NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

CONFIDENCE REPORT:

Solar for Trucks and Trailers

ABSTRACT This report documents the confidence that North American Class 8 trucking should have in solar technology. The study team engaged with the entire industry in generating the findings that are presented here. Thanks to all of those who contributed to this important work.

NORTH AMERICAN COUNCIL FOR FREIGHT EFFICEINCY, (NACFE) is a nonprofit organization dedicated to doubling the freight efficiency of North American goods movement. NACFE operates as a nonprofit in order to provide an independent, unbiased research organization for the transformation of the transportation industry. Data is critical, and NACFE is proving to help the industry with real-world information that fleets can use to take action. In 2014, NACFE collaborated with Carbon War Room, founded by Sir Richard Branson and now a part of Rocky Mountain Institute, to deliver tools and reports to improve trucking efficiency. Learn more at www.nacfe.org.

June 28, 2018

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June 28, 2018

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Executive Summary

SOLAR FOR TRUCKS AND TRAILERS

The fuel costs faced by the trucking industry are a significant part of the expense to operate a tractor-trailer in North America. Over the past decade fuel has been as high as $0.65 per mile driven and then dropped to $0.34 by 2016. At these two points, fuel costs accounted for 39% and 21% of the total cost of operating a commercial vehicle respectively. The price per gallon for diesel as of June 2018 has now risen to around $3.28 per gallon ($0.48 per mile) from the 2017 yearly average of $2.65.

In addition, the United States Environmental Protection Agency (US EPA) and the National Highway Traffic Safety Administration (NHTSA) have enacted greenhouse gas emissions regulations on commercial vehicles extended to 2030 that require manufacturers to develop and sell technologies to improve efficiency. These factors have driven fleets, manufacturers, and others to improve the efficiency of over-the-road tractor-trailers.

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 payback for investment into these technologies. To overcome those barriers and facilitate the industry's trust in and adoption of the most promising cleaner operating technologies, the North American Council for Freight Efficiency (NACFE) produces a series of

Confidence Reports, of which this report on solar for trucks and trailers is the sixteenth.

Interest in solar panels is growing among fleet managers because truck batteries are often no longer able to meet the power needs of today's trucks due to increased driver comfort demands, idle reduction regulations, and increased tracking requirements. However, because solar photovoltaic (PV) panels are so new to the trucking industry, many are unsure how to calculate payback when considering investing. The goals of this Confidence Report are to: (a) explain solar applications for trucks and trailers, (b) describe considerations to take into account when evaluating whether to invest in solar panels, and (c) create awareness about the major trends driving and influencing the field of solar technologies as applied to trucks.

TECHNOLOGIES CONSIDERED IN THIS CONFIDENCE REPORT

This report only considers solar panels and associated systems that are currently available on the market for over-the-road applications. The panels differ a great deal from the "traditional" panels many are used to seeing in residential, community garden, or even utility-scale applications. Whereas those panels tend to be rigid and thick, the solar panels designed for the trucking industry are flexible, thin, lightweight, and capable of being affixed to the curves of a tractor fairing. The panels designed for trucks are also specially designed to handle more than the standard hailstorm—with most products capable of surviving intense vibration and thermal cycling, branches, and even truck washes.

SOLAR APPLICATIONS FOR TRUCKS

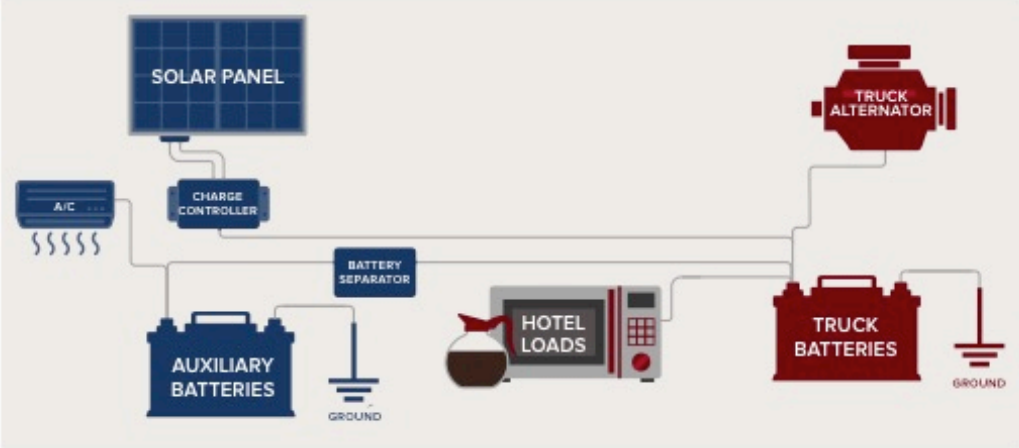
Solar panels have applications both on the tractor and the trailer. The roof fairing of the tractor has historically gone unused and has ideal access to sunlight. The main uses of solar on tractors are to supplement battery HVAC systems and hotel loads without adding additional batteries.

Battery HVAC support: Battery HVAC systems have gained popularity thanks to increased driver comfort demands, idle reduction regulations and noise ordinances across the country, and reduced maintenance and operational costs (compared to engine-based systems). Solar panels can extend the runtime of battery HVAC systems, not only to help the HVAC system make it through the night without draining the truck's batteries, but also to reduce the load on the alternator the next morning, resulting in fuel savings. The solar system can extend the life of the batteries and dramatically reduce, if not completely eliminate, costly roadside assistance calls for dead batteries.

METHODOLOGIES

This report's conclusions were generated through desk research and interviews with solar panel and cabin heating, ventilation, and air conditioning suppliers; tractor and trailer builders; and many large and small fleets with experience using solar. The study team also used the spring 2018 truck shows to meet with and learn from many of the key industry stakeholders.

FIGURE ES1
SOLAR PANELS CONNECTED TO TRUCK BATTERIES



Hotel loads: As electric devices and appliances such as refrigerators, TVs, coffee pots, and microwaves become more and more popular and more and more expected in cabs, these items can place an enormous load on the truck's electrical system. The combined load of all of these devices might only be sustained for about eight to 10 hours by a truck's batteries before reaching a critically low voltage. Solar panels can augment the energy coming from the truck batteries and maintain the batteries at a higher state of charge, extending the battery life and increasing driver comfort by allowing hotel loads to operate for longer periods of time.

Trailers have traditionally been powered by the seven-way connector between the tractor and the trailer, which powers brakes, running lights, and blinkers. However, as trailers have evolved, a number of other electrical loads have been added to trailers that make the electrical system significantly more complicated. Many of these electrical demands can be supported by solar panels. Solar applications for trailers include support for liftgates, telematics, and refrigeration units.

Liftgate support: The extra power available from the solar panel can augment that coming from the engine alternator, maintaining the liftgate batteries at a higher average state of charge, thus extending battery life. The solar panel may also make it possible to eliminate a DC-DC voltage converter to boost the voltage to the trailer batteries.

Refrigeration and telematics support: Some trailers are equipped with transport refrigeration units (TRUs) that have a battery dedicated to starting the small diesel engine that drives the refrigerant compressor when needed to maintain the cargo at the proper temperatures. The diesel engine in most units has an alternator to make sure the battery stays charged and can supply power to other trailer-mounted devices like telematics systems. A properly sized solar panel can provide additional current and battery charging capacity to help manage these devices, maintaining the batteries at a higher state of charge and extending battery life.

BEST PRACTICES FOR EVALUATING SOLAR FOR YOUR FLEET

In evaluating the overall benefits of operating tractors and trailers with solar panels, one must consider factors such as total energy produced, fuel saved, wear/panel life, battery life extension, and a fleet's total energy profile when determining the total cost of ownership of the panels. The following should be taken into account when evaluating if solar panels are a good investment for your fleet:

- System installed cost
- Panel rating vs. physical size. In some cases, the area to mount the solar panel may be limited.
- The fleet's battery replacement rate
- The historic number of roadside assistance calls to jump-start or replace batteries

- Area of the country in which the vehicle predominantly operates

Specifically for tractors, considerations include cost savings due to reduced idling, less load on the alternator during normal tractor-trailer operation, increased battery life, and avoidance of emergency roadside assistance. There will also be savings due to driver satisfaction and retention, although that is harder to quantify. Tractor trade cycles should also be considered, as solar panel life is generally longer than the typical fleet trade cycle.

For trailers, considerations include analyzing electrical requirements for liftgates, refrigeration units, telematics, lighting, pallet jack charging, etc.; the duty cycle the trailer electrical system is likely to encounter; and cost savings due to increased battery life and avoidance of emergency roadside assistance. The average trade cycle in most fleets for trailers is typically longer than that for tractors, allowing the investment for solar panels to be spread over a larger number of years, potentially making the business case more viable.

TRENDS INFLUENCING SOLAR FOR TRUCKS

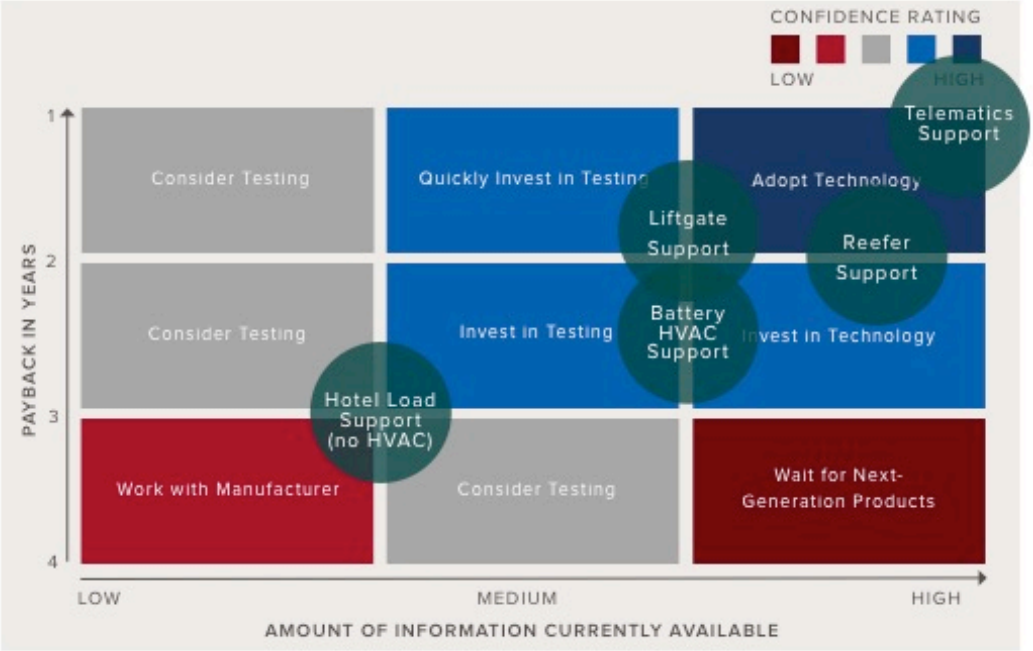
Some major trends are driving and influencing the field of solar technologies as applied to trucks including the shortage of truck drivers, hours of service regulations, the solar investment tax credit, solar tariffs, and even the emergence of commercial battery electric vehicles. Solar technology is also constantly evolving, and the future might lead to improved technologies, cost reductions, more electrification of trucking loads, and extended trade cycles.

CONFIDENCE RATING

The matrix below indicates how confident the NACFE study team believes trucking fleets should be in the investment case for solar systems for various trucking applications.

Given these conclusions, NACFE believes that fleets should seriously consider investing in solar systems, following the best practices described in this Confidence Report. We think the application of solar panels on trailers with

FIGURE ES2
CONFIDENCE MATRIX FOR SOLAR ON TRUCKS



extra electrical loads like telematics, refrigeration units, and liftgates make sense as a means of improving battery life and reducing the need for roadside assistance. This is especially true if the trailer spends long periods without being attached to a tractor. And the opportunity to extend the run time of battery HVAC systems makes installing solar for battery HVAC support a good solution.

CONCLUSIONS AND RECOMMENDATIONS

After years of development globally and in North America, the status of solar systems for the trucking industry today and for the future can be summarized in four key messages:

1. Solar technology for trucks has progressed to the point where the panels on the market are flexible, thin, easily installed, and reliable. Some applications, like supporting the batteries for trailer telematics systems, are an excellent application of the technology and should be strongly considered for future purchases. For other applications of solar technology, the cost versus benefits should be evaluated to see if it makes sense in the specific application.
2. Fuel savings are generally a very small part of the overall benefit that comes from a solar panel installation.
3. Solar panel installations need to be sized appropriately for their intended application. For example, the size of a solar panel to support a battery HVAC system on a tractor might be limited by the area available on the tractor fairing, whereas a solar panel to support a refrigeration unit only needs to be large enough to provide a small trickle charge to the refrigeration unit starting battery.
4. We don't yet have hard evidence from fleets that the payback from the investment in solar panels matches that claimed by the manufacturers. We have verified that the benefits fall in several categories with the biggest benefits being from extending battery life and avoiding emergency roadside assistance for dead batteries. Many fleet users are happy with the investment they made and intend to continue to use solar panels in the future.

"Frequently drivers would have issues with short run times on battery powered APUs. On many occasions drivers would find the battery bank wasn't fully charged at the beginning of their rest period, however with the addition of the solar panel the battery banks were ready when they were needed. The solar is also tied to the battery start bank which lessened the need for jump starts and service calls within the fleet."

-Allan Dahringer, MVT Director of Maintenance

For tractor solar panel applications involving sleeper cabs equipped with or without battery HVAC systems, we recommend using the payback calculator provided with this Confidence Report to help evaluate whether a system makes sense. This tool allows fleets, manufacturers, and anyone else to input various fleet-specific data into a calculator that economizes the benefits and consequences for specific operating practices.

Typical solar panel expected life is generally longer than the typical large fleet trade cycle for tractors and, to a lesser degree, trailers. Currently, the installation methods do not allow the transfer of a solar panel from one vehicle to another economically. If a solar panel installation could be easily transferred from one truck to another, it could be an advantage for the overall fleet investment. There could be improvements over time where solar panels could be incorporated into the fairings and trailer roofs to make the installation cleaner and less expensive.

NACFE 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 solar for trucks.

"Sitting here at the dock, in the hot sun, having solar power to keep my batteries charged and have the air conditioning inside the cab works out very nice since the addition of the [solar] system to my truck. It's quite a contrast to the other trucks that are sitting here in the hot sun with their trucks idling away and not managing to save fuel while they're sitting at the dock. It's quite an advantage to use the sun itself to keep you cool."

–Henry Albert, Owner Operator, Albert Transport, Inc.

NACFE

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www.nacfe.org

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Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.rmi.org

GET INVOLVED

NACFE provides an exciting opportunity for fleets, manufacturers, and other trucking industry stakeholders.

Learn more at: www.nacfe.org
Or contact: Mike Roeth at mike.roeth@nacfe.org

Introduction

This Confidence Report forms part of the continued work of the North American Council for Freight Efficiency (NACFE) highlighting the potential of fuel efficiency technologies and practices in over-the-road (OTR) goods movement. Prior Confidence Reports and initial findings on nearly 85 available technologies can be found at www.nacfe.org.

The fuel costs faced by the tractor-trailer industry have been swiftly and steadily rising over the past decade (Figure 1), with diesel recently surpassing $3 per gallon. As Figure 2 shows, fuel costs are now approximately $0.34 per mile, the second largest expense for fleets, behind only driver wages. The price per gallon for diesel as of June 2018 has now risen to around $3.28 per gallon ($0.48 per mile) from the 2017 yearly average of $2.65. And all indications are that fuel prices will continue to be volatile, thus the industry is in need of solutions that reduce its fuel dependency if it is to stay profitable.

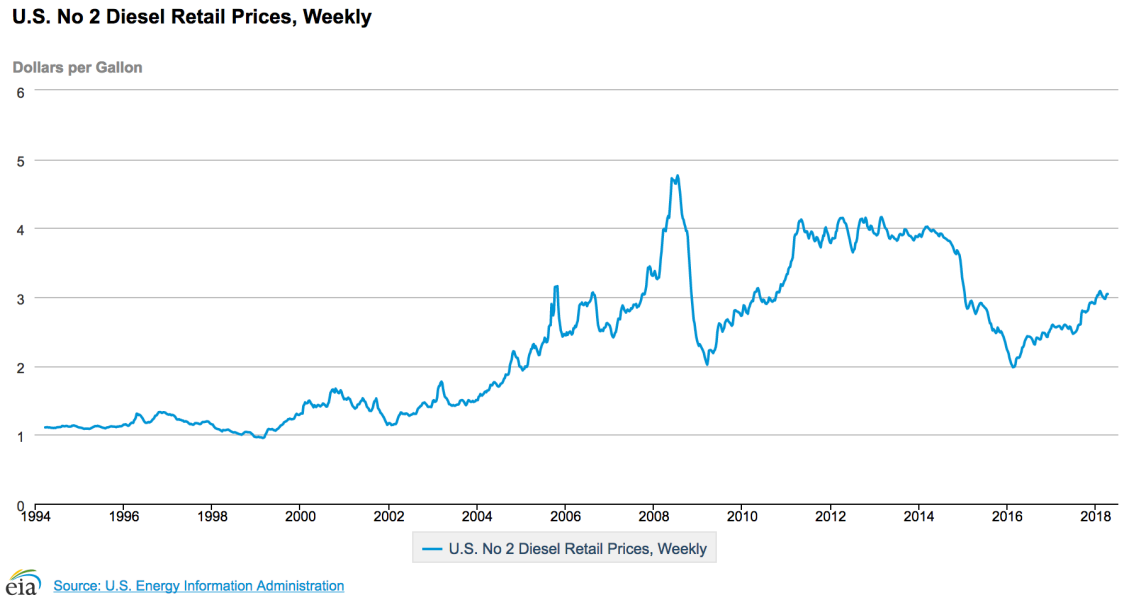


Figure 1: US Diesel Fuel Prices

Table 8: Average Marginal Costs per Mile, 2008-2016

Motor Carrier Costs	2008	2009	2010	2011	2012	2013	2014	2015	2016
Vehicle-based									
Fuel Costs	$0.633	$0.405	$0.486	$0.590	$0.641	$0.645	$0.583	$0.403	$0.336
Truck/Trailer Lease or Purchase Payments	$0.213	$0.257	$0.184	$0.189	$0.174	$0.163	$0.215	$0.230	$0.255
Repair & Maintenance	$0.103	$0.123	$0.124	$0.152	$0.138	$0.148	$0.158	$0.156	$0.166
Truck Insurance Premiums	$0.055	$0.054	$0.059	$0.067	$0.063	$0.064	$0.071	$0.074	$0.075
Permits and Licenses	$0.016	$0.029	$0.040	$0.038	$0.022	$0.026	$0.019	$0.019	$0.022
Tires	$0.030	$0.029	$0.035	$0.042	$0.044	$0.041	$0.044	$0.043	$0.035
Tolls	$0.024	$0.024	$0.012	$0.017	$0.019	$0.019	$0.023	$0.020	$0.024
Driver-based									
Driver Wages	$0.435	$0.403	$0.446	$0.460	$0.417	$0.440	$0.462	$0.499	$0.523
Driver Benefits	$0.144	$0.128	$0.162	$0.151	$0.116	$0.129	$0.129	$0.131	$0.155
TOTAL	**$1.653**	**$1.451**	**$1.548**	**$1.706**	**$1.633**	**$1.676**	**$1.703**	**$1.575**	**$1.592**

Figure 2: Trucking Operational Costs
(Source: American Transportation Research Institute[1])

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 85 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 primary finding of the most recent Fleet Fuel Study, completed in 2017, is that fleets are increasing their rate of adoption of these technologies and that they are enjoying improved fuel economy as a result. The overall adoption rate for the technologies studied in this report has grown from 17% in 2003 to 42% in 2016.

