage transmission, as well as Meritor 14X drive axles. They claim 2-4% in fuel savings. They also shared with the study team that their newest models had responded to complaints about a lack of acceleration by adding some of torque back in at lower gears.

## 4.8 PACCAR

Paccar also offers a downsped drivetrain called Fuller Advantage, combining its MX engine with the Advantage transmission in its Kenworth and Peterbilt truck brands. They claim 2-4% in fuel savings are available from this technology.

## 4.9 Volvo

Volvo originated modern downspeeding in 2011 when it released its XE 13 powertrain, which now has been expanded to include its 16-L engine. The original offering had 425 horsepower, but in early 2012 the power rating was upped to 455 hp. The Volvo XE combines an I-Shift transmission and a custom-designed 17-in. clutch with an organic lining from Volvo Sachs, a combined effort between Volvo and a European clutch manufacturing company. The organic lining was chosen for its smoother operation. Either Dana or Meritor driveshafts and rear-axles carry the drive to the rear wheels.

Bulk-hauling fleets that only travel loaded on one leg of their routes can spec Volvo's XE-Adaptive Gearing drivetrain. This arrangement runs in direct-drive while loaded on the way out, and in overdrive with the engine at a lower cruise rpm when the truck is empty on the return trip. Volvo recently introduced the XE super direct-drive, a combination of a direct-drive I-shift, a 2.28:1 Meritor 14X drive axle, and RPL 35 driveshafts. Cruise in this system occurs at 1,265 rpm at 65-mph, which gives a 1.5% improvement in fuel efficiency as compared with a direct-drive transmission running with a 2.47:1 axle. Maximum torque of up to 1,850 lb ft and GCW to 80,000-lb are allowable.

Volvo Truck's product marketing manager-powertrain, John Moore, did not offer an improvement percentage to the study team, but he did offered some perspective on when fuel is actually saved: "LTL carriers are using our XE package, and it is performing well while delivering excellent fuel efficiency. The fuel efficiency in city operations is comparable to conventional drivelines with payback coming from open road use." Thus, the savings need to be evaluated by considering the percentage of time each vehicle spends on the highway versus running at lower speeds.

# 5 Benefits of Downspeeding

The benefits of downspeeding are twofold – above all, that it lowers fuel consumption, potentially by up to 6%, when placed in combination with other complementary technologies. The industry also reports that downsped trucks are easier and more pleasurable to drive helping fleets to improve the driver satisfaction, retention and attraction of new drivers, all of which are significant industry issues.

## 5.1 Increased Fuel Economy

Fleets told the study team that downspeeding is a strong part of their current and future attempts to lower fuel consumption and save money. However, they also shared that with so many specification decisions in the powertrain area, it is difficult to separate the savings for such items as downspeeding, automated manual transmissions, some engine parameter settings, 6x2 axles, etc.

Given all of the data reviewed by the study team, downspeeding saves 2-3% on the fuel bill. By combining it with other powertrain features, such as automated manual transmissions, some engine parameter settings, etc. savings of 3-6% can be achieved – all in just a single powertrain specification change by a fleet.

Downspeeding accomplishes this fuel savings in large part because it keeps the engine nearer to its most fuel efficient rpm, in response to the reduced cruise power requirements of tractors that have generally seen continual aerodynamic refinements, lower rolling-resistance tires, and other more efficient drivetrain components. Downspeeding simply finds the lower-rpm sweet spot that is ideal for the minimal amounts of power needed to run these latest tractors. Figure 9, demonstrates the reduced power demand of these aerodynamics can move the operation of the engine into a region of less efficiency (lighter blue regions). Downspeeding can bring the cruise point into a more efficient region, characterized by the darker blue portion of this graph.

