AESS Issues and Challenges

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1.0 AESS Background

Automatic Engine Stop/Start (AESS) systems are an EPA verified Idle Reduction Technology, which allows the locomotive to shut down its engine when certain requirements are met to reduce excessive idling, which in turn reduces fuel consumption, emissions, and noise. These systems are made by various manufacturers, but all generally operate in the same way, as specified in AAR S-5502[1]. While setpoints can vary, the requirements for AESS shutdown are usually based on the following in some way:

Table 1. AESS Monitor Parameters

Battery State of Charge	Generally has minimum voltage and maximum charging current requirements
Main Reservoir Air Pressure	Usually based on Main Reservoir 2 pressure, though constant compressor cycling can also delay or eliminate shutdowns
Ambient Temperature	AESS will disable at high and low ambient temperatures
Crew Input	Crews are capable of delaying shutdown
Distributed Power Status	Often locomotives in DP will not shut down
Number of Restarts Day/Week	Some AESS Systems limit the number of restarts, and will no longer shut the engine down once that limit is reached

1 *S5502 Automatic Engine Start/Stop System* - AAR Manual of Standards and Recommended Practices

The AESS system monitors the parameters and determines if the locomotive can be shut down safely. To do this, it breaks down idle into two categories. Those idle categories are defined below.

> ***Essential Idle*** – Any time the locomotive is idling and one or more of the AESS requirements for shutdown are not satisfied.
>
> ***Non-Essential Idle*** – Any time the locomotive has been idling for over 15 minutes after all AESS requirements for shutdown are satisfied.

AESS systems cannot reduce essential idle time, as it determines that it is unsafe to shut the engine down.

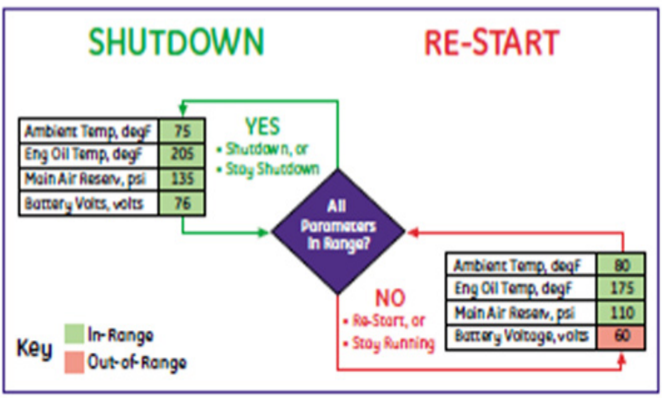


Figure 1. Example AESS Logic Chart

1.1 AESS Impact on Fuel Consumption

In order to estimate the impact of AESS systems on fuel consumption, we will look at three typical locomotive types and estimate the average fuel consumption (and fuel consumption savings). Table 2 shows these three scenarios.

Table 2. Idle Fuel Estimates for Various Locomotive Use Cases

	Locomotive 1	Locomotive 2	Locomotive 3
Power Rating	2,000 THP	3,000 THP	4,500 BHP
Duty Cycle	Switch	Medium	Linehaul
Hours/Day	8	12	16
Operating Days/Year	260	300	330
Gallons/year (total)	29,500	118,000	310,000
Gallons/year (idle)	5,800	8,500	10,200
% of fuel consumption at idle	19.7%	7.2%	3.3%

In the above scenarios, if we assume that on average the split between "Essential" and "Non-Essential" idling on the current locomotive fleet is 50/50, and we assume that currently AESS systems eliminate half of all non-essential idling time, this implies that currently AESS systems reduce fuel consumption on the order of 1,500-2,500 gallons per year per equipped locomotive, which is good but could be greatly improved.

There are two ways to increase the fuel savings from AESS systems. The first way to accomplish this is to increase the shutdown percentage during non-essential idling. This can vary locomotive to locomotive and by AESS system, but is generally a byproduct of the AESS system algorithm and railroad requirements for shutdown. While this is possible with better technology and better AESS systems, it is not the subject of this paper.