The fleet-wide average efficiency for these fleets in 2016 reached 7.11 mpg, a 1% improvement over the same fleet in 2015, a 10th consecutive year efficiency improved.

The 19 fleets surveyed, representing both regional and long-haul tractors and trailers, in both dry goods and refrigerated cargo movement, and boasting a combined inventory of 71,124 trucks saved $499,265,226 in 2016 compared to the national average of all trucks on the road.

NACFE'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 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 NACFE for the purpose of the reports), in order to centralize an unparalleled range of testing data and case studies on a given technology set.

Solar panels are one such technology set. The core objective of this Confidence Report, therefore, is to provide the leadership of fleets with a comprehensive overview of the total cost of ownership for solar panels for improved fuel efficiency. As this report will demonstrate, there are many (sometimes competing) factors that a fleet must weigh in its decision-making process for solar purchasing. This report therefore does not conclude with a guide of which solar panels will be right for which fleets, but rather with a decision calculator that fleets can use as they assess their own duty cycles, business models, supplier relationships, and other considerations.

The sun's energy may be free, but the fuel economy benefits of operating tractors and trailers with the panels capable of capturing it must be compared against factors including total energy produced, fuel saved, wear/panel life, and a fleet's total energy profile when determining the total cost of ownership of the panels.

Visit www.nacfe.org to view this and other completed reports on over 85 efficiency technologies for Class 8 tractor trailers. NACFE has also begun to guide future changes by completing Guidance Reports on emerging technologies such as electric trucks.

Technologies Considered in this Confidence Report

This report only considers solar panels that are currently available on the market for over-the-road applications. These panels differ a great deal from the "traditional" panels many are used to seeing in residential, community garden, or even utility-scale applications. Whereas those panels tend to be rigid and thick, the solar panels designed for the trucking industry are almost all flexible, thin, lightweight, and capable of being affixed to the curves of a tractor fairing. The panels designed for trucks are also

specially designed to handle more than the standard hailstorm – with most products capable of surviving intense vibration and thermal cycling, branches, and yes, even truck washes.

While we did review panels with different cell and connection technologies for this report (which we will touch on briefly later), the main distinguishing factor between panels is their wattage.

Methodology

NACFE's Confidence Reports are researched by an unbiased team of trucking industry experts. For this report the core study team included: Kevin Otto, Consultant and NACFE Technical Lead, Jessie Lund, NACFE Program Manager; and Mike Roeth, NACFE Executive Director.

In November 2017, this study team began assessing the current state of solar panels for improving the fuel efficiency of Class 8 tractor-trailers. The team used a "360" degree technique to gather existing data on solar, in order to uncover any points of industry-wide agreement or areas of confusion. The first step in this research was for the team to meet with or use phone interviews to speak with solar panel and cabin heating ventilation and air conditioning suppliers, tractor and trailer builders, and many large and small fleets with experience using solar. The team also used the spring 2018 truck shows; specifically, the Technology & Maintenance Council (TMC) meetings in Atlanta and the Alternative Clean Transportation (ACT) Expo in Long Beach, to meet with and learn from many of the key industry stakeholders.

The study team confidentially interviewed 13 fleets and eight major solar manufacturers/providers. All 13 fleets had at least some experience with solar panels. Finally, the study team presented its initial findings, drawn from these interviews and the literature review, to groups of fleets, manufacturers and other participants in NACFE Workshops held in March and May 2018.

Preliminary Study Questions Used in Study Team Interviews

Sample Questions:

- What use cases are there for solar panels on trucks?
- How much energy can solar panels produce?
- Where are panels located on the truck?
- How are panels mounted to the truck?
- How large, heavy, efficient, etc. are solar panels?
- Are all solar panels created equally?
- How are solar systems connected to the overall vehicle electrical system?
- Do solar panels deliver fuel savings?
- How much of an effect do solar panels have on fuel expense?
- What are the advantages and disadvantages of solar panels?
- What is the total cost of ownership?
- How is solar panel use, effectiveness, uptake, etc. impacted by the Solar Investment Tax Credit, Hours of Service regulations, the Food Safety Modernization Act, anti-idling legislation, etc.?

Background on Solar

Why Solar?

There was a time when the electrical load on a truck was minimal and a truck's main starter batteries were capable of delivering enough power to meet the demand. However, thanks to increased driver

comfort demands, new anti-idling legislation, and increased tracking requirements, the main truck battery is often no longer able to meet the power needs of today's truck.

Enter the solar panel. While solar panels have been used for decades to produce power for residential and commercial buildings, their application to the trucking industry is much more recent. However, the panels built for trucks today have certainly taken advantage of the immensely reduced costs and increases to efficiency that were gained thanks to residential and commercial deployment. And now that the cost of the panels has come down so dramatically, fleets are starting to become interested in the potential for harnessing the "free" power of the sun.

Figure 4: Solar panels providing power to a home

However, because this technology is so new to the trucking industry, many are still confused by it and unsure about what to look for and how to calculate payback when considering investing.

Though the most progressive and innovative fleets have begun deploying solar and experimenting with the technology, as evidenced by NACFE's recent Run On Less event, a first-of-its-kind cross-country roadshow to showcase advancements in freight efficiency. Of the seven fleets that participated in the Run, three had solar installed on the truck during the Run and one has since put solar on that particular truck to better understand its value. And while it's impossible to say how much solar contributed toward their fuel efficiency during the Run, it was certainly part of the package that allowed the trucks in the Run to achieve an average 10.1 MPG, compared to the national average of 6.4 mpg for the over-the-road tractor-trailer population.

Figure 5: Run on Less trucks with solar
(Photo Credit: Schaller LLC)

Solar Systems for Trucks

Solar cells are based on a principle called the photoelectric effect that was discovered by Heinrich Hertz in the late 1800s. The technology eventually evolved over time and became a reality in the mid-1950s in research pioneered by Bell Labs and many others. By the early 1960s, solar cells were applied as a source of power for communications satellites. Over the ensuing years, solar cells have evolved to become more efficient, use better materials, provide better reliability, and be less expensive to manufacture. In fact, the price of solar has come down so dramatically in recent years while the efficiency of the panels has skyrocketed that annual installed capacity has more than doubled in just the last five years. (See Figure 6.)

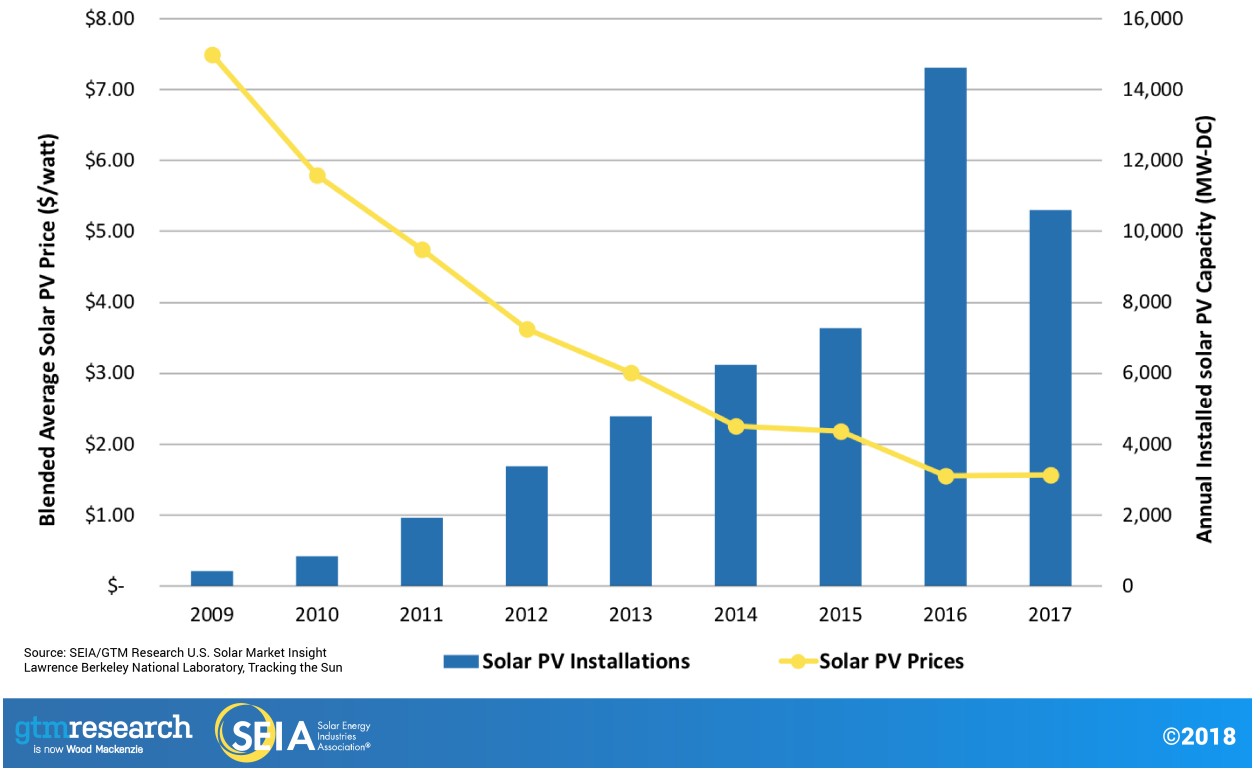


Figure 6: The Falling Price of Solar
(Source: Solar Energy Industries Association[2])

The solar panels that are now available for the trucking industry are thin and flexible so they can be mounted to curved surfaces. They are coated with materials that allow dirt to be washed away easily. The panels may use a variety of cell technologies (monocrystalline, polycrystalline, amorphous silicon, thin film, etc.). Also, the individual solar cells are connected together with a variety of technologies – bus bars, grid technology, etc. However, the discussion of both the solar cell and its construction can be quite technical and confusing. In the end, understanding things like physical size, rating, benefits and consequences are the most important factors in determining whether implementing solar technology makes sense for a particular application.

The solar panel has wires and a sealed connector that needs to be connected to a device called a charge controller. These wires may need to be routed around and/or through the bodywork of the vehicle to connect to the rest of the vehicle electrical system. The charge controller takes the output of the solar panel(s) and makes it compatible with the truck's electrical system. The charge controller is able to adjust to the electrical conditions present. For example, the truck will have a lower battery voltage when the key is off. However, when the engine is running, the alternator voltage regulator takes over and manages the vehicle voltage rather than the batteries.

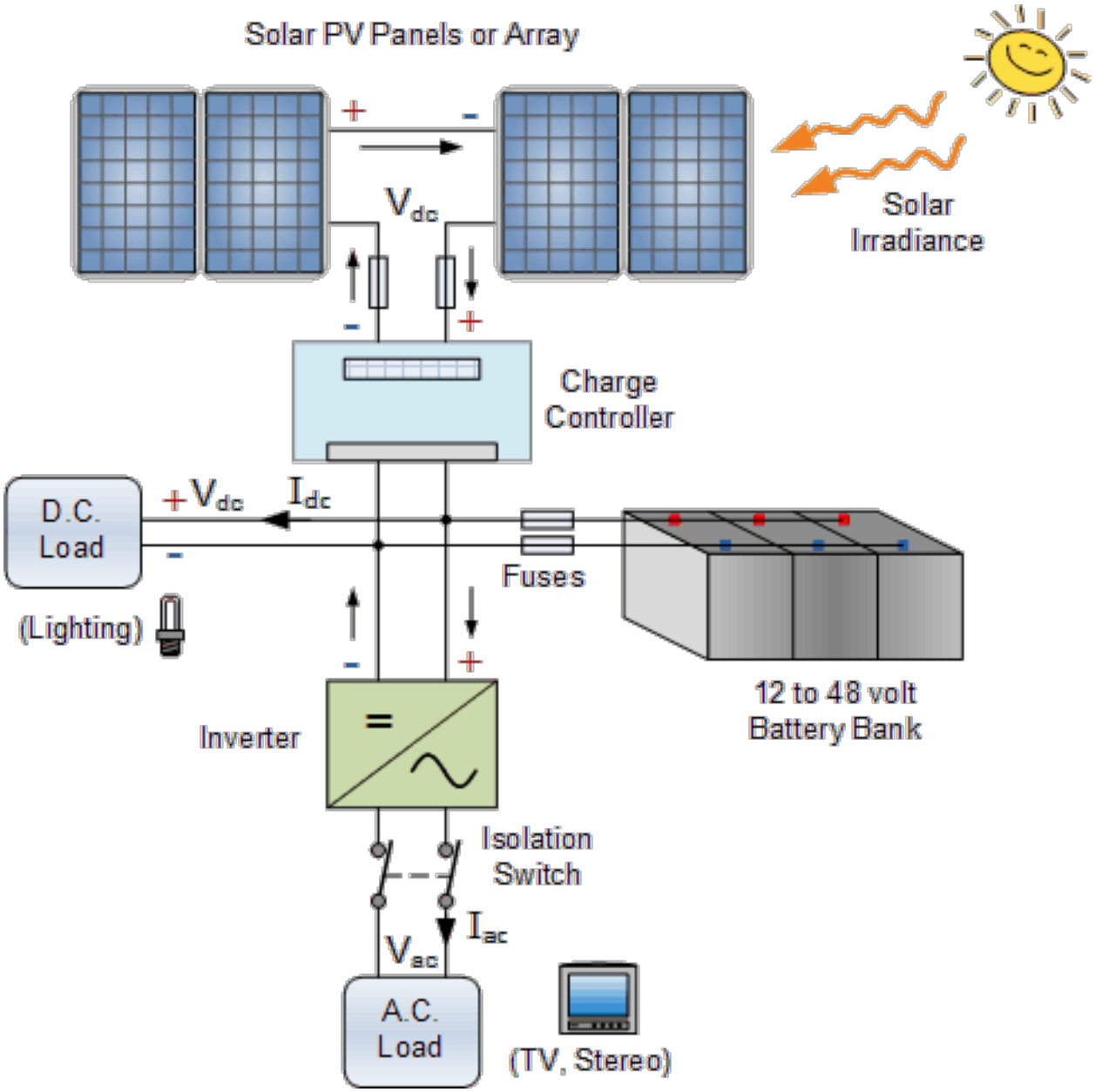


Figure 7: Simple PV System
(Source: Alternative Energy Tutorials[3])

Most solar charge controllers available on the market today use a technique called Maximum Power Point Tracking, or MPPT, to manage the solar panel output. Solar panel efficiency varies based on sun angle, temperature, and a number of other factors. The MPPT controllers are designed to optimize and maximize the panel's power output based on these factors. The MPPT controller also senses battery voltage (an indicator of battery charge level) and optimizes the voltage output to the truck's electrical system to deliver the highest power output. It is worth noting that if the truck batteries are fully charged and the truck is not using any power to drive the engine or accessories, all of the solar panel output cannot be used. For this reason, it is generally recommended to size a solar system not to the available area for installation, but rather to maximize the value of the output based on the typical electrical load of the truck.

Solar panel charge controllers are normally sized to handle more than one solar panel output, but sizing and application of the charge controllers should be discussed with the suppliers to assure the components are matched properly. Sleeper tractors can have as many as six or more panels, usually on top of the cab, but have been known to also be attached to the hood.

Figure 8: Tractor with Multiple Solar Panels
(Photo Credit: Roeth)

Key characteristics to consider when evaluating solar panel systems include:

- System installed cost.
- Panel rating vs. physical size. In some cases, the area to mount the solar panel may be limited.
- Is the fleet's battery replacement rate excessive?
- Is the number of roadside assistance calls to jump start or replace batteries high?
- Area of the country that the vehicle predominantly operates in.

There are many other factors that can feed into the determination of whether solar panels make sense for a given application. Later in this report, we will discuss some of these factors in more detail. We will also provide a simple spreadsheet that you can use to estimate the payback period a solar panel might have for your particular operation.

Truck Electrical System and Solar Panel Basics

To better understand the benefits and consequences of implementing solar panels on heavy-duty vehicles, we need to start with a discussion about the basics of a typical truck electrical system and how a solar panel integrates with that system. Generally, a heavy-duty truck has a bank of four Group 31 batteries that are used to store electrical energy for starting the engine and to stabilize the electrical system as the vehicle runs down the road. There is an alternator that is driven by the engine that supplies all the electrical power needs for the vehicle (except in the rare case that shore power is connected). The alternator is used to power electrical loads like running the engine electronics and powering the lights, but it is also used to charge the batteries as they become discharged.

Some vehicles also have an electric Auxiliary Power Unit (APU) that supplies air conditioning for the sleeper compartment as well as power for lights, cell phone charging, TVs, and refrigerators when the

vehicle is parked, and the engine is not running. The APUs are generally either diesel or battery electric. Electric APUs or Battery HVACs generally have four additional Group 31 batteries that store energy so it can be used when the engine is not running.

So, how much energy can those batteries store? In electricity, the amount of stored electrical power is measured in watt-hours. A watt is a standard unit of energy and the hours designate how much energy is used over a period of time. So, if you have a 100-watt light bulb and have it on for 1 hour, it will use 100 watt-hours of power. Now back to the batteries on the truck, a typical Group 31 battery when fully charged has about 1100-watt hours of energy stored in it. Therefore, it could power that 100-watt light bulb for about 11 hours before the battery was fully discharged.

Sometimes, battery capacity is described in amp-hour terms rather than watt-hours. The amount of amp-hours in a Group 31 battery is simply the number of watt-hours divided by the battery's voltage. The battery's Open Circuit Voltage (OCV) when fully charged is generally about 12.6 V, so a Group 31 battery contains about 1100/12.6 or about 85 amp-hours of power. This means that you can run a 5-amp refrigerator about 17 hours before you completely discharge the battery.

