Hybrid Technology - Solving the Industry's APU Dilemma

Auxiliary Power Unit (APU) systems have been available within the trucking industry for many years, however, all popular systems have significant drawbacks. Traditionally, APUs are grouped into two distinct categories; Electric & Diesel powered, each with its own set of shortcomings.

Current electric systems typically suffer from insufficient cooling capacity and runtime which is compounded by a rapid degradation of performance over time. Running the main diesel engine to recharge the batteries and provide additional capacity (runtime) leads to excessive truck idle time and drastically undermines the value proposition and return on investment (ROI). From a maintenance point of view, traditional battery based APUs are plagued with inadequate battery life and troublesome auxiliary battery relay systems.

Mechanical diesel APUs are the current alternative to electric systems, however, they have significant challenges of their own. While they do provide adequate runtime and cooling capacity the initial unit cost, installation cost, fuel cost and maintenance costs of these systems make any value proposition tenuous at best. Diesel systems also require additional emissions control systems to meet CARB requirements, further complicating the value proposition.

DClimate set out to solve the core issues presented by these traditional approaches and the resulting ***Hybrid*** systems provides an optimized solution for both drivers and fleet owners.

Trucking companies face many challenges in today's competitive environment: regulation compliance, driver recruitment and retention and operational cost control are amongst the highest priority concerns.

Idle reduction systems, when properly applied, can positively impact all these critical areas.

Anti-idle laws and hours of service regulations (HOS) restrict the flexibility that fleets and drivers have regarding when & where driver breaks occur. Engine emissions regulations add significant complexity to truck emission control systems and make them much less tolerant of extended periods of engine idling. These factors drive up the cost of running a trucking fleet. In order to remain competitive, maximizing MPG performance is a top priority for fleets as illustrated by the rapid adoption of aerodynamic solutions (e.g. trailer skirts, trailer tails). However, maintaining a low idle percentage remains the single biggest potential contributor to MPG improvement.

Effectively providing heating, cooling and accessory power to the truck cabin without idling the main diesel engine goes a long way toward addressing company financial concerns. It is however, equally important in today's tight labor environment that this be achieved without compromising the quality of life for drivers.

When done poorly, idle reduction systems will add cost without significantly reducing main diesel engine idling behavior. The inability to reliably provide the driver with a safe and comfortable environment also forces fleets to rely more heavily on driver discretion on when to idle, taking control of overall MPG performance out to the fleet owners hands.

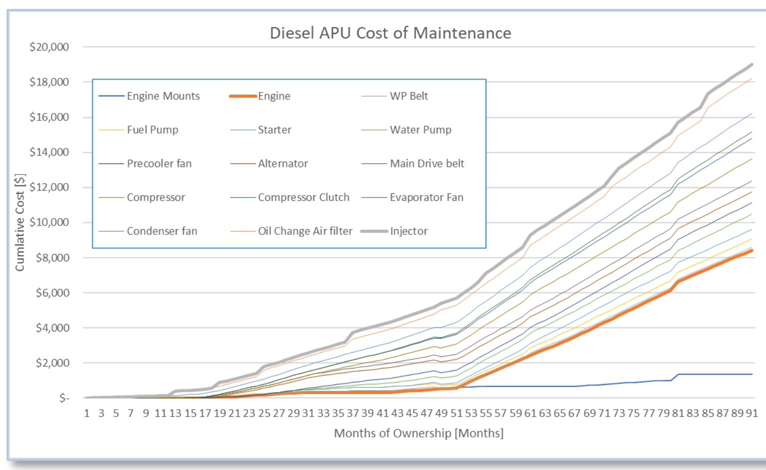
Any trucking company with anti-idle system experience can recount many situations where currently available systems are disappointing. In fact, many fleets have stopped using anti-idle equipment as they find that after purchase the equipment, they don't see a significant engine idle reduction and/or the total life cycle costs make the return on investment unattractive. It is the objective of this whitepaper to review current weaknesses of existing diesel and electric system designs and illustrate how these deficiencies are uniquely addressed by DClimate's Hybrid design.