The second way to increase the fuel savings from AESS is to reduce the amount of essential idling. As noted above, essential idling is any time the AESS parameters for engine shutdown are not met. Often, but not always, this is the results of a maintenance issue on the locomotive or rail cars and can be prevented. By addressing these maintenance issues, AESS functionality can be increased which in turn will reduce fuel consumption and locomotive based emissions[2]. This paper will cover common maintenance-related issues that have a large effect on AESS system performance.

1.2 AESS Limitations

Locomotive engines, especially older ones, are not designed to be turned on and off in the same way as automobiles are. There's a limit to how many times a large diesel engine can be shut down and started in any given 24-hour period, otherwise you begin to prematurely wear out your engine starting system

2 *"Emission Reduction Technologies"*, Amarjit Soora – LMOA Annual Meeting Proceedings, 2022

components like starters, ring gear, batteries, and contactors. Road failures caused by starting system problems can magnify the cost impact on the railroads – it isn't just about maintenance and component costs. AESS performance depends on overall health of the equipment. In the following sections we will discuss the common issues that can reduce the effectiveness of AESS systems, how to spot them, and potential solutions.

2.0 Air Leaks

Air leaks on locomotives and rail cars are common and they can have large impacts on both fuel consumption and AESS performance. As an example, Figure 2 below shows the engine speed profile of a locomotive idling over a twenty-four-hour period. Note that the air leaks on this were within all applicable FRA air test limits. The unit started, on average, nine times every twenty-four-hour period and, while running, would consistently have to increase engine speed to run the compressor.

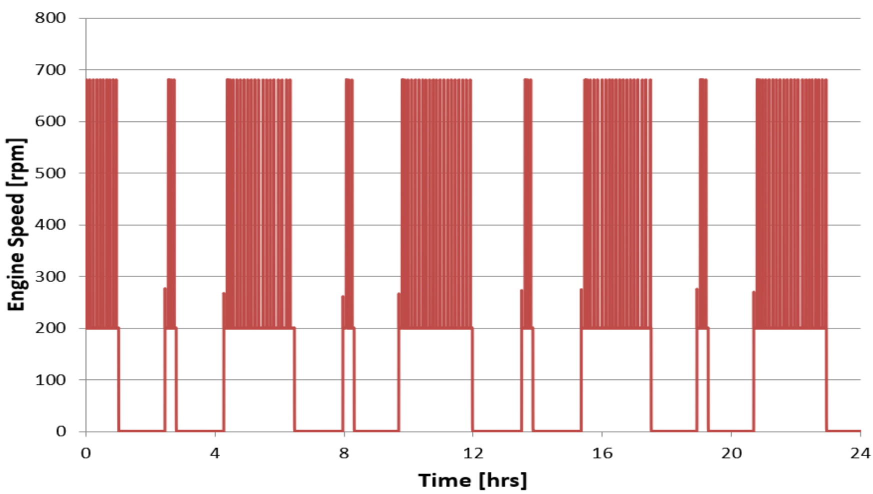


Figure 2. Locomotive engine speed profile over a 24 hour period before air leak repairs

After numerous air leaks were repaired (Figure 3), a significant change to the AESS profile was noted. The locomotive went from an average of nine restarts per day to an average of one restart per day. The result was a reduction in fuel consumption of 62% (43 gal/day) and a reduction in overall engine on time of 60%. On locomotives that have daily and weekly restart limits, the impact of air leaks on fuel consumption and emissions can be even more severe as a leak can exhaust all of the allowed restarts in hours, causing the locomotive to then idle continuously for the remainder of the day or week.

