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."

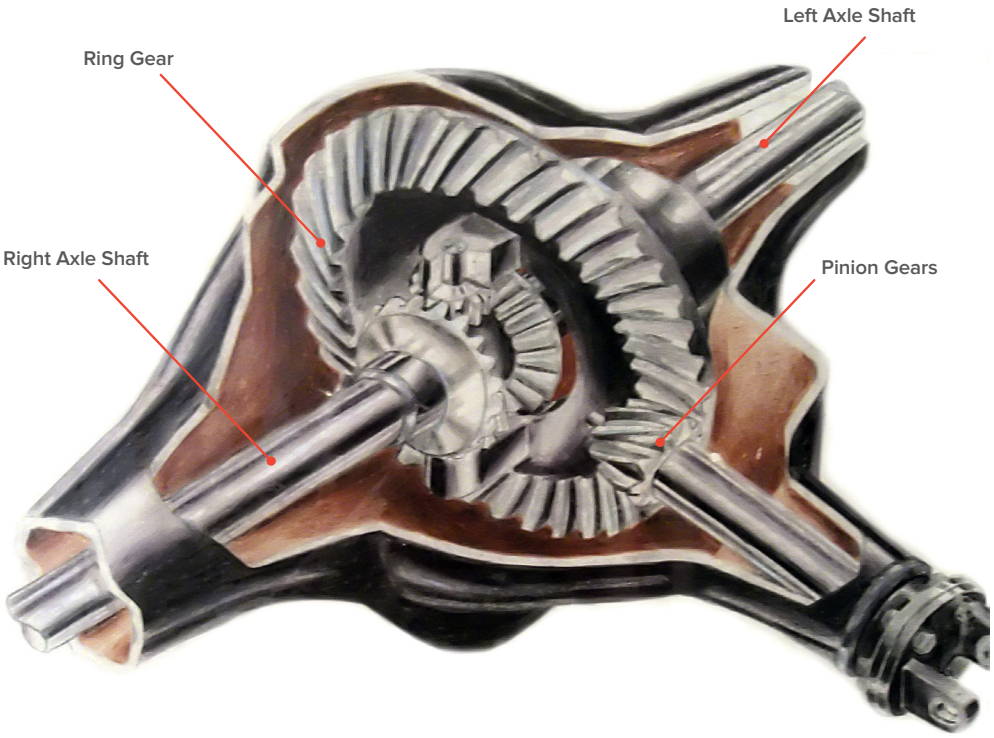
Methodology

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

FIGURE ES1: COMPONENTS IN A REAR AXLE



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.

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

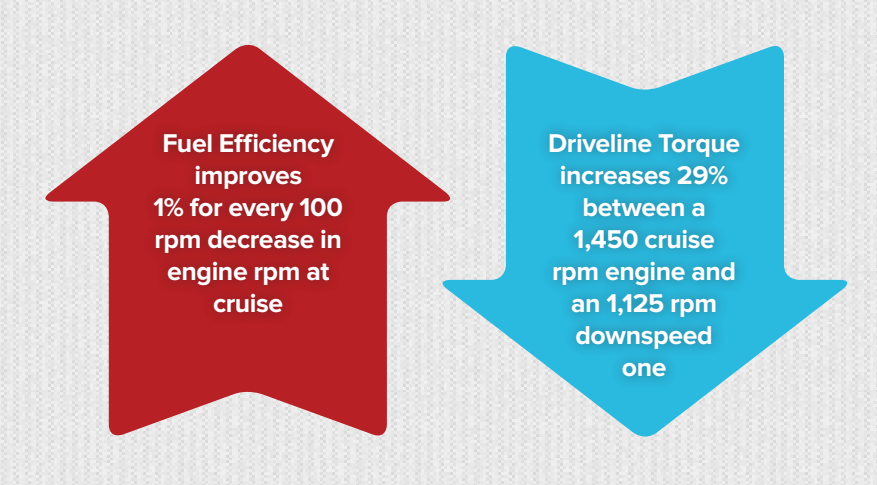
In trucking, downspeeding specifically entails reducing the 65-mph cruise engine rpm (also known as the engine's speed) from 1,600 rpm or higher to less than 1,200 rpm, corresponding to a reduction in rear-axle ratios from over 4.00:1, to around 2.47:1 common today. Recent product announcements and new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

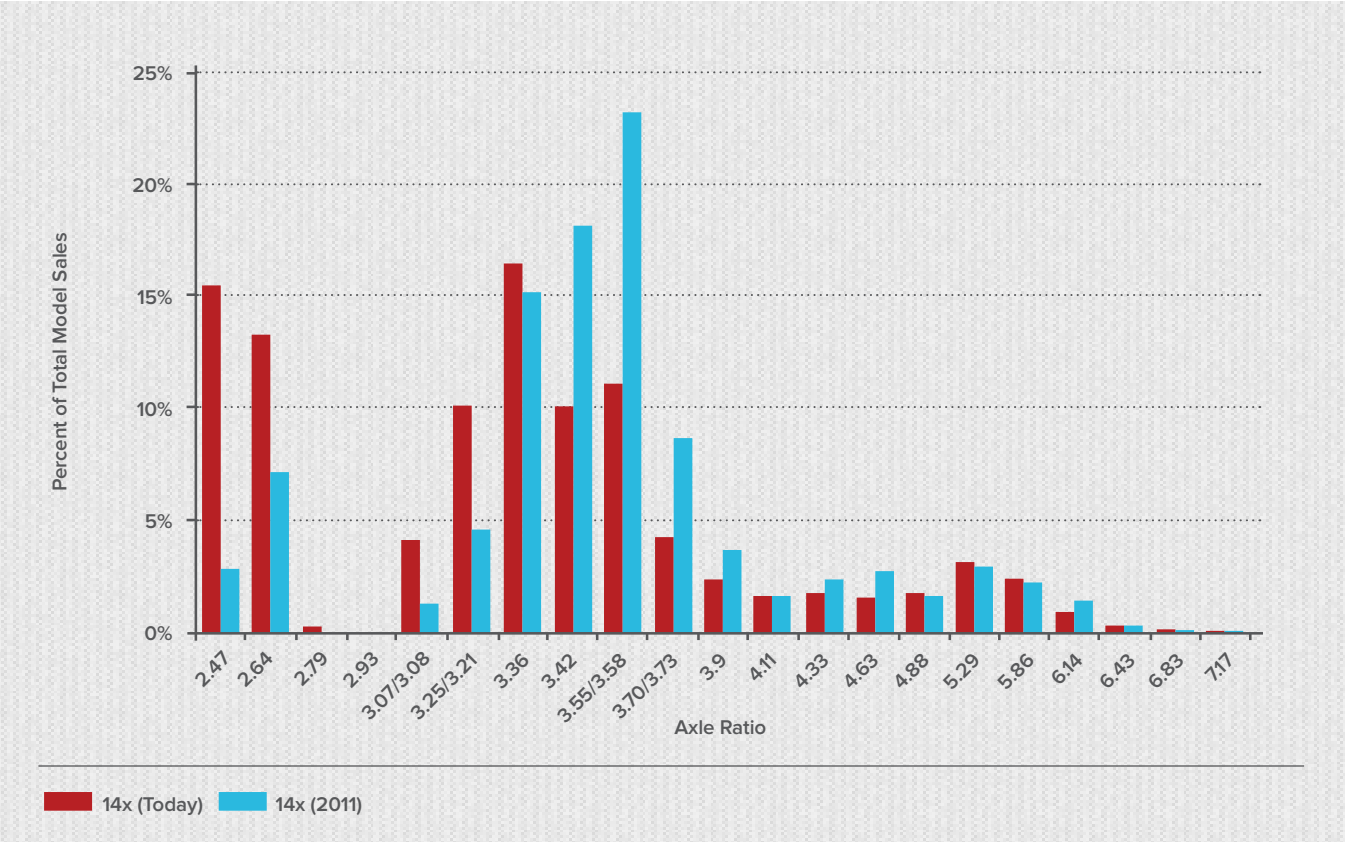
Downspeeding faces two major challenges to adoption: the greater potential for driveline failure if improperly spec'd, and the higher upfront costs of the needed components for an optimally downsped truck.

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.

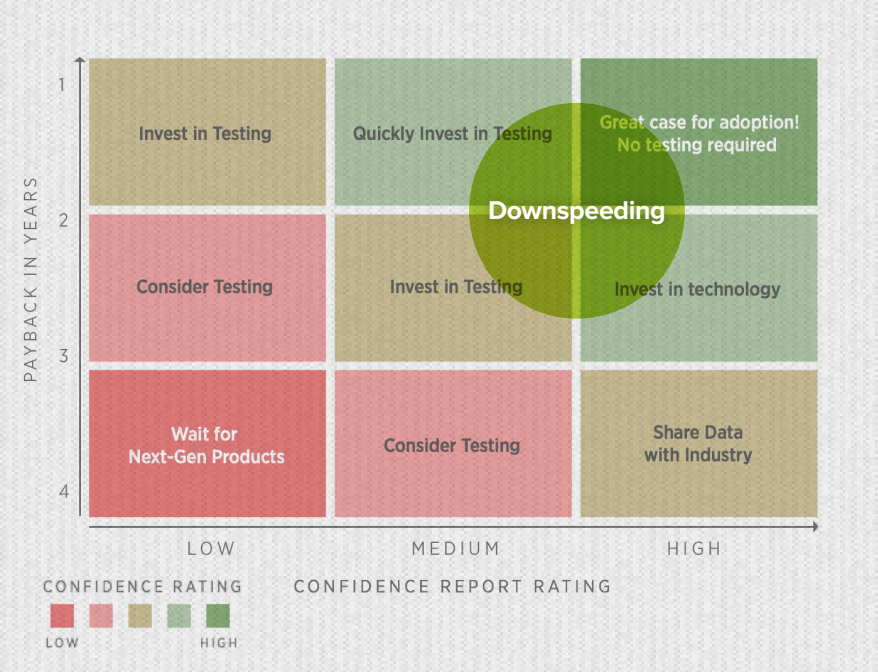
Looking ahead, Trucking Efficiency finds that over the next 5–10 years, "aggressive" downspeeding options will become widely available, with rear-axle ratios of 2.28:1 or lower. This Confidence Report is therefore timely, as it gives fleets insights into the current situation of downspeeding, with ratios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

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