The primary goal of any idle reduction system is to satisfy the occupant's needs while the main engine is off. In order to make economic sense, the system must have an affordable purchase price and low life cycle costs.

Traditional anti-idle systems take two basic approaches; diesel engine powered systems or battery powered electrical systems.

Let's first examine diesel engine powered systems. These systems are favored by truck drivers because of generally good air conditioning performance, no runtime concerns and the assumption that they will keep the truck starting battery properly charged. However, owners of a diesel engine system soon learn that the system can be as much of a headache as an asset.

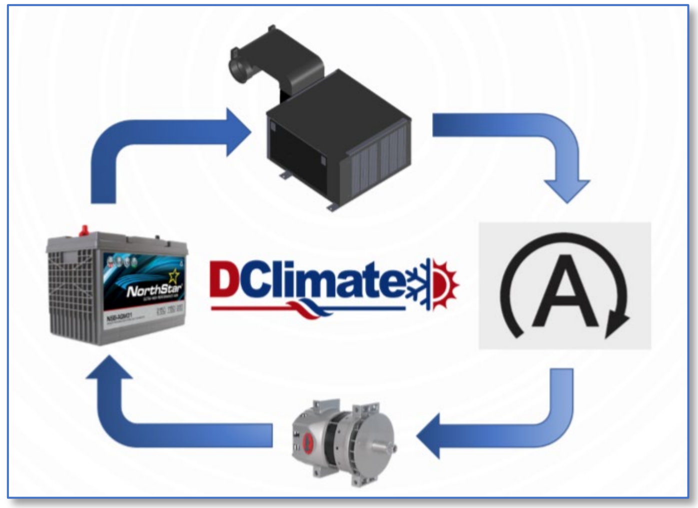
Typical fuel consumption is approximately 0.3 gallons per hour for normal operation, with fuel at $3.00 per gallon the fuel cost to run a diesel system is $0.90 per hour. Maintenance for the first year of ownership is typically low with only an oil change and filter replacement required, bringing the total operational cost to about $1.00 per hour. The cost profile changes dramatically after the first year as mechanical components of the diesel engine system begin to wear out. The second year and beyond typically bring repairs exceeding $1,000 per year. In addition, the systems are typically worked on by specialized APU dealers, requiring the truck and driver to be out of service while the driver goes to the service location and the system is repaired. Finally, running the diesel engine system alternator at over 14 volts for extended periods will overcharge the truck starting batteries and actually shorten their useful life requiring a typical 18 to 24 month replacement cycle. Adding all this up, a typical fleet can expect a total operational cost of $1.60+ per hour. This cost also assumes that none of the additional emissions abatement equipment required for CARB compliance is fitted. Coupling the initial purchase and installation cost with high life cycle operational costs makes the ROI period challenging at best.



*Cost estimate assumes $100/hour labor rate.

When the cost of ownership and burden of maintenance of a diesel engine system are too much, battery electric systems are often considered the next logical alternative. However, the owners of battery electric systems quickly learn that these systems have many shortcomings of their own. Drivers regularly complain of poor air conditioning capacity and runtime - particularly in higher ambient conditions. This requires the fleet owner to relax ECM auto shutdown settings and provide the driver with more discretion on when to idle the truck. When the truck engine must restart to charge depleted auxiliary batteries, the truck engine typically runs for 4+ hours, further driving up idle percentages. In addition, the fleet owner will experience a constant deterioration of A/C system runtime with battery replacement commonly required every 12-18 months. Although scheduled system maintenance costs are lower in battery electric systems, these benefits are quickly off-set by high idle percentages, frequent battery replacement and poor levels of driver satisfaction.

Clearly a better alternative is needed …



Introducing the DClimate's Hybrid Electric system.

In brief, the DClimate system consists of a high efficiency, high capacity Heating & A/C system, industry leading battery energy storage, a patented battery management system, a high capacity alternator for rapid recharge and truck engine auto-start system. Altogether, the DClimate system provides maximum driver comfort while reliably delivering low to mid-single digit long idle percentage and industry leading life cycle costs.