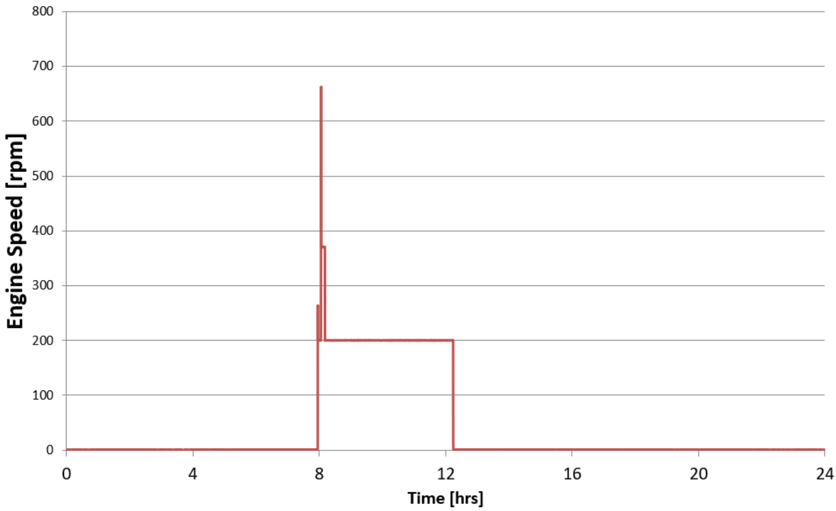


Figure 3. Locomotive engine speed profile over a 24-hour period after leak repairs

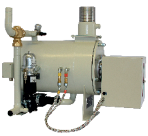
In addition to their effects on AESS performance, air leaks also cause significant increases in locomotive fuel consumption during normal operation[3]. Repairing air leaks is an easy concept, but not always easy in practice. Finding air leaks alone is a labor-intensive process, as air leaks are invisible and often difficult to hear, especially in rail environments. There are commercial tools available to help shop personnel with detection, which range from simple sensors that require the operator to point directly at a leak location to advanced detection systems that can pinpoint a leak from 20 feet away. The prices of these systems vary in the range of $1,000-$30,000 per unit.

In addition to handheld detection systems, the Federal Railroad Administration (FRA) is currently funding an ongoing field development of a wayside air leak detection system, which will be available for use at the conclusion of that development effort. Wayside detection could further reduce the labor necessary in finding air leaks on rolling stock, as mechanical personnel would know the location of leaks before the equipment ever entered the shop.

Finding the leaks is only the first part of the equation though, as repairs must be made to realize a significant improvement in AESS performance and overall

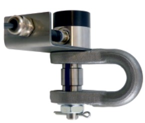
3 *"Autonomous Detection of Compressed Air Leaks on Trains"*, Christopher Stoos – LMOA Annual Meeting Proceedings, 2022

Idling of locomotives is no longer required.
Let us show how your railroad can achieve your goal of reducing the carbon footprint with our Idling Stop Technology.



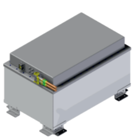
Fuel Operated Engine Heater

No more idling to maintain cooling water.



Handbrake Sensor

No more idling to maintain reservoir pressure.



Battery Energy Storage System

No more idling to maintain battery voltage.

Idle Free

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fuel consumption. Mechanical personnel will need to be given the time and resources necessary to perform these repairs and railroads will need to implement leak checks/limits that go above and beyond the current FRA requirements.

3.0 Locomotive Batteries

Railroads struggle with maintaining their locomotive lead acid batteries in an optimal way. That fact alone could hinder the possible gains in emissions reduction & fuel consumption. With more on-board electronics like positive train control (PTC), locomotive digital video recorder (LDVR) as well as powerful locomotive computers being introduced in newer locomotives, battery depletion leading to shortened battery life and start failures are a real concern when locomotive is shut down on AESS mode. Figure 4 shows an example of battery voltage and current during AESS. The current draw on the battery of this particular locomotive (with lights and HVAC system off) averaged 10 amps continuous while the locomotive was off. It is time to look at newer battery technology as well as addressing these new essential load requirements where possible.