The typical alternator on a heavy-duty truck can supply approximately 150-200 amps of electrical current at a slightly higher voltage of 13.6 to 14.4 volts. The voltage needs to be higher than the battery voltage so current will flow into the battery and the energy will be stored in the battery cells. This job is managed by the alternator voltage regulator. The voltage regulator varies the system voltage to optimize the battery charging process. Once the batteries are charged, the voltage regulator just supplies a small amount of current to the batteries to keep them in a fully charged state for the next time they are needed to start the engine.

As the truck is going down the road, it takes an average of 40 or 50 amps to drive the electrical loads of running the engine, lights, gauges, etc., and it also needs additional current to charge the batteries if they have become discharged. This extra current can be substantial if the APU batteries need to be charged. To charge four batteries that are mostly discharged after a 10-hour rest period in 4 hours, it could take as much as 80 amps. If all eight batteries are discharged, it will take quite a bit more current than 80 amps.

This is why most APU manufacturers recommend that customers upgrade to a premium alternator that can charge at around 250 amps.

It is also important to note that the electrical power to run the vehicle and recharge the batteries is not free. It takes fuel to turn that alternator. Fortunately, the cost per kilowatt hour of generating electricity going down the road is not that high when the engine is running at its most fuel-efficient level. We've estimated that cost to be about $0.35 per kWh to generate the power, assuming the cost of fuel is about $3.50/gallon, so it takes less than a gallon of fuel to fully charge eight discharged batteries. As a comparison, the average cost per kWh for residential power in the US is about $0.12. When the engine is idling to charge the batteries during a 10-hour rest period, the story is quite different. The cost per kWh of electricity under those conditions can be $2 to $3 or even more depending on the situation.

Now, let's switch gears and talk about solar panels. A solar panel converts energy from the sun that falls on it into electrical energy that can be used to power loads on the truck or charge batteries. There are a number of manufacturers now selling solar panels that can be added to the truck to augment the

amount of power generated by the alternator. Most of the manufacturers have a number of things in common:

- They make panels of various sizes to fulfill different needs.
- Panels are usually specified by their peak watt output – i.e. the very highest output the panel can generate in perfect conditions before any losses from the electrical management system or less than optimal solar illumination. The number of watts that the panel is specified for is not what you should expect in useable power in daily operation.
- Almost all the panels are very thin and flexible, so they can conform to curved surfaces. This is different than the rigid panels that are used in residential and commercial building applications.
- Products have been tested to be durable in the rather demanding trucking environment.
- They are installed with an electronic device called a charge controller that regulates the output of the panel to be compatible with the vehicle's electrical system.
- Most panel manufacturers use a charge controller that uses Maximum Power Point Tracking (MPPT). This is the most efficient way to get the most useable energy out of the solar panel. We'll describe this in more detail later in this report.
- The panels are essentially maintenance free. However, snow or heavy dirt accumulation on the panels will significantly hamper their output.
- Most panel outputs to the vehicle electrical system are a small fraction of the power that's available in a single Group 31 battery.
- The panel will work as long as there is sufficient ambient light whether the engine is running or not.

Of course, the solar panel only supplies additional power to the vehicle's electrical system when there is enough light hitting it so that it can generate adequate power to supply the system. With today's modern panels, this starts in fairly low light conditions and increases as the sun gets higher in the sky.

The angle of the solar panel relative to the sun is also an important factor in generating usable output. Therefore, a solar panel angled toward the sun will output more power than one that is facing the wrong direction. If the solar panel is mounted flat on the top of a trailer, it will output less than one that is directly facing the sun at the optimal angle. Figure 9 shows the relationship.

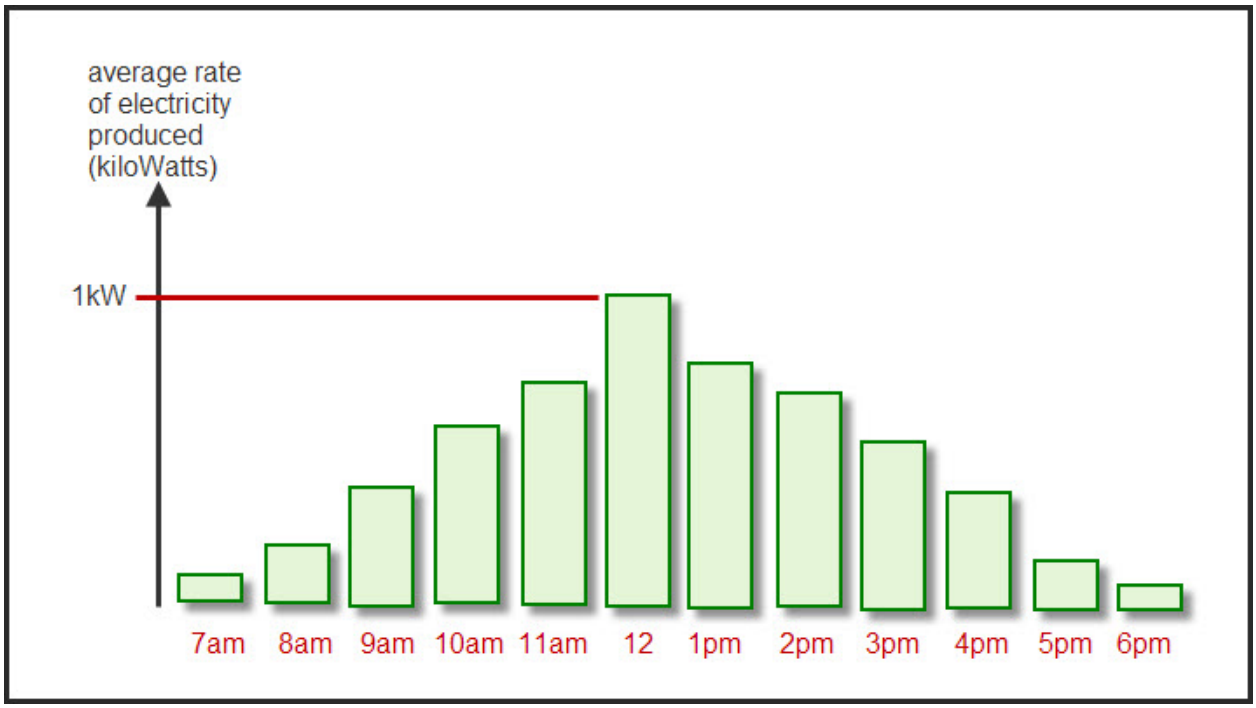


Figure 9: Average Electricity Generated Throughout the Day from a Flat-Mounted Solar Panel (Source: Solarquotes[4])

Note that the power produced in the early morning or late evening hours is a small fraction of the power that is produced at mid-day. Of course, if the panel is facing opposite the sun or mounted horizontally on the top of the trailer, the outputs would be less than ideal.

How much energy can a solar panel realistically produce related to the power that is stored in the batteries on the truck? Here's an example:

Let's assume the following:

- You have a sleeper truck with a battery HVAC system installed to avoid idling the engine during 10-hour rest periods.
- The truck is equipped with four new Group 31 batteries and the battery HVAC is also equipped with four new Group 31 batteries.
- The vehicle is in the Southwest on a sunny day and it will be sunny for the entire 10-hour rest period. It is summer and hot outside, so APU air conditioning of the sleeper compartment is required.
- The driver has a refrigerator, CPAP machine, TV and a few other items that take power when the engine is not running.
- The batteries are fully charged from driving overnight.
- The truck is equipped with a 300W solar panel mounted on the fairing and pointed directly at the sun when it reaches high noon.

Let's further assume that the power consumption under these conditions with no power from the solar panel would discharge the batteries to their lower limit setting in eight hours.

The starting batteries would be automatically disconnected at 40% charge to protect engine starting and the APU batteries would set an alarm at 20% charge level. Both of these protect the batteries and end the time where the energy stored in the battery can be used by the truck's components.

Given the previous discussion on battery capacity, the truck would use the following amount of energy in eight hours:

- Total energy stored in starting batteries: 4 x 1100-watt hours = 4400-watt hours
- Total energy stored in APU batteries: 4 X 1100-watt hours = 4400-watt hours
- Total energy used in 8 hours = 4400-watt hours x 60% + 4400-watt hours x 80% = 6160 watt hours
- In other words, about 770-watt hours per hour

Under these more or less ideal conditions, the 300-watt solar panel would produce approximately the following amount of additional energy in the eight hours:

- Total solar energy delivered = 300 watts x 0.5 average efficiency x 8 hours = 1200-watt hours
- This is about equivalent to adding another battery to the system
- This would equate to an additional 1½ to 2 hours before the engine would have to be started to charge the batteries.
- This also means that idling the engine to charge the batteries can be avoided for the 1½ to 2 hours, saving about one gallon of fuel per hour.

The above scenario describes quite severe conditions for the APU function and essentially the best-case scenario for the solar panel power on the truck. Results will vary significantly based on any number of factors. For example:

- If the health of the battery system is less than a new state, or the charge is not complete on the batteries at the start of the period, then the time to battery discharge will be shorter.
- If the conditions are cooler outside, then less energy will be needed to maintain cabin temperature and the batteries will last longer before becoming discharged. Though cooler conditions will also increase the efficiency of the panels.
- If the sun intensity is less due to being further north, power from the solar system will be less.
- The angle of the solar panel relative to the sun matters, so if the truck is facing the wrong direction or is in the shade, the solar panel will produce less energy.
- If conditions are cloudy, power from the solar system will also be less.
- Of course, if the 10-hour rest period is only partially during the daytime, the solar system output would be less.

Note that solar panels have some other significant benefits that are not directly related to power supplied during rest periods. These will be discussed in detail in later sections of the report.

In summary:

- Solar panels will supply at least some power to the system during the day, even in early morning or late evening. However, the amount of power generated can vary greatly due to many factors, some of which are mentioned above.
- The power can be used to satisfy needs for electrical power or battery charging while the key is off or the truck is travelling down the highway.

- If the batteries are fully charged, then the power from the solar panel can only be used for satisfying other electrical loads like lights, running the engine electronics, refrigerators, etc.
- The amount of electrical power generated in a day by a typical solar panel is generally much less than the energy contained in a single Group 31 battery.
- The solar panel can provide "trickle charge" capability when the truck is parked for the weekend. If the panel is on the trailer, it can provide power to batteries for liftgates, refrigeration units, telematics, etc. to maintain their charge while disconnected from a tractor.

Understanding Solar Panel Output

As we have discussed, it is difficult to estimate the output of a solar panel system on a truck compared to the needs for power in various modes of operation. One way to put this in perspective is to evaluate what the panel's output would be if all the energy that it generates could be used in some way to either charge the batteries or satisfy electrical loads on the vehicle.

The National Renewable Energy Lab, a National Lab of the US Department of Energy, has a solar energy calculator that can give an estimate of how many kilowatt-hours of energy a given solar panel in a specific location in the United States or Canada can produce in a year. This tool, called PVWatts® can be used to provide a rough estimate of how much energy a truck-mounted solar panel can produce. You can then use the output to compare against how much that energy might cost to produce using the truck alternator.

The calculator can be found at this website:

http://pvwatts.nrel.gov/pvwatts.php

Of course, the solar panel has additional benefits that must be taken into account to understand the overall return on investment of the solar system. Let's go through an example of how much power could be expected for a fairing-mounted solar panel on a truck for a couple of locations in the U.S. to put this in perspective.

Let's try Phoenix, Arizona. Below is what you should see in the tool after you select Phoenix. You then need to select a weather station location and hit the go to system info button.

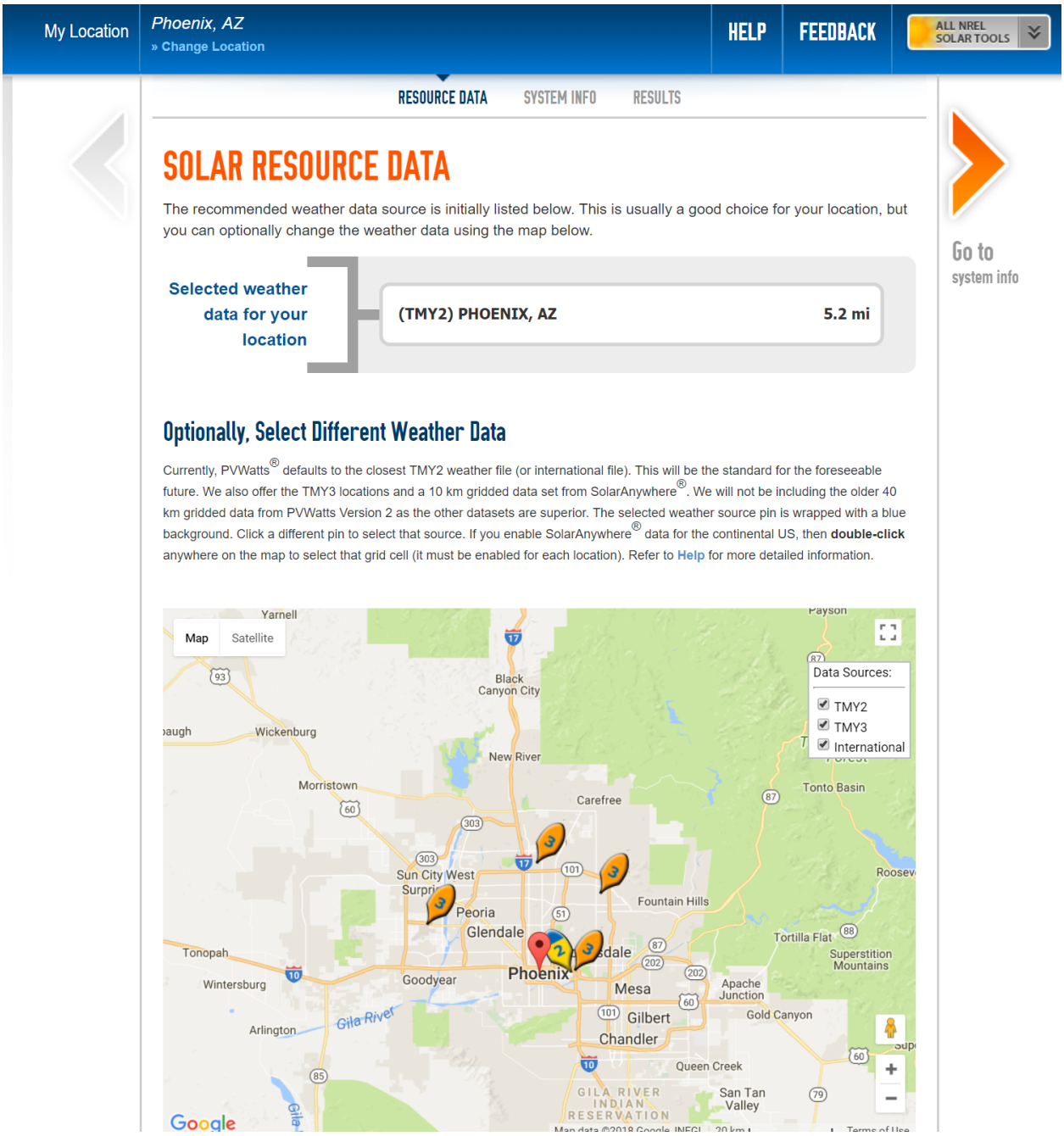


Figure 10: PVWatts screenshot
(Source: PVWatts, NREL[5])

The screen will then show the following tool. Adjust the inputs to those shown on the screen and hit the Go to PVWatts results button.