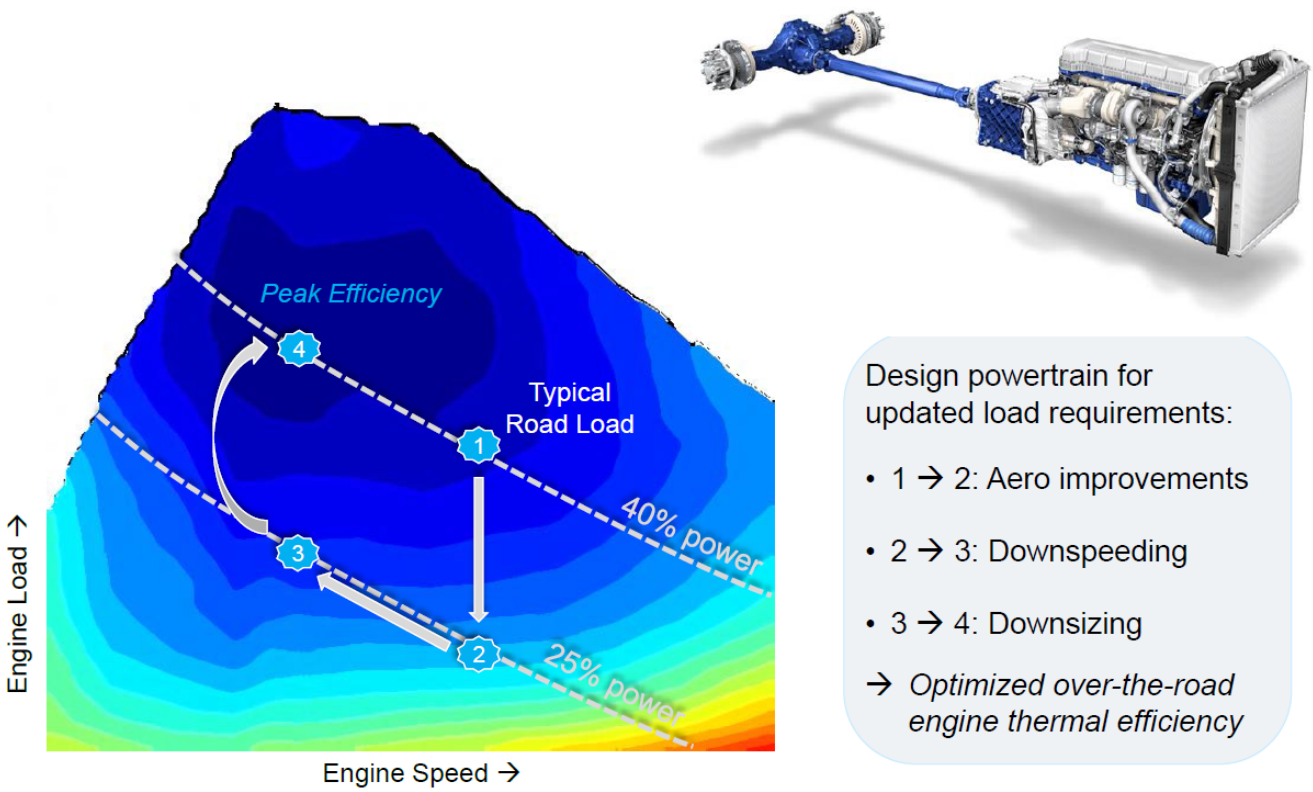



*Figure 9: Downspeeding Fuel Benefits (Volvo SuperTruck, 2013 DOE Merit Review)*

But, why does turning the engine more slowly, by about 200 rpm, save fuel? The reasons include:

- Reduced friction and parasitic losses in the engine;
- Reduced effort required to ingest air and expel exhaust with more time for air and exhaust flow;
- A higher fuel/air ratio in the cylinder, which results in higher peak temperatures and pressures because the amount of fuel injected during each power stroke is greater. This also increases turbo boost.

Downspeeding also imposes a subtle, but very definite, limit on available power, a fact stressed by International's Aaron Peterson, chief performance engineer of on-highway tractors, who told the study team: "the most significant source of gain is in the management of available power, giving the driver only the power needed." In a downsped engine horsepower is not only limited at cruise rpm, normally to about 400 rpm (with power dropping rapidly with a reduction in speed), but moreover, with a closer split down to the next gear, the amount of power gained after the shift is much less than the 150 hp that is commonly available with the typical 10-9 gear split of a conventional 10-speed.

If axles in the lower range of 2.65:1 with overdrive transmissions were specified without other changes, poor performance and driver complaints about the need to shift frequently would result. Well done downsped drivetrains sidestep this problem in several ways, one of which is to universally equip vehicles that have downsped engines with electronically controlled transmissions (either automated

manuals or fully automatics), which make much earlier and more frequent downshifts practical. Other changes, like modifying the engine's torque curve by extending it down to 1,050 or even 1,000 rpm, have been universally applied and also help. In order to make the most of downspeeding, the transmission must also include at least one short-step gear change so that the engine can be kept in the most efficient area of its rpm range even after a downshift, thus ensuring the engine stays at a downsped rpm in almost all highway cruise conditions. In some systems, engine torque output is substantially higher in the top two gears, which greatly increases the number of situations in which the drivetrain can keep the engine at a downsped rpm. This also helps to protect the drive-shafts, axles, and other parts from excessive torque when starting out or running in the lower gears.

