Fuel economy and CO_2 improvement potential of Conventional ICE powertrains

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2 Abstract

Truck operators benefit from lower operating costs when trucks have better fuel economy; the industry is required to meet greenhouse gas reduction targets from various sources and these two goals are complementary. Greenhouse gas emissions are a direct result of consuming fuel; therefore, improving the fuel economy is directly proportional to reducing greenhouse gas emissions. This means that we can use the Environmental Protection Agency's greenhouse gas simulation tools to assess the fuel economy benefit of various technologies. This study examines how mature current and emerging technologies can enhance fuel economy and reduce greenhouse gas emissions in heavy-duty vehicles with conventional powertrains. In doing so it identifies routes for truck purchasers to specify their vehicles to suit their needs, reducing the fuel consumption and greenhouse gas emissions from conventionally powered trucks while zero emission technologies continue to mature and infrastructure develops, enabling more widespread adoption of higher complexity solutions.

This analysis will show:

- Low complexity idle reduction technologies can reduce fuel consumption/greenhouse gas emissions in non-tractor vehicles by double digit percentages.
- Automatic engine shutdown systems in sleeper cab tractors can achieve similar reductions.

- These, less complex and more mature, technologies can make fuel consumption/greenhouse gas emissions reductions equivalent to noticeable Zero Emissions Vehicle (ZEV) adoption.

3 Introduction

To maintain competitiveness, truck operators and manufacturers have been optimizing fuel economy for decades. In more recent years, greenhouse gas emissions reduction requirements have created non-economic drivers to reduce fuel consumption. These two motivations tend to go hand in hand. Fleets can use an objective review of the available options to maximize the operating cost savings and environmental benefits while minimizing the impact on operational efficiency and driver satisfaction.

3.1 Why Greenhouse Gas Emissions Model (GEM)?

Measuring fuel consumption can be fraught with difficulty, due to innate complexity and many variables. Some challenges include selecting a route that represents typical use, specifying the vehicle correctly, achieving repeatable results from real world testing or like for like data from competitors for simulations. The EPA had to navigate these same difficulties when aiming to measure and reduce greenhouse gas emissions. By leveraging the Greenhouse Gas Emissions Model (GEM), developed by the EPA to model greenhouse gas emissions, we can draw objective conclusions about the relative merit of fuel-saving technologies, because greenhouse gas emissions are directly proportional to the volume (and therefore cost) of fuel a vehicle burns. GEM only factors tailpipe emissions. The model does not reflect grid electricity and hydrogen consumption and costs. GEM is a simplified model intended to represent a cross-section of each subsegment of the market. This means there are assumptions made about the performance of a typical engine, driveline and chassis and about the typical use of each truck type. It does however provide a fair environment for us to compare technologies against one another, to assess and quantify their fuel consumption merits. For the remainder of this article, we shall refer to the benefit of various technologies through the lens of how GEM measure them.

4 Idle reduction technology

An engine sits in 'low idle' condition when it is not required to provide power. The engine keeps spinning, consuming enough fuel to overcome internal friction and vehicle loads and to keep its aftertreatment in the right temperature range to maintain emissions compliance. This process emits greenhouse gas. This could be because the vehicle is parked, the vehicle is stationary in congestion, at a stop sign or traffic signal. It could also be because the transmission has shifted into neutral while the vehicle coasts. Idle reduction technology aims to reduce the amount of fuel used to idle the engine. The proportion of time a vehicle spends idling varies significantly depending on its use case. Day cab tractors tend to idle the least, as they spend their time moving from place to place. Sleeper cab tractors also idle infrequently during their work shift but can spend considerable time idling during what is known as hoteling. This is to drive electrical and heating, ventilation, and air conditioning (HVAC) systems overnight. Pick-up and delivery and vocational vehicles can spend significantly more periods of time idling. They also often drive higher vehicle loads (such as power take offs (PTOs) or automatic transmissions with torque convertors) so the proportion of their fuel burn at idle can be high. Idle reduction technologies have been primarily targeted for use in pick-up and delivery and vocational vehicles. GEM only recognizes idle reduction technology benefits in non-tractor vehicles. The benefits generated in GEM are contingent on the system being tamper proof without a ‘disable’ button.