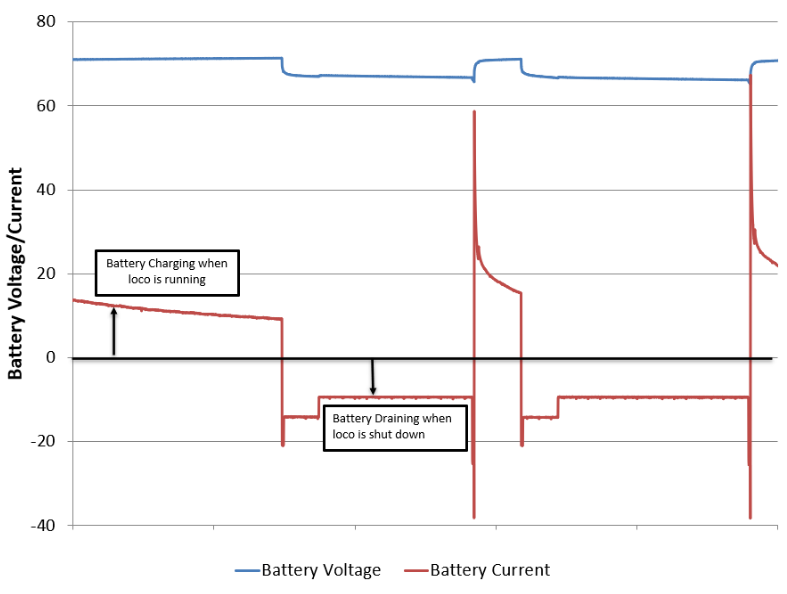

Figure 4. Example Battery voltage and current during AESS restarts

3.1 Battery Chemistries

There are quite a few locomotive starting battery chemistries available on the market in varying stages of technology readiness available for potential use in the rail industry. Below is a list of a few of those that are available:

1. Lead-acid battery:
Traditional type with relatively low cost.
Widely used in various industries.
Essentially 100% recyclable.

2. Maintenance-free lead-acid battery locomotives:
Adopt maintenance-free technology, reducing manual work and maintenance costs.
Suitable for applications where frequent maintenance is difficult or inconvenient.

3. Lithium-ion battery:
High energy density and long service life.
Gradually replacing lead-acid batteries due to superior performance and efficiency.
Higher initial cost compared to lead-acid batteries.

4. Supercapacitor battery:
Feature rapid charging and discharging, long lifespan and environmental friendliness.
Emerging technology with great potential for future development.

5.Nickel-Metal Hydride (NiMH):
Another high energy density, lead-free option for locomotive starting batteries is Nickel-Metal Hydride (NiMH) Batteries. NiMH batteries are generally cheaper than Li-Ion batteries, but do self-discharge over time. The energy density of these batteries is higher than lead-acid, but lower than Li-Ion batteries.

6. Lithium iron phosphate (LiFePO4/LFP) batteries :
A newer subset of Li-ion chemistry that offers numerous advantages over traditional lithium-ion batteries as well as NiCd and lead acid. LiFePO4 batteries were invented in 1996, but the technology has vastly improved and has seen much broader adoption in recent years. LFP batteries are not in the locomotive batteries yet but may be a contender in a few years.

While these various battery chemistries all have pros and cons associated with them, the two most likely in the short term are:

- **Lead Acid batteries** who have been in use for many decades in the railway industry
- **Lithium-ion batteries** who made their debut in the railway industry in the mid 1990's.

There are pros and cons for each of these two battery types, some of which are discussed in detail below.

Figure 5. Traditional Locomotive Lead-Acid Battery Cell

Advantages of Lead-Acid Batteries:

1. Cost-Effective: Lead-acid batteries are cost-effective to manufacture, resulting in more budget-friendly options for locomotive purchases.
2. Mature Technology: Lead-acid battery technology is well-established, with stable market availability. Maintenance and upkeep are relatively straightforward, but often ignored.
3. Vibration Resistance: Lead-acid batteries exhibit robust resistance to vibration and rough conditions, making them suitable for use in challenging work environments.
4. At or nearly 100% recyclable.

