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Recommendations Regarding Future Trailer Energy Efficiency and Performance

Developed by the Technology & Maintenance Council's (TMC)
Future Trailer Productivity Task Force

ABSTRACT
Significant opportunities exist to collect or harvest energy using systems or technology on the trailer for improving the energy efficiency of the vehicle combination. Two such sources, solar energy collection and regenerative braking are being investigated in earnest and are in the early stages of commercial development. The purpose of this paper is to facilitate increased performance and energy efficiency for trailers. Additionally, this paper offers goals for energy efficiency improvement related to the design and operation of semi-truck trailers to encourage and accelerate development of appropriate technology.

INTRODUCTION
Transportation consumes a major portion of the energy used in the U.S. Heavy-duty vehicles represent a significant percentage of all vehicle miles traveled and truck-tractors pulling semi-trailers total some 2.8 million vehicles on the road today.

Estimates are that 60 percent of the energy used for transportation each year is consumed by medium- and heavy-duty (HD) vehicles and efforts to increase energy efficiency of those units have gained the attention of fleets, industry groups and regulators alike. Considerable attention has been focused on increasing the energy efficiency of truck-tractors and recognition that the trailer plays a vital role in vehicle efficiency has long been recognized as well.

Trailers contribute to energy dissipation of the combination vehicle primarily through rolling resistance and aerodynamic losses. Efforts to minimize those effects have been championed by such programs as the U.S. Environmental Protection Agency's (EPA) SmartWay initiative and by regulatory efforts such as California's Air Resources Board (CARB). In addition, the EPA and the National Highway Traffic Safety Administration (NHTSA) recently announced their Phase 2 Greenhouse Gas Emissions

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(GHG2) final rule which for the first time will impose federal regulations on trailer OEMs. The final legislation mandates features to reduce energy consumption for many types of trailers used in heavy duty operations.

In addition to reducing energy consumption by the tractor as a result of pulling the trailer there are other energy losses associated with the trailer's operation such as thermal losses in refrigerated trailer operations and kinetic energy dissipation thru braking. Significant opportunities exist however to collect or harvest energy using systems or technology on the trailer for improving the energy efficiency of the vehicle combination. Two such sources, solar energy collection and regenerative braking are being investigated in earnest and are in the early stages of commercial development.

The purpose of this paper is to facilitate increased performance and energy efficiency for trailers. Additionally, this paper offers goals for energy efficiency improvement related to the design and operation of semi-truck trailers to encourage and accelerate development of appropriate technology.

NOTE: This paper will not address any operational changes that a carrier may be able to identify and implement which may tend to reduce the number of "parked trailers," although this is certainly a desirable goal.

A. AERODYNAMICS

Aerodynamic (aero) energy losses (above approximately 40 MPH) dominate overall energy usage of the combination vehicle at highway speeds. The tractor and trailer act as a system to haul freight and likewise must be thought of as a system as far as aerodynamic losses. Some of the aerodynamic drag is clearly related to the interaction of the tractor and trailer, such as the aero drag associated with the gap or interface area between the tractor and trailer. Other areas of drag such as the underside of the trailer aren't as obvious in terms of interactive effect. The drag at the rear of the trailer might at first seem to be purely a function of the trailer geometry, but in reality all of these areas involve both the tractor and trailer as contributors to energy dissipation.

The trailer's influence on the total energy consumed to overcome aerodynamic drag is considerable. In simplest terms the trailer's drag can be divided into drag at the front or gap area, and the underside and rear as noted above. A significant portion of the drag is pressure drag due to the influence of the trailers geometry (shape) in the presence of the airflow over the trailer body, but some drag also exists due to friction at the surface layer. Both effects can be minimized with appropriate trailer geometry and significant opportunities exist for energy conservation. Aero drag on the trailer has been well known for decades, but commercial solutions focused on fuel savings have emerged only in the last 15 years or so. Today these solutions exist largely in the area of "add on" devices which can be installed by the trailer OEM at the time of purchase or retrofitted after the trailer has been put into service. To date these devices or systems have primarily been marketed for van or box type trailers.

Gap devices on tractors, trailers and dollies will become more commonplace and are already designed and manufactured to automatically adapt to one another. These allow the gap to be closed at speeds where aero improvement is possible and allow articulation at maneuvering speeds. Gap devices are generally constructed of resilient recycled materials and are not be easily damaged during even abusive operations.

Operators of commercial HD vehicles are focused on costs and rates of return on investment, and aerodynamic solutions are, in some situations, viewed as tools for fuels savings in the absence of regulatory requirements. Fleets typically look for economical and robust solutions that require minimal maintenance over the intended life of the vehicle. Aerodynamic devices are expected to be tough resilient systems and devices that are lightweight and not easily damaged, and that pay for themselves in fuel savings in a relatively short period of time considering the life of the trailer. This payback period must also consider the tractor to trailer ratio, which varies from approximately 1:1 in some operations to more than three trailers per tractor (3:1) in dry-van fleets that utilize "drop and hook" methods.

In the future, trailer aerodynamic solutions must be available for more trailer types and must lead to increased fuel and energy savings. Areas of development for trailer devices and systems abound and many vendors offer both devices and services leading to aero improvements. Goals for aero devices and systems are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Aerodynamic systems and devices must consider the tractor and trailer to be a unified system going forward. Improved trailer aero performance is possible when combined with tractor aero technologies. Innovation in true system design looking at a complete tractor-trailer vehicle with required aerodynamic performance would provide maximum return for fleets. However, one must also recognize that tractor and trailer manufacturers each also have a goal — to maximize the penetration of their product across all brands of "attached/attachable" vehicles. Thus, there will likely be a continuing need for add-on aerodynamic devices and potential energy capture and reuse systems such as regenerative braking and solar panels as mentioned in this position paper.
- TMC Study Groups S.11 Sustainability and Environmental Technologies, S.7 Trailers, Bodies and Material Handing, and/or S.4 Cab & Controls may wish to continue to monitor this or perhaps develop or refine an Recommended Practice (RP).

Actions:

TMC believes increased efforts and investigation should be undertaken regarding:

- Development of aerodynamic devices for other types of trailers such as flatbeds (platform trailers), tank trailers and other types that travel at highway speeds. For flatbeds, this would include development of recommendations for load positioning based upon dimension and weight and possible development and use of collapsible air shields that could be positioned in front of and/or behind the loaded materials. The American Transportation Research Institute (ATRI) is likely the best group to determine what should be pursued in this regard. TMC may wish to forward this to ATRI through ATA.
- Development and deployment of automated systems on the trailer to tune aerodynamic performance based on operating conditions. Such systems, for example, may provide a "kneeling" capability based on vehicle speed to more complex systems that adjust aerodynamic surfaces based on speed and wind conditions.
- Design and development of underside devices (including skirting) compatible with other items under the trailer such as tire carriers, side door steps, platforms and liftgates, pallet and beverage canister racks, etc. The Truck Trailer Manufacturers Association (TTMA) should keep this in mind as they go forward with new or revised designs or options.
- Design and development of underside devices intended to manage airflow beneath the trailer coming under, thru or around the tractor as well as from the side of the trailer. This will allow improvement

in aero performance beyond that of the trailer in a "yawed" condition. S.7 and/or the TTMA may wish to coordinate efforts in this regard.

- Design and development of underside devices constructed of resilient, recyclable materials with a memory that will allow the devices to return to shape and continue to be effective if they are deformed from interactions with fixed objects or obstacles. S.7 and/or S.11 may wish to develop or refine an RP on this topic.
- Design and development of underside devices designed and configured for shape optimization for different operating conditions like maneuvering speeds where additional ground clearance is required vs. highway speeds where maximum aero benefit is required. S.7 may wish to develop or refine an RP on this topic.
- Design and development of systems compatible with boat tail and other active rear devices intended to remove the need for driver interaction. Different types of speed sensors or mechanical pulley mechanisms already automatically open a boat tail at or before highway speeds and device versions should also be available that automatically fold themselves closed when the vehicle is traveling in reverse. These devices can also be designed so that they and can be used to slow the vehicles and save brakes.
- Design and development of rear devices built to undergo in service aerodynamic shape optimizations to maximize fuel savings depending on operative environmental conditions.
  - Overall trailer aerodynamics could become further optimized as the rear of the trailer becomes more integrated into the beginning of the boat tail shape.
- How rear devices such as "full" boat tails and boat tail plates for both swing type (barn) doors and overhead or roll door van trailers should/could integrate with or coordinate with other devices on the rear of the trailer such as lighting and conspicuity systems and door hardware such as vents and locking hardware to allow improved performance of both the aero system and the other trailer devices.

B. ROLLING RESISTANCE

Tire Technologies

Rolling resistance of the trailer dominates trailer based energy losses at low and moderate speeds. Trailer tire technologies are continually advancing with regard to rolling resistance and many trailer tires today are considered low rolling resistance (LRR) by the EPA SmartWay program which verifies tire technologies for HD vehicles. LRR tires are available in both dual and wide-based tire (WBT) types and both types are designed to minimize energy loss as a tire rolls, decreasing required rolling effort and resulting in improved fuel efficiency. WBT's can offer the added benefit of reduced tire and wheel weight, and typically have lower rolling resistance than equivalent duals, but in some operations WBT's do not generally provide the life and wear characteristics achievable with dual tires. Also not all retread shops are well practiced or equipped with the correct equipment to retread WBT's.

Trailer tires are a major operating expense for trucking fleets. Tires are designed and intended for long life and are expected to be retreaded several times over their lifespan to lower overall operating costs. Trailer tires are available in different models or configurations with various body or "carcass" designs and tread patterns and depths for various purposes. Tire re-treading is widely available to the fleets in many tread types including low rolling resistance configurations. Tires are also often moved from other positions to the trailer further complicating management of tires within a fleet. This process can be simplified to more easily track tires through multiple tread lives and positions with the use of imbedded RFID tagging.

Energy is dissipated as the tire rolls down the road due to the tire sidewalls flexing, the tread blocks compressing, and the contact patch interacting with the road surface. LRR tires are constructed using technologically advanced compounds with special tire construction techniques to help minimize rolling resistance while maintaining other necessary tire design and performance characteristics.

LRR tires can have tradeoffs in terms of performance as compared to standard tires, notably in tread life and to some degree traction characteristics. Initial costs of LRR tires and wheels may be higher, but the fuel savings associated with the use of LRR tires are typically recovered over their operational lifetime. Tire manufacturers continue to advance the design of these tires to deliver even higher fuel savings with less trade-offs in traction and tread life. It is important to select the right tire for the job considering service conditions. (TMC's S.2 Tire and Wheel Study Group has already developed and issued a number of RPs relative to this topic).

LRR tires are defined by their coefficient of rolling resistance (CRR) in a standardized test. According to the EPA, SmartWay verified LRR tires achieve rolling resistance of less than 5.1 kg/ton. LRR tires achieving rolling resistance of less than 4.7 kg/ton are currently commercially available for some applications and it is expected that in the future tires will continue to be developed and commercialized with perhaps lower rolling resistance. There is a suggestion that a "lifetime" CRR value be provided which would include accounting of and reporting for "true lifetime tire average rolling resistance." The Future Truck Committee defers this to TMC's S.2 Tire and Wheel Study Group to determine if an RP of some sort is appropriate.

TMC RP 235B, *Guidelines for Tire Inflation Pressure Maintenance* already addresses tire pressure and the impact the correct pressure has on effective tire wear and overall fuel economy.

As trailer tires wear there is a reduction in their rolling resistance because there is less tread to deform. Thus if a tire has even wear that prevents premature removal it can reduce fuel consumption and overall cost of ownership by both achieving longer life and being used longer at more efficient, lower tread depth. However, wear of trailer tires results in additional energy usage as a result of tire replacement or retreading. Reducing wear per vehicle mile traveled ultimately saves energy, but must be balanced against other tire characteristics. In addition to reducing wear via good usage practices such as inflation and alignment, a reduction in sensitivity to usage and operational factors such as these is very desirable for future tire designs.

Tire manufacturers continue to improve tire technology thru aggressive development programs. Goals for tires and tire development are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Improve load bearing capability thru material or design changes. S.2 and/or the Society of Automotive Engineers (SAE) may want to continue monitoring this for further development.
- Reduce wear due to "alignment" irregularities. S.2 may wish to research this further.
- Use of a harder compound and or changes to tread design intended to reduce "squirm" in an effort to improve wear characteristics thru both compound and construction design and manufacturing without adversely affecting traction characteristics. Consideration by S.2 and/or the Rubber Manufacturers

Association (RMA) for further review may be appropriate.

- Reduce tire weight to allow more trailer payload capability.
- Reduce diameter to allow lowering the trailer floor to increase trailer carrying capacity (trailer volume or cubic capacity).

Actions:

TMC believes increased efforts and investigation should be undertaken regarding:

- Development of advanced inflation technologies intended to:
  - Reduce or eliminate (through the development of airless tire/wheels combination) dependence on inflation. (See TMC Future Truck Position Paper: 2017-3, *Performance Expectations for Zero-Pressure Commercial Truck Tires.)*
  - Reduce tire rolling resistance and irregular wear as a function of inflation pressure variation.
- Development of active, application specific and intelligent inflation control to optimize tire inflation pressure with temperature, speed, load, etc. to improve both tire life and fuel efficiency.
- Development of a simplified tire carcass tracking method allowing more efficient utilization of tire inventory and carcass history.
  - Review of recycling options for possible improvement (S.11).
- Adoption or creation of an RP relative to a suggestion that was submitted, which follows: "Rolling resistance under SmartWay and GHG rules is a value measured for a new tire. It does not reflect the life-of-tire net rolling resistance which changes as tires wear and accumulate mileage. As tires have different life expectations, including retreading, there is a need to understand for fleets and regulators the true life-time-tire-average rolling resistance. Understanding the true net CRR over the life of a tire would permit better product comparison and selection, and a clearer understanding of the true performance of the trailer tire system. Also, under GHG2, there are objectives for future significant reduction in CRR over current SmartWay low rolling resistance threshold levels (Level 2 and Level 3 in 2025). However there is no stated expectation on tread life, lifetime mileage or lifetime average CRR."

Axle, Suspension & Wheel End Systems

Trailers roll down the road on tires and wheels supported by axles under suspensions. The tires and wheels themselves rotate around axle journals with the aid of lubricated bearings. All of these components contribute to rolling resistance which ultimately can be reduced, if not eliminated altogether.

Suspension systems exhibit hysteresis which results in not only damping, but energy loss into generated heat. Trailer axles add weight to the trailer and take up space underneath that could be used for other purposes. The trailer axles also contribute to aero drag as air under the trailer impinges on them.

Trailers utilize oil- or grease-lubricated tapered roller bearings. Such bearing systems are mechanically robust, easy to maintain and are durable.

Component manufacturers continue to improve axle, suspension and wheel end technologies. Goals for development are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Minimize the energy losses associated with hysteresis and to minimize maintenance.
- Reduce or eliminate the negative effects of the trailer axle (weight and aero drag). (S.11, S.7.)
- Enable optimization of maintenance to

extend component life as well as drive improvements in lubrication.

Actions:

TMC believes increased efforts and investigation should be undertaken regarding:

- Development of new suspension types (such as magnetic suspensions) for trailers which would lead to less energy lost to damping. (S.7)
- Development of wheel end systems with integrated, smart diagnostics (e.g. temperature, vibration characterization to predict life, failure). (S.7 and/or S.12)
- Development of lighter weight axles or "axleless" suspensions (think about certain pre-front-wheel drive passenger vehicle suspensions) to reduce energy consumption by the combination vehicle. (S.7)
- Systems relative to lubrication, bearings and their materials and adjustment systems should be investigated for improvement relative to both improved durability and reduced energy losses due to friction. (S.6 and/or SAE may wish to review existing nano-particle materials in this respect.)

C. TRAILER THERMAL EFFICIENCY

Certain trailers are expected to maintain cargo or contents at or near a desired temperature. Such trailers are generally referred to as refrigerated trailers or reefers, but trailers are also built where heating or cooling is necessary. In general such trailers are known as controlled temperature (CT) trailers.

CT trailers generally are designed to maintain a temperature difference between the interior of the trailer and the surrounding environment. Insulating materials are used to promote resistance to thermal energy transfer thru the trailer surfaces and special design and manufacturing techniques are employed to reduce this "thermal bleed". A transport environmental control unit is usually employed to maintain a protective air envelope around the load and thus maintain interior temperatures in light of inevitable energy transfer due to the interior/exterior temperature difference. In some cases trailers are designed and built with heating (only) capability where ambient conditions and cargos dictate.

Trailer insulation materials vary, but the most widespread and efficient material currently in use is polyurethane (PU) foam. The polyurethane foam used in a trailer is typically "blown" with a material like HFC 245fa, a "blowing agent". Blowing agents such as HFC 245fa and "next generation" blowing agents such HCFOs are typically contained in one of the two chemical components that are reacted to create the foam. The blowing agent then serves to expand the foam into a cellular structure with minimal solid content and ultimately is it is contained within the foam's cells. A property of the blowing agent is that its vapor thermal conductivity is much less than that of air, giving the PU foam its excellent insulating properties. PU foam also contributes structural capability to a trailer, allowing the panels themselves to act as structural sandwich panels to some degree.

CT trailers are typically aluminum-intensive due to the need for light weight, and aluminum, PU foam and other plastic materials typically make up a large portion of the trailer's body structure. While the PU foam and the plastic content of the trailer body are excellent insulators, the aluminum components of the trailer are not. Aluminum is used due to its mechanical properties and corrosion resistance and its use is balanced against the relatively poor thermal properties it affords.

The CT trailer size and design characteristics such as the wall thicknesses and basic structure combine to determine its overall heat transmission coefficient or UA (see TMC RP 718B, *Method For Classification Of Controlled Temperature Vehicles*). The trailer's UA is a direct measure of the energy transfer thru the body due to an interior/exterior temperature difference. This in turn equates to a heating or cooling power value to maintain that temperature difference. In order to minimize that heating/cooling power requirement, the UA can be lowered by use of thicker trailer walls for example. Thicker walls however, add weight and restrict interior dimensions, so trailer fleets typically balance the trailer UA vs. the trailer interior dimensions, weight and cost.

A primary goal for increasing the thermal efficiency of trailers would be to increase the resistance to thermal bleed by lowering the trailer's UA without reducing interior or exterior trailer dimensions. More efficient insulation systems than the present PU foams should be studied with the intent to allow trailers with lower UAs to be designed and produced. This may be able to be accomplished thru the use of new blowing agents or thru the development of "nano" PU foams that are being researched. Other technologies to improve PU foams should of course be investigated as well. Hybrid foams employing other materials such as aerogels may hold promise in the future as well.

Alternate insulation technologies exist, such as vacuum insulated panels (VIPs) which typically consist of a core structure surrounded by a multi-layer bag-like covering that is then evacuated to a near vacuum. Available commercially as standalone panels, VIP's can be several times as efficient as PU foam, typically R30-R50 as opposed to PU foam at roughly R6. VIP's have seen limited applications in commercial CT trailers, with cost, mechanical durability and the inability to provide structure to the trailer being the chief limitations. In the future though VIPs may offer significant thermal benefits versus or in addition to the use of PU foams if the cost of VIPs can be reduced.

Future CT trailers will be improved over present day trailers and trailer manufacturers work with materials suppliers and on their own on development programs. As with trailer aero systems and rolling resistance technologies areas of development for trailer insulation technologies are considerable. Goals for CT trailers their development listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Increase thermal resistance thru the development of improved insulation materials and technologies.
- Improve thermal resistance thru the reduction in the use of highly thermally conductive materials like aluminum and an increase in the use of non-metallic materials like reinforced composites.
- Foster development of alternative insulation technologies such as vacuum panels, improved PU foams and aerogels. (SAE)
- Reduce weight and cost of the trailer. Lighter trailers will allow more payload and reduction in CT trailer costs will allow fleets to better balance thermal performance vs. operational capabilities.
- Increase longevity of CT trailers. Longer lived trailers reduces energy consumed as a result of new trailer production.
- Increase mechanical strength and durability. This will allow CT trailers to be more versatile overall. (SAE)

Actions:

We believe increased efforts and investigation should be undertaken regarding:

- The use of highly thermally conductive materials in CT trailer design and construction should be reviewed and minimized. Non-metallic high stiffness reinforced composite materials offer great promise as a replacement for aluminum in certain applications. The reduction of thermal bleed of metallic materials by the use of technologies such as aluminum foam may prove commercially viable in the future as well. TTMA, SAE, S.7 may all wish to coordinate efforts in this regard. (We note the development of "clear wood" *http://www.huffingtonpost.com/entry/transparent-wood_us_56fd3c14e4b0daf53aeee8e6*)

D. TRANSPORT ENVIRONMENTAL CONTROL UNITS

Transportation refrigeration units (TCUs) provide a cooling or heating effect to allow a CT trailer to maintain an interior/exterior temperature difference. Typical TCUs are diesel powered and utilize a vapor compression cycle to transfer heat between a condenser and evaporator. Some TCUs act as a host unit to control and power remote evaporators when used with compartmentalized trailers used in multi-temperature configurations. Some TCUs utilize direct driven (mechanically driven) compressors and some utilize a generator or alternator to in turn power an electrically powered compressor. Some TCUs have the capability of running in a "standby" or "shore powered" mode to allow cooling or heating operation without the need to run a diesel engine.

Trailer TCUs have existed for many years. Typical TCUs are powered by a small engine and are used to cool temperature sensitive loads by circulation a protective air envelope around the load in the trailer. This air envelope is cooled by the TRU's evaporator section, where compressed refrigerant is expanded cooling the evaporator coils as air circulates thru them. Heat absorbed by the refrigerant is rejected to the atmosphere by the condenser of the host unit. Operation of the TCU is typically controlled by a microprocessor, allowing both precise control of operation and efficient operation. Trailer TCUs may be run in start-stop mode(s) where the payload allows (frozen goods as an example) or the load may require continuous run mode, such as for respiring produce.

Other types of TCUs exist beyond mechanical vapor compression types. TRU's that expand nitrogen or carbon dioxide have been and are in use. These TCUs require a tank (pressure vessel) of compressed gas to be carried with the trailer in lieu of a diesel fuel tank mounted to the trailer. Additional infrastructure to periodically replenish the compressed gas to be subsequently expanded is required. This is not the case for diesel powered TCUs which can be fueled when the tractor is fueled.

Some TCUs utilize "cold plates" that contain a solution that removes heat while undergoing a phase change. These TCUs can be "recharged" during periods of inactivity or by means of electric power generated by the vehicle while in use. While not as popular as TCUs using vapor compression cycles, cold plate technology is a viable method of cooling that may in the future prove to be very valuable technology.

Future trailer TCUs will be improved over present day units. TRU manufacturers work with users and suppliers of components and technologies as a part development programs to improve performance and reduce energy consumption and emissions. As with other trailer technologies areas of development for trailer TCUs are considerable. Goals for trailer TCUs their development listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- A major focus for future trailer TCUs is the development of alternative power sources. Small diesel engines that power most of today's TCUs may be obsolete in the future.
- Development of alternative refrigeration/heating technologies (as opposed to vapor compression) should be a priority as well. Alternative heat transfer mechanisms may allow better energy efficiencies than present day technologies.
- Increased durability of the TCU itself will lead to less TCUs being produced over

time and less energy expended during their manufacture. More durable TCUs that remain more efficient over their lifetime will improve energy efficiency as well.
- The development of systems that maximize the heating/cooling effect will lead to more efficient TCUs. Refrigerants in use can continue to be improved with regard to working characteristics and reduction of undesirable properties. New refrigerants can be developed to further those goals as well.

Actions:
TMC believes increased efforts and investigation should be undertaken regarding:
- Development of:
  - All-electric/plug-in/battery/vehicle generator powered TCUs.
  - All-electric/plug-in/cold plate TCUs.
  - Hydrogen fuel cell-powered TCUs.
  - All-electric/plug-in/battery/solar-assist TCUs.
  - Alternative fueled engine powered TCUs.
  - Use of "vacuum with liquids" (such as water). As a vacuum is created, moisture is drawn off (as vapor) resulting in significant temperature reduction. Of course, the vacuum cannot be maintained while traveling as the trailer construction may not support the pressure differential and/or the product in question could be frozen beyond acceptable levels.

- Several technologies being used today that justify further development are:
  - Cryogenic TCUs.
  - TCUs utilizing cold plate technologies.

E. ENERGY HARVESTING

Solar Energy
Solar energy impinges on the earth's surfaces at a rate that exceeds imagination. Currently solar power generation for electricity generation is beginning to take hold in areas where solar arrays are expected to have a "clear view" of the sun during much of the day, and much of the year depending on climactic conditions. Solar power is starting to make inroads into transportation and specifically for semi-truck trailers as well. Current applications are for battery charging for trailer "reefer" units (trailer TCUs), for liftgates and for tracking systems, although other uses certainly exist.

The large planar areas of a trailer offer much promise for collecting solar energy, although the mobile nature of trailers complicates optimal orientation. The roof of a trailer provides many square feet of surface area for mounting arrays. Properly designed solar energy collection systems are capable of supplemental charging needs of batteries used in trailer liftgate systems and for TCUs when needed because of deep cycling or long periods of inactivity. Similarly trailer tracking systems on trailers that are sometimes parked for long periods of time without access to other means of charging use solar arrays to great effectiveness.

Solar energy generation is limited by array effectiveness, energy transfer efficiency and by the means for energy storage. Array effectiveness depends largely on several factors, the foremost being orientation. Additional factors that come into play are the degree of solar radiation impingement due to such effects as weather conditions and seasonal effects, cleanliness and of course overall array size (surface area). Current transfer efficiencies are sometimes only single digits and costs per watt generated vary greatly. Different types of solar energy collection systems exist but for practical use on transportation systems only photovoltaic systems are being considered here. As such batteries are the typical storage elements for such systems, and various types of batteries are commonly used. Improvements in array and energy storage technologies will help further solar energy use in transportation and specifically for truck trailers. Advancements in these two key areas will help solar energy harvesting grow into a more economical and widespread practice where practical.

As previously mentioned, solar arrays continue to improve in general but need to improve specifically in terms of transfer efficiency and durability. Means for orienting the arrays for optimal sun angle are practical in some fixed applications, but for mobile trailers a focus on array cost and areal power generation density may be a better approach. Additionally a means for or design for automatically maintaining array cleanliness is an important part of array effectiveness in the mobile environment.

Electrical energy storage systems, specifically battery (and capacitor) technology is continually evolving as well. Cost and weight reduction, and deep cycling capability are primary goals as is overall cycle life. The ability to charge slowly but release energy quickly when called for is important for some applications as well.

Future trailers may all incorporate some sort of solar energy collection systems due to the abundance of impinging energy. Solar systems will undoubtedly be superior to present day units. System manufacturers work with users of trailers to better design systems to accommodate in-service needs. As with other trailer technologies areas of development for trailer solar energy harvesting systems are considerable. Goals for solar system development are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Improve transfer efficiency of the overall system. TMC suggests a goal of doubling (as a minimum) or perhaps tripling the efficiency of present day systems.
- Improve array technology in many areas. The list below contains suggested areas of improvement:
  - Produce arrays that are less sensitive to orientation or alternatively devise alignment technologies to assist arrays to maximize performance.
  - Reduce the overall size requirements for arrays based on area power density capability and maximize power output for a given array size.
  - Address the issue of cleanliness by developing self-cleaning arrays.
  - Develop and design systems that are less affected by weather and seasonal effects.
  - Continue to develop films or coatings that convert solar energy into useful electric energy and can be used in lieu of traditional arrays.
- Improve battery technology by reducing cost and weight and improving cycling capability (overall lifetime cycle capability and deep cycling capability).
- Reduce system and component costs thru design and production techniques.
- Improve durability of system components, particularly arrays and batteries.

Regenerative Braking

Trailer kinetic energy losses through braking represent wasted energy, dissipated as heat, that could be recovered thru regenerative braking systems. Long a part of hybrid car technologies regenerative braking is well known and practical in those applications. Several efforts are currently underway to develop commercial systems for trailers. In those systems energy harvested by braking effort is stored onboard the trailer for later reuse as motive power or to provide electrical energy for various purposes.

Due to their drive cycle, some trailers could be an excellent source of energy thru regenerative braking, however, not all are. Conventional trailers typically don't have a "good" means for storing the energy that could be harvested thru braking and similarly most don't have a good means of utilizing the energy if it had been stored onboard the trailer. Conventional trailers also do not have a means of transferring the energy to the tractor for later use, so many challenges exist to effective use of regenerative braking on trailers. Finally regenerative braking systems typically do not serve as the only brakes on vehicles. Conventional braking systems are still required to actually brake the vehicle in many situations including hard stops and parking. Although all these issues represent challenges, all represent areas of opportunity for regenerative braking systems for trailers.

In addition to systems currently under development to convert trailer braking energy into motive power, systems are being tested that convert braking energy into useful refrigeration effect. This further illustrates that energy harvesting systems can be designed and implemented to interact with the other systems on the trailer that utilize energy in a practical and productive manner. Such relationships help lower the costs and increase the practicality of both the harvesting system and the TCU increasing the cost effectiveness of both while reducing emissions.

As with solar systems all future trailers may incorporate some sort of energy collection system associated with braking due to the fact that all trailers have and use brakes. Braking energy system manufacturers must work with users of trailers to better design systems to accommodate in service needs and trailer usage patterns. Although the challenges are considerable, the potential benefits of braking energy harvesting systems are also considerable. Goals for regenerative braking system development are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- The primary goal of a braking energy harvesting or collection system is to design a practical system(s) in terms of system cost and weight. The ability to efficiently collect the energy, store it and then reuse it are primary to any practical system. If motive power is employed as a means of using the harvested energy then appropriate means of use including a safe robust control system to allow such use, is paramount.
- In order to reduce cost it is necessary to maximize the durability of such systems. The area of the trailer where this system is expected to survive is certainly challenging (the trailer underbody) and the system must be designed to exist in this environment for the life of the trailer with minimal maintenance.
- Trailer usage varies considerably and one way to reduce cost of these systems is to reduce the effects (influence) of the "drive cycle." Systems should be considered, designed and manufactured to maximize capability for a variety of trailer usage scenarios.
- It will be necessary to encourage or foster development of a variety of energy usage options. The use of the collected energy (friction or static electricity, for example) as electric energy or as motive power should be primary goals.

F. ONBOARD ENERGY STORAGE

Many opportunities exist to harvest or collect energy and some have been previously mentioned and briefly discussed. Solar and braking energy harvesting or collection are currently being pursued thru the development of commercial systems, but other opportunities surely exist. For example static electricity collected from the trailer body created by air friction may possibly be a viable energy source in the future. Likewise a small wheel mounted generator can be an energy source in the future to support trailer electrical demands independent of the tractor.

A common problem for the collection and reuse of harvested energy is where to store it efficiently and in a cost effective manner.

Electrical energy is typically stored in a battery and many types of batteries currently exist and are used on trailers. Capacitors are also used to store electrical energy and some energy harvesting systems for trailers use capacitors for that purpose.

Improvements in onboard energy storage systems are a part of the development of successful and cost effective energy harvesting systems. Goals for onboard energy storage system improvement are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Improve overall storage capacity of the energy storage system or device.
- Improve energy density of the storage system or device.
- Reduce storage system overall and life-cycle cost.
- Reduce the weight of the energy storage system.
- Improve storage system life (overall and cyclic capability)
- Optimize rate of energy storage and release.

Actions:

TMC believes increased efforts and investigation should be undertaken regarding:

- Mechanical or chemical