4.1 Neutral idle (NI)

When an automatic transmission is in park or neutral the vehicle loads on the engine are exceptionally low, restricted to just those from engine driven accessories such as alternator, air compressor, power steering, transmission lubrication and HVAC systems (assuming a PTO isn't engaged). The load on the engine can be higher while the vehicle is stationary/in drive (due to the load applied by the torque convertor), increasing the rate that the engine must burn fuel to keep spinning. A popular option is a system that automatically shifts the transmission into neutral when the vehicle comes to a stop and back into drive when pulling away, reducing load on the engine and therefore saving fuel. This feature is already available on the market today, in some cases as an optional extra. The engine keeps running (and driving all the vehicle accessories as normal) and there is a short delay when pulling away for the transmission to re-engage drive. Neutral idle functionality can provide a 4.6% CO_2 reduction in GEM for a Class 6 pick-up and delivery box truck or 6.3% for a class 8 refuse collection vehicle.

4.2 Automatic engine shutdown (AES)

Though the external loads on the engine are low while the transmission is in park, as discussed above, fuel is still being burned (and greenhouse gas emitted from the tailpipe) to keep the engine spinning. Sometimes this fuel is being purposefully used, such as when the PTO is being used, or the HVAC system is maintaining a comfortable working environment for the driver. Sometimes the engine is only running because the driver simply has not made the active decision to shut down the engine. By implementing logic (within the definition of EPA regulation 40 CFR 1037.660) that shuts the engine down when parked for more than 60 seconds, if it is not required to perform one of the functions previously mentioned, a significant amount of fuel can be saved. The algorithm can also check that the engine will reliably be able to restart by checking battery state of charge and for any active diagnostic warnings. When combined with Neutral Idle, the total saving is 9.6% in GEM for a Class 6 pick-up and delivery box truck or 11% for a class 8 refuse collection vehicle. In some cases, drivers are required to shut the engine down when parked by their employer, as part of policies designed to reduce fuel consumption. By ordering a vehicle with AES this can be automated, made more robust and the greenhouse gas savings that are already being made will be recognized without any real change to what the engine and vehicle is doing. AES is not applicable to tractors, there is an equivalent system that will be discussed in section 5 Automatic engine shutdown systems (AESS).

4.3 Stop-start (SS)

It's possible to combine the best parts of the two strategies already discussed and shut the engine down when the vehicle is stationary but in drive, known as stop-start. As with AES, it is important to have an algorithm that checks whether the engine is being used to run the PTO or HVAC is maintaining a comfortable environment for the driver and that the engine will be able to restart quickly and reliably when the driver releases the brakes. It does not make sense to combine this system with Neutral Idle as they typically operate at the same time. There is only a small benefit in doing so as the transmission can shift to neutral when the Stop-Start system decides to leave the engine running. Combining with AES makes sense though, as the systems are similar, with one operating during parked idle and the other during drive idle. When Stop-Start and AES are combined, the total saving is 14.2% in GEM for a Class 6 pick-up and delivery box truck or 15.7% for a class 8 refuse collection vehicle. A tractor could save fuel when equipped with Stop-Start, but we cannot quantify it in GEM. It is also likely to be a lower proportional saving because those vehicles spend less time stationary/in drive than vocational vehicles, on average.

Stop-start, while more complex than NI or AES, is less technologically complex than possible ZEV solutions, with correspondingly less operational and monetary impact.

4.4 Greenhouse gas savings by Idle Reduction Technologies

Combining these technologies to create a ladder makes logical sense. Starting with the technology that is the least complex, easiest to implement and least impactful on the driver (neutral idle), then complementing the reduction in fuel spent idling the vehicle in drive by tackling the fuel spent idling in park (AES) and finally maximizing the impact by replacing neutral idle with Stop-Start to further reduce the fuel consumption (at the expense of higher complexity).