Disadvantages of Lead-Acid Batteries:

1. Lower Energy Density: Lead-acid batteries have lower energy density compared to Li-ion batteries.
2. Shorter Lifespan: Lead-acid batteries have a comparatively shorter lifespan, necessitating more frequent replacement and maintenance, which can increase operational costs and downtime.
3. Explosion Risk: Though rare, lead-acid batteries produce hydrogen and oxygen when charging which can cause explosions if not ventilated correctly.
4. Corrosion: The acid in Lead-Acid batteries is highly corrosive and can deteriorate the surrounding steel if spilled during battery maintenance.
5. Maintenance: Lead-Acid batteries require continual maintenance with deionized water.

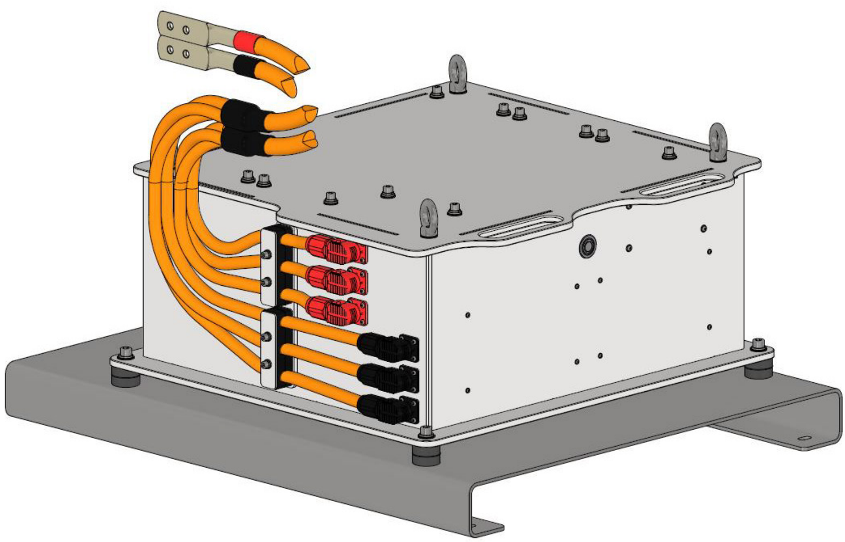

Figure 6. Example of lithium-ion battery packaging

Advantages of Lithium-Ion Batteries:

1. High Energy Density: Lithium-ion batteries boast a significantly higher energy density and increased power output.
2. Lightweight: In comparison to lead-acid batteries, Li-ion batteries are notably lighter. This makes replacing the batteries safer and easier for mechanical personnel.
3. Longevity: Lithium-ion batteries exhibit a longer service life, enduring more charge and discharge cycles. This reduces the frequency and cost of battery replacements over the locomotive's lifetime.

4. Rapid Charging: Li-ion batteries charge swiftly and efficiently, reaching full capacity in a short time frame.
5. Half the size: A single lithium-ion battery replaces two traditional lead acid batteries, allowing the existing battery space to be utilized for an additional battery for hotel loads if desired.
6. Lower Voltage Sag: Lithium-Ion batteries give less voltage sag in high load conditions, like starting. The consistently higher voltage means less current and therefore less heat, improved starter life and higher efficiency.
7. Maintenance free.

Disadvantages of Lithium-Ion Batteries:

1. Higher Cost: Manufacturing Li-ion batteries comes at a higher cost compared to lead-acid batteries.
2. Fire Risks: Though rare, Lithium does carry some inherent safety risk during accidents or during the charging and discharging processes, including issues such as overheating, short-circuiting, and fire hazards. Managing and safeguarding against these risks may necessitate special precautions.
3. Environmental Impact: The production and recycling processes of lithium-ion batteries can have environmental implications, including resource consumption and waste disposal considerations.