DClimate Integrated Heating & Cooling

The DClimate system consists of a combined heating and air conditioning system to provide maximum driver temperature control and air distribution while minimizing the system footprint.

DClimate Air Conditioning

Efficiency and capacity rating conditions for air conditioning systems are determined by testing an A/C system at a constant 95F ambient with an occupant environment of 80F and 50% relative humidity. Not only is this condition rare, it's not particularly comfortable for the occupant. However, given that this is the industry standard measurement condition, many manufacturers work to optimize their system design around these numbers. At DClimate we realize that the system must perform over a wide range of ambient conditions and the occupants generally prefer a cooler than 80F cab temperature for comfortable sleep. In addition to delivering industry leading performance at the 95/80/50 conditions, DClimate has designed the air conditioning system to meet diverse driver needs.

Air conditioning system design optimization isn't about a single component that allows the system to achieve excellent capacity and efficiency but rather the combination of many small improvements that work in harmony to provide breakthrough results.

For example, DClimate uses variable speed permanent magnet motors for all the major components (A/C compressor, condenser & evaporator fans). Not only do they provide industry leading component efficiency, but variable speed components allow the system to operate at peak efficiency across the wide range of environmental conditions expected when moving freight. Also, all the components are able to work together to stabilize the inside air temperature for maximum driver comfort.

DClimate also utilizes a 48V high efficiency, variable speed A/C compressor for improved capacity while still achieving excellent efficiency.

The criteria for component selection in the DClimate A/C system is: (a) high efficiency over the wide range of environmental conditions and (b) long design life. High efficiency components are a key enabler for DClimate's unmatched runtime capability. Long design life drives a high level of system reliability while minimizing lifecycle operational costs. This significantly enhances the ownership experience.

Heating System

When heating is required and fuel is available, the most direct and efficient way to satisfy the need is to burn that fuel. DClimate partnered with Webasto and uses a standard, and Smartway approved, fuel operated heater to fulfill heating requirements. The heater is neatly packaged within the DClimate unit to minimize the system footprint and to take advantage of the air distribution system, discussed later. An additional benefit is that this approach to heating is already broadly accepted by the trucking industry and is backed by a mature service and support network.

Microprocessor Control

Operating both A/C and heating systems with variable speed components at peak performance, over a wide range of conditions, would not be possible without a sophisticated control system. DClimate's engineers used their extensive application experience to develop a microprocessor controller that delivers unprecedented functionality, such as: State of Health monitoring (SOH). SOH monitoring means the system is constantly scanning multiple parameters to detect out of range behavior, giving notice to the operator to address and issue before a system failure occurs. Moreover, this feature eliminates the need for full system checks at regular service intervals thereby minimizing fleet expense.

Also, the system has full data logging capability so a technician can easily see the full life history and easily diagnose any problem. Data logging also helps with understanding real world driver usage behavior and can be used to educate the driver on optimal use of the system.

With a sophisticated microcontroller system, it's easy for DClimate to add a Telematic link so a fleet manager can monitor the fleet of systems, react to minor concerns before they become major concerns or even remotely configure key settings to fit individual drivers needs.

Air distribution

Effective air distribution is critical to both occupant comfort and heating and cooling efficiency. Uniquely, DClimate engineers custom design air delivery ductwork and distribution systems for each OEM application. Our focus is to provide the right combination of air velocity and temperature conditioned air to create a comfortable environment throughout the cabin area. Air is delivered in the same fashion in both heat and cool mode, closely mimicking household forced air systems. Optimized duct design also ensures that system efficiency is maintained through to the point of air delivery.

Exploring the typical use cycle

For battery electric A/C systems, once the battery system is depleted, the only way to operate the system again is by starting the truck's big bore engine or by finding a shore power connection. DClimate's unique hybrid system design addresses this issue by solving three critical areas of historical deficiency with battery electric systems:

1. Battery Management - Available Power Per Cycle
2. Alternator Specification
3. Continuous Availability

Combining these features allows DClimate to deliver a high level of functionality while delivering low to mid-single digit long idle percentages which distance the DClimate Hybrid solution from all others.

