TRAILER ELECTRIFICATION

Position Paper

INTRO

While electrification of Transport Refrigeration is evolving and progressing, several significant barriers exist to a compelling value proposition and as such regulation will very likely drive adoption ahead of total cost of ownership (TCO) parity. Discussed in this article are some of the barriers and future solutions to Battery Electric TRU (BETRU) adoption and what fleets can expect.

Among the many hurdles to the future point of capable and cost efficient BETRU's are two major barriers that must be overcome. The first main barrier to BETRU adoption is infrastructure. The two sub-issues are having enough total power from the grid, and having that power be in the proper place to charge a BETRU (E.g. Charging station location).

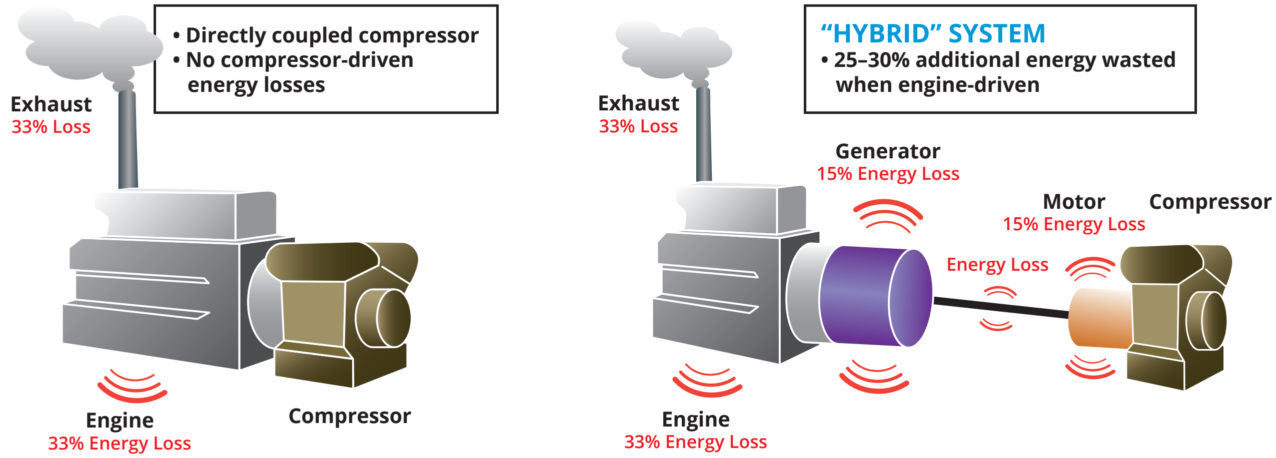
Batteries are the second major barrier as it relates to both cost and weight/size. As the batteries and related power electronics currently account for as much as 50% or more of the cost of a BETRU, the continued downward cost trend is critical to TCO parity. Battery weight & size (aka Power Density) is also a critical factor as they need to continue to combine more power in a smaller space to reduce the added weight to a trailer as well as the related space required to mount them.

This paper does not address current electric standby operations or infrastructure requirements and instead focuses on the longer-term issues and solutions for transitioning to fully electric BETRU's.

TRU DEFINITIONS

TRU architectures have been called many things over the years and some misunderstandings or misapplications of nomenclature have been applied which will only complicate future discussions as we transition from diesel powered TRU's to all-electric. Perhaps the most misunderstood terminology in TRU's is the "eTRU" which is often used to describe TRU's with electric standby capability. The issue with the "eTRU" terminology is that it implies the TRU runs on electric 100% of the time without any engine power source. While this is certainly applicable for engineless TRU's, it is not a logical application to engine based TRU's since a TRU that consumes diesel fuel for most of its runtime cannot suddenly become an electric TRU or "eTRU". Furthermore as TRU's become all-electric the "eTRU" definition could be easily mis-applied and therefore these systems should be referred to as electric-standby capable TRU's which while not as short or elegant as "eTRU", serves to describe the reality of where the TRU gets its power from or how green it truly is.

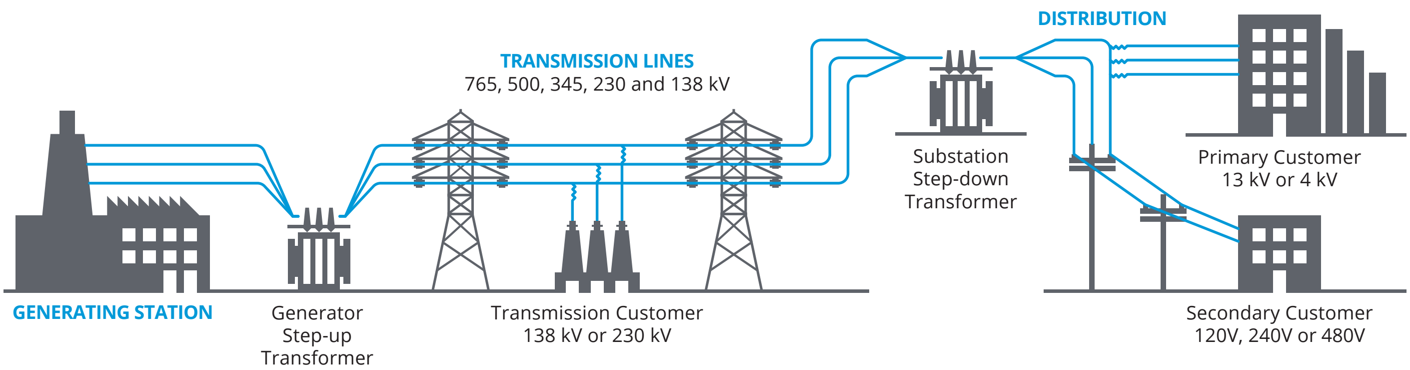
The second most mis-used label is the "Hybrid TRU". The impression of a "hybrid" system is that it's more energy efficient than a non-hybrid system and while this is true in the traditional sense, the term as it has been applied to TRU's turns this completely around. In traditional automotive terms, a hybrid is a system that has an engine-based system and a parallel battery-based system whereby the batteries are either charged by the engine or from the grid. Regardless the hybrid term is used to denote that the system can run in EITHER electric or engine mode which creates fuel efficiencies based on application need. The misapplication of "Hybrid TRU" often comes when describing TRU's that have an engine that drives a generator which then powers all other components. Since a generator powers all TRU components it is marketed as being more energy efficient and therefore greener than a mechanically driven system that is also deriving its power from an engine. In either case an engine is providing the power for the TRU when not running off of shorepower which as discussed is typically where a unit spends the majority of its life. What's ironic about the hybrid nomenclature is the reality that using an engine to drive a generator is LESS fuel efficient than a directly coupled mechanical system due to the power losses in the generator when operating in diesel mode. Therefore, fleets touting the green aspect of having "hybrid TRU's" are often burning more fuel than the alternative and being less green unless they plug in those units for the vast majority of their life. To offset the additional fuel burn, the units must be plugged in significantly more which is generally not the operating reality of most TRU's. With that said, fleets that have transitioned to more shorepower based usage will benefit from a system that is shorepower optimized and bypasses the engine altogether due to higher electrical efficiency of inputting power directly at the compressor itself.