3.2 Smart Batteries and Battery Management Systems

*__*NOTE__: The AAR has set up a TAG committee to establish standards for Smart Batteries.*

A smart battery pack is a rechargeable battery pack with a built-in battery management system (BMS) which consists of built-in electronics system with information about its power status to conserve power intelligently. Smart batteries are designed to constantly track their own capacity whether they are being charged, discharged or stored.

Internally, a smart battery can measure voltage and current and deduce charge level and SoH (State of Health) parameters which can indicate the health of the cells. Externally, a smart battery can communicate with a smart battery charger and the locomotive via the CAN bus interface. A smart battery can demand that the charging stop, request charging, or potentially demand that the locomotive switch the secondary battery (if equipped).

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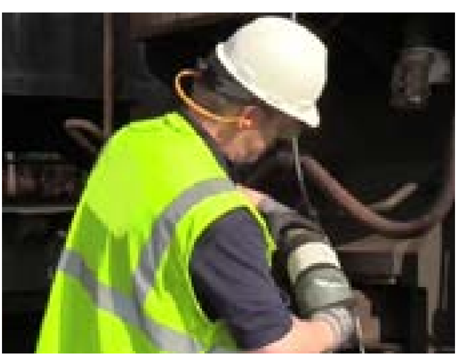
Diagnostic tools that can increase repair velocity, and decrease repeat defect rate



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Smart Battery technology permits features like:

- Onboard monitoring of critical cell and power electronic parameters, short circuit & over current protection, charge & discharge voltage protection, high and low temperature protection
- Sensing feature that will reduce potential of flattened battery fail to start occurrence
- Smart battery - functions like LCS and others available. Communications outputs to integrate the system into a locomotive log event. Onboard monitoring for performance and safety.
- User interface - simple LED indications of status and modes. Button switchable for further function and safety
- Remote fault analysis - cloud based battery parameter upload available to have vendor assistance/diagnose issues.
- AESS extension – certain battery chemistries increased power output and capacity, which means high demand items like HVAC could run off the batteries during AESS shutdown time. This has the potential to reduce operator overrides that account for a significant portion of excess idle time
- Adjusting the battery charging strategy based on battery age and health

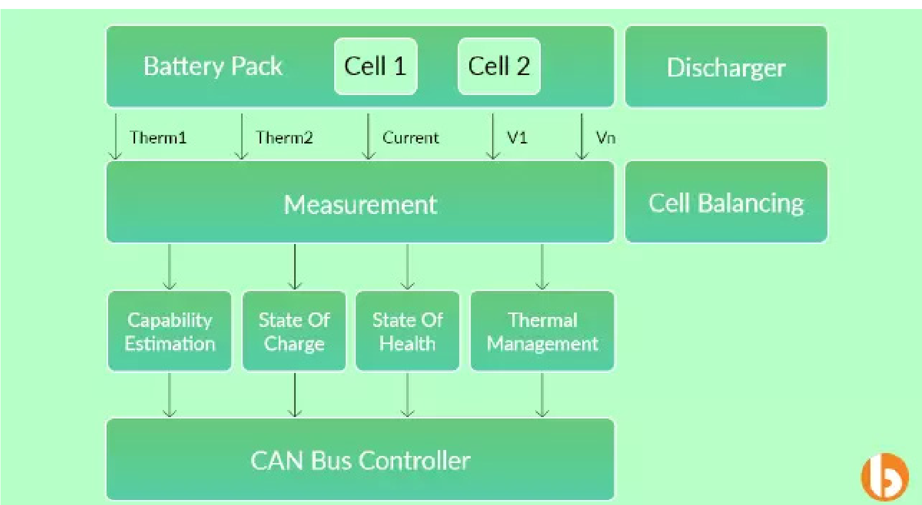


Figure 7. Example of smart battery communication diagram

Battery Management Systems (BMS) have become crucial due to the increasing intricacy of battery technology, especially in lithium-ion systems. The role of a smart BMS is to monitor and report the associated battery's health, performance, and maintenance. Key features of BMS include:

- **Battery Health Monitoring:** The BMS oversees elements such as voltage, temperature, and current movement. This guarantees that the battery operates within secure limits, reducing any potential harm.
- **Enhancing Performance:** The system manages the charging and discharging cycles to optimize both battery longevity and effectiveness.
- **Avoiding harm:** The battery management system identifies possible problems such as overheating or excessive discharge and can implement necessary measures to protect the battery.

4.0 Ambient Conditions

Ambient conditions can cause AESS systems to become less effective. This is especially a concern for railroads that operate in extreme temperatures. There is very little a railroad can do to truly mitigate ambient temperatures, but there are things that can be done to reduce the impact of extreme ambient conditions on the fuel consumption and emissions of a locomotive.

The most prevalent solution to countering the effects of extreme ambient conditions is Auxiliary Power Units (APU). APUs are made by various manufacturers and generally consist of a diesel burner or a small engine, pumps, and heating elements. It allows the oil and engine coolant to be kept warm while burning significantly less fuel than would be used by the running the prime mover. APUs can also be paired with a small generator to power hotel loads and charge the locomotive batteries and even a small air compressor to maintain main reservoir pressure when the locomotive engine is shut down.

Figure 8. Examples of production APUs designed for locomotive use

The benefits derived from APUs are that they allow you to run a much smaller, efficient engine instead of the prime mover. This means a significant reduction in fuel consumption and emissions[4].

APUs are not without their issues though, as space limitations and the necessity of maintaining another engine has greatly limited their adoption. APU maintenance requirements (and the complete lack of maintenance) are also a significant issue which has caused railroads in the past to abandon the technology. While unpopular and potentially a touchy subject, APUs remain a realistic, commercially available solution to reducing fuel consumption and emissions from idling locomotives.

5.0 Train Crews

Train crews often are responsible for delaying or disabling AESS shutdowns and systems. This occurs for various reasons, but often it is associated with crew comfort or convenience. When on board, keeping things like air conditioners or heaters running is one cause, and in switching operations it can be as simple as the crew not wanting to go through the startup process when they get back from their break.

Crews often come up with rather ingenious ways of bypassing AESS systems, and it isn't always easy to tell the difference between an underperforming locomotive and a locomotive that has been altered to underperform (Figure 9) without inspection.

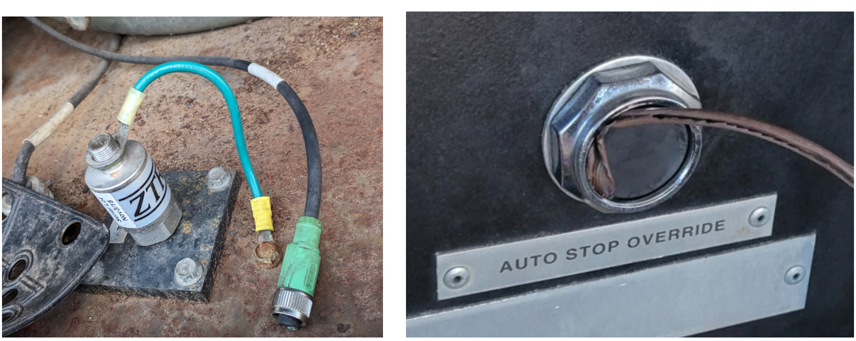


Figure 9. Crew "modifications" to AESS systems

One potential solution is having a dedicated battery set for starting the locomotive diesel engine and use a second battery that would look after hotel/ essential loads when locomotive is shut down by AESS. While not feasible when using traditional lead-acid batteries, a single lithium-ion battery replaces two