In terms of measuring fuel savings, several drivetrain component and engine manufacturers have compiled data from a number of sources to develop a range of fuel economy improvement percentages cited in this report. The study team talked also to many fleets in reaching these findings.

## 5.2 Easier to Drive

Many of fleets shared with the study team that downsped trucks are much more pleasurable and easier to drive, not to mention quieter. As Trucking Efficiency reported in December 2014, electronically controlled transmissions (ECTs) —both automated manuals (AMTs) and fully automatics – are becoming much more common, if not the norm, for OTR tractors due to their improved functionality, cost, and most importantly drivability. The fact that these transmissions are usually part of a downspeeding strategy likely contributes to the sense that downsped trucks are easier to drive. This report suggests that a downspeeding strategy should also include adoption of ECTs.

Along with the benefits of ECTs, numerous fleets and the OEMs reported that downsped trucks are much quieter due to the lower engine speed operation. "I hadn't driven one of these new trucks in a few years and was amazed at how fun they are to drive! And it starts with how quiet they are," said a major fleet manager, who is taking advantage of one of the more aggressive downspeeding options. This fleet has been buying AMTs for over 10 years, so the additional drivability benefits of downspeeding is clear. Another shared that "this is where our earlier investment in AMTs is benefiting us. We are now able to quickly take advantage of downspeeding and we expect more technologies to come along of this type. We want to stay abreast and ahead of each one, so that we don't fall behind."

Some drivers share with fleets concern with the reduction in horsepower available to them from downsped drivetrains.

Aaron Peterson, chief performance engineer of on-highway tractors at International, gave the following example: "At 1,150 rpm and 1,750 lb. ft. of torque, only 400 hp. is available. At 1,000 rpm, you've lost another 50 hp. With a standard drivetrain, the driver has a 38% split, meaning they can pick up as much as 150 hp with a single downshift. With downspeeding, you have a closer ratio and don't move the rpm up as far; (in a downsped system) shifting is to maintain speed rather than speed up, so drivers have enough power to climb the hill rather than accelerate."

However, overall driver dissatisfaction was not cited by fleets as a major impediment to downspeeding. Most drivers, once they gain experience with a downsped truck, find that downsped drivetrains perform in a more-than-acceptable manner. This is largely because the combination of an earlier downshift and the extension of the torque curve down to about 1,000 rpm combine to make the effect of the faster gearing very subtle. On a typical significant grade, the truck will not lose much more speed than before, and there will be plenty of power available to hold cruise speed in rolling terrain.

Dissatisfied drivers is also a minimal challenge, as in fact drivers like the quieter cruising, not to mention that drivers who receive a fuel economy bonus will love the fuel savings. The most common complaints come from drivers through extreme terrain, drivers who are paid by the mile, or drivers who feel an exceptional pressure for fast deliveries.

# 6 Challenges

There are two challenges to specifying a downsped drivetrain: an increased risk of driveline failures and the associated higher cost of more robust components.

## 6.1 Potential for driveline failures

Drivetrain vulnerability is a critical concern of maintenance managers and other fleet executives. Cruising at a lower rpm means using much faster axles, with ratios in the range of 2.47:1 or even faster. This confidence report finds that these failures are mitigated with appropriately specifying more robust driveline components and optimizing engine and transmission parameter settings for use with downsped powertrains. The downspeeding tipping point for the increase in robustness of drivelines and other components will depend on the duty cycle of the truck and the manufacturers themselves.

The potential for driveline damage is much greater when very fast axles are used. Such damage can include breakdowns when tractors and trailers are maneuvered in the yard. This heightened risk is partly due to improvements in engine responsiveness at low rpm, but research by Meritor found that such damage is both greater and more frequent with downsped drivetrains, likely because the stronger components used in such axles incorporated are much more sensitive to sudden shocks than those used in traditional axles because they are less flexible. In fact, Meritor found that the damage occurs so much more frequently with the faster axles employed by downsped drivetrains that they had to revise their formulas for predicting such problems.

Another likely reason for the increased risk of driveline failure in downsped trucks is that the torque carried by the drive-shafts, the inter-axle differential, and the input shaft and the gearing of the rear-axle increases in direct proportion to the reduction in rpm. Thus, if cruise rpm drops 18%, the torque should increase 18%. However, calculating the real effect of the increased torque gets complicated. Lower rpm means not only more torque, but also that torque spikes are applied to all the driveline parts at a lower frequency, which can translate into gear chatter or wear issues unless driveline

dampening is enhanced. In a case shared by Dana where cruise rpm was reduced from 1,450 to 1,125 rpm, the torque carried by the drivetrain parts increased by 57%.