Battery Management – Available Power Per Cycle

A chief concern of any user of APU equipment is that operation of the system should never interfere with normal operation of the truck and its mission to deliver goods.

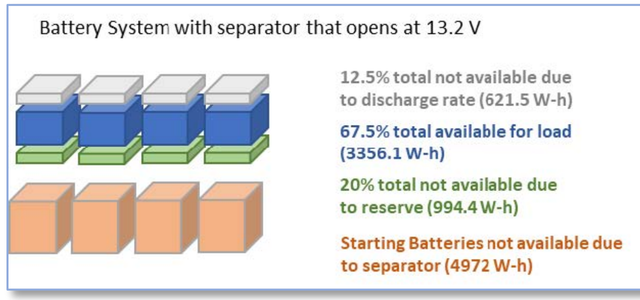
Traditional thinking dictated that the engine starting batteries and electric APU auxiliary batteries should be separated from each other by an electronically controlled separation relay. This approach is employed by all legacy battery electric APU systems. The thinking is that the auxiliary batteries may be excessively depleted without risk of over depletion of the truck starting batteries. This approach brings about a need for very complicated interactions between the batteries and charging system, typical of current battery electric APU systems.

History & impact of the battery separator design approach. When a battery separator system is used, consider the instant that the truck engine starts after the auxiliary batteries are depleted down to a 20% State of Charge (SOC) and the main engine starting batteries are at a 50% SOC (the cabin inverter is commonly hooked to the starting batteries so starting batteries depletion is normal). At the instant the truck engine starts, a significant portion of the alternator capacity is consumed by the engine, emissions controls systems, Engine Control Unit (ECU) and cab accessories. Any extra alternator current capacity is channeled to the starting batteries. When the starting batteries achieve approximately 75% SOC the separator relay closes allowing current to flow to the auxiliary batteries. Since the auxiliary batteries are at such a low SOC, they will try to draw more current than the typically specified alternator can provide. When this happens, the system voltage drops and the separator relay opens because it is sensing the voltage drop and thinks the system is low on charge. Once the relay has opened, system voltage returns to normal and the separator closes, creating a continuous cycle.

Cycling the relay in this manner will shorten relay life and reduce system reliability. When designers realized this flaw, they chose to limit the rate at which the auxiliary batteries could accept charge and thereby reduce the separator relay cycling. One common solution is to use an underside connection wire between the auxiliary battery and the main charging system and thereby add connection resistance to limit the battery charge rate. By doing this, the time required to charge the auxiliary batteries was increased. That helps the separator relay but causes three new problems.

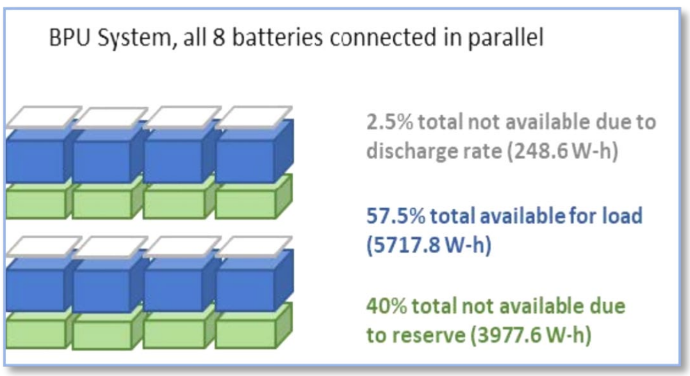
1. Leaving the battery at a low SOC for a longer time accelerates damage to the battery and its ability to hold a full charge.
2. Limiting the rate of charge on a deeply discharged lead acid battery limits the ability of the charging current to break down and re-dissolve sulphate build up on the batteries lead plates. Even though the damaging effects of each charge / discharge cycle are small they are cumulative.
3. The requirement to have 4+ hours of drive time to recharge the system, as commonly stated by current manufacturers, is impractical due to load pick-up and delivery schedules. Both activities regularly require wait time, requiring use of the APU to eliminate idling.

Finally, the battery separator design creates three more significant challenges/limitations.