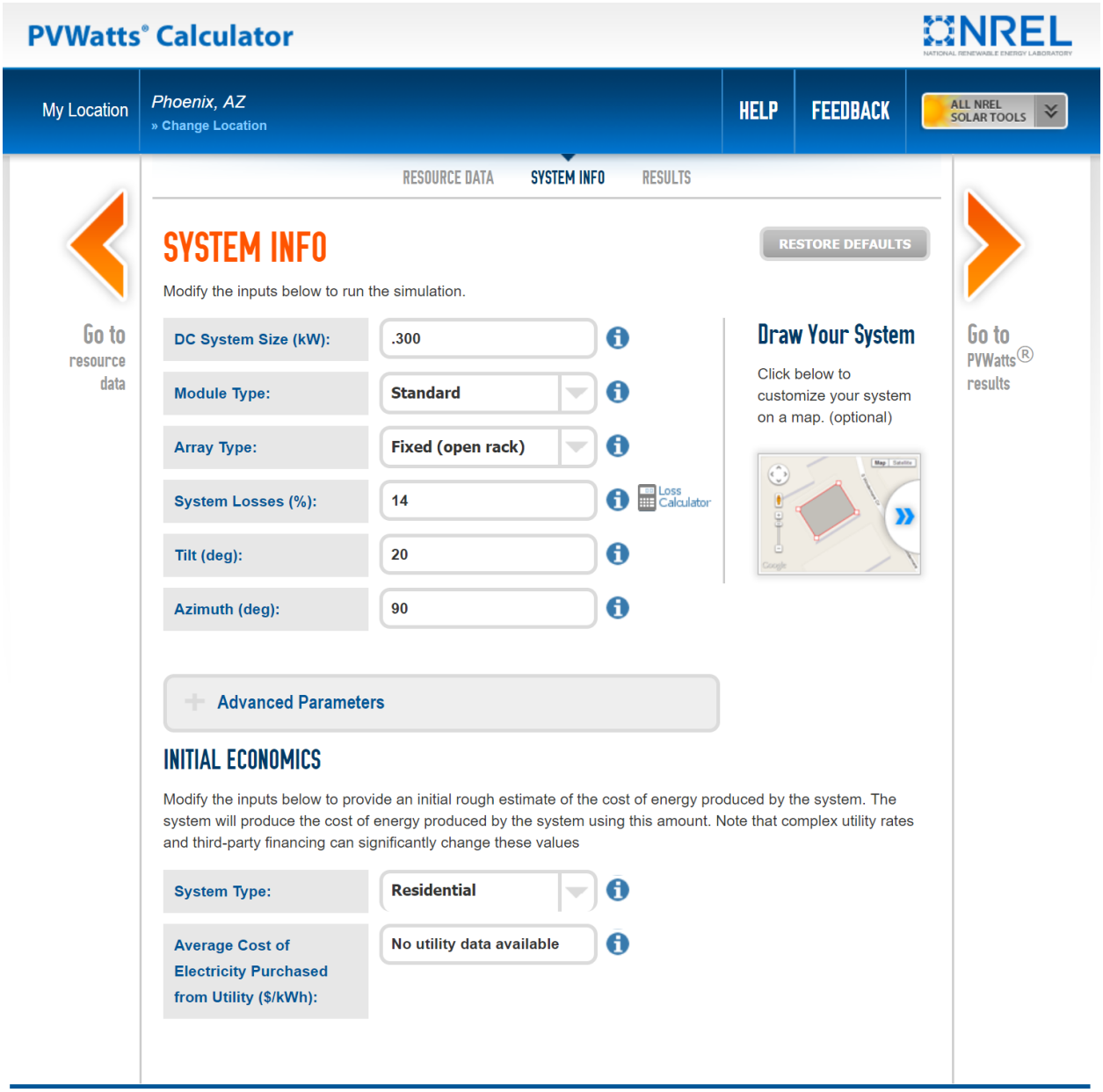
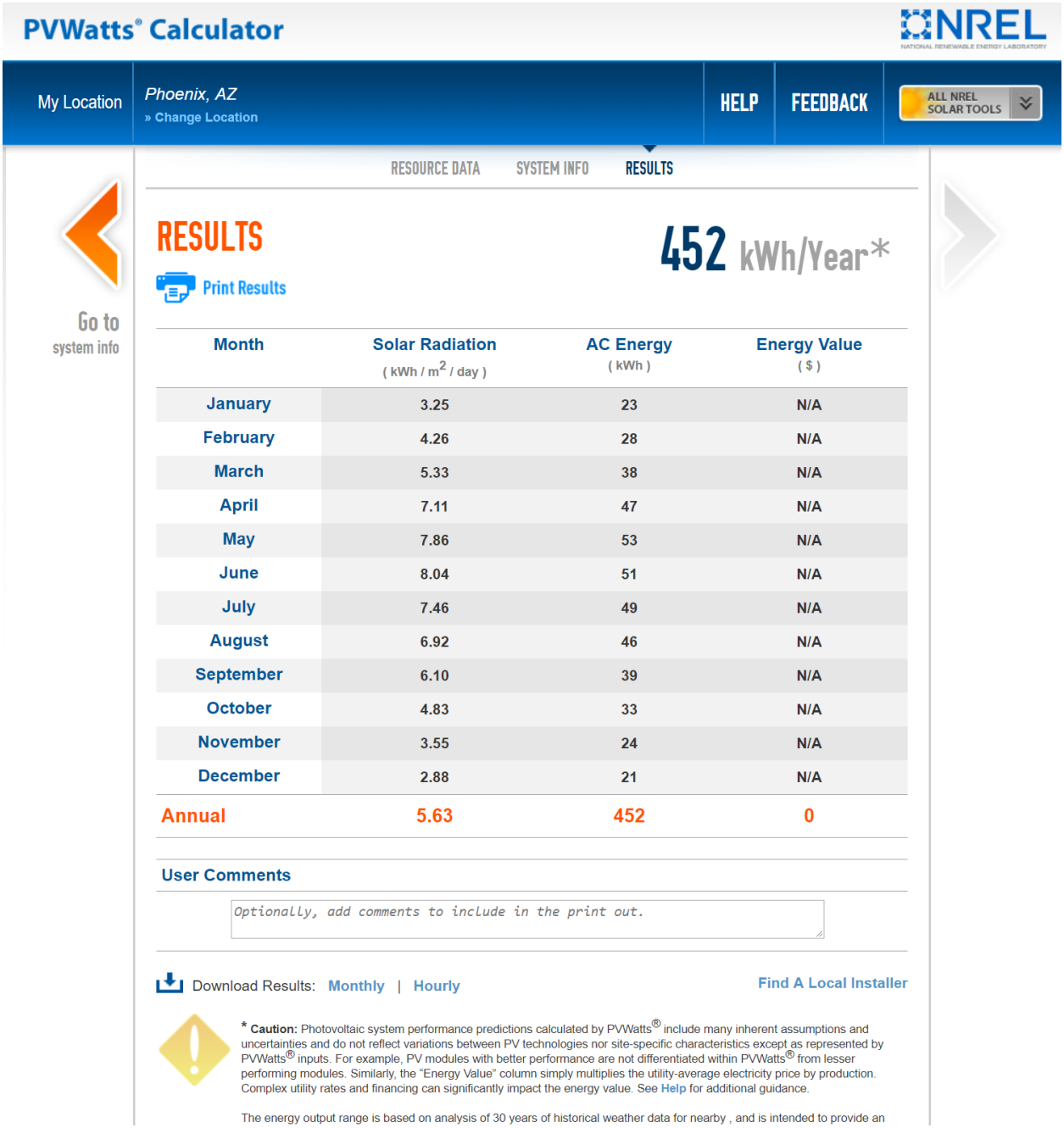


Figure 11: PVWatts screenshot

You will note we changed the size of the solar panel to 300 watts, which is about the size that fits on a truck cab fairing. We also changed the incline angle to 20 degrees to simulate the tilt of the fairing. The Azimuth term is the direction that the sun is coming from. We changed this to 90 since that number turns out to be about the average if the truck is randomly going in any direction relative to the sun. Now let's look at the results.



PVWatts® Calculator

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

My Location | Phoenix, AZ » Change Location | HELP | FEEDBACK | ALL NREL SOLAR TOOLS

RESOURCE DATA | SYSTEM INFO | RESULTS

Go to system info

RESULTS

Print Results

452 kWh/Year*

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	3.25	23	N/A
February	4.26	28	N/A
March	5.33	38	N/A
April	7.11	47	N/A
May	7.86	53	N/A
June	8.04	51	N/A
July	7.46	49	N/A
August	6.92	46	N/A
September	6.10	39	N/A
October	4.83	33	N/A
November	3.55	24	N/A
December	2.88	21	N/A
Annual	5.63	452	0

User Comments

Optionally, add comments to include in the print out.

Download Results: Monthly | Hourly

Find A Local Installer

* **Caution:** Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Similarly, the "Energy Value" column simply multiplies the utility-average electricity price by production. Complex utility rates and financing can significantly impact the energy value. See Help for additional guidance.

The energy output range is based on analysis of 30 years of historical weather data for nearby , and is intended to provide an

Figure 12: PVWatts screenshot

This tool indicates that a truck with most of its operation in the Southwest near Phoenix would produce approximately 452 kWh of electricity per year. Taken another way, this is about 1.25 kWh per day of energy or a little over the amount of energy stored in a Group 31 battery.

Now let's take a look at what you could expect if operating near Albany, New York.

PVWatts® Calculator

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

My Location | Albany, NY » Change Location | HELP | FEEDBACK | ALL NREL SOLAR TOOLS

RESOURCE DATA | SYSTEM INFO | RESULTS

Go to system info

RESULTS

Print Results

299 kWh/Year*

System output may range from 286 to 304kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Energy Value ($)
January	1.69	14	2
February	2.59	19	2
March	3.11	25	3
April	4.07	31	4
May	4.94	36	4
June	5.17	36	4
July	5.32	38	4
August	4.72	34	4
September	3.67	26	3
October	2.59	20	2
November	1.40	11	1
December	1.32	11	1
Annual	3.38	301	$ 34

User Comments

Optionally, add comments to include in the print out.

Download Results: Monthly | Hourly

Find A Local Installer

* **Caution:** Photovoltaic system performance predictions calculated by PVWatts® include many inherent assumptions and uncertainties and do not reflect variations between PV technologies nor site-specific characteristics except as represented by PVWatts® inputs. For example, PV modules with better performance are not differentiated within PVWatts® from lesser performing modules. Similarly, the "Energy Value" column simply multiplies the utility-average electricity price by production. Complex utility rates and financing can significantly impact the energy value. See Help for additional guidance.

Figure 13: PVWatts screenshot

Note that the predicted energy on an annual basis would be about 300 kWh or about two thirds of that available in the Southwest. This means you can expect about two thirds of the electrical benefit from the solar panel if it is located mostly in the Northeast. Of course, this is due to the slightly lower sun angle and the average number of days that are sunny vs. cloudy compared to the Southwest. The solar intensity data that drives these estimates is from averages taken over a number of years, so the average in a given year will be different.

Based on the model's output, the cost of the panel system plus installation, and the expected number of years to get a payback, it is possible to estimate the cost of power generated by the panel per kWh from the solar panel. This becomes one input to the model to understand the potential return on

investment because the extra electricity coming from the panel has additional benefits to the truck operation, like the potential to extend battery life and avoid (if not eliminate) emergency roadside assistance calls due to dead batteries.

Earlier in the report, we mentioned that generating power with the engine alternator generally costs about $0.35/kWh when the truck is running down the road and between $1 and $3/kWh when the truck is parked and running the engine to generate power.

Voltage Regulation Systems

Solar panels can essentially provide two electrical functions when installed on a vehicle. If the vehicle has demand for current to operate appliances, run a trailer liftgate, lights, run the engine, etc., then the solar panel can supply some current to those systems to assist the batteries or the alternator, depending on where the power is coming from. A solar panel can also provide supplemental battery charging. When batteries become discharged, electrical current flow must be reversed and supplied to the battery to recharge them. There is a specific procedure that is used to recharge the lead acid batteries on a truck to charge them as quickly as possible without damage. The voltage regulator that is normally installed in the alternator provides this function.

Voltage regulators normally provide charge to the batteries in three stages as shown in Figure 14:

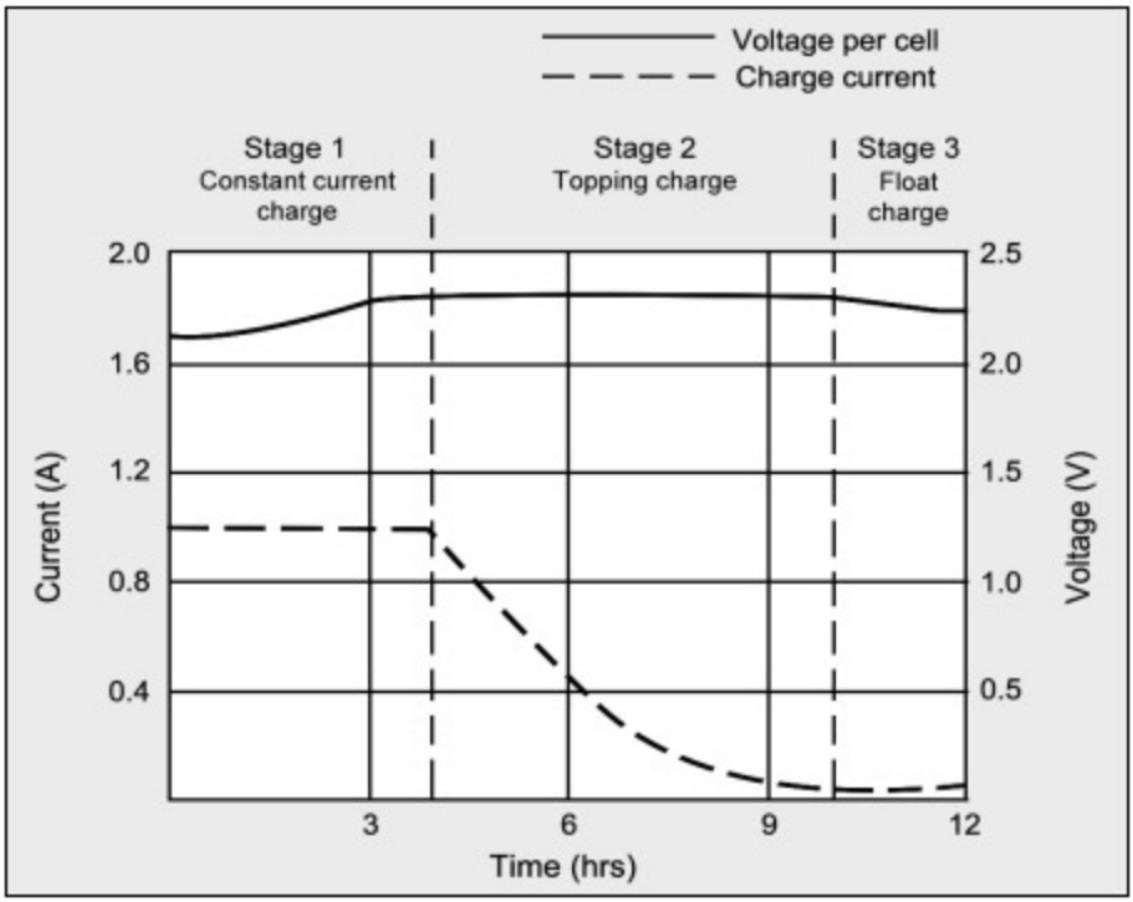


Figure 14: The Three Stages of Voltage Regulation
(Source: Battery University[6])

Note that lead acid batteries charge at a relatively slow rate, so it can take up to 10 hours to return a discharged lead acid battery to a fully charged state. In the first charging stage (sometimes called bulk charging), the current flowing to the battery is managed so that the battery is not damaged due to the high current. This stage takes roughly half the time of the total charge. The second stage is called the topping (or absorption) charge where charging voltage remains constant, but the current flowing into the battery is slowly decreased. The third stage is called float, where a very small current is supplied to the battery just to maintain it at a fully charged state. This current is small enough that the battery won't be damaged due to overcharging. This has often also been called "trickle charge."

So, you might ask, how does a solar panel work with the alternator's voltage regulator? The charge controller for the solar panel can sense the truck system voltage and adjust the voltage of the panel output so that current will flow from the solar panel into the system. Based on the voltage levels sensed from the vehicle, the controller manages the voltage it supplies so that the maximum amount of current possible flows from the panel into the truck's system. It doesn't matter at that point

whether the current flows to the batteries to recharge them or is used to power electrical loads on the truck. If the vehicle is turned off and has no loads on the batteries, then all the current will flow to recharge the batteries. If the batteries are fully charged, then the solar charge controller works just like the alternator voltage regulator and only supplies a trickle charge to maintain the batteries.

It's important to note that the long charging time that is described above presents some challenges for batteries as they are used on trucks, particularly in certain applications. The first of these would be trucks that are used in an extreme start-stop mode. An example of this is the package delivery business where many deliveries per day are made where the engine (and alternator) are turned off as the packages are delivered. A second application is one where a liftgate is being used frequently to deliver heavy loads to customers in a crowded urban environment. The third is a battery HVAC system where the batteries are discharged substantially during a 10-hour or longer rest period. Keeping batteries charged in these kinds of applications can be challenging because there may not be enough run time between events to restore the batteries to a fully charged state.

There are also other conditions that put a strain on the trucks' batteries. These conditions include times when the truck is stopped and not idling, and the batteries must power hotel loads such as refrigerators, CPAP machines, TVs, etc. Because these sorts of conditions fail to keep the batteries topped off, resulting in more frequent deep discharges, it is not unusual for battery life to be shorter than 24 months in some applications. Solar panels can help mitigate at least some of these deep discharges and therefore extend the life of the batteries.

The following documents from the Technology & Maintenance Council (TMC) of the American Trucking Associations are good references related to truck electrical systems and the application of solar panels to commercial vehicles:

- RP 177, *Solar Power for Commercial Vehicles*
- RP 178, *Battery Management and Cable Guidelines for Meeting Hotel Load Requirements*
- RP101C, *Heavy Duty Truck Alternator Mounting*
- RP105C, *Battery Cable Assemblies*
- RP129A, *Heavy Duty Vehicle Cranking & Charging Troubleshooting; 12-Volt Systems*
- RP136B, *Managed/Isolated Battery Systems for Electric Start Systems*
- RP139B, *Battery Selection Criteria*
- RP140A, *Understanding Key Off Parasitic Loads*
- RP 160, *Wiring & Circuit Protection Guidelines For 12-Volt DC to 120-Volt AC In-Cab Inverter Systems*
- RP162A, *Design Guidelines for Electrochemical Capacitors Used in Starting Applications*
- RP 166, *Low-Voltage Primary Electrical Cable Specification for Heavy-Duty Electrical Repair*

To obtain a copy of any of these Recommended Practices, please visit tmc.trucking.org. The manuals can be purchased separately or are one benefit of membership in TMC if you choose to join.

Solar as Applied to Trucks

Tractor Applications

One of the most visible places you'll see solar on trucks – both on the road and in the solar marketing collateral – is on the roof fairing of the tractor. Aside from the occasional branding or sleeper skylight found there, this space has historically gone unused. This prime "real estate," combined with its access to sunlight, makes it an ideal place for solar panels.

However, actually mounting the panels to the fairing isn't quite as straightforward. Panels are usually mounted with a strong adhesive and/or screws through grommets. But the curved surface of the fairing means that any solar panels need to be flexible enough to hug the roof without breaking and without sticking out, creating aerodynamics issues. As one fleet representative we spoke with explained the process, "it's a bit like trying to glue a flat piece of paper on a basketball." While certainly not impossible, proper application requires a trained technician.

Figure 15: Solar panels mounted to the tractor fairing
(Source: Bergstrom)

Once the panels are mounted on the fairing (and occasionally, in the case of leading innovative fleets like Groupe Robert, on the hood as well), the panels are then wired through a charge controller, which will send the power where it is needed. For tractor applications, the power is usually used to support in-cab battery HVAC systems and/or hotel loads.

In general, here are some key items to keep in mind when specifying a solar panel as part of a solution to tractor electrical demands:

- A solar panel system generally cannot supply the current necessary to drive large tractor loads like battery HVACs or refrigerators. However, it may be able to supplement the power stored in the truck's starter and/or HVAC batteries.
- The solar panel system will only supply additional power during the day when the panel is exposed to sunlight. If the panel is heavily shaded due to loading docks, tall buildings, or heavy clouds, there will be less output.
- Correct wire sizes, good connections, and good electrical maintenance practices are still required to get the best performance out of the electrical system.
- A solar panel system will generally help maintain truck batteries at a higher state of charge than the system without the solar panel.

- Understanding the electrical loads of the tractor is critical to making sure the right components are specified.
- The addition of a solar panel system to a tractor may both extend battery life and reduce emergency roadside assistance calls due to dead batteries. If there is a positive return on investment for the addition of a solar panel system, this is where to expect the savings.

Battery HVAC Support

With driver attraction and retention becoming a growing concern given the current driver shortage,[7] "creature comforts" for drivers have become more important than ever. This includes auxiliary climate control systems like cabin heating, ventilation, and air conditioning (HVAC), which have become more commonplace in sleeper and even day cabs in recent years because of their ability to provide climate control to the truck cabin while the truck is parked.

And while the original HVAC systems were engine-based, all truck manufacturers now offer factory-installed battery-based (a.k.a. electric) systems.

Battery HVAC systems have gained popularity thanks to increased anti-idling ordinances and noise ordinances across the country, as well as reduced maintenance and operational costs (compared to engine-based systems).