To handle these issues, the study team finds that the vehicle and component manufacturers have developed heavier-duty components that can handle the increased torque produced when engines turn at reduced rpm, augmented by more subtle but critically important elements of electronic control. This starts with more robust drivelines that are currently available and should be specified with downsped powertrains. Driveline manufacturers have developed mature recommendations for fleets to pursue and should be consulted, as mentioned numerous times in this report. Also, it appears that enhancements to the torsional dampers used in clutches fitted to downsped drivetrains are handling this issue effectively.

In addition to specifying the appropriate axle and driveshaft system, de-rating the engine is a common, reasonable strategy for addressing certain issues, and it can reduce the likelihood of catastrophic driveline failures during vehicle launches from zero speed with sudden acceleration. However, it does not prevent high torque spikes created by powertrain inertial loads caused by backing into a low trailer or into a loading dock wall. Additionally, no matter what is done to re-program the engine to reduce spikes in starting torque, it does not sufficiently address the high-cycle fatigue that results from long-term higher torque stresses on the drivetrain with operation at cruise speed.

Still, fleet buyers need to manage their downsped truck purchases with an unprecedented level of attention to the drivetrain. It will not be enough to simply fortify individual parts – it will be necessary to integrate the entire system of features to ensure strength and durability, to avoid creating new problems each time you solve an old one.

Various manufacturers echoed this to the study team, recommending that OEMs and fleets take a whole-systems approach and acknowledge that when their engine changes, the other parts of the powertrain need to be upgraded to match. Optimally, downspeeding will include an axle and driveshaft system specifically engineered for downsped engines, including robust tandem axles that offer the fast ratios required to fully leverage the efficiency offered by downspeeding, as well driveshafts that can withstand higher torques – both in the short- and long-term.

Overcoming the challenge of increased driveline failures resulting from downspeeding requires that fleets take a careful look at how the vehicle they are specing is going to be used. For example, which routes will it follow? Will it be long-haul or inter-city? Many trucks in fact see mixed use, i.e. they are used in long-haul service during the day, and then at night may see a different form of use where driveline parts are stressed by factors like acceleration in much greater frequency. Thus, it is vitally important that fleets discuss with their OEMs *exactly* how they are going to use the truck.

## 6.2 Greater upfront cost

The upfront cost of a fully optimized downsped power train will be higher than that of a "regular" truck. The truck payment will be increased by the need to spec an automated transmission with a

higher output torque capability, a certain clutch with a higher capacity damper, and higher torque driveshafts and rear-axles. The total cost upfront of the optimal powertrain for each fleet will vary with the duty cycle, fleet business strategies and the manufacturer involved. Given many interviews, the study team predicts a cost increase of about $500 - $1,000 for the more robust drivelines to support current levels of downspeeding. However, the predicted 2-3% fuel savings of downspeeding should be sufficient to recoup those upfront costs in less than a year. With diesel fuel at the 2014 average cost per mile of $0.59 and running 120,000 miles per year, one will see a reduction in fuel cost of $2,300 per year with a 3% gain in fuel economy. At current 2015 levels of about $2.86 per gallon, this still equates to about $1,600 in savings.

# 7 Insights from the Industry

The following includes some additional insights from the industry.

## 7.1 Fleets

One fleet executive shared that "Each year there are more introductions of downspeeding drivetrains; first there was the Volvo XE and then Freightliner with its Detroit Integrated powertrain. Some fleets are running 2.26:1 axles now and 405 hp versus 450, but torque went up again. AMTs are used 100% and many units have direct-drive".

Another, "Drivers like to talk in terms of horsepower, but these trucks, the way they are set up, give the impression that they are snappy, yet very quiet. They cruise at 1100 rpms with a 12-speed now, rather than a higher cruise rpm with a traditional 10-speed".

Phil Braker at Nussbaum Transportation drove one recently and reports, "I was blown away by how it drove. In top gear, it would run down to 800-900 rpms, hanging in there very well. And, it was extremely quiet. So one advantage is that it's very quiet, the engine is not roaring. And, when it goes into E-coast, it's even quieter. "Drivers like it. They worry about getting up to speed, and it does that ok. We're not sure whether or not it does have the power to do the mountains, though."

Asked if there a disadvantage with drivelines breaking, he responded, "We've had none here at Nussbaum with current drivelines." Braker believes this probably happens only with driver error, most likely when trailer tandems are being moved. We asked whether or not he has resale concerns specific to downspeeding. "No not really." His feeling is that there will be no penalty when Nussbaum goes to trade their trucks.