1. Using four batteries to power the A/C load doubles the battery discharge rate in the auxiliary battery pack. When the battery discharge rate goes up, more losses occur in the batteries and therefore they have less energy available to support the load.
2. When using the battery separator, the auxiliary batteries are required to be deeply discharged to power the A/C load. Deep discharging any battery dramatically increases cycle damage to the batteries and limits their useful life.
3. Using only 4 batteries to power the A/C load limits the amount of available power at the start of each cycle. With new batteries this is approximately 3.4 kw-h, this can deteriorate rapidly over time due for the reasons outlined in this section.

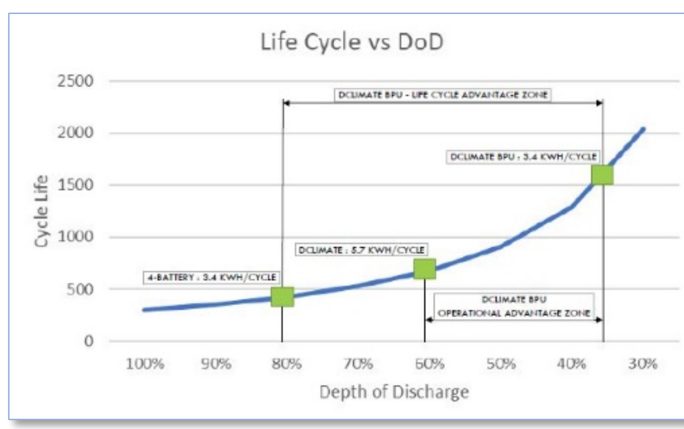
The DClimate approach to Battery Management – Available Power Per Cycle



In contrast to the battery separator approach, DClimate uses a patented design where all 8 truck batteries are connected by equal value, low resistance charging paths. In this manner, all batteries receive maximum output from the alternator when the alternator is active and equally share the load when air conditioning is required.

This arrangement has a number of key advantages that differentiate the DClimate solution from all other battery electric APU solutions.

1. Significantly shortens the charging cycle
2. Minimizes losses due to a lower discharge rate per battery
3. Provides a substantially higher level of available stored energy per cycle (5.8 kw-h). Combined with the high efficiency of the A/C system this leads to significantly longer runtimes, enabling consistent delivery of low long idle percentage.
4. A higher level of stored energy is delivered while maintaining lower battery discharge rates. This creates an environment for long battery life and ensures truck starting capability is never compromised. Backed by a manufacturers application specific warranty, this feature addresses one of the primary challenges to both performance and return on investment on systems that use battery separators. The relevant extract from the NorthStar warranty bulletin is pasted in below …



This bulletin clarifies NorthStar's 4-year warranty commitment for batteries used as part of DClimate's APU solution. The application calls for the use of eight dual-purpose NSB-AGM 31 batteries, designed for a combination of cycling and vehicle starting.

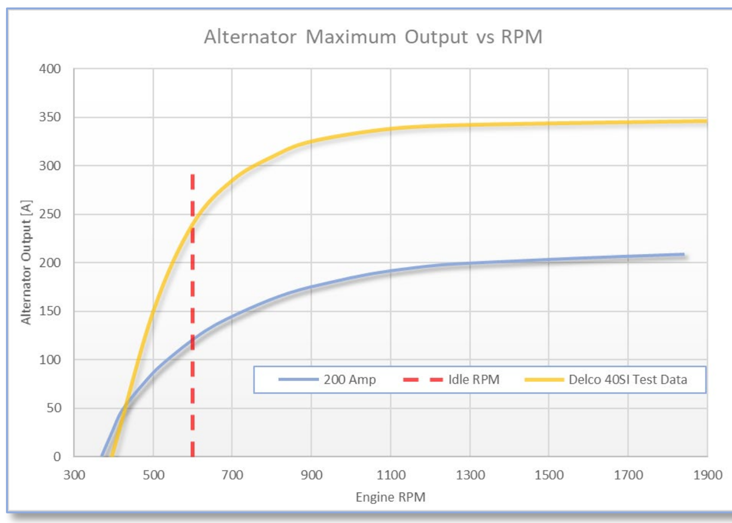
Based on extensive joint testing we have determined that the system design dictates that the batteries will never discharge more than 60%, and on average no more than 50% on a typical daily cycle. This, coupled with the rapid recharge characteristics of the DClimate system, mean the battery application falls within the design specifications for 4-year minimum life expectancy. As a result, the DClimate warranty will be based solely on months of service.