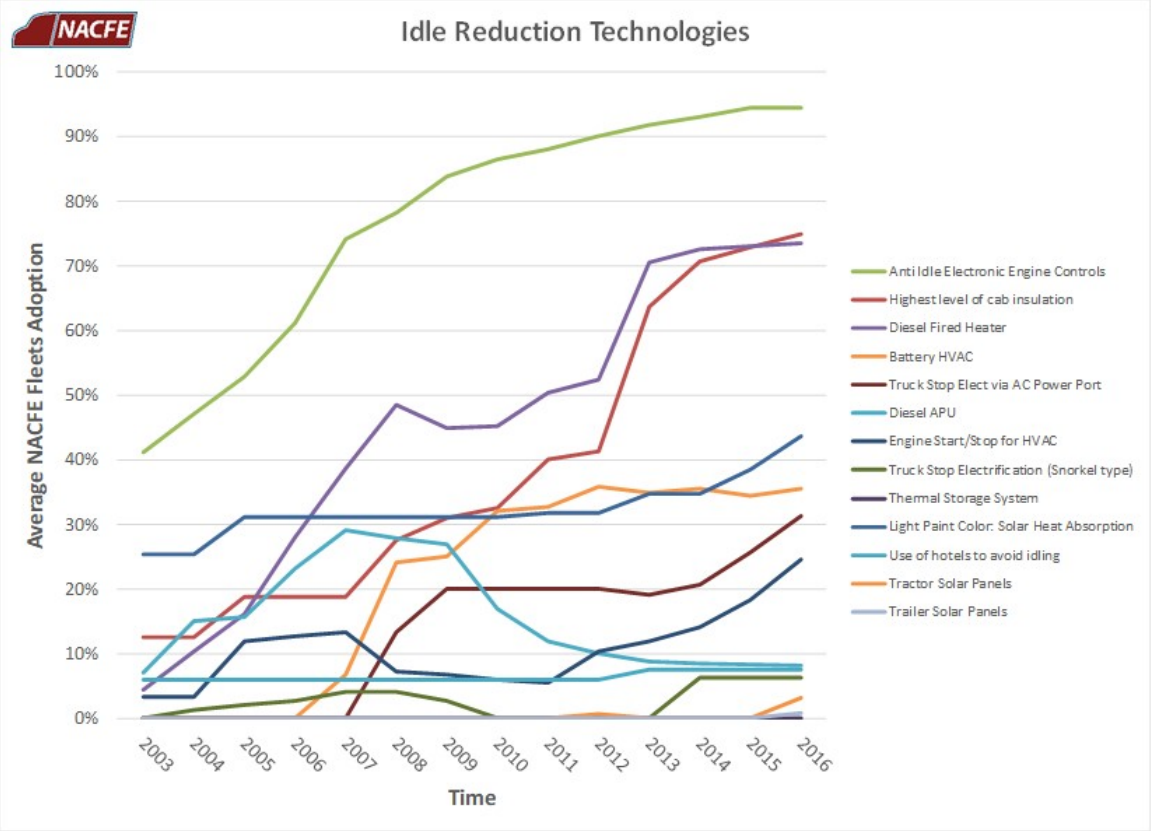


Figure 16: Historical Adoption of Idle Reduction Technologies
(Source: NACFE Annual Fleet Fuel Survey 2017)

As NACFE's 2014 Confidence Report on Idle-Reduction Solutions found, "these systems capture energy produced by the truck engine's alternator when the truck is running and store it in AGM batteries.

When the truck engine is turned off, the energy stored in the batteries can be used to power air conditioning and hotel loads and in some cases heating systems. To get the most from battery HVAC systems, drivers should pre-cool their trucks, pull curtains between the cab and sleeper and use window shades."[8]

However, historically, many battery HVAC systems have not been able to provide enough cooling capacity for long rest periods or when operating in very hot temperatures. One solution to the limited battery life has been to add an automatic start/stop system to charge the battery when the truck is stopped for extended periods of time in order to allow the system to operate longer. This technology (described in more detail later in the Complementary Technology section) maintains sleeper temperatures and battery charge without adding significant weight or componentry to the vehicle or increasing maintenance requirements.

However, the truck suddenly turning on near the end of the rest period has been known to wake drivers, disturbing the sleep the HVAC system was designed to support.

Another fleet strategy for overcoming the limited hours the battery HVAC system can function has been to use the systems in conjunction with off-board AC power/truck stop electrification. However, truck stop electrification is far from ubiquitous and therefore cannot always be relied on.

Enter solar. One of the benefits of solar is its ability to extend the runtime of battery HVAC systems. The idea here is not just to help the HVAC system make it further through the rest period before the engine has to be started, but also to reduce the load on the alternator the next driving period, resulting in a small amount of fuel savings.

This is because best practices of solar connection for battery HVAC support dictate that the solar panel should be connected via a charge controller to the main truck batteries rather than to the auxiliary batteries.[9] A battery separator is then used to connect the two battery banks, allowing either system to charge but giving priority to the truck batteries until a set voltage is achieved (i.e., 13.2). Then the main battery will move energy to the auxiliary batteries until it reaches a low voltage threshold (i.e., 12.5), at which point the process would start again. This ensures that the burden on the alternator to start the main truck batteries is kept to a minimum, thereby saving fuel. (See Figure 17 below.)

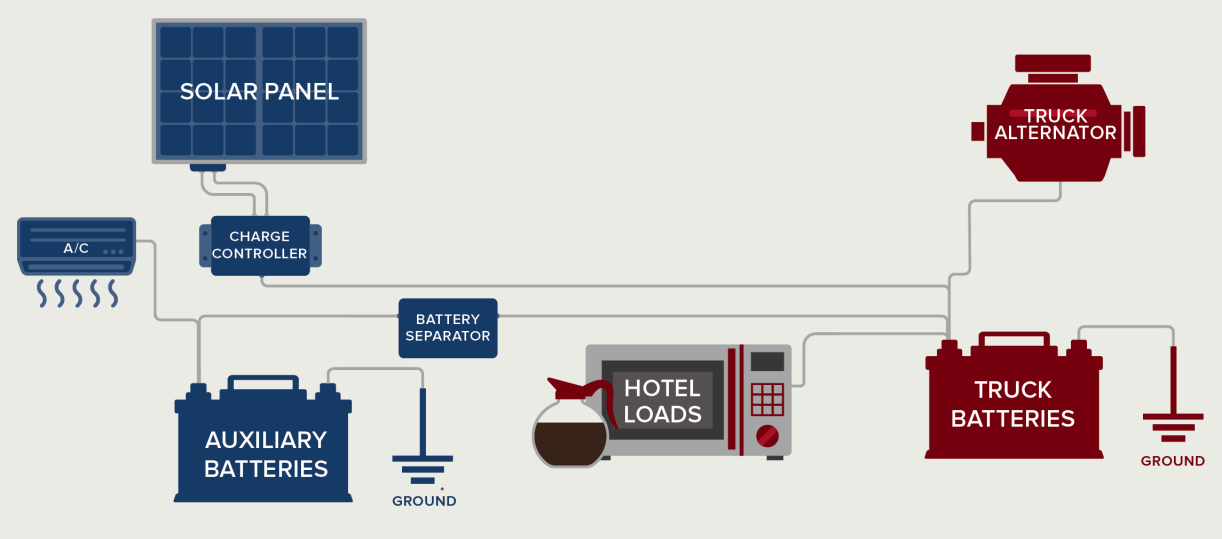


Figure 17: Solar Connected to Truck Batteries
(Source: Rocky Mountain Institute)

Benefits of solar panels for battery HVACs:

Take it from owner-operator, Henry Albert, who in July 2017, installed three 310-watt panels on the roof of his trailer. Albert explains that before the panels, after a 10-hour rest period running his battery HVAC system, his battery voltage in the morning would be approximately 12.6. But now, with the panels, Albert says the voltage is about the same when he wakes up, but by the time he's dressed, made the bed, and eaten breakfast, the voltage is up to about 14 volts, depending on his parking location and the angle of the sun.[10] [Note: Henry Albert has a unique situation in which his tractor is always connected to the same trailer. The size and location of this set up (930 watts on the trailer) may not be feasible for other drivers who don't always have the same trailer attached.]

Figure 18: Solar Panels Mounted to Trailer Roof
(Source: Team Run Smart[11])

And there are additional benefits of solar panels too. For example, Albert notes that he can now leave his truck refrigerator on rather than unloading all of his food during time off – again, another "creature comfort" that makes a driver's life just that much easier. Clark Reed, who has been testing two 220-watt panels for Nussbaum, noted similar benefits when we spoke with him. He also noted that he can now run his microwave during a rest period without having to idle his truck or worry that he would kill the truck's batteries, as he did before the solar panels. He estimates this saves him from burning approximately two gallons of diesel each weekend. While this may not seem like much fuel, this ability to refrain from idling the truck is especially nice for drivers like Reed who earn bonuses based on low idling times – a common practice in the industry.

Because drivers are happier, solar also benefits fleets with respect to driver attraction and retention. And while it's very hard to quantify this (due to the near impossibility of knowing exactly why a driver chooses to stay or leave a fleet), it was one of the major benefits noted by the majority of the fleets we spoke with who have chosen to invest in solar for tractors. Said one fleet manager we spoke with, "My drivers used to always come into my office complaining about runtime of the battery HVAC systems. But that's stopped since we bought the solar panels. And that alone makes it a worthwhile investment for me." And with signing bonuses at some fleets estimated to be between $3,000 to $7,000, or even more, and the cost of training a new driver estimated at $7,000, any improvement in retention can mean real savings to a fleet. Fleets should therefore consider factoring these reductions in recruiting, training, and retention costs into their payback calculations when evaluating solar systems. Each fleet will have to assign a value to those factors based on their knowledge of their own operations and their specific current costs for these aspects of driver management. (More info on this in the Trends and Future Perspectives section.)

Albert also expects to see an extended life from the eight batteries on his truck (four main batteries and four APU batteries) due to less frequent deep cycling. Many of the manufacturers and battery experts we spoke with confirmed that battery life – whether traditional flooded cell or AGM – could be extended dramatically – possibly even up to double the life. That can make a huge difference for fleets like those we spoke with that are on a four-year trade cycle with their trucks and tend to replace all the batteries after about two years. With solar, they may now be able to make the factory batteries last the full four years, a savings, which, alone, can go a long way toward paying back the cost of the solar system. Though it's important to note that since solar is such a new technology in the trucking industry, even the fleets that have been experimenting with it the longest haven't had it long enough to confirm or deny the real-world results with regard to battery life extension.

Another benefit of having solar connected to the truck batteries is that it potentially reduces, if not eliminates, costly roadside assistance calls for dead batteries. A properly wired and managed solar system is able to trickle charge the truck batteries, ensuring they maintain a minimum voltage, whether over a 10-hour rest period or a 34-hour restart. Just one emergency roadside call to jump-start or replace dead batteries can be as much as $600, depending on the distance from help and on-the-road pricing.—According to the fleets we surveyed, approximately one dead battery call per truck per year is average, making the payback on a solar system two years maximum just relying on this one benefit.

One additional benefit of the solar panels is their simplicity. Most panels on the market today require no additional maintenance, save perhaps cleaning them off should they become covered with snow. But other than that, drivers need not do anything differently. In fact, except for the monitoring equipment in the cab, drivers might not even know the solar panels are there.

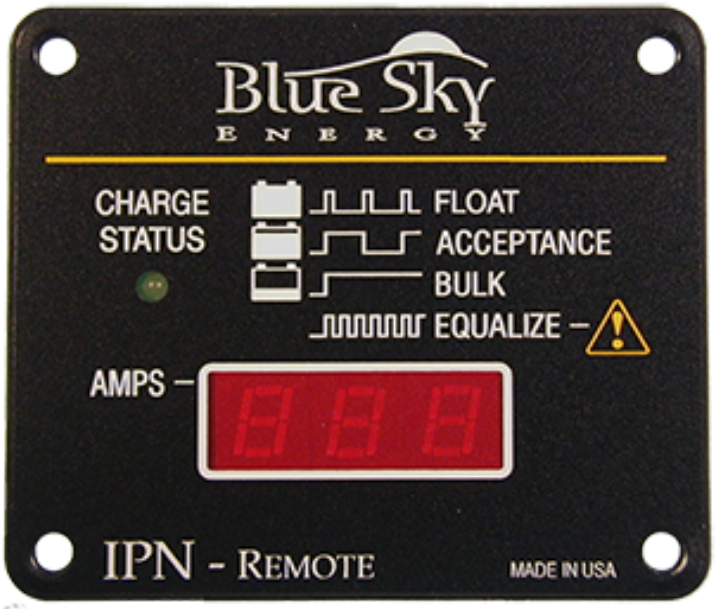


Figure 19: Example Remote in Cab Showing Charge Status
(Source: Blue Sky Energy[12])

Challenges of solar panels for battery HVACs:

While there are clearly a lot of reasons for fleets to consider investing in solar for battery HVAC support, one obvious challenge with solar technology is the initial system cost and installation. Of course, the cost of the system would be amortized over the life of the truck it is installed on. Though because tractors typically have shorter trade cycles than trailers, the investment can be spread over a fewer number of years than that for a system on a trailer (more on this later). And fleets' purchasing departments may have payback requirements for investments that are much shorter than their normal trade cycles.

It is also important to note that results may vary, depending on many of the things mentioned earlier in this report (geographic location, weather, etc.), but also depending on the fleets' drivers' schedules. For example, if a fleet's biggest concern is extending the runtime of the HVAC system, it's important to understand that runtime can be extended significantly longer when the driver's rest period includes daylight hours than it can be if that rest period is all at night. Daylight hours will be impacted by seasonality (i.e. more in the summer); however, the biggest difference will come from whether the drivers tend to drive at night and sleep during the day – something most do not right now. (See the Trends and Future Perspectives section for more information on how this may be changing.)

Another potential challenge regarding solar for HVAC support is the typical tractor trade cycle in the industry. Based on our interviews, an average trade cycle for tractors is approximately four years. However, the average warranty for a solar system is five years. Therefore, even if a fleet purchases solar for its brand-new trucks, they won't be realizing their full benefit if they trade the truck after only four years. There are a few potential scenarios here. One strategy is that fleets extend their trade cycle – an action that may be helped by solar's potential ability to extend battery life to this timeframe. Another strategy would be to try to remove the panels and re-install them on a new truck. However,

the process of applying heat and peeling off the module would likely damage the solar panel, so it's more likely that a fleet would install a new panel but transfer the rest of the kit (wiring, charge controller, etc.) across. Panels are sold separately for this purpose.

There is also the possibility that the market develops to the point that there is a residual value for solar panels on tractors. Though due to the recent nature of the technology and the relative uncertainty that surrounds it, this resale value does not seem to exist today.

Even though a fleet may not plan to use solar for its full five-year lifetime, that does not mean that it is not a good investment. As with each of the use cases we will discuss in this report, it is important that fleets first understand the challenges they're trying to address if they are to be able to accurately determine the potential for solar to address these challenges.

Hotel Load Support

Another application of solar for tractors is to help power hotel loads for sleeper tractors without a battery HVAC. As electric devices and appliances become more and more popular and more and more expected in cabs, these items can place an enormous load on the truck's electrical system. Examples of devices that contribute to hotel loads include:

- Refrigerators
- TVs
- Coffee pots
- Microwaves
- Laptop computers
- CPAP machines
- Cell phone chargers
- DVD players

These devices can draw anywhere from 10 watts for a cell phone charger up to 1,200 watts or more for a coffee maker (in brew mode) or a microwave oven.[13] In addition, the combined load of all of these devices can only be sustained for so long by the truck's batteries before the batteries reach a critically low voltage.

So again, with driver retention and creature comforts being a major issue for the industry, many fleets are looking for ways to extend the amount of time the truck's electrical system is able to support these hotel loads – at a minimum, to the full 10-hour rest period, and ideally, to the full 34-hour restart period. They also need to ensure that the truck's batteries have enough voltage at the end of these periods to start the truck. Otherwise, without technology like an automatic engine start-stop device, the hotel loads can draw down the batteries so much that they result in an emergency roadside call to replace or jump-start the batteries.

One solution to this challenge is to add additional battery packs or APUs to the truck. However, additional batteries can be quite costly, as well as heavy. While the majority of trucks on the road today cube out before they weight out, no one wants to be hauling more non-payload weight than they have to.

Another potential solution is to invest in an automatic engine start-stop system. Similar to what was mentioned about this technology in the HVAC use case, these devices maintain hotel loads and battery charges without adding significant weight to the vehicle or increasing maintenance requirements. However, it will likely increase idle time, and from a creature comfort standpoint, many drivers complain of being woken in the early hours of the morning when the device starts the truck engine.

Another solution to this challenge is to mount a solar panel on the tractor to help keep the truck batteries charged. As long as the sun is shining, the solar panel can provide a small but constant current to the batteries, helping ensure there is enough power to not only support the hotel loads but also to keep the truck batteries charged.

Solar for hotel load support is specified and installed in much the same way as solar for HVAC support, except that it's sized for the specific hotel loads in the cab and is connected to the main truck starter batteries rather than to both the starter batteries and the HVAC batteries.

Benefits of solar panels for hotel loads:

- The extra power available from the solar panel can augment that coming from the truck batteries and ultimately maintain the batteries at a higher average state of charge.
- Maintaining the batteries at a higher average state of charge will extend battery life compared to a system with no solar panel.
- Maintaining the batteries at a higher state of charge should also minimize the number of emergency roadside calls to replace or jump-start dead batteries or incidents where the vehicle must be idled just to charge the batteries.
- Maintaining the batteries at a higher average state of charge will allow the batteries to support hotel loads for longer periods of time, thereby increasing driver comfort. For example, as we mentioned in the previous section on HVAC support, tractor-mounted solar now means drivers do not need to empty out and turn off their in-cab refrigerator every time they're home for a 34-hour restart. This sort of added creature comfort can lead to reduced costs for driver attraction and retention. (See the Trends and Future Perspectives section for more information.)
- There is a fuel consumption benefit from not having to idle the engine to power hotel loads. Idling the engine for this purpose will consume about 1 gallon/hour of fuel. Generally, we think this benefit is quite small.

Challenges of solar panels for hotel loads:

- Initial system cost and installation. Of course, the cost of this system would be amortized over the life of the tractor it is installed on. Though tractors typically have shorter trade cycles than trailers, so the investment can be spread over a fewer number of years than the trailer use cases described later in this report.
- There is some small maintenance cost associated with installing solar panels on top of a tractor. Occasional cleaning will improve performance. Electrical performance needs to be checked periodically to assure the system is working properly. Perhaps a few system checks should be integrated in the normal battery PM program for the vehicle.
- It is unlikely that the solar panel installation will significantly change the residual value of the equipment, so this should not be included in ROI calculations.
- Current installation techniques do not allow for easy removal of solar panels from a piece of equipment so that they can be reinstalled on another vehicle.