Another fleet said, "I haven't heard from any drivers yet about the mountain pulling. Fortunately our drivers drive for fuel efficiency, anyway. You don't necessarily need driver engagement here. It's best to not even share the change with your drivers. They don't need to know and not knowing you've changed the horsepower rating helps them not to over-react to a change they can hardly feel in actual performance."

Ezel Baltali of Ryder shared, "Any effort with downspeeding must take into account the duty cycle the truck will be used in. Driveline failures can occur if this is not taken seriously. Also, the second buyer of the trucks should understand the capabilities of these downsped specifications."

## 7.2 Tractor OEMs

International's Peterson says, "We've collected a lot of data. An improvement of 3-6% is what you'll see; I'm very comfortable predicting an improvement of 3%". He added that when downspeeding is combined with other improvements in fuel economy-related aspects of design, fleets could reasonably be expected to see as much as a half mile per gallon.

Kurt Swihart of Kenworth did not attempt to separate out downspeeding from the aerodynamic and other enhancements that he said produce "large improvements" in fuel economy. But, he did say, "Downspeeding is one of the engine/drivetrain features that helps our customers realize those large savings."

John Moore, Volvo Truck's product marketing manager-powertrain, suggested that "Most drivers experiencing an XE package for the first time are already driving a Volvo I-Shift automated manual transmission or another AMT and have already bought into the concept."

He continued, "Drivers transitioning directly from a manual transmission to a downspeeding driveline must get used to not shifting and allowing the driveline to do the work. Of course, this probably is easier said than done for a driver who has upshifted, downshifted and double-clutched for years. They must also adapt to the transmission shifting gears at engine rpms of approximately 1250 rpm instead of manual shifts at around 1800 rpm. Peak engine torque is available down to 1050 rpm, allowing these drivelines to perform at lower engine rpm. Drivers also like never having to worry about which gear they are in, especially on steep negative grades."

Kurt Swihart, commented on downsped trucks with automated manual transmissions, saying, "In a lot of cases, drivers are not able to tell the difference in performance between downsped powertrains and traditional gearing. The biggest issue is retraining drivers on the new shift points. They have built habits of running the engine RPMs high to remain in the peak torque band of the engine. As that band drops, there really is a learning curve for drivers on when it is necessary to shift. That is a critical step in realizing all of the potential fuel economy benefit."

Scott Kuebler, Director of Component Sales, Daimler Trucks of North America, said, "In regards to downspeeding with direct-drive, we're focusing on line-haul/long-haul only, 80K or less, 65 miles per hour or less, 80% or more in top gear and 2-4 starts/stops per day. Specific to the question of durability, we don't currently have ratios available that would allow trucks equipped with DD engines to cruise at less than 1200 rpm at 65 mph. Even with overdrive, our axle ratios are capped at 2.85. This is more of a SmartAdvantage strategy where they're using 2.64s and 2.79s with OD. Downspeeding in non-line-haul/long-haul applications (short-haul/pickup and delivery) can effectively be accomplished with overdrive."

## 7.3 Component Manufacturers

Bob Ostrander of Meritor pointed out that, while direct-drive setups often use a manual transmission and axles as fast as 2.47:1, most downsped drivetrains use automated gearboxes. This is a big advantage. He says, "Automated transmissions will help, especially when accelerating while entering the driving lane on a highway, or pulling out of a loading dock, when running fast axles. Merely having maximum torque limited to the top two gears may not solve all the potential problems. Automated manuals and automatic transmissions are very good ways of heading off a lot of issues. Using the engine electronic controller to control the torque output of both the engine and transmission via the ability of the two components to communicate with one another is very helpful."

As if to underscore this point, Karl Mayer, director product strategy-axles at Meritor outlined what's allowed in various applications. "Number 1 is that long-haul or line-haul, over-the-road is the only place ratios as fast as 2.47:1 are allowed." He added that direct-drive drivetrains often use such axles. "But, even when running line-haul during the day, and city delivery at night, you'll run into issues with axles that are that fast."

Ostrander elaborated on why drivetrain protection has become so critical. He said, "Where you run a greater risk of getting into trouble is when you don't have control over the drivetrain the way you do with an automated transmission. Engine torque response characteristics have changed. EPA 2010 engines reach peak torque from an idle condition *much* faster than engines did in the past. Response time is normally well under one second, and may be as little as ½ of a second. "Also, we used to be able to assume the torque applied to the components would be limited by wheel slip, but even tires have changed, with the latest tread compounds providing considerably more friction. The driveline is therefore exposed to very different loading conditions, another fact the OEM must consider. This is something else the integrator of the vehicle must deal with," he said.