Table 1 – Non-Tractor Idle Reduction Technology Benefits

GEM sub-category	Medium Heavy Duty – Urban (MHD_U)	Medium Heavy Duty – Multipurpose (MHD_M)	Heavy Heavy Duty – Urban (HHD_U)	Heavy Heavy Duty – Multipurpose (HHD_M)
Example vehicles	Street sweeper	Class 6 P&D	Refuse truck	Class 8 box truck or Roll-Off
NI GHG reduction	6.0%	4.6%	6.3%	5.4%
NI + AES reduction	12.0%	9.6%	11.0%	9.4%
AES + SS reduction	17.4%	14.2%	15.7%	13.3%

While individual results may vary, the benefits above show a significant total impact when combining technologies in this way. Vehicle buyers are given the option to make substantial reductions in fuel consumption and greenhouse gas emissions with familiar, mature technology.

5 Automatic engine shutdown systems (AESS)

As discussed in section 0

Idle reduction technology, day cab tractors do not spend much fuel idling and sleeper cab tractors mainly do so for hoteling. The most effective way to reduce idle fuel consumption in tractors is to enhance the efficiency of meeting hoteling requirements in sleeper cabs.Many of these technologies are already in use today, including Auxiliary Power Units (APUs) powered by either diesel or batteries, engine stop-start systems (that run the engine to recharge batteries when they have depleted, but shut the engine down when the batteries are charged, differing from those described for in section 4.3 Stop-start (SS)) and fuel operated heaters (FOH).

The benefit of these technologies is fixed in 40 CFR 1037.520(j)(4), with percentage 'discounts' to the greenhouse gas emissions given depending on the technology type chosen and whether the AESS engine control system (designed to shut the engine off when parked for more than 5 minutes) is locked on or can be adjusted by the user. The benefit can be as high as 6% for a sleeper cab tractor fitted with a battery APU and with the AESS locked on.

Table 2 - Tractor AESS and related technologies benefit

Technology	Fuel Consumption / GHG reduction benefit	
	Adjustable AESS	Locked-on AESS
Standard AESS	1%	4%
With diesel APU	3%	4%
With battery APU	5%	6%
With automatic Stop-Start	3%	3%
With FOH	2%	3%
With diesel APU + FOH	4%	5%
With battery APU + FOH	5%	6%
With Stop-Start + FOH	4%	5%

6 Fleet composition scenarios

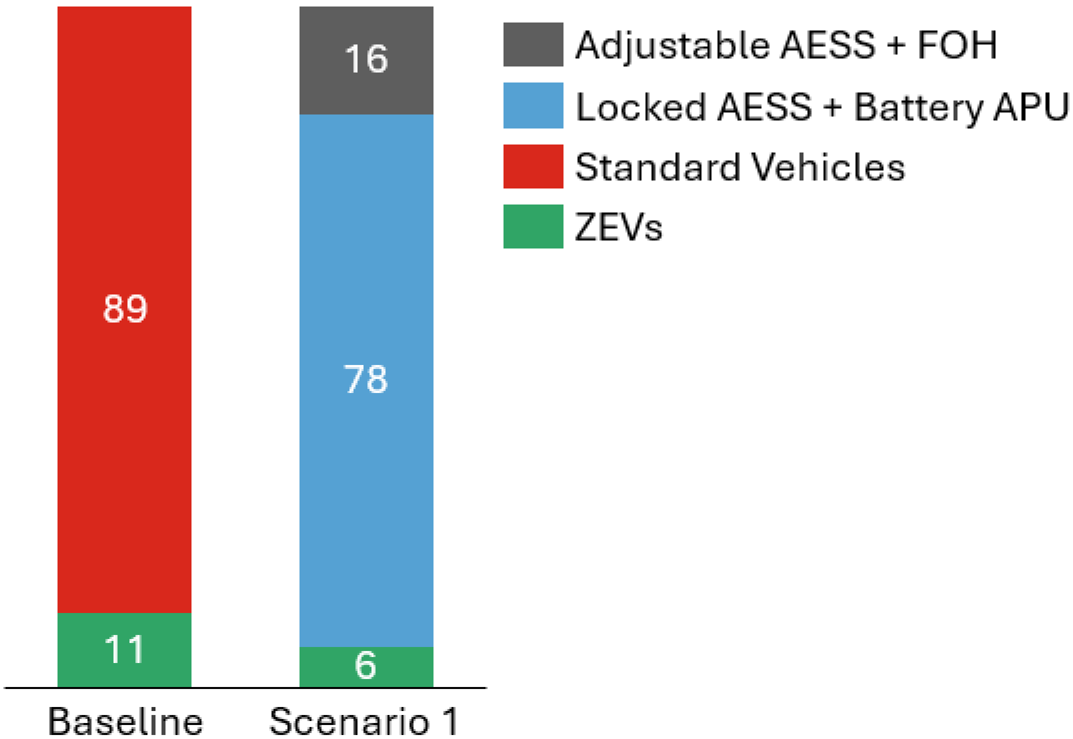
If we consider a fleet buying 100 vehicles in 2030 then we can illustrate equivalent fuel consumption/greenhouse gas emissions reduction scenarios. First, using the ZEV adoption forecast for 2030 from the National Renewable Energy Laboratory (NREL - NREL/TP-5400-82081). Then by applying the familiar, mature technologies discussed above to reduce the number of ZEVs required to meet the same reduction in fuel consumption/greenhouse gas.