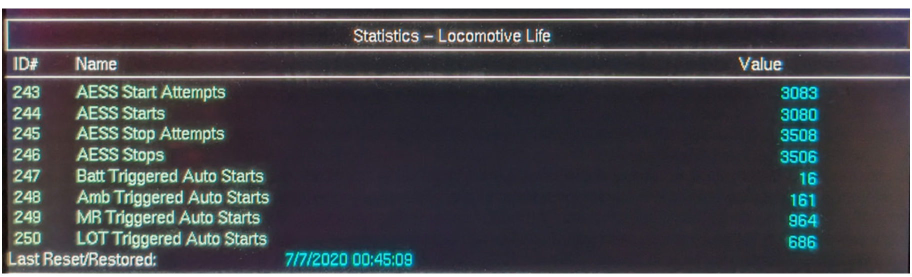
4 *"Reducing Locomotive Idle Fuel Consumption and Exhaust Emissions by Applying an Auxiliary Power Unit (APU)",* L. Biess, T. Stewart, D. Miller, and S. Fritz – ASME ICES 2003

lead-acid batteries on a locomotive, enabling the second available battery box on the locomotive to be used by another lithium-ion auxiliary battery. This could allow the cab HVAC to be operated for a few hours while the engine is shutdown. Other motor-driven accessories and cab electronics can also be run off this battery.

Other potential solutions for crew related issues are covered above, as APUs have the ability to keep crews comfortable even when the prime mover is shut down. Additionally, incentivizing crews has worked for some railroads in the past with respect to fuel consumption. This is a complex, human issue though and unfortunately there is no "one size fits all" solution to human behavior.

6.0 AESS Tracking

As AESS systems and locomotives in general have become smarter, the ability to track AESS data electronically has grown. Whether through the cab screen or with an electronic report (often as a subscription), railroads can now track the AESS status of their locomotives. This data can vary in how much information is available depending on age, manufacturer, etc. An example of the cab data available on some locomotives is shown in Figure 10.


Statistics – Locomotive Life

ID#	Name	Value
243	AESS Start Attempts	3083
244	AESS Starts	3080
245	AESS Stop Attempts	3508
246	AESS Stops	3506
247	Batt Triggered Auto Starts	16
248	Amb Triggered Auto Starts	161
249	MR Triggered Auto Starts	964
250	LOT Triggered Auto Starts	686

Last Reset/Restored: 7/7/2020 00:45:09

Figure 10. AESS data is available in the cab screens of some locomotives

Looking at and analyzing this AESS data provides the opportunity to spot locomotive health issues long before they become a problem in the field. Flagging locomotives that restart more often (or never shut down) and repairing the issues causing the restarts can significantly reduce fuel consumption and, in turn, emissions.

There is no standard solution to AESS tracking, as each AESS system vendor and each railroad approaches the situation differently, but taking advantage of the data available is paramount to increasing the effectiveness of AESS systems.

7.0 Conclusions

While there are many issues that contribute to AESS systems underperforming, there are solutions available to make AESS work as intended. Increasing the effectiveness of AESS systems is extremely important to increase the lifespan of key components, reduce railroad fuel consumption, and in turn, reduce greenhouse gas and constituent emissions.

Locomotive and railcar maintenance is key to this effort. It may require going beyond the FRA required checks, meaning "good enough" is no longer good enough and railroads may need more stringent requirements built into their maintenance practices. Railroads need to provide mechanical forces with the time and labor necessary to address issues prohibiting AESS from functioning as intended. This may require incentivizing the additional maintenance needed or, at a minimum, removing disincentives that exist that are currently preventing this from being done.

Railroads also should seriously look at other possible solutions to reduce the necessary idle time, like APUs and different battery chemistries, to allow AESS systems the ability for even further idle reduction. All together the reduction in idle time will help railroads towards their GHG goals, reduce community complaints, and save railroads significant money in unnecessary fuel consumption.