Ostrander went on to say, "We've found driver training is not bulletproof with the latest engines when it comes to protecting the drivetrain. It takes quite a bit of learning to get good control. We have learned that we need to take a whole different approach. The engine maker needs to modify the engine's response under zero-speed events. We've found this can be done even though the driver's impression will be that 'Nothing has changed.'" For that reason, "It's incumbent on the OEM that puts the truck together to create a complete drivetrain package."

International's Aaron Peterson says that, in his experience, the vast majority of downsped drivetrains are not subject to such problems. "Most failures occur with direct-drive. The driveshaft torque is proportional to the first gear ratio. With a higher rear-axle ratio, the torque is not nearly as great out of the transmission tail-shaft. Already proven hardware is compatible with the 2.64:1 and 2.69:1 axle ratios normally used with a transmission that has a single overdrive top gear."

Echoing Mayer, he said, "You need to run very fast axles with a direct-drive transmission. A 2.47:1 drive axle with low profile tires gives 1,350 rpm at cruise. You need to run a direct-drive arrangement like that over the road. You can't set it up that way and then do pickup and delivery."

Steve Slesinski, Director of Global Product Planning Dana Commercial Vehicle Driveline Technologies, said, "Faster axle ratios – those with numeric values less than 2.93 or so – significantly increase the torque input into the driveshaft and axle system when compared with a conventional 3.55 rear axle ratio. Axle and driveshaft systems that are optimized and properly specified for the higher torque that results from engine downspeeding do not result in additional failures.

Bob Ostrander, chief engineer-drivelines, Meritor North America, commented on the applicability of ultra-fast axles to different applications. He said, "When spec'ing, you need to ask, 'How is it going to be used?' Will it be used on route A or route B? The spec'ing dilemma is that line-haul constitutes one type of usage, while city delivery includes stop and go situations with frequent acceleration. These are very different vocations. Fast axle ratios are appropriate only in certain situations.
"Many trucks see mixed use where they are used in line-haul service during the day, and then at night may see a different form of use where driveline parts are stressed by factors like acceleration in much greater frequency. Thus, it's vitally important to discuss *exactly* how you're going to use the truck with the OEM.

# 8 Perspectives on the Future

Phase 1 greenhouse gas emission standards, which focused on tractors, launched in 2014 and will take full effect in 2017. Phase 2 of these regulations will add a focus on trailers in 2018 and includes tractor GHG reductions in 2021, 2024 and 2027. Downspeeding will be included in the GEM model, the tool that calculates the GHG emissions levels for each truck produced, offering the compliance benefits to the truck builders. Overall these standards will require truck, engine, and other suppliers to continue to develop, integrate, and sell features for improved freight and fuel efficiency. As a result, fuel saving options, such as downspeeding, will need to be a priority for the industry.

Aggressive downspeeding with rear-axle ratios of 2.26 and 2.08 and maybe even faster, are being designed, prototyped and tested to offer even better levels of fuel efficiency.

Dana is also currently collaborating with several truck manufacturers to engineer axle disconnect technology that will accommodate even further engine downspeeding to the 900 rpm range at highway speeds. To that end, they introduced the Spicer AdvanTEK Dual Range Disconnect tandem axle arrangement at the 2015 Mid-America Trucking Show. According to Dana, that system "... improves efficiency by seamlessly combining the traction and dependability offered by a 6x4 configuration with the reduced drivetrain losses and improved fuel economy of a 6x2 configuration." Furthermore, the company claims efficiency at cruise speeds is improved between 2-5% with this technology.

The Spicer AdvanTEK Dual Range Disconnect tandem axle system is fairly unusual for the industry, as it combines a very fast front drive axle (approx. 2.1:1) with a very high-ratio rear drive axle. The inter-axle differential is designed to allow a high degree of differential action without undue wear. When the truck starts out, both axles are fully engaged. At about 38 mph, the axle system's processor locks out the inter-axle differential, disengages the rear-axle's ring gear and differential from the axle shafts, and

allows the front drive axle alone to drive the truck, almost exactly as in a 6 x 2 arrangement, and with a ratio of only 2.1:1, allowing 900 cruise rpm. The processor reduces engine rpm to a precise degree, allowing this to occur with no driver involvement and no need to disengage the clutch or to provide synchronizers inside the axles. By combining the two outputs, the inter-axle differential of this system is able to produce an effective drive ratio of about 3.2:1. This arrangement reduces drivetrain stress, and even reduces stresses on the frame and suspension, because it reduces the engine and driveline torque required to start up and accelerate. Dana additionally claimed that this technology will give traction in snow that greatly exceeds that of a 6 x 2 even after weight is shifted to the forward, live axle.