- Many fleets do not have a good handle on battery replacement frequency/costs or costs for emergency roadside calls related to dead truck batteries. This complicates estimating the improvement in maintenance costs associated with installing the solar panel systems.

Trailer Applications

Trailers have traditionally been powered by the seven-way connector between the tractor and the trailer defined by the SAE J560 standard. This standard was originally defined to power brakes and running lights, blinkers, etc. on the trailer with the source of the power coming from the tractor. However, as trailers have evolved, a number of other electrical loads have been added to trailers that make the electrical system significantly more complicated. Examples of these include:

- Trailer ABS controls and lamps
- Liftgates
- Refrigeration units
- Telematics systems for location and cargo monitoring
- Electric pallet jacks
- Interior trailer lights

Some of these loads have additional demands that require that batteries, or another source of electrical power, be added to the trailer. If the current needed for an item, like in the case of a liftgate, is higher than the wires from the tractor can carry safely, then batteries must be used to power them. In addition, power is frequently necessary for these items when the trailer is disconnected from the tractor. Examples of this include operating refrigeration units and trailer telematics systems. Since the equipment on the trailer has a wide variety of demands, the electrical system installed on the trailer must be specified to ensure that adequate power is available to perform all the functions of the vehicle.

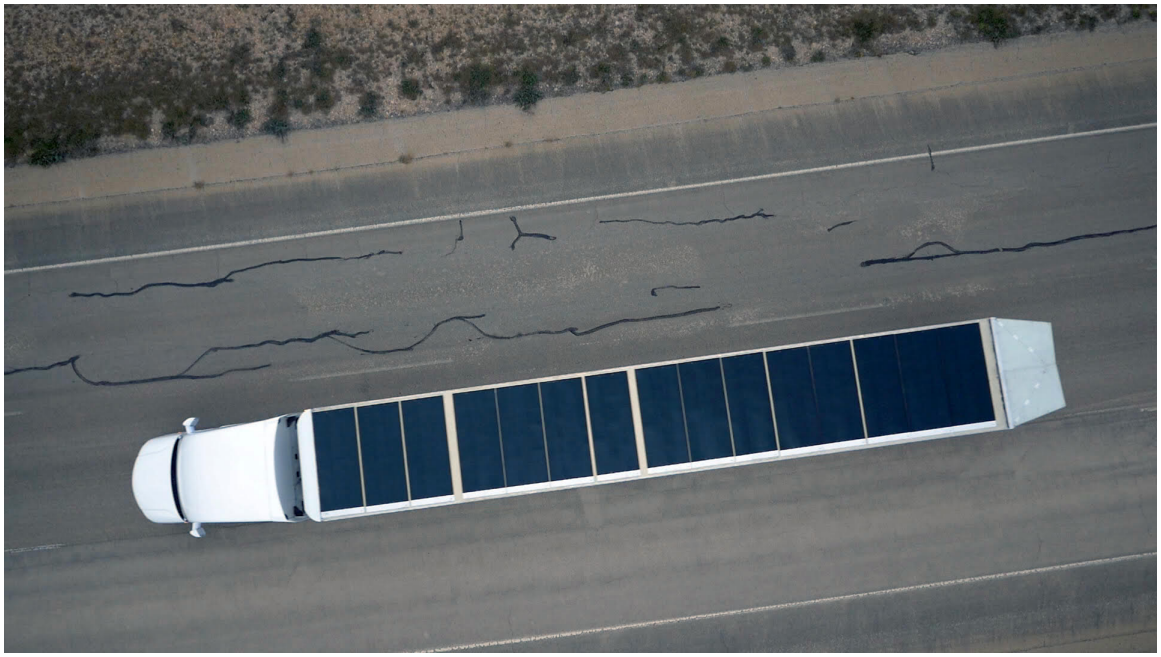


Figure 20: Solar panels mounted to the trailer
(Photos courtesy of Freightliner Trucks)

Once there are batteries on the trailer that can be discharged, then they must be recharged from the alternator on the tractor engine or the alternator on the refrigeration unit if that trailer is so equipped. In some cases, the wiring from the tractor going through the SAE J560 connector is not of sufficient size to carry the current to both charge the trailer batteries as well as drive all the electrical loads that the trailer has. In these cases, an additional cable from the tractor to the trailer is added (called a stinger) to ensure sufficient current is available to both charge the trailer batteries as well as take care of the electrical loads.

An issue that frequently occurs on trailers with liftgates and other loads is that the voltage drop caused by electrical resistance in the long wire lengths and connections is high enough that sufficient current is not available to the trailer batteries to charge them at a reasonably fast rate. When this happens, the batteries can run out of capacity before the end of a shift and result in the need for emergency roadside assistance to replace or jump-start the batteries.

There are multiple solutions to this kind of problem. One that has been employed for some years is to put a voltage converter near the trailer seven-way connector that will boost the voltage to a higher level and allow sufficient current to flow to the batteries for charging. Of course, adding an additional battery is also an option, but that incurs an additional cost, and wiring issues must be fixed or the same problem can recur.

Another solution to this dilemma is to mount a solar panel and charge converter on the trailer to supplement the current that is coming from the tractor for battery charging. As long as the sun is shining, the solar panel can provide a small but constant current to the trailer batteries that will supplement any power that is coming from the tractor or refrigeration unit alternator.

Key items to keep in mind when specifying a solar panel as part of a solution to trailer electrical demands include:

- A solar panel system generally cannot supply the current necessary to drive large trailer loads like liftgates or starting the refrigeration unit engine. However, it may have enough current available to power small loads like trailer interior lighting or telematics systems when the system is active.
- The solar panel system will only supply additional power during the day when the panel is exposed to significant light. If the panel is heavily shaded due to loading docks, tall buildings, or heavy clouds, the output will be less.
- Battery and wiring specifications should not change as a result of installing a solar panel system to supplement electrical power. This would include the use of stinger cables if they are required.
- Correct wire sizes, good connections, and good electrical maintenance practices are still required to get the best performance out of the electrical system.
- A solar panel system will generally help maintain trailer batteries at a higher state of charge than the system without the solar panel.
- Understanding the duty cycle of the trailer electrical system for a specific operation is critical to making sure the right components are specified to satisfy the electrical loads.
- The addition of a solar panel system to a trailer may both extend battery life and reduce emergency roadside calls due to dead batteries. If there is a positive return on investment for the addition of a solar panel system, this is where to expect the savings.

- It may be possible to eliminate a trailer voltage converter if a solar panel system is implemented. We strongly encourage some testing beforehand to validate whether that would be a good choice during the trailer equipment specification process.

Liftgate Support

This use case is to help evaluate the benefits of a solar panel system on a trailer or box truck that is equipped with a liftgate system for loading and unloading. In this case, the assumption is that the trailer or box is not equipped with a refrigeration unit so the power to recharge the liftgate batteries would come from the tractor engine electrical system. If a solar panel is included, we will assume that it would mount on the top flat surface of the trailer or box.

Figure 21: Solar panels mounted to the trailer to power a liftgate system
(Source: Go Power![14])

Liftgates come in many configurations and weight capacities, depending on their intended use. In addition, liftgates get used in a variety of different ways both in frequency of use and typical weight carried. Some cities have no idle requirements where delivery trucks are not allowed to idle while freight is being loaded or unloaded. Therefore, assuming no shore power, the liftgate must operate only on battery power since it is getting no help from the engine alternator. To truly evaluate the benefit that a solar panel system might give a particular liftgate configuration would require analyzing the factors above plus understanding the fleet history of similar applications in the past.

A typical liftgate motor might use anywhere from 75 to 150 amps when it is operating. Fortunately, the cycle of the liftgate is relatively short or the batteries would be discharged quite quickly. We suggest talking to the liftgate manufacturer to get details on the power required to operate the liftgate. This information combined with a usage profile will help put boundaries around the power required to

complete a pickup and delivery shift with the vehicle. Given this information, selection of number of batteries, cable sizing, etc. can also be made.

Some additional information that is helpful to know is the battery replacement rate and cost for the trailer batteries. Knowing the number of emergency roadside calls per vehicle per year for trailer battery replacement is also helpful. This could aid in understanding if the system has been underspecified in the past.

Figure 22 below is an example of a truck and trailer electrical system where the trailer is equipped with a liftgate:

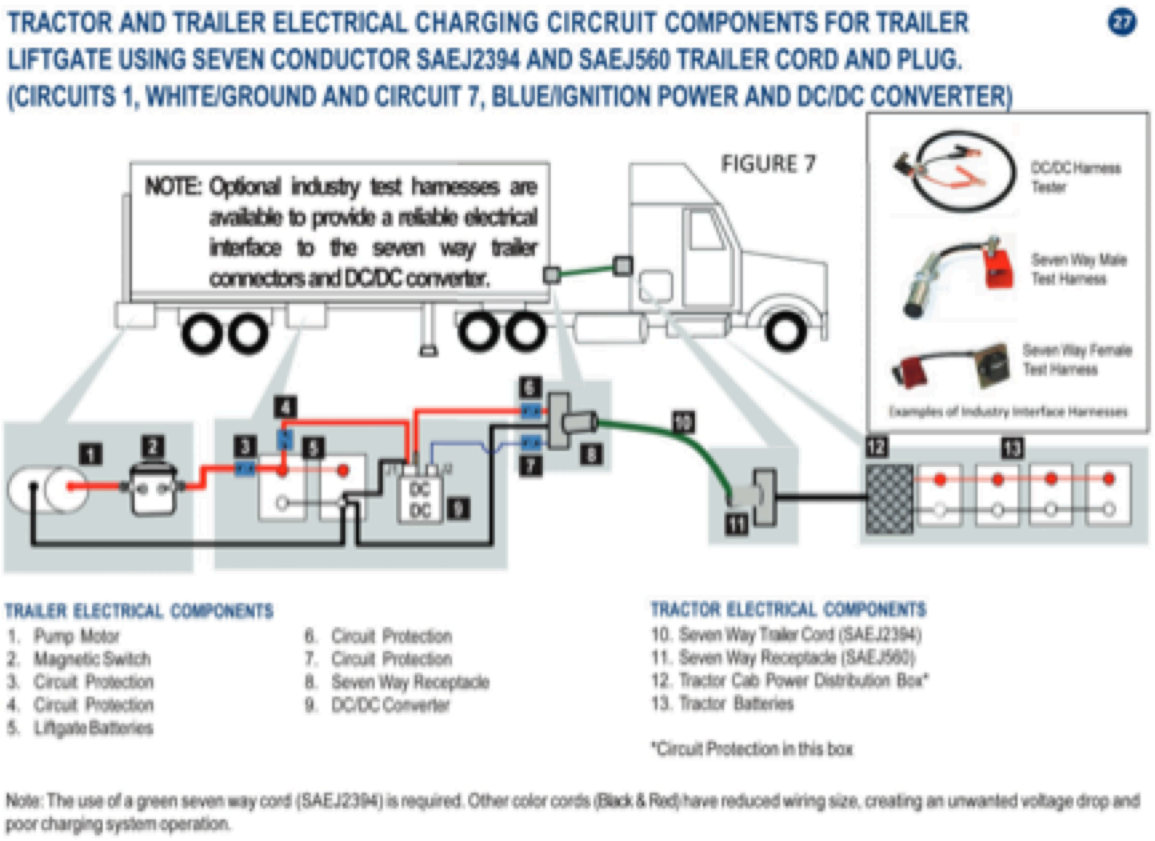


Figure 22: Electrical Charging Circuit Components for Liftgate
(Source: Recommended Practice 179: Liftgate Charging & Pump Motor Diagnostic & Maintenance Guidelines, Technology & Maintenance Council (TMC) of the American Trucking Associations)
[To obtain a full copy of the Recommended Practices, please visit tmc.trucking.org. The manual can be purchased separately or is one benefit of membership in TMC if you choose to join.]

Some of the basics of evaluating the value of a solar panel installation that we discussed earlier in the report still apply to this use case. If you know the panel rating, you can use the PVWatts calculator described earlier to evaluate what power you can expect to get in a year from the solar panel. Of course, this power will augment the electrical power that comes from the engine alternator to charge the liftgate batteries.

Benefits of solar panels for liftgates:

- The extra power available from the solar panel can augment that coming from the engine alternator and ultimately maintain the liftgate batteries at a higher average state of charge.
- Maintaining the batteries at a higher average state of charge will extend battery life compared to a system with no solar panel.
- Maintaining the batteries at a higher state of charge should also minimize the number of emergency roadside calls to replace or jump-start dead batteries or incidents where the vehicle must be idled just to charge the batteries.
- If a trailer with a liftgate system frequently spends extended times disconnected from a tractor, a solar panel can help maintain the battery state of charge for the next trailer use.
- The only fuel consumption benefit of using a solar panel is if idling the engine to charge the trailer batteries or operate the lift gate can be avoided. Idling the engine for this purpose will consume about 1 gallon/hour of fuel. Generally, we think this benefit is quite small.
- A solar panel may make it possible to eliminate using a DC-DC voltage converter to boost the voltage to the trailer batteries. Generally, testing would be necessary to make this determination.

Challenges of solar panels for liftgates:

- Initial system cost and installation. Of course, the cost of this system would be amortized over the life of the trailer or truck it is installed on. Trailers typically have longer trade cycles than tractors, so the investment can be spread over a greater number of years.
- Solar panel systems, since they produce power only during daylight hours, are a system to augment the electrical equipment that drives the liftgate system. The systems should not change the battery, wiring size and connection specifications of the liftgate system.
- If deliveries occur mainly at night when the solar panel is not active, the main benefit of the solar panel is to assure batteries reach the highest state of charge possible before the next use of the vehicle.
- There is some small maintenance cost associated with installing solar panels on top of a trailer or box. Occasional cleaning will improve the performance. Electrical performance needs to be checked periodically to assure the system is working properly. Perhaps a few system checks should be integrated in the normal battery PM program for the vehicle.
- It is unlikely that the solar panel installation will significantly change the residual value of the equipment, so this should not be included in ROI calculations.
- Current installation techniques do not allow for easy removal of solar panels from a piece of equipment so they can be reinstalled on another vehicle.
- Many fleets do not have a good handle on battery replacement frequency/costs or costs for emergency roadside calls related to dead trailer batteries. This complicates estimating the improvement in maintenance costs associated with installing the solar panel systems.

Refrigeration and Telematics Support

For some operations, trailers are equipped with Transport Refrigeration Units (TRUs). Today's TRUs generally have a battery dedicated to starting the small diesel engine that drives the refrigerant compressor when needed to maintain the cargo at the proper temperatures. The diesel engine in most

units has an alternator to make sure the battery stays charged and can supply power to other trailer mounted devices like telematics systems.

However, these batteries can become discharged for a number of reasons. The trailer may sit unattended for a long period of time with the refrigeration unit not running with small current draws including:

- Trailer location and telematics systems
- Trailer interior lights inadvertently left on
- Trailer cargo or door sensors that draw small amounts of current

More recent refrigeration units have features that will notify the vehicle operator or the home office if the battery is becoming discharged to the point that it will not start the engine. Some units can even be started remotely to charge the battery if it is needed. However, many delivery yards and locations do not currently allow the remote starting of refrigeration units due to safety concerns, so remote starting the unit to charge the battery is not always an option.

Refrigeration unit manufacturers and aftermarket suppliers are now selling small solar panels that can be mounted on the unit or on top of the trailer to help maintain the state of charge of the battery, especially when the unit is turned off. They offer a number of sizes to choose from, depending on the application and various loads on the trailer electrical system in addition to just starting the refrigeration unit engine. These solar panels are essentially automatic trickle chargers that supply a small current to the battery any time the sun is shining.

The payback for this type of solar system is really isolated to extending the life of the refrigeration unit battery and avoiding emergency roadside calls to jump-start or replace a battery. If you can identify the costs of battery replacements and emergency roadside calls separately, then the ROI calculation should be pretty straightforward.

Some companies are now marketing all-electric, solar-based refrigeration systems. While this recent development is exciting, much more testing needs to be done. And it should be noted that these systems require many solar panels and many large batteries, which are primarily charged via electric shore power when not in use.

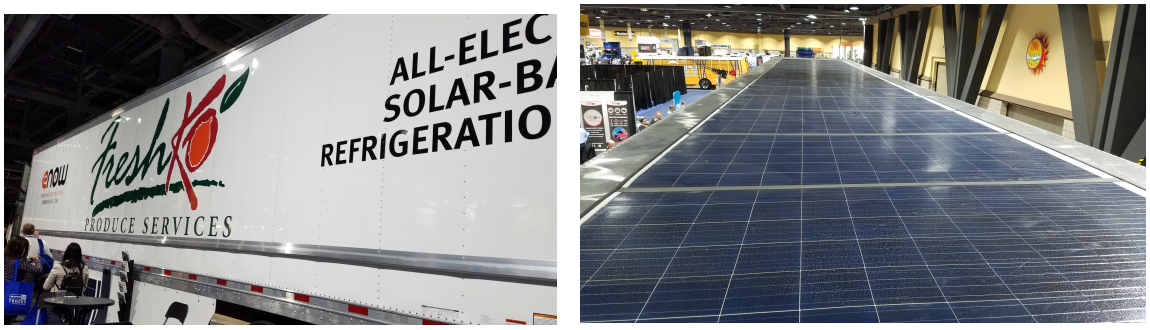


Figure 23: eNow's all-electric, solar-based refrigeration system for a 53-foot tractor-trailer was unveiled at the ACT Conference in Long Beach, CA, May 2018
(Photo Credit: Jessie Lund)

If the trailer is equipped with only a location and/or telematics system, the discussion is quite similar to the above. Some telematics systems get their power from either the tractor batteries or the

refrigeration unit battery if it is so equipped. The telematics systems generally have small batteries that can maintain the operation of the unit for a few days to a few weeks without being charged. A small solar panel that is designed to keep the telematics system battery charged is ideal to guarantee that the trailer can always be located. Some more recent telematics systems are self-powered. In these cases, a small solar panel is required to keep the system battery charged at all times. These panels are likely to be built right into the unit as opposed to a separate device.

Figure 24: Solar-powered telematics system
(Photo Credit: Schaller LLC)

In summary, if a trailer has small electrical loads like a telematics system, then a small solar panel that ensures that the system will have virtually 100% availability for trailer location and other related data makes a great deal of sense. The small solar panels can easily keep up with the demands placed on the batteries of these systems, even when the light is intermittent or less than ideal. For larger electrical loads like reefer engine starting, liftgates, electric pallet jacks, etc., then solar panels may well make sense to help extend battery life and lower maintenance costs. Please keep in mind that the solar panels will not provide near the full amount of power necessary to run these devices, but their supplementary power can be quite helpful to the overall operation of the trailer. Proper specification of electrical components, cables and connectors is still necessary to ensure the system will provide the type of performance and life expected of these systems.