Note that while each scenario offers the same conventional fuel consumption / greenhouse gas reduction, the ZEVs require charging/fuelling and so scenarios with more ZEVs will still have a higher overall energy cost.

6.1 Example sleeper cab tractor fleet

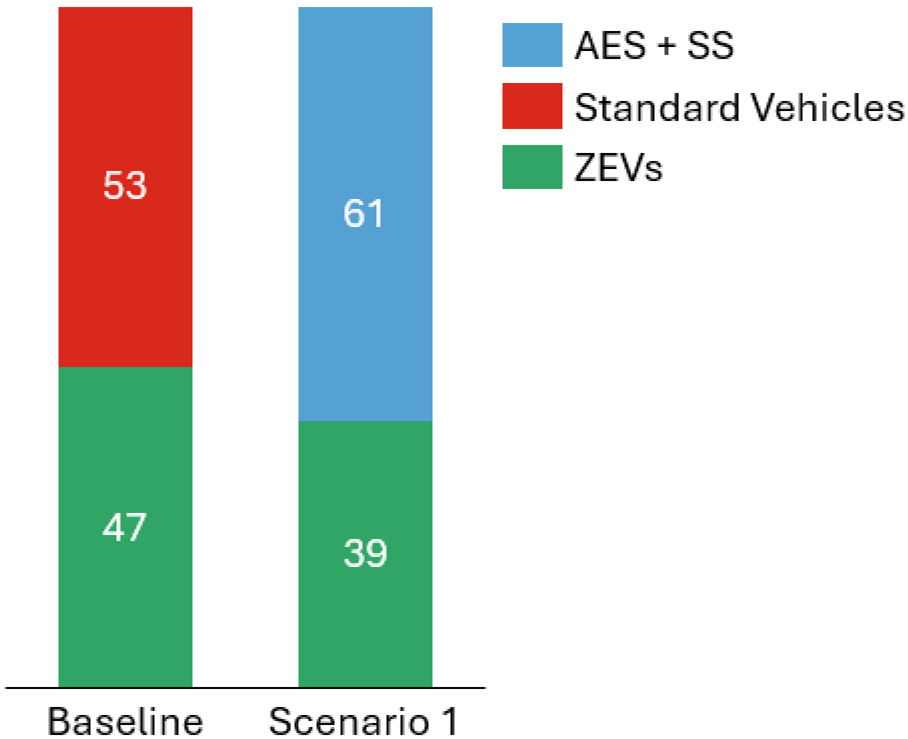
- Baseline – 11x ZEV, 89x standard vehicle – 11% fuel consumption/GHG reduction