No production date was provided for this new product.

# 9 Conclusions

Downspeeding as a concept has been around for decades, but recent complementary technologies have made it much more attractive for fleets. Above all, the increased adoption of electronically controlled transmissions is greatly facilitating investment into downspeeding for two reasons: First, a downsped powertrain will require much more frequent downshifting under highway conditions. This is because the engine operates much closer to its torque peak, which means a shift to a more powerful transmission gear ratio will be required after only a minimal drop in vehicle speed to ensure adequate hill climbing performance and cruise speed maintenance. Such frequent shifting would be objectionable to most drivers. Second, electronically controlled transmissions control clutch engagement very precisely by allowing the engine and transmission to communicate, thus ensuring shock-free engagement of the clutch.

Regulations are also incentivizing fleets to adopt downspeeding technologies at present. Phase 1 greenhouse gas emission standards, which focus on tractors, launched in 2014 and will take full effect in 2017. Phase 2 of these regulations will add a focus on trailers in 2018. Overall these standards will require truck, engine, and other suppliers to continue to develop, integrate, and sell features for improved freight and fuel efficiency, of which downspeeding is a strong option.

As of this report, all North American manufacturers offer downsped powertrains, and all are working intimately with engine, transmission, driveline, and rear-axle manufacturers to optimize their various combinations of products for the industry.

Looking ahead, Trucking Efficiency finds that over the next 5–10 years “aggressive” downspeeding options will become widely available, with rear-axle ratios of 2.08:1 or lower. This Confidence Report is therefore timely, as it gives fleets insights into the current situation of downspeeding, with ratios of 2.47:1 or higher, and allows them to prepare for the additional pending advances.

## 9.1 Recommendations

Three key recommendations emerged from this research:

- Fleets in long-haul duty cycles should strongly consider downspeeding their powertrains with direct drive and incorporating a complementary suite of other technologies, in order to obtain significant improvements in fuel efficiency, as well as increased driver satisfaction.
    - Optimally, downspeeding will include an electronically controlled transmission; an axle and driveshaft system specifically engineered for downsped engines, including robust tandem axles that offer the fast ratios required to fully leverage the efficiency offered by downspeeding; and driveshafts that can withstand higher torques—both in the short- and long-term.
- Fleets should work with their tractor and driveline suppliers to appropriately specify all of the components for their specific duty cycle, avoiding driveline failures.
    - It is critical for fleets to make sure their OEM knows exactly how they are going to use the vehicle, and how its usage could change in the future.
    - Fleets must also ensure they allow their OEM to specify the necessary premium components—downspeeding is not a place for upfront cost-cutting, given the risk of those savings being erased by failed parts and downtime.
- Manufacturers should continue to advance their downspeeding product offerings, and to work with fleets to appropriately specify components for their specific use.

## 9.2 Confidence Rating

The confidence matrix (Figure 10) illustrates the Trucking Efficiency study team's confidence in the investment case for downspeeding technologies adopted alone, and for downspeeding adopted as part of an optimized powertrain strategy.