INFRASTRUCTURE

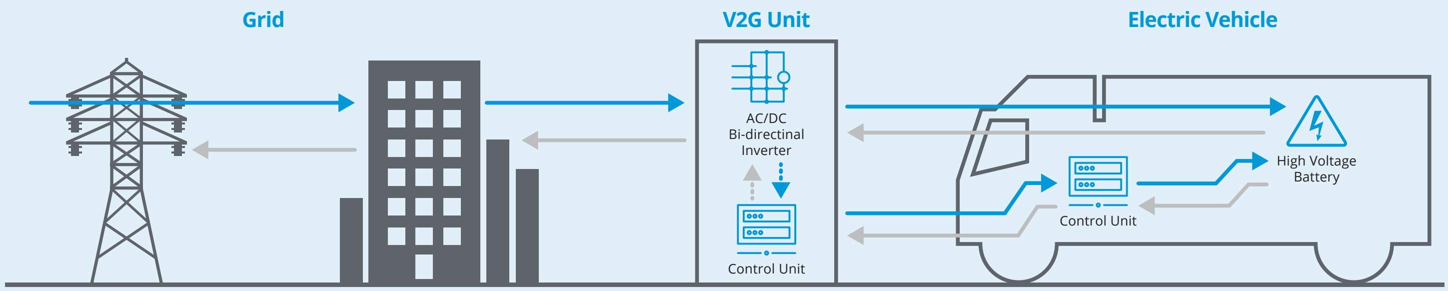
There must be both enough power in total and for it to be available in the right place to serve a fleet's operational logistics. In the next 3-5 years it is largely expected that trailers won't need to charge mid-route while away from a distribution center (either picking up or cross dock applications) as early adoption will likely be focused on regional day trip applications where the asset comes home to charge every night. Multi-day trips will some day be possible but will likely follow heavy duty truck EV sleeper cab adoption which won't become a major reality until the mid 2030's.

The constraint on power supply is typically in the distribution portion of the grid which denotes the micro-grid of a distribution center as an example. EV charging for commercial vehicles like trucks, tractors, and TRUs will certainly strain the local distribution network but with enough planning and lead-time utilities can account for this. Many utilities across North America are eager to help scope and size charging power requirements and the associated variables such as peak charging power, number of units charging at the same time, TRU pulldown, etc. A separate paper will dive deeper into infrastructure requirements, power grow needs, and charging standards.



VEHICLE-TO-GRID (V2G)

Several technologies are in process to aid in reducing the burden on the grid and include Vehicle-to-Grid (aka, V2G), smart charging networks, and on-site power storage, and local power generation (E.g solar). V2G is the process whereby EV's can put power back into the grid to even to peak demand. An example would be a fleet's home base that has 50 pairs of electric tractors on-site. In a given day if a surge of units need to charged midday but either peak demand charges make the cost unsustainable or the grid is incapable of supplying enough power, other on-site units can provide power upstream to the local facility grid. Later in the day as demand has decreased, the remaining units can be recharged. The obvious disadvantages are increased battery cycling which would reduce battery life and the need for greater operations planning so that units that have just shed power to the grid don't suddenly need to be deployed with less than a full charge. However, in this example the option to have all 50 units be mostly charged and capable of deployment vs perhaps only some units fully charged and capable might provide a compelling reason to adopt V2G.

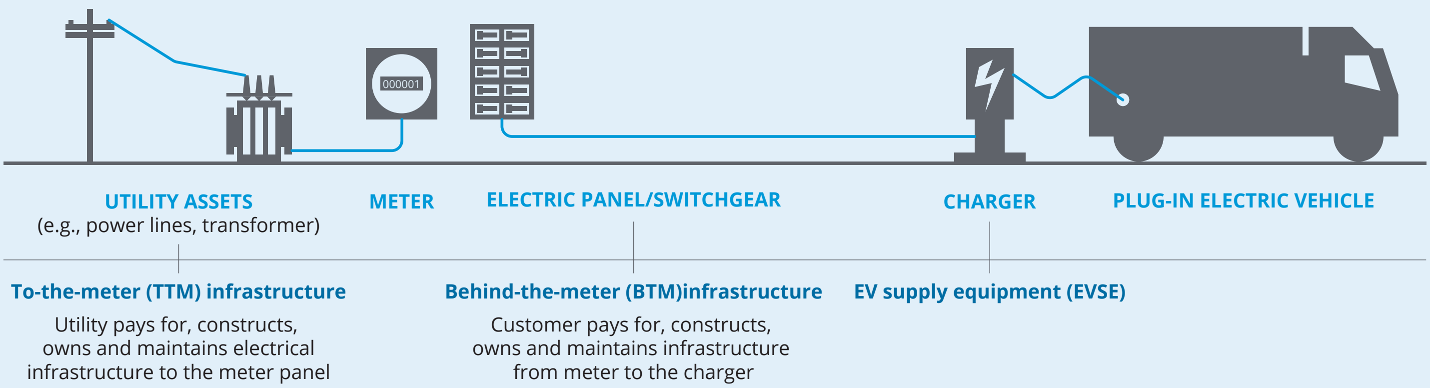


SMART CHARGING NETWORKS

Smart charging networks are on-site charging stations that coordinate charging output based on a central controller that understands when and where charging will need to occur as each of the charging stations would understand the state of charge (SOC) of the unit they're connected to. Few disadvantages exist besides upfront and reoccurring costs but the advantages of operations and dispatch being able to pinpoint which units need higher charging or longer charging could have big implications on unit uptime. Furthermore, the ability to flex charging among every unit plugged in at a facility could allow for power consumption to be smoothed out to reduce peak charges and overloading the grid. Additionally, 3rd party or "visitor" charging and a fee structure and payment / validation still needs to be put in place, but in many cases, fleet fueling programs can likely easily translate into charging networks including bulk power purchase contracts.

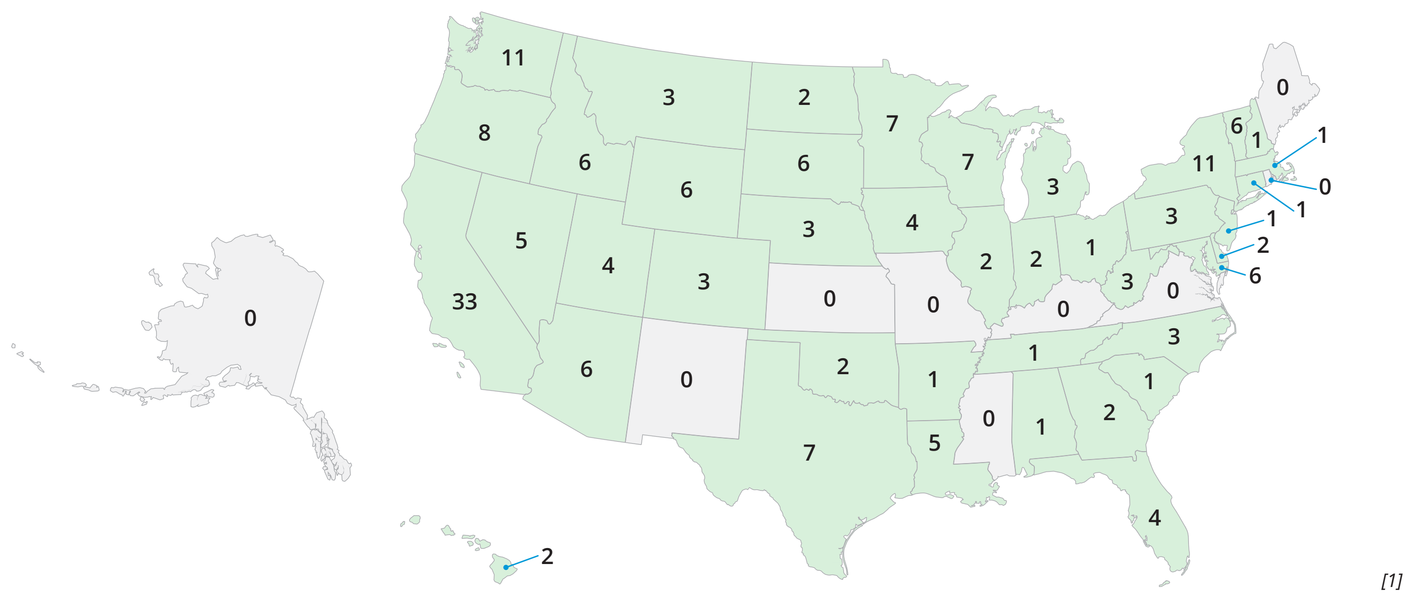
Lastly on-site power generation such as solar and on-site storage will be a big advantage to facilities that can afford the infrastructure. On-site power generation could help prevent brownouts or blackouts caused by storms and grid failures and on-site storage will allow that power to be flexed throughout the day and into the night. On-site power storage will likely be a big business in the coming years as old EV batteries are recycled into a second life as stationary power storage. Regardless of what technologies the industry finds to be cost efficient and effective, one or more will be needed to reduce the overall burden on the grid and fleet power bills.

Planning for infrastructure to charge an electric TRU can be a difficult process. The high costs and long lead-time are often a result of needing to run power all the way upstream for the charger which consists of the Behind-the-meter (BTM) and To-the-meter (TTM) sections. By planning ahead of constructing part or all of this up to the charging location, companies can save a tremendous amount of money and headache.



ELECTRIC UTILITY CHARGING AND VEHICLE INCENTIVES

While few incentives and grants currently exist for purchasing zero emission and electric TRU's, many states and utilities do have incentives to pay for infrastructure improvements partially or fully. Some incentives are tailored only toward shorepower installations while others are for EV charging with the graphic below visually depicting the number of utility charging and vehicle incentives by state. The graphic highlights the outsized number of incentives on the west coast and New York and implies geographic areas where electrification is more progressive.



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CHARGING EQUIPMENT & RATE

Regardless of if a fleet is planning on migrating to shorepower or eventually skipping direct to zero emission, one option is to install a 480 Volt, 50 Amp, 3phase circuit (Aka 480V/50A/3ph). This will allow for TRU shorepower running in all cases in the near term and the installation could be heavily subsidized. When the time comes to convert installations to EV charging, a dedicated 25kW CCS1 DC fast charger can be installed at the end of the circuit for under $15K with current costs (additional costs incurred for connectivity/remote diagnostics) and this has the potential to be cheaper and/or be subsidized in the future. One other advantage is that this infrastructure path supports both TRU trailer AND EV trucks for cases where both are charged at the loading dock. A 30amp circuit would also suffice but provide less overhead for quicker charging, especially during pulldown. What makes the 480 Volt ideal over 240V is the ability to provide greater than 20kW of charging power into the BETRU's batteries while pulling down the trailer which can also take upwards of 20kW at peak power. However, while most CCS (Combined Charging Standard) chargers currently available run off of 460-480V AC power, some are able to boost 208–240V up to voltages as high as 800V. Therefore, with the goal of not losing out on battery power while running, the TRU would need at least 20kW which the 480V circuit can provide. Additionally, the 480V circuit is also ideal to provide shorepower to current electric standby systems on TRU's due to faster pulldown times.

CHARGING EQUIPMENT & RATE – 100 KWH BATTERY EXAMPLE

	Level 2 EVSE	Level 2 EVSE	DC Charger	DC Fast Charger	MCS–Mega DC
Power Specs	240V 1Ø/32A	240V 1Ø/80A	240V or 480V 3Ø	480V, 3Ø	Medium Voltage
Equipment Cost	$600	$2,200	$10,000	$150k–250k ++	Millions $$$$ ++
Grid Interface	Plug in NEMA 14–50	Hard Wired	Hard Wired	Planned Infrastructure	Utility Grid capability
Total Power Availability	7.6kW	19.2kW	22.5kW – 24kW	175kW–350kW	4.5MW
Time to charge 100kWh battery pack	12 hours/OBC required*	5 hours/OBC required*	4 Hours—no OBC*	20-45min*	Minutes if battery compatible

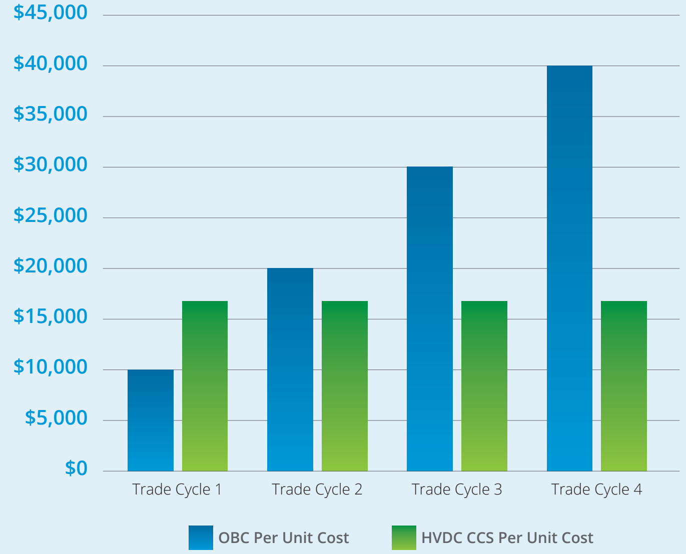
*Approx charge time, assume charge from 0% to 90% SOC, OBC = On Board Charger

++May require significant installation cost, wiring, transformers etc.

CHARGING ARCHITECTURE

Assuming the BETRU has a High Voltage DC (HVDC) architecture, one critical design factor in BETRU design is where to place the AC/DC converter. This is the cornerstone of many industry discussions that has profound implications on infrastructure requirements. The obvious choice (option 1) that many operators immediately come to due to cost and infrastructure simplicity is to provide AC power directly into the BETRU unit and have an On-board charger (OBC) convert the incoming AC power from a level 2 charger into the High Voltage DC (HVDC) power that the battery pack will need. While this saves money on the infrastructure side, it adds significant cost to EVERY BETRU, adds weight, is another potentially expensive component to eventually fix, and ultimately provides less than 20kW of power input which reduces charging potential. The counterargument (option 2) is to have the converter be on the charging station and feed HVDC directly into the BETRU via a HVDC CCS charger. This is significantly cheaper in the long run (1 stationary charger vs an OBC on every BETRU ever purchased) but also limits the applicable charging locations for the BETRU. Ultimately, it's believed that options for both will have to exist to accommodate BETRU charging in locations that don't have HVDC charging capabilities. The graph to the side illustrates how investing in HVDC CCS chargers nets a rapid return after just 2 trade cycles when it becomes more economical to use the same infrastructure for each unit. The economics are even better if a single HVDC CCS charger can service multiple BETRUs and is flexible for other vehicles as well.

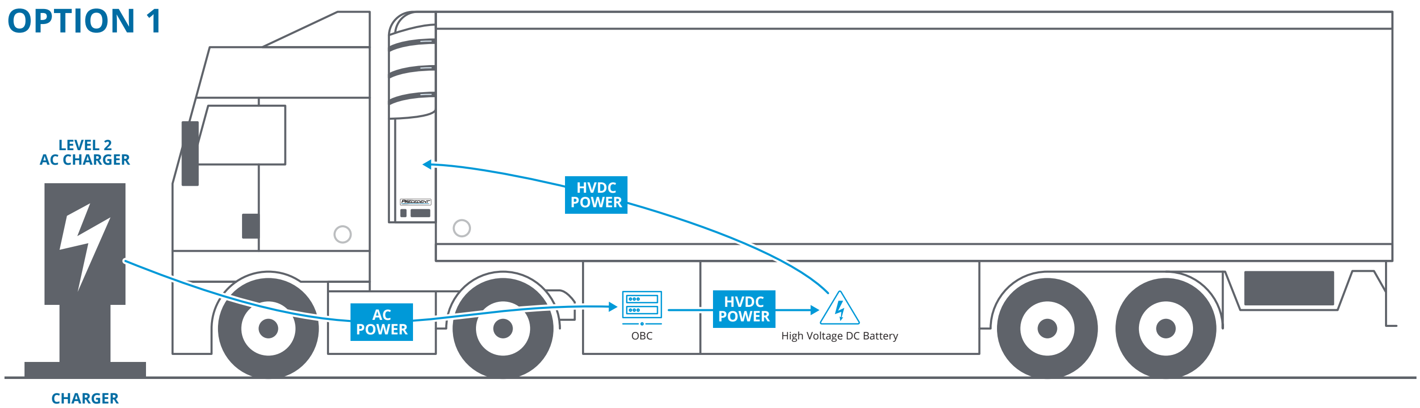
20 Year Total Cost Comparison for OBC vs HVDC Infrastructure



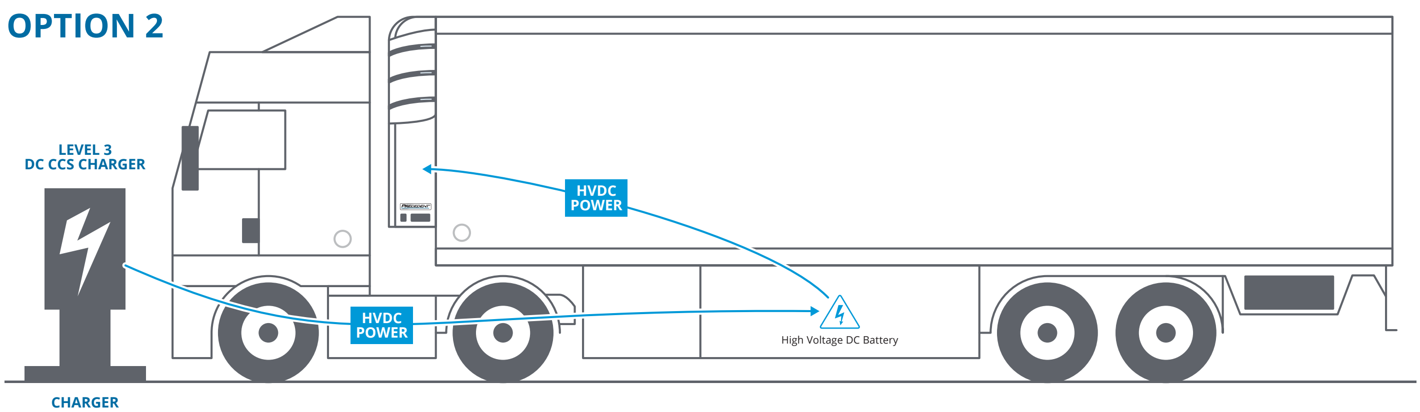
Assumes 7yr trade cycle (3 trade cycles calculated here). Assumes OBC cost of $10K, HVDC CCS1 installed cost of $17K, & 1:1 unit/charger ratio.

Equipment costs provided for reference illustration only.

OPTION 1



OPTION 2



BATTERY COST AND WEIGHT

Despite constant improvements in battery power density (which reduces weight while improving performance) and cost, batteries on the scale needed to support a battery powered TRU have several more years of further maturity to start to become practical. This is due to the added complexity of optimizing the development, mounting, and integration of the high voltage batteries onto a trailer in addition to the power electronics required to run the TRU. Unlike in passenger or commercial vehicles where the batteries are often integrated into the floor of the chassis where they are inherently protected, under a trailer (the most practical location) they are exposed to road hazards like railroad crossings and roll-overs. Real-estate on shorter trailers (under 40') is also an issue especially when additional under-trailer accessories are present like liftgates and ramps. The ideal location for battery mounting is in the floor of a trailer similar to the "skateboard" architecture of most EV's.

Optimal battery pack & system operating voltage is often debated given the contradicting pros and cons. Low voltage systems, considered 48V or less, have the primary benefits of lower cost and more widely available componentry, easier service, and an easier method of charging the batteries with readily available industrial chargers like forklift chargers. The major downsides of low voltage systems are the significant power inefficiencies versus higher voltage systems and significantly higher operating currents upwards of 400 Amps which require massive power cables. These power cables add significant system weight, cost, and generate large amounts of heat which add to the power inefficiencies and signficantly reduce component life as a result of the high heat.

In contrast, high voltage systems enjoy many benefits such as high power efficiencies, smaller cables, and long component reliability. These greater efficiencies result in less batteries required which results in lower system weight, system costs, and smaller components. However, the negatives of high voltage systems are more difficult upfront system design and component sourcing, and more expensive charging infrastructure (Similar to commercial EV needs). Consensus from the EV industry is putting in the added effort upfront creates lasting customer value that far outweighs the quick wins associated with low-voltage systems. Ultimately, it's believed that the higher voltage systems will be the dominant type used due to the resulting higher efficiencies and similarities to EV systems and components. So, if warehouses and distribution centers want to maximize infrastructure investments across tractors and trailers for inbound vehicles as well as their own fleet vehicles, the likeliest best solution would be the higher voltages found on vehicles and avoid the temptations of low voltages.

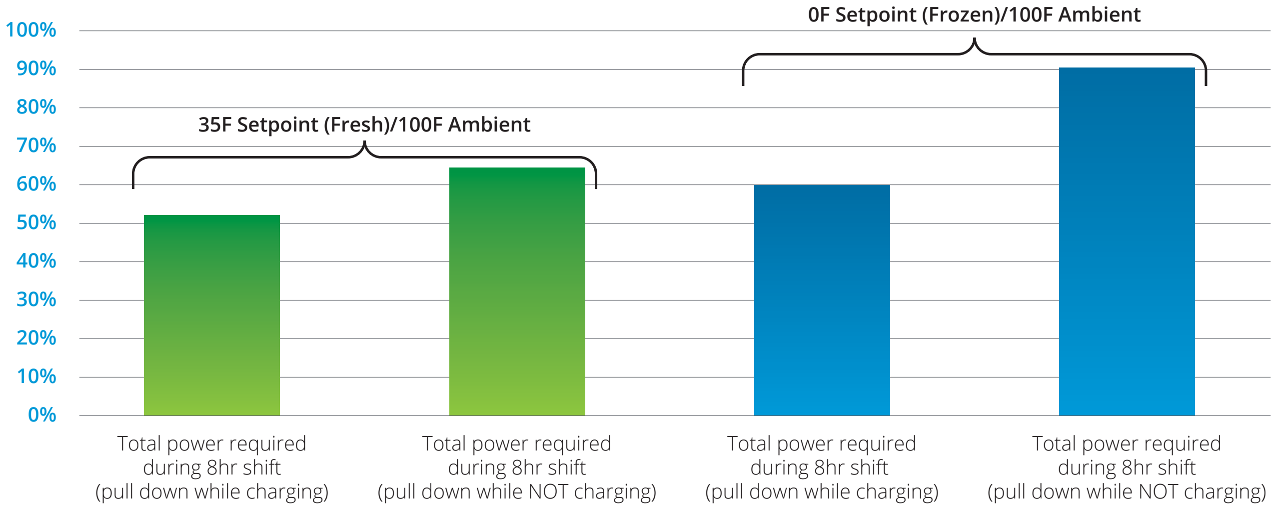
ARCHITECTURE TYPE

	48V	400-800V
Current transmission	>500A	20-30 Amps
Wire Size	Larger than 4/0 cable (.5lbs/ft)	10ga (.05lbs/ft)
Efficiency	High drive losses, heat generated in wires and components, short component life	High efficiency, low heat, long component life
Commonality with EV Chassis	None	Same as EV Chassis
Infrastructure Required	Basic 48V chargers (Equivalent to Forklifts)	HVDC CCS Chargers

BATTERY SIZE

Daily power requirements for a TRU can vary wildly based on operating variables like setpoint, ambient temperatures, door openings, cycle sentry vs continuous operation, etc. However, an instantaneous power requirement is around 15-20kW during steady-state running. Often the nomenclature of unit "runtime" vs "protection time" can confuse debates about how much total power storage is required. "Runtime" is defined as actual compressor "on" time or put another way when the unit is blowing cold air. "Protection time" is when the unit is on but may or may not be running. For example, in an 8hr shift with a 53' single-temp trailer that has a Fresh Setpoint at 35F and is operating in a constant 100F environment, the power consumed during pulldown is ~12kWh with another 52kWh consumed during operation. Additional variables like solar heat load, door openings, and insulative integrity will add to total runtime and total power consumption by as much as 2x. One important factor to note is the 12kWh consumed during fresh pulldown and the 30kWh with a frozen setpoint. When possible pulldown should always be performed while plugged into the grid to avoid consuming precious battery power that should be reserved for en-route operation to minimize the chance of running out of power.

Total Daily Power Consumption (53' Single Temp Trailer)



Due to the limited power in battery packs and daily variables that can make total power requires vary wildly across North America, ultimately it is expected that more regionalized & application specific power solutions will be required to optimize battery size required. Additionally, different operating regions may require different levels of battery thermal management (E.g heating or cooling) to allow the unit to run or charge most efficiently. For example, a BETRU operating at fresh setpoints (35F) in northern climates will likely require less than half of the battery size of an equivalent system operating at frozen (0F) setpoints and in the American southwest. Therefore, full understanding of the application is required to provide the end-user with the best possible chance of daily success with the lowest cost system.

ALTERNATIVE POWER GENERATION

Application specific power solutions also include various technologies that exist to potentially reduce the size requirement of battery packs. These include solar, regenerative axles, and ePTO power sharing as the predominant and most mature technologies currently available.

Solar

Solar has had a recent surge in popularity in transport applications in support of battery tending applications like TRU batteries, liftgates, and chassis batteries. Unfortunately the strong performance in those applications has skewed the perception that solar would be equally valuable in electric TRU operations when scaled up to multi-kilowatt applications.

As the broader solar industry has shown us, solar is a technology that is very niche. In applications like southern California the performance is quite good and stable and as a result that is where all the solar powered demonstration trailers have been stationed to-date. This application overstates solar's true application potential when in reality solar has many drawbacks when used in electric TRU operations. You can put about 6–7kW on a 53' trailer which in SoCal can produce about 30–35kW in a day which can provide about 2hrs of runtime. Additionally, a 6kW solar array comes at a cost of about 500lbs in added weight and $15–20K in product & installation costs. From a performance standpoint this is the BEST-case scenario as that same solar roof might only produce 10kWh or less in the Northeast, Northwest, or anywhere else on a cloudy day. Take an example where you have a TRU that typically runs 5 hrs per day on a cloudy day in the summer. In this situation a 6kW solar array may provide only 10kWh during the shift which equates to only 30–45min of runtime support. However on a sunny day in the summer the same TRU would likely have to run 7–8hrs per day but solar input jumps to 25kWh which equates to 1.5hrs of runtime support for a net loss of over 2hrs of runtime support. These two scenarios highlight that not only is solar input highly variable based on weather but more solar charging also increases solar heat load on the trailer and generally will cause more runtime and therefore power usage than what is gained from solar charging. This kind of variability and uncertainty makes it very difficult for fleets to plan. You can't simply add more battery power on that day and you stopping to charge the batteries for a few extra hours in the middle of the day is highly disruptive.

Another scenario is a long-haul operation starting in southern California and running up the coast to Seattle. The difference in solar performance is nearly 3x between the two regions which makes reliance on solar highly variable and difficult to plan for.

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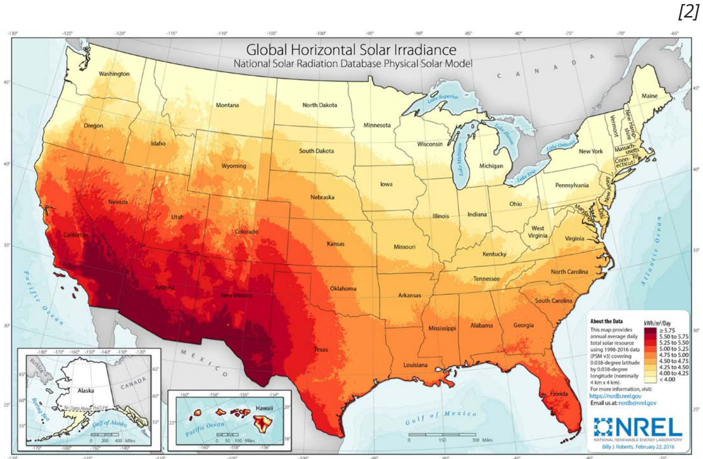


Lastly performance degradation is a major concern. Dents and dings from rocks, and soiling will reduce performance after just one year, but a single tree strike can ruin an entire roof. Soiling alone can account for anywhere from 2-25% output loss within a year. Snow scrapers can also be dangerous in northern climates where solar performance is already non-existent in the winter. Performance degradation is expected with any solar panel and while it creates a minor impact to battery-tending applications it presents a much larger impact in BETRU applications where a 25% reduction on a 6kW array can mean a 7kWh reduction in daily output.

When evaluating the future of solar and how it will fit into BETRU applications, one important factor is technology improvements over time which for solar have essentially plateaued. Various advancements in labs just haven't made it to practical application and performance increases average only 1-2% per year. This means that solar as a future way of providing daily reliable and predictable power to a trailer will continue to lose out to other methods like eAxles, and ePTO power sharing, as well as the annual double-digit gains of batteries in both power density and cost which will increasingly look more compelling over utilizing solar to improve daily range.

A secondary reason for putting solar on trailer roofs is that it will reduce the burden on the amount of grid powered required at a charging center. But that logic is flawed for a couple reasons. First, to install solar on a trailer roof the cost per is $3–4/Watt vs on a building you can do it for $2.87/Watt on average before tax credits. Also, you won't incur the wear and degradation on a building roof as you do on a trailer. Plus, in most cases, parked at a loading dock will result in the building shading the trailer and tying up charging infrastructure just to feed back to the grid is an expensive use of the trailer asset. Lastly, a larger stationary grid can be paired with power storage that can even out peak demand charges. So if you're looking to help unburden the grid the obvious choice is the roof of the charging location/home base. Also, incentives for roof-top solar will likely be better than trailer roof solar.

The last argument for adding solar to a trailer roof is that it reduces the charge time burden when it reaches home or a charging station. While it is true that every kWh of power generated by solar while en-route reduces charging time later, in context a solar roof generating even 30kWh in a day will only reduce charging time by a little over an hour which in most cases will not dramatically improve the turn-around time given that the trailer will likely need several additional hours of charging time to fully charge the battery bank. However in applications where power usage is low, solar power is high and reliable, and turn-around time is short, solar can be a benefit.

Overall, the key to BETRU adoption is having on-board daily reliable and predictable power. Enough variables already exist to make the limited on-board power available to future BETRU's hard to predict, size, and apply across North America. Adding in a highly variable power source like solar could significantly add to the complexity of designing and deploying a BETRU and the added cost and weight of solar can be better applied elsewhere.

REGENERATIVE AXLES

The basic components needed to capture braking energy are a generator, an inverter, and batteries. There are numerous examples of regenerative axles, (aka e-Axles) in electric cars and trucks that perform this function, and this technology can certainly be extended to trailers. Regenerative braking is essentially the opposite of powering a motor to accelerate a vehicle. In this case, the motor is used to slow the vehicle, acting as a generator, which produces AC output current that is then converted to DC by an inverter, and that energy is then stored in the battery.

The desired benefit of regenerative braking is harvesting and storing “wasted” energy lost to braking. In electric vehicles, regenerative braking is considered a range-extension technology. It is opportunistic energy capture, but it is variable, and is not predictable enough to rely on it in order to make it to your destination in some cases. Just imagine the difference in braking events driving in downtown San Francisco vs. driving across a Kansas highway. Additionally, even within the same city or even the same route, daily driving variables will affect power generation and add to the complexity and cost of having a common equipment spec across a local fleet. Obstacles to implementing this technology in refrigerated trailers will be component reliability, brake system integration, and Return on Investment.

For component reliability, the underside of a trailer is an extremely challenging environment for electronics to survive, especially for the expected asset life cycle. But, we see axle OEMs making good progress on electrification of straight trucks and tractors, and believe that durable components will be eventually be available. Regenerative brakes are not currently able to eliminate traditional braking systems, and they will need to avoid interfering with ABS and stability control systems. So, brake system integration will have to be addressed between the axle generator and the brake controller OEMs.

That leaves cost and return on investment as the remaining challenge. In an electric vehicle, the cost of the motors, inverters, and batteries are already accounted for in the core vehicle function. But, for trailers, they are all extra components that have some added cost and weight associated with it. However despite some technical maturity required, regenerative axles have the potential to be a promising source of power for trailers if the units stay in a known area (e.g Local and regional routes) with repeatable braking events where power can be reliably modeled.

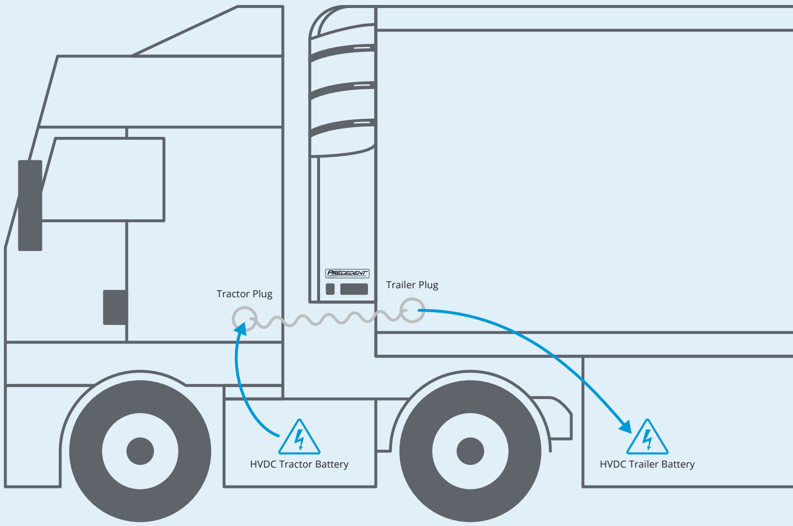
Alternatively, using an e-Axle 100% of the time in what's called a "dragger" application provides power input constantly to the system. By generating power while any forward motion is occurring, an e-Axle can be an incredibly good source of power generation but it has the drawbacks of generally not being allowed when pulled by a engine-driven vehicle as well as reducing the overall range of an EV tractor. Regardless of what is pulling the tractor in a "dragger" application, the power has to come from somewhere.

POWER SHARING (ePTO)

One of the big issues plaguing TRU manufacturers is how much power does a TRU need to ensure it can get through the day without power failure which could result in a very expensive load-loss. A promising technology to reduce the burden of designing for the top end of all use-cases is power sharing with the electric tractor that’s pulling it via an ePTO.

The argument against this approach is you’re reducing the range of the tractor by consuming power for the TRU which while true, it should be put into perspective. Most regional tractors in the near-term will end up with 300-500kWh battery packs that allow for 125–300mi range. So, if a trailer TRU is nearly done with its route but is low on power and needs another hour of runtime to get through the day, by pulling only 15kW for an hour of runtime, which equates to only 5% or less of a tractor’s power, then the argument is that is the best use of that power. Certainly this depends on the tractor having sufficient range as well and being able to balance the needs. The biggest benefits of the TRU being allowed to take power in times of need is significantly reduced cost and weight on the trailer.

This same approach has been discussed with diesel tractors pulling an electric TRU, but most regulations won’t allow for that to be considered a zero emission TRU since it’s receiving part of its power from an engine. Unfortunately, the technical equipment standard does not yet exist and the equipment to do it does not readily exist for the trucking industry as it requires specialized cables capable of high power transfer from tractor to trailer and more importantly safe disconnect and power removal. Like most new technologies, collaboration among the OEM’s is critical to gaining consensus and creating a standard.



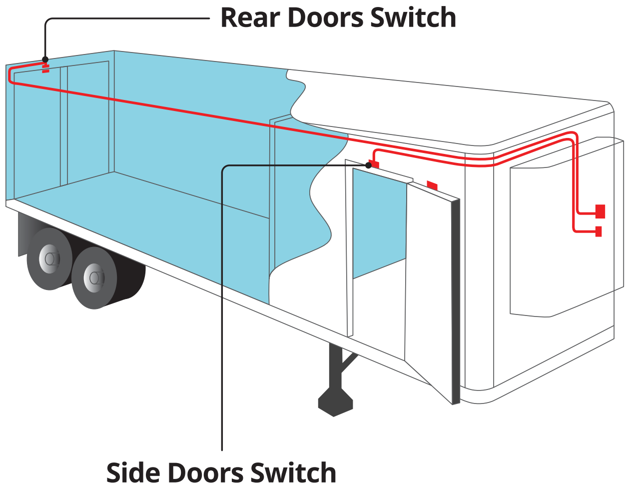
EFFICIENT REFRIGERATION BEHAVIOR

Other methods for reducing the need for large, costly, and heavy battery packs is smarter TRU operation. While creating TRU's that are very efficient in diesel operation provides a solid ROI to customers, the necessity to take things a step further has never been more critical when considering the impact of a small gain in power and operating efficiency can have on the battery pack required.

Several possible avenues for TRU improvements revolve around allowing the TRU to temp drift more if power starts to get low. While subject to the needs of the load being hauled, this can save significant power, versus maintaining a tight temperature band.

Smarter route planning will also play a part in creating the most efficient operations schedule that reduces the total shift length which can reduce mileage needs on the tractor as well as daily shift runtime on the TRU.

With door openings being one of the largest variables that impact TRU runtime, the need for door switches should be standard. Many misconceptions exist that while performing a drop-off, either at a store or a warehouse dock, the TRU should run to maintain the temperature in the trailer. This couldn't be further from the truth. Having the TRU run while having the trailer door open creates a situation where warm air is being pulled in on the bottom (across product still in the trailer) and then cooled by the TRU. This means the operator is actually actively heating up the contents of the trailer by allowing the TRU to run with the doors open and even when the doors are shut the TRU must now run even longer to cool everything back down. Door switches have been proven over and over to reduce runtime by double digits and therefore will be critical in reducing electric TRU runtime where power is not infinite.



TRAILER THERMAL EFFICIENCY

Thermal efficiency can play a big part in daily runtime and trailer maintenance that includes the insulation system and therefore power requirements. Diesel TRU's allow for less efficient trailers because they can provide enough cooling output to overcome efficiencies and the main penalty is more diesel fuel. BETRU operation will be much more sensitive to trailer thermal efficiency and therefore spending more on premium features such as thicker insulation on all sides, better insulation coverage, a moisture intrusion liner, and better ceiling and floor construction can all contribute to a more thermally efficient trailer. More advanced options that are coming to market include composite construction and vacuum insulation panels which have the promise of greatly improving overall thermal efficiency but have yet to be widely adopted.

SUMMARY

In summary, the electrification of trailer refrigeration units continues to progress but significant barriers exist as it relates to runtime reliability, incremental unit cost, operations adjustments, and charging infrastructure. Transition timing will likely be tied to the broader trucking industries' transition to electric as that transition will bring with it equipment and infrastructure subsidies, battery cost reductions and performance improvements, and learnings on operations adjustments. The industry will need to fail early and often in order to learn what it means to operate a BETRU paired with an electric Tractor but these early learnings will pave the way for a broad transition within the next 20 years.

The information provided in this position paper is for general informational purposes only. If you have any questions about this information, you should consult with industry professionals to provide you with the applicable or appropriate guidance for your particular refrigerated transportation needs. The information is provided "as is" with no representations or warranties with respect to the accuracy of the information to a specific situation.

Sources:

[1] https://www.electrificationcoalition.org/dashboard/

[2] https://www.nrel.gov/gis/assets/images/solar-annual-ghi-2018-usa-scale-01.jpg

THERMO KING

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