5. In addition to the performance gain in the anti-idle functions, all 8 batteries are used for truck starting. This is a major benefit in cold start situations providing much higher cranking capability than the standard 4 starter battery approach.
6. Enhanced system reliability is provided by DClimate's passive battery management approach by eliminating inherently problematic components from the system design.

Alternator Specification

Consider the following situation:

- A typical truck draws anywhere from 60 to 100 amps load to run the truck engine ECU, fuel injection system, emissions equipment, dashboard and any accessories during idle.
- The battery electric APU auxiliary are depleted to 20% SOC and the system shuts down, initiating the need for a recharge cycle to begin.



The graph shows a truck with idle speed of 600 RPM. Assuming a moderate electrical load of 70 amps for the truck and accessories the alternator has an excess capacity of only 50 amps which will be fully directed to replenish the starting batteries. When starting batteries have an initial State of Charge (SOC) of 50%, it will take little more than 2 hours to charge the starting batteries enough for the separation relay to connect the auxiliary batteries and under the best conditions. After the separation relay closes, it will take the alternator more than 6 hours to charge them. The options available to the fleet in this situation are limited to (a) allow the driver to idle the truck and utilize the OEM engine driven A/C system or (b) shut all systems down and force the driver to wait out the balance of his rest period without A/C or accessory power. Clearly neither option is appealing as one leads to excessive idling needed (commonly reported problem by fleets using these types of system) or a very dissatisfied & frustrated driver.

Even if the truck idle speed is increased to 900 RPM by ECU adjustment and the 200 amp alternator is used, the alternator will have excess capacity of 100 amps which will be fully directed to replenish the starting batteries. When starting batteries have an initial State of Charge (SOC) of 50%, it will take about 1.2 hours to charge the starting batteries enough for the separation relay to connect the auxiliary batteries. And, under the best conditions, it will take the alternator another 4 hours to charge the auxiliary batteries.

Given the fact that its likely that systems with this design architecture will regularly hit the 20% SOC threshold (for the reasons discussed earlier) it’s easy to understand the frustration and disappointment frequently heard from users of these systems.

The DClimate Hybrid architecture utilizes a high efficiency brushless Delco 320 Amp 40SI alternator. Combining this alternator, proper ECU setup and the DClimate patented battery connection system allows the alternator to simultaneously charge all 8 truck batteries from a 40% SOC to 80% SOC in a little over an hour.

Some argue that a larger alternator will place an additional load on the engine and drive down fuel economy. Absolutely not true! While a larger alternator will certainly draw more load when high output is needed, the alternator will not draw any more load than a smaller alternator after the high output battery charging event is complete. In fact, the Delco 320 amp 40SI is more efficient than cheaper brush alternators so will actually improve fuel economy. In addition, a large lightly loaded brushless alternator will run cooler and be more reliable than an overloaded brush type alternator, saving on unanticipated road repairs and improving up-time.

Continuous Availability

Tying it all together is the engine **Auto-Start system**.

To make driver comfort a seamless experience in extreme conditions, a truck engine auto-start is used by the DClimate system. If ever the ambient temperature gets too low, the engine can start and prevent fuel from gelling or if the system consumes the 5.8 kw-h of available energy because of extreme temperatures or a particularly long driver break (34 hour reset period), the truck engine will automatically start to charge the batteries. Because of the large alternator and patented DClimate charging system, all batteries receive maximum alternator output and are quickly returned to a useable state of charge. The engine will then automatically shut off and the DClimate system continues to keep the driver comfortable, all while delivering low to mid-single digit long idle percentages.

In conclusion, all the elements of the DClimate Hybrid APU work together as a system to provide legislative compliance, environmental stewardship, maximum driver comfort and an industry leading return on investment.