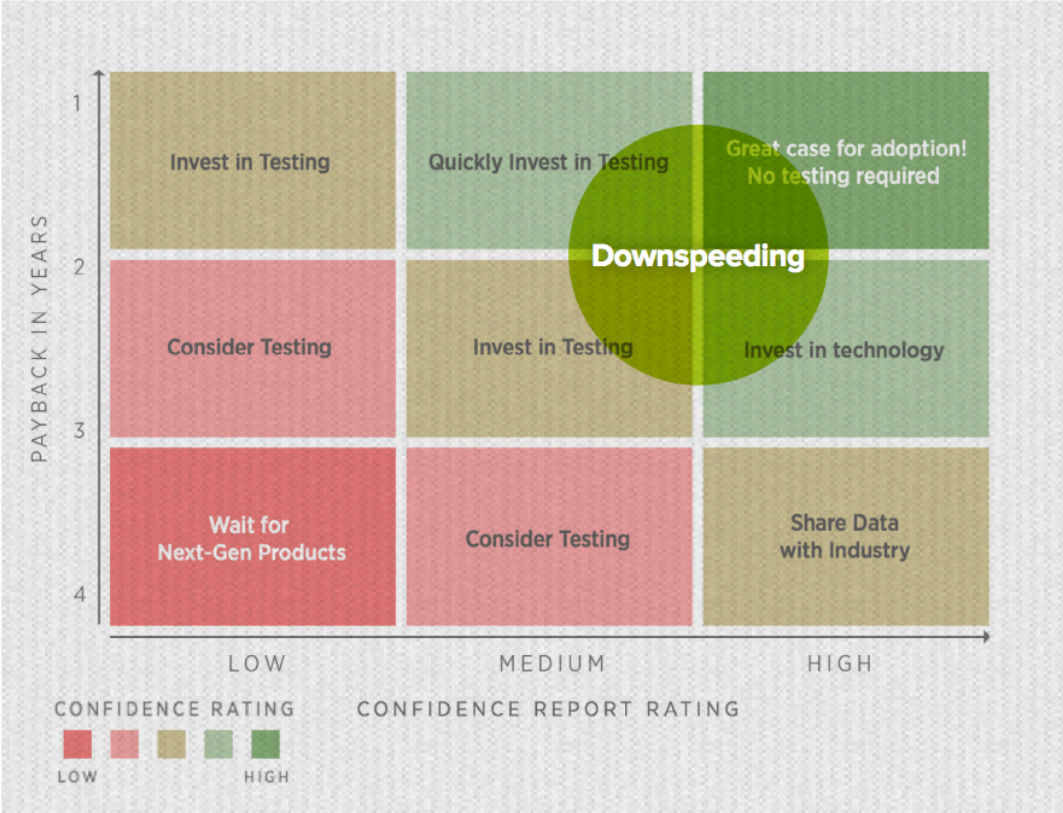



*Figure 10: Confidence Rating for Downspeeding*

This Confidence Rating indicates that fleets should look to invest in downspeeding, as overall it offers significant gains in fuel efficiency. Certain duty cycles will be better served by downspeeding than others, and each fleet will have to make its own assessment of the potential trade-offs, in order to decide which configuration of downspeeding and complementary technologies will be best for them. Trucking Efficiency hopes that this report will catalyze significant additional interest in the package of fuel efficiency technologies that together offer an optimized downsped powertrain and up to 6% fuel savings.

*Trucking Efficiency is always seeking to expand the data or case studies that we can provide to the industry. We invite you to share your own experiences with downspeeding technologies.*

# 10 References


Allison Transmission, "How can tractors get 5% better fuel economy?", brochure from Allison Transmission on the Allison TC10 tractor transmission, January, 2014

Cummins, Inc, Interview with Mario Sanchez, Technical Sales Support Director, Cummins, Inc. July, 2014

Daimler, Written comments from Scott Kuebler, Director of Component Sales, Daimler Trucks North America, February, 2015

Daimler Detroit Powertrain Product Information, https://www.demanddetroit.com/powertrain/, June 2015

Dana, Written comments from Steve Slesinski, Director of Global Product Planning , Dana Commercial Vehicle Driveline Technologies

Dana Product Information, http://www.danacv.com/danacv/advantek40/, June 2015

Deal, Bob, CCJ Magazine, http://www.ccjdigital.com/the-real-deal-ccj-career-leadership-award-recipient-bob-deal/ June, 2003

Eaton, Written comments from Ryan Trzybinski, product planning manager – Eaton, February, 2015

Kenworth, Written comments from Kurt Swihart, Kenworth marketing director, February, 2015

Mack, Written comments from Roy Horton, Mack director of product marketing, February, 2015

Meritor, Interview with Meritor experts: Bob Ostrander Chief Engineer – Drivelines, Ken Lang Sr. Product Line Manager – Drivelines, Karl Mayer Director, Product Strategy – Axles, February, 2015

Meritor Product Information, http://meritordownspeeding.com/, June 2015

Navistar, Interview with Aaron Peterson, Chief Performance Engineer-on-highway Tractors, International, February, 2015

Nieman, Andy, "The right solution for downsped engines", http://www.danacv.com/advantek40/pdf/Downspeeding_WhitePaper.pdf , 2014

Ostrander, Bob, "Understanding the effect of engine downspeeding on drivetrain components," http://www.meritor.com/ourcompany/news/whitepapers/pdfs/Meritor-WhitePaper-EngineDownspeeding.pdf, 2014

Spears, Matt and Tamm, Jim, “Update on Phase 2 on the Heavy-Duty Greenhouse Gas and Fuel Efficiency Standards” by Matt Spears, U.S. Environmental Protection Agency, and Jim Tamm, National Highway Traffic Safety Administration, SAE, 2015, p. 9.

Volvo, Written comments from John Moore, Volvo Trucks product marketing manager-powertrain, February, 2015