Benefits of solar panels for telematics and refrigeration units:

- A properly sized solar panel can provide additional current and battery charging capacity to help manage these devices.
- The solar panel system should help maintain the batteries at a higher average state of charge than a system that is not equipped with solar panels. This should extend battery life.
- The solar panel system should reduce the number of emergency roadside calls to jump-start and/or replace batteries of a refrigeration unit system.
- If the trailer is only equipped with a trailer telematics, a small solar panel to maintain battery charge for extended periods without being attached to a tractor is highly beneficial.

Challenges of solar panels for telematics and refrigeration units:

- Initial system cost and installation. Of course, the cost of this system would be amortized over the life of the trailer or truck it is installed on. Trailers typically have longer trade cycles than tractors, so the investment can be spread over a larger number of years.
- There is some small maintenance cost associated with installing solar panels on top of a trailer or box. Occasional cleaning will improve the performance. Electrical performance needs to be checked periodically to assure the system is working properly. Perhaps a few system checks should be integrated in the normal battery PM program for the vehicle.
- It is unlikely that the solar panel installation will significantly change the residual value of the equipment, so this should not be included in ROI calculations.
- Current installation techniques do not allow for easy removal of solar panels from a piece of equipment so they can be reinstalled on another vehicle.
- Many fleets do not have a good handle on battery replacement frequency/costs or costs for emergency roadside calls related to dead trailer batteries. This complicates estimating the improvement in maintenance costs associated with installing the solar panel systems.

Best Practices

The following is a list of pointers to consider when evaluating if solar panels are a good investment for your fleet. We have split the suggestions into considerations for tractors and trailers.

Tractors

Purchase decision:

- We are providing a model with a variety of inputs to help estimate the return on investment of specifying solar panels on tractors.
- NACFE has not been able to validate with fleets that have implemented solar panels on tractors whether they have realized these savings. A major motivator in these fleets has been the "soft" benefits of increased driver satisfaction and retention.
- The largest portion of financial savings associated with implementing solar panels on tractors is related to increased battery life and avoiding some emergency roadside calls for dead batteries.
    - Key inputs include cost of battery replacements (both individual and in sets) and the cost of emergency roadside calls for dead batteries. We have found that many fleets do not account for these expenses in a way that they can be estimated easily. However, the approximate numbers can often be estimated by looking at the costs of batteries at a fleet level and analyzing a sample of breakdown instances to determine if they are battery-related.
    - Estimating the savings due to "soft" benefits of driver satisfaction and retention is very difficult. If the tractors are equipped with battery HVAC systems, being able to extend the time of operation without running the engine has more value to drivers than just the idle reduction fuel savings. In addition, the cost of recruiting even one additional driver is likely to be significant to the fleet. We have put a modest amount of savings into the model for this factor, but each fleet will have to ascertain if these are factors to incorporate in their individual analysis.

- Potential fuel savings associated with solar panels really revolve around two items:
    - Savings associated with reduced idling due to extended run time of battery HVAC systems. This could be in either a 10-hour rest period or a 34-hour reset where the driver is in the cab. Keep in mind that a 300-Watt tractor solar panel average output per day is worth approximately the energy stored in one Group 31 battery. Of course, this average output will vary based upon geographic location and cloud cover. The timing of the rest periods is also important relative to the amount of sunlight expected during the period.
        - If the tractor does not have a battery HVAC, then the above discussion does not apply.
    - Savings associated with removing load from the alternator during normal tractor-trailer operation. These savings, though not negligible, are generally very small. The average annual fuel savings from this factor based on a 300 W panel would most likely be less than 0.1%.
- Tractor trade cycle is a key factor in determining the return on investment of solar panels. Solar panel life is generally longer than the typical fleet trade cycle and it is unlikely that having the solar panel on the vehicle will increase residual value. The panels cannot easily be moved to a new tractor due to the cement used to glue them to the tractor roof – removing them would be labor intensive and damage both the panel and the roof of the tractor.
- Consider that there may be a loss in branding space or sleeper skylights when panels are added to the fairings.
- Some fairing designs have curvature in two different directions (cylinder shape vs. sphere shape). If it curves in two directions, several smaller panels will make for a cleaner installation vs. a single large panel.

Managing tractor solar panels once purchased:

- Decide what key measures you are going to be using to evaluate/monitor the investment.
- Look at what things might need to be added to the PM program related to the panels.
    - Are the panels working?
    - Do they need to be cleaned periodically?
    - Does the manufacturer specify a procedure or cleaning agent?
    - Does your battery PM program need to change (interval, changing one battery vs. entire set)?
- Understand and comply with manufacturer warranty requirements.
- Do items need to be added to the driver feedback system related to the solar panels or is informal feedback sufficient?

Trailers

Purchase decision:

- There are two to three trailers for every tractor in most fleets, so many trailers experience a significant amount of time when they are not hooked up to a tractor. Therefore, any batteries installed on the trailer don't always have a ready source of power for charging.
- The trailer power requirements need to be carefully evaluated to assure proper function during operation. This includes items like liftgates, refrigeration units, telematics, lighting, pallet jack

charging, etc. Although each of the above devices requires trailer-mounted batteries to operate, they all have different electrical current and charging demands.

- Frequently, these devices are combined on a given trailer, so all electrical demands need to be considered when choosing wiring configuration and battery capacities.
- Solar panel systems should not be expected to compensate for equipment specification errors or poor maintenance of wiring and connections.
- Solar panel sizing should be determined by the duty cycle that the trailer electrical system is likely to encounter. This can be evaluated by temporarily putting a data logging system on a trailer for a period of time to determine the true loads that the batteries will typically see. Many suppliers have these devices that can be used for short periods to evaluate needs.
- Use the NREL PVWatts® tool to evaluate the approximate expected output of a solar panel for your location compared to the system demands. Frequently the optimum solar panel size is significantly less than the total average power output the trailer needs. The rest of the power to operate the trailer and charge the batteries will come from the tractor or refrigeration unit alternator.
- The main function of the solar panel is to maintain the trailer batteries at a higher average state of charge vs. just charging with the tractor or refrigeration unit alternator.
- Savings of implementing solar panels are primarily associated with increasing battery life and reducing emergency roadside calls to jump-start or fix dead batteries.
- We have found that many fleets do not account for battery replacement or emergency roadside call expenses in a way that they can be estimated easily. However, the approximate number can often be estimated by looking at the costs of batteries at a fleet level and analyzing a sample of breakdown instances to determine if they are battery related.
- Determining a return on investment for a solar panel system is a simple calculation looking at the potential savings in battery replacement costs and emergency roadside call expenses vs. the total system installation costs.
- The average trade cycle in most fleets for trailers is typically longer than that for tractors. Given this, the investment for solar panels can be spread over a larger number of years, making the business case more viable.
- If the trailer only has a telematics system on it without additional equipment, then a solar panel to keep that battery charged is generally an excellent investment. On some newer systems, the telematics is not even hooked into the truck electrical system, so in these cases a solar panel is required to keep the battery charged.
- With trailers equipped with liftgates and other electrical equipment, the business case depends on potential savings vs. the cost of implementing the solar system.

Managing trailer solar panels once purchased:

- Decide what key measures are going to be used to evaluate/monitor the investment.
- Look at what things might need to be added to the PM program related to the panels.
    - Are the panels working?
    - Do they need to be cleaned periodically?
    - Does the manufacturer specify a procedure or cleaning agent?
    - Does the battery PM program need to change (interval, changing one battery vs. entire set)?
- Understand and comply with manufacturer warranty requirements.

Complementary Technologies

As mentioned throughout this report, solar panels make sense for fleets, not as a stand-alone technology, but rather as a complement to other technologies that more and more fleets are choosing to invest in. The most common ones noted by solution manufactures, fleets, and others are:

- Battery HVACs
- Automatic Engine Start-Stop Systems
- Electric Trucks

After a fleet has identified one of these technologies as the best option to meet its specific needs and goals, solar systems should be evaluated for their potential to complement them.

Battery HVACs

As discussed in the Battery HVAC section, fleets that choose to invest in this technology (usually to keep drivers comfortable and happy) often run into issues with the system not lasting the entire night and/or restart period without completely draining the batteries. While one solution to this issue is an automatic engine start/stop system, another is a solar system. (Note that fleets should invest in one system or the other, not both.) Rather than starting/stopping the engine at key points to ensure the batteries stay charged (and thereby increasing idling time and/or waking the driver), the solar system is able to trickle charge the batteries during daylight hours to ensure the truck is always able to start. This trickle charging also reduces deep cycling of both the truck and HVAC batteries, thereby extending their lives. For more information on the complementary benefits of solar for battery HVAC systems, please see the Battery HVAC Support section earlier in this report. These two systems are most often mutually exclusive in that no fleets will not likely have both a start/stop system and solar panels on the same truck.

Electric Trucks

As the trucking industry begins to embrace electrification, we expect electrical loads onboard to increase. This trend may increase the need for solar to help support the truck's electrical loads. For more information on battery electric commercial vehicles, see NACFE's recent Guidance Report—*Electric Trucks – Where They Makes Sense*.

Perspectives on Future Systems

Trends

One thing that became very clear to the study team in the course of compiling this Confidence Report is that there are some major trends driving and influencing the field of solar technologies as applied to trucks.

Driver Attraction and Retention

With the economy growing stronger and baby boomers retiring, the driver shortage has regained its status as the trucking industry's most pressing concern for the first time since 2006. [15] However, technologies like solar, which support driver comfort (for tractor use cases), can help make the profession more attractive and aid in driver attraction and retention – especially at a time when drivers are needed to power more electrical devices than ever. This improvement in driver attraction and

retention presents a large opportunity for cost savings. With signing bonuses at some fleets estimated to be between $3,000 and $7,000, and the cost of training a new driver estimated at $7,000, any improvement in retention can mean real savings to a fleet.

In addition, outfitting tractor-trailers with sustainable technology like solar panels could make the profession more appealing to Millennials, who are expected to make up half the USUSUS workforce by 2020.[16] Three-quarters (76 percent) of Millennials consider a company's social and environmental commitments when deciding where to work. And nearly two-thirds (64 percent) won't take a job if a potential employer doesn't have strong corporate social responsibility (CSR) practices. [17] So how does solar fit in here? With regard to renewable energy, 31 percent of Millennials in "mature markets" like the USUSUS say they care about issues like climate change and protecting the environment, though only 10 to 13 percent feel their organizations are doing something to address these challenges. [18] This is a clear opportunity for improvement for companies looking to retain talent, given that Millennials have a more positive employee sentiment and intend to stay longer with those employers that engage with social and environmental issues like these. Therefore, sustainable business practices like investing in solar power, if communicated to current and potential employees, may encourage the next generation of drivers to sign on with a certain fleet and help retain those drivers once hired.

For the purposes of the payback model, we've assumed an average savings of $100 per truck per year in attraction/retention, though fleets can play with this number in the model to match their assumptions.

Lack of Data

The study team was quite surprised to learn that none of the fleets we spoke with that had invested in solar (whether for testing or full-scale deployment) were tracking the additional power output of the panels or their impact on battery life extension, though both of these were frequently mentioned as benefits of the technology. There seems to be a high amount of faith and a very low amount of concrete evidence with regard to the value of the panels. This may be due to the fact that solar is such a new technology as applied to the trucking industry, that even the fleets that have been experimenting with it the longest haven't had it long enough to confirm or deny the real-world results, especially regarding things like battery life extension. This lack of data may also be due to the fact that the most cited benefits of solar technology by fleets are creature comfort and driver retention – things for which it is extremely difficult to measure the return on investment.

Policies

Hours of Service Regulations

As mentioned in earlier sections, the effectiveness of solar panels can vary quite dramatically depending on the drivers' schedules. While it may seem obvious, the solar panels can only produce power when exposed to sunlight. And while daylight hours will be impacted by seasonality (i.e. more in the summer), the biggest difference will come from whether drivers tend to drive at night and sleep during the day – something most do not right now. Though there is speculation that this schedule may become more popular again once the 34-hour restart rules are formally rolled back. The rollback is expected to take place after a USUSUS Department of Transportation (DOT) study concluded in March 2017 that truckers operating under 2013 hours of service rules – requiring two 1 a.m. to 5 a.m. periods be included in the restart – showed no greater safety levels than those not abiding by the rules.[19]

Solar Investment Tax Credit (ITC)

The solar Investment Tax Credit (ITC), a 30 percent tax credit for solar systems, is one of the most important federal policy mechanisms to support the deployment of solar energy in the United States and has provided industry stability and growth since its initial passage in 2006.[20] Installations surged in 2016 ahead of a potential drop down of the ITC, but an extension in late 2015 has created federal policy stability through 2021.

Solar systems on commercial properties (such as trucks) are eligible for the credit under Section 48 of the ITC, though it's important to note that the ITC applies only to individuals and companies paying income tax in the United States. Many solar providers in the trucking industry, can help provide fleets with basic information on the ITC, including how it may reduce the cost of their investment, however any fleets interesting in taking advantage of the credit should speak with their accountants to fully understand its implications on their tax liability. All solar providers we spoke with insist on a quick payback period (<2 years) for solar systems, with or without the ITC.

The ITC is scheduled to step down to 26% in 2020 and 22% in 2021. After 2021, the residential credit will drop to zero while the commercial and utility credit will drop to a permanent 10%. Therefore, fleets interested in investing in solar and taking advantage of the ITC should plan to do so sooner rather than later.

Solar Tariffs

In early 2018, the US International Trade Commission (ITC) imposed 30 percent tariffs on imported solar cells and panels. Solar experts estimate that the tariff will increase solar prices by 10 to 12 cents per watt.[21] This increase in price is expected to slow the growth of the solar industry at large, but only minimally. However, a majority of US voters oppose these solar tariffs[22], and there's a chance that the tariffs may be repealed.[23]

Perspectives on Future Systems

It was also apparent to the study team that the field of solar as applied to trucks is a constantly and rapidly evolving one. The options discussed within this report are currently available on the market today and seem to have a good track record of functionality, though they may be more or less economical depending on the specifics of a fleet's operations. However, the future may hold some combination of the following ideas with regard to solar:

Improved technologies

As discussed earlier in this report, solar panel technology has dramatically improved in terms of both efficiency and price over the last decade. And while we expect continued improvements in cell technology, we also expect dramatic improvements in battery technology in the coming years. Being driven primarily by the electric vehicle industry, battery prices have recently come down dramatically, and we expect this trend to continue. Improved battery prices and weights may eventually reduce the need for solar to help support the truck's electrical loads.

Electrification

As the trucking industry begins to embrace electrification, we expect electrical loads onboard to increase. This trend may increase the need for solar to help support the truck's electrical loads. For more information on battery electric commercial vehicles, see NACFE's recent Guidance Report—*Electric Trucks – Where They Makes Sense*.

Trade Cycles

With the potential for solar to increase battery life (and therefore decrease procurement and maintenance costs), fleets may feel comfortable extending their trade cycle for tractors. They may also want to extend their trade cycle in order to realize the full value of the solar panels, which are often warrantied for five years, longer than most current trade cycles. Though if a secondhand market develops around solar for trucks, fleets may be able to capture the residual value of the panels in their resale price instead.

Conclusions and Confidence Rating

Confidence Rating

The below matrix (Figure 25) summarizes the findings of the desk research, interviews, and workshops conducted for this Confidence Report by indicating how confident the NACFE study team is in the investment case for solar systems for various trucking applications.

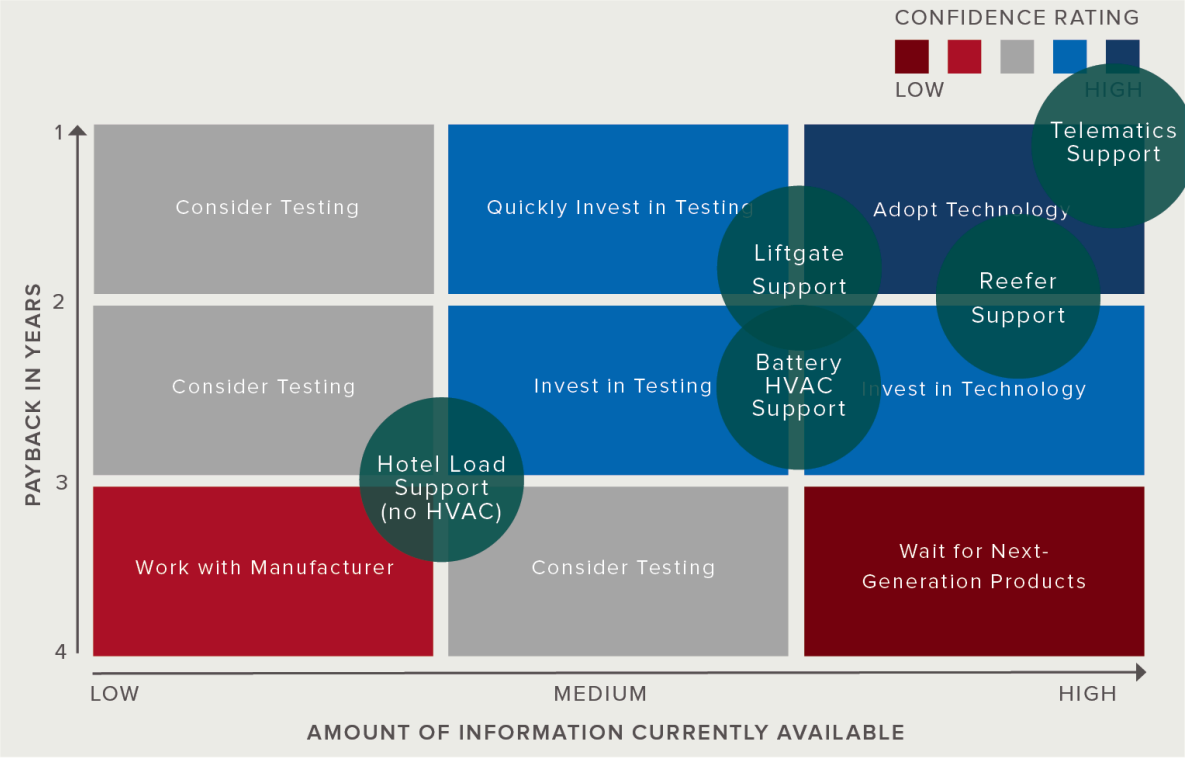


Figure 25: Confidence Matrix for Solar

Key Conclusions

After years of development globally and in North America, the status of solar systems for trucking today and for the future can be summarized in four key messages:

1. Solar technology for trucks has progressed to the point where the panels on the market are flexible, thin, easily installed and reliable. Some applications, like supporting the batteries for trailer telematics systems, are an excellent application of the technology and should be strongly considered for future purchases. For other applications of solar technology, the cost versus benefits should be evaluated to see if it makes sense in the specific application.

2. Fuel savings are generally a very small part of the overall benefit that comes from a solar panel installation.
3. Solar panel installations need to be sized appropriately for their intended application. For example, the size of a solar panel to support to support a battery HVAC system on a tractor might be limited by the area available on the tractor fairing, whereas a solar panel to support a refrigeration unit only needs to be large enough to provide a small trickle charge to the refrigeration unit starting battery.
4. We don't yet have hard evidence from fleets that the payback from the investment in solar panels matches that claimed by the solar panel suppliers. We have verified that the benefits fall in several categories with the biggest benefits being from extending battery life and avoiding emergency roadside assistance for dead batteries. Many fleet users are happy with the investment they made and intend to continue to use solar panels in the future.

Given these conclusions, NACFE believes that fleets should seriously consider investing in solar systems, following the best practices described in Chapter 4.

Next Steps and Further Research

Next steps:

For most solar panel applications on trucks, NACFE recommends that they be seriously considered with new purchases.

We think the application of solar panels on trailers with extra electrical loads like refrigeration units and liftgates make sense as a means of improving battery life and reducing the need for roadside assistance. This is especially true if the trailer spends long periods without being attached to a tractor.

For tractor solar panel applications involving sleeper cabs equipped with or without battery HVAC systems, we recommend using the model provided to help evaluate whether a system makes sense. In some cases, the payback period may be longer than fleet purchasing guidelines to offset the installation costs of the added hardware. A solar system can help provide an improved environment for drivers during their normal 10- and 34-hour break periods, but it is difficult to put a value on that benefit.

Further research:

We do not expect that there will be any dramatic improvements in panel efficiency over time, but small incremental improvements should be expected. However, we do expect to see gradual cost reductions over time.

Typical solar panel expected life is generally longer than the typical large fleet trade cycle for tractors and, to a lesser degree, trailers. Currently, the installation methods do not allow the transfer of a solar panel from one vehicle to another economically. If a solar panel installation could be easily transferred from one truck to another, it could be an advantage for the overall fleet investment.

There could be improvements over time where solar panels could be incorporated into the fairings and trailer roofs to make the installation less expensive and cleaner.

Appendix A: Payback Calculator

Payback Calculator User's Guide

The Excel file calculator that is provided with this report is designed to help fleets evaluate what the value of investing in solar technology on new tractors. As we have discussed, there are many factors to consider related to solar technology on trucks and evaluating the value of the benefits vs. the costs can be quite difficult. Factors like area of the country and normal driving cycle can make a big difference in the effectiveness and benefits of solar panels. In addition, one of the key benefits of solar technology on tractors is improving the life of batteries and avoiding some service calls due to dead batteries.

The Excel model has a short questionnaire that asks the user to fill in responses. Once responses are filled in, hit the 'Calculated Savings' button and the spreadsheet will return numbers about expected annual savings per truck and calculate a rough estimate of the payback period for the investment.

We have identified five areas where a solar panel system installed on the tractor can provide financial benefit to the fleet:

- Reduction of engine idling during mandatory rest periods
- Improvement in battery life due to maintaining the batteries at a higher average state of charge
- Reduction in vehicle jump start incidents due to dead batteries
- Fuel savings due to solar power production reducing alternator load during normal vehicle operation
- Savings in driver retention and hiring expenses due to the technology being installed on the vehicles

Explanation of the Questions:

When you first load the Excel file, a button may appear at the top of the screen asking if you want to enable editing. Press this button to allow the spreadsheet to accept inputs.

Please select the type of solar system you want to assess from the drop down list

This model is set up to take responses related to two different scenarios. One is 'Sleeper Cab with battery HVAC'. The second is 'Sleeper Cab without a battery HVAC or a Day Cab'. Pick the most appropriate one for your application and a list of additional questions to be answered will appear.

Quoted hardware + installation cost per truck

- In order to evaluate an investment in solar panels, you need to understand the front end cost of both the hardware and the installation. Of course, this will vary based upon the size of the panel or panels selected as well as the projected installation cost per unit.

Select the city most near the truck's area of operation from the drop down list

- The area of the country that the vehicle runs has a significant effect on the energy that a solar panel can produce. For this item, we selected 50 or so large metropolitan areas around the US and Canada to make this a straightforward choice. We used the output from a solar panel tool called PVWatts maintained by the National Renewable Energy Lab that calculates the expected

energy output of solar panels based on average solar illumination data that has been accumulated over several years in each of these areas.

- Note: We have assumed the solar panel would be mounted on the truck fairing and that its angle is 20 degrees inclined. Some fairings vary from this angle, so the solar panel output would vary slightly accordingly. We have further assumed that the orientation of the panel to the sun is an average of 90 degrees off from ideal. This accounts for the fact that the orientation of the truck relative to the sun, which cannot be controlled, will vary the full 360 degrees and average out over time.

# of 10-hour rest periods/week in sleeper

- Enter the number of 10-hour rest periods per week that the driver will spend in the sleeper vs. somewhere else. One primary benefit of installing a solar panel on a sleeper with a battery HVAC is to help minimize engine idling during the required 10-hour rest periods. Since there are several of these per week vs. one 34-hour reset period where the driver may or may not be in the truck sleeper berth, we used this as a means of estimating one of the benefits of the solar panel.

% of rest periods in the sleeper that take place during the day
Weeks per year battery A/C needed
% rest periods where HVAC batteries are insufficient
Average hours of sun during rest period during day
How long do your HVAC batteries typically last before you have to start the engine?

- One benefit of solar panels is to assist the truck and battery HVAC batteries during 10-hour rest periods. To estimate this benefit, we need to understand a few things about the vehicle operation. First, since the primary function of the battery HVAC unit is to provide air conditioning to the sleeper berth during hotter weather without idling the engine, we need to estimate how often that function is needed. The batteries are generally able to provide hotel load support for a very long time if A/C is not required.
- To estimate the effect of the solar panel, you need to assume which part of rest periods actually occur during the daylight hours. The added power produced by the solar panel will have the effect of extending the time before the engine needs to start to recharge the batteries. Solar panel production at night is minimal and will not help extend the number of hours that the battery HVAC system will provide comfort to the driver.
- If the battery system has enough power to supply the needs of the driver for the full 10-hour rest period, then a solar panel will not help avoid engine idling during that rest period. The questions are trying to ascertain how often and to what degree the battery HVAC has insufficient power to complete a rest period. When this is the case, the power generated from the solar panel will help eliminate engine idling.
- As noted in the report, idling the engine to charge batteries and run hotel loads consumes approximately 1 gallon/hour of diesel fuel.

Total number of Group 31 batteries on truck

- This would normally be either 4 or 8 depending on your application. The total energy available in the batteries on the vehicle is part of calculating the additional contribution that a solar panel will make in avoiding idle time.

Total watts produced by panels

- This item is the total number of rated watts of the solar panels proposed for the installation. This can vary based upon the fairing area and the number of panels proposed. If there are two or more panels proposed, just added the watt ratings up for each individual panel and enter the total.

Average Hotel Load during 10 hour rest period in amps
Average fleet idle time %
Expected idle time avoided due to solar - %

- These items are unique to the Sleeper Cab without Battery HVAC or a Day Cab case. Calculating savings from the installation of a solar panel is slightly different when a Battery HVAC unit is not present. It is possible that the power from the solar panel could allow some small amount of reduction in the idle times, particularly where hotel loads over a rest period might require idling but the temperature is not high enough to require the engine to be running to provide air conditioning or heating. For example, if loads due to refrigerators, CPAP machines, etc. are high enough that the engine needs to be started before battery voltage becomes so low that the engine will not start, the solar panel can offset some of those loads and therefore avoid idling. Enter the average fleet idle times and the percent reduction expected to get an estimate of these kind of savings.

Average Battery life in months – truck
Average battery life in months – HVAC
Cost plus labor per battery replacement - 4 batteries

- Since one of the benefits of solar panels is to help extend battery life, we need to determine what the current average life of the batteries in the fleet are. Since it is possible that the starting batteries for the truck have a different average life than the ones for the battery HVAC system, we decided to allow the entry of different numbers. If the fleet data is insufficient to separate these, then just enter the same number in both lines.
- Some fleets reported that their average battery life was around 18 to 24 months while others stated that their average life was around 4 years. Of course, this number depends on a wide variety of factors, including maintenance practices, driver controls, vehicle duty cycle, battery technology selection, etc. It seems that about 24 months or so was the most common answer to this question.
- Many fleets have a maintenance program where individual batteries are replaced before a certain age, after which they are replaced as a set of 4. We would recommend using an average life for a set that includes both types of replacement. Depending on the type of records the fleet maintains, this may be difficult to determine. Often, fleets have the records that indicate the total battery replacements for a given year by vehicle group. If this is the

case, it is possible to make a pretty good guess of average battery life from these types of records.

- If a fleet has a maintenance strategy of replacing batteries at a fixed mileage regardless of their condition, then the fleet would need to consider whether a change to that maintenance practice makes sense if they invest in solar panels.

% improvement expected in battery replacement rate

- We think it is feasible that battery life could be extended by 50% as a result of installing a solar panel on the tractor. However, this number could vary significantly depending on a wide variety of factors as stated above.
- Fleets that have implemented solar panels have indicated that they think battery life has been extended compared to before using solar panels, but this data was anecdotal. Logically, the improvement in battery life should be there, but we have not been able to verify this with data from a large-scale study.

Jump starts/year for entire fleet
Average Cost per jump start (internal/external)
Fleet size (# trucks)
Expected % of jump starts to be avoided with solar

- Another benefit of installing solar panels on a tractor is the potential to avoid expensive jump starts because the solar panel can help maintain the batteries at a higher average state of charge. The above questions are targeted at determining what the cost of these jump starts are and the amount that might be avoided with the implementation of solar panels.
- Many fleets told us that they don't track jump start incidents closely. They indicated that if a jump start is needed in one of their internal yards that the incident and cost is often not tracked at all, but rather just included in the overall maintenance expense. Also, jump starts that require battery replacements are tracked in the battery category vs. emergency repairs. In the end, this expense is one that can be quite expensive at times and the costs might be avoided with the implementation of solar panels.
- Fleets that have implemented solar panels indicated that jump starts have indeed decreased compared to before implementing solar panels, but this data was also anecdotal. However, it stands to reason that if battery life is extended as a result of implementing solar panels that the number of jump starts required would also decrease.
- We think that it's feasible that the number of jump starts required would decrease by 30% to 50%. However, it would be wise to look at the reasons for the jump starts within the fleet to determine if there are other factors involved besides batteries getting to the end of their life or hotel loads draining the batteries during 34-hour reset periods. The power from the solar panel would help in these situations, but in others it might not. An example of conditions where the solar panel might not help would be leakage current due to poor electrical connections or grounds. Another example might be a failed battery due to low fluid or a defect in one or more of the cells.

Average fleet miles per gallon
Average truck mileage per year

Average Fuel Cost per gallon

- To calculate how much fuel might be saved due to the solar panel providing some of the power as the vehicle travels down the road, we need to understand the average miles travelled per year and average fuel economy. From this, along with other numbers provided above, we can calculate the effect of the contribution of the solar panel current on alternator load. Generally, this savings is a relatively small number compared to the others, but it is nevertheless a real savings.
- The change in vehicle fuel economy from this effect would be undetectable by normal measurement techniques, so this calculation is based on an engineering estimate of the power available from the solar panel annually. We have assumed that the alternator efficiency is about 45% in this calculation – that is, it would take a little over twice as much power going into the alternator from the engine to generate the power that the solar panel would provide.

Annual savings in retention/hiring

- Since most fleets we talked to implemented solar panels primarily based on an assumption of improving driver retention and thus avoiding hiring and training expenditures, we have included this line item to put a value on this assumption.
- We think it is reasonable given the very high cost of hiring and training drivers that a benefit of $100 per truck per year is a valid assumption if solar panels are installed on the vehicle. However, we recognize that each fleet will value this benefit differently, so the user should enter a number that seems reasonable for their particular operation.

Results:

Annual savings from avoided jump starts
Annual savings from extended battery life/reduced replacements
Annual fuel savings via reduced idle time
Annual fuel savings due to solar energy production while moving
Annual savings in retention/hiring
Total cost savings per truck per year
Payback period (in years)

- From the inputs, we calculate the annual potential benefits in each of the five categories mentioned above. The total cost savings is the sum of these five factors and the payback is a simple calculation of including the initial purchase cost vs. the benefits. We did not attempt to calculate the payback period using standard time value of money parameters since the numbers are simply directional and not meant to be an exact financial calculation.

Examples of calculator output

Solar for Trucks Payback Calculator

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Instructions: Please fill out the form below in order to estimate the financial savings and associated payback period for a solar system investment for your truck. Once you have completed filling out the form, click the calculate button below to view your results. Each time you make a change to one of the values you will need to click the calculate button again to see the updated results.

Question #	Questions	User Responses	Suggested Ranges	Notes
1	Please select the type of solar system you want to assess from the drop down list	Sleeper Cab with a battery HVAC		
2	Quoted hardware + installation cost per truck	$2,200.00	$0 to $5,000	
3	Select the city most near the truck's area of operation from the drop down list	Phoenix	n/a	please select a city that represents the average (e.g. Kansas City, MO)
4	# of 10 hour rest periods/week in sleeper	5	0 – 6	
5	% of rest periods in the sleeper that take place during the day	50%	0 – 100%	
6	Weeks per year battery A/C needed	30	0 – 52 weeks/year	
7	% rest periods where HVAC batteries are insufficient	50%	0 – 100%	Insufficient = batteries don't last full rest period and either truck needs to be idled or HVAC needs to be turned off
8	Total number of Group 31 batteries on truck	8	3 – 10 batteries	
9	Average hours of sun during rest period during day	5	0 – 10 hours	
10	How long do your HVAC batteries typically last before you have to start the engine?	8	4 – 10 hours	
11	Total watts produced by panels	300	20 – 600 watts	
12	Average Battery life in months - truck	24	0 – 60 months	
13	Average battery life in months - HVAC	18	0 – 60 months	
14	Cost plus labor per battery replacement - 4 batteries	$600.00	n/a	
15	% improvement expected in battery replacement rate	50%	0 – 100%	It is unlikely that the solar panel will do more than double the battery life
16	Average fleet miles per gallon	7	Range 4 – 10 mpg	
17	Average truck mileage per year	110,000	40,000 – 250,000 miles	
18	Jump starts/year for entire fleet	1,250	n/a	
19	Average Cost per jump start (internal/external)	$350.00	n/a	
20	Fleet size (# trucks)	1,000	n/a	
21	Expected % of jump starts to be avoided with solar	50%	0 – 75%	
22	Average Fuel Cost per gallon	$3.50	n/a	
23	Savings per truck per year in retention/hiring	$100.00	$0 – $300	We estimate the typical savings in retention/hiring for the HVAC use case to be ~$100/year

Results: Cost savings and payback period (per truck)	
Annual savings from avoided jump starts	$218.75
Annual savings from extended battery life/reduced replacements	$233.33
Annual fuel savings via reduced idle time	$229.06
Annual fuel savings due to solar energy production while moving	$37.52
Annual savings in retention/hiring	$100.00
Total cost savings per truck per year	**$818.66**
Payback period (in years)	**2.69**

Calculate Savings and Payback Period

Reset Form

Solar for Trucks Payback Calculator

NACFE
NORTH AMERICAN COUNCIL FOR FREIGHT EFFICIENCY

Instructions: Please fill out the form below in order to estimate the financial savings and associated payback period for a solar system investment for your truck. Once you have completed filling out the form, click the calculate button below to view your results. Each time you make a change to one of the values you will need to click the calculate button again to see the updated results.

Question #	Questions	User Responses	Suggested Ranges	Notes
1	Please select the type of solar system you want to assess from the drop down list	Sleeper Cab without a battery HVAC or a Day Cab		
2	Quoted hardware + installation cost per truck	$1,100.00	$0 to $5,000	
3	Select the city most near the truck's area of operation from the drop down list	Phoenix	n/a	please select a city that represents the average (e.g. Kansas City, MO)
4	# of 10 hour rest periods/week in sleeper	5	0 – 6	
5	% of rest periods in the sleeper that take place during the day	50%	0 – 100%	
6	Total number of Group 31 batteries on truck	4	0 – 6 batteries	
7	Average hours of sun during rest period during day	5	0 – 10 hours	
8	Total watts produced by panels	100	20 – 600 watts	
9	Average Hotel Load during 10 hour rest period in amps	8	0 – 50 amps	
10	Average fleet idle time %	30%	0 – 50%	
11	Expected idle time avoided due to solar - %	0%	0 – 25%	It is possible that some idle time would be avoided, but 0% is the most likely scenario
12	Average Battery life in months - truck	24	0 – 60 months	
13	Cost plus labor per battery replacement - 4 batteries	$600.00	n/a	
14	% improvement expected in battery replacement rate	50%	0 – 100%	It is unlikely that the solar panel will do more than double the battery life
15	Average fleet miles per gallon	7	Range 4 – 10 mpg	
16	Average truck mileage per year	110,000	40,000 – 250,000 miles	
17	Jump starts/year for entire fleet	1,250	n/a	
18	Average Cost per jump start (internal/external)	$350.00	n/a	
19	Fleet size (# trucks)	1,000	n/a	
20	Expected % of jump starts to be avoided with solar	50%	0 – 75%	
21	Average Fuel Cost per gallon	$3.50	n/a	
22	Savings per truck per year in retention/hiring	$75.00	$0 – $300	We estimate the typical savings in retention/hiring for the non-HVAC use case to be $0/year

Results: Cost savings and payback period (per truck)	
Annual savings from avoided jump starts	$218.75
Annual savings from extended battery life/reduced replacements	$100.00
Annual fuel savings via reduced idle time	$0.00
Annual fuel savings due to solar energy production while moving	$12.51
Annual savings in retention/hiring	$75.00
Total cost savings per truck per year	**$406.26**
Payback period (in years)	**2.95**

Calculate Savings and Payback Period

Reset Form

Appendix B: List of Solar System Suppliers

Advanced Energy Machines
http://aem.green/

Bergstrom
https://us.bergstrominc.com/solar

Carrier Transicold
http://www.carrier.com/tru-solar

eNow
https://enowenergy.com/

Go Power!
https://gpelectric.com/

MiaSolé
http://miasole.com/

Merlin
https://www.merlinsolar.com/

Orbcomm
https://www.orbcomm.com/en/hardware/devices/gt-1100

Purkeys
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