- Scenario 1 – 6x ZEV, 78x Tamper proof AESS + battery APU, 16x adjustable AESS + FOH – 11% fuel consumption/GHG reduction



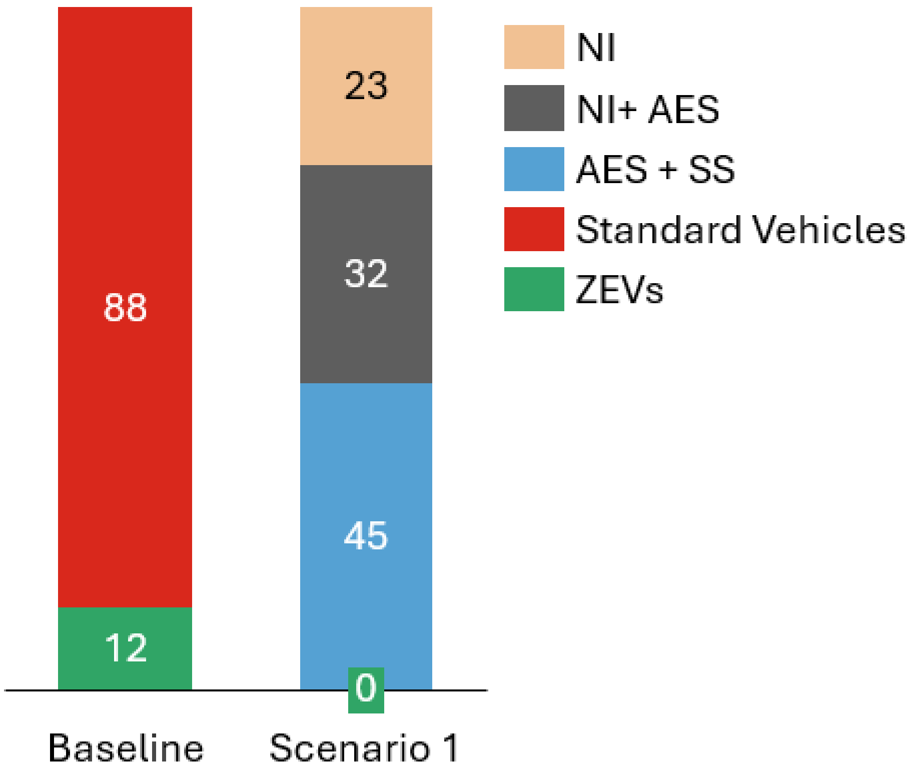
6.2 Example Class 6 P&D fleet

- Baseline – 47x ZEV, 53x standard vehicle – 47% fuel consumption/GHG reduction
- Scenario 1 – 39x ZEV, 61x AES + SS – 47% reduction



6.3 Example Refuse Truck fleet

- Baseline – 12x ZEV, 88x standard vehicle – 12% reduction
- Scenario 1 – 0x ZEV, 45x AES + SS, 32x NI + AES, 23x NI – 12% reduction



7 Conclusions

By recognizing the intrinsic link between greenhouse gas reduction and fuel economy benefits, we have demonstrated that significant improvements are possible for existing trucks, by applying mature and familiar technologies in new ways. These benefits are significant enough that they can make greenhouse gas savings equivalent to noticeable ZEV adoption, helping to smooth the energy transition. While many of the technologies discussed are feasible today, some require investment before they will be available in the market. It is our hope that by illustrating the benefits of these technologies, truck buyers and operators will recognize their value in saving fuel without requiring a revolution in infrastructure and operating practices and push the industry to make these options available to them to purchase. Ultimately, truck operators need a portfolio of options to suit their individual requirements. The technologies mentioned are a key component of that portfolio due to their low complexity, low operational impact, maturity and familiarity. The availability of these technologies will allow fleets to make fuel consumption and greenhouse gas emissions reductions quicker and allow for the pace of ZEV adoption to match the pace at which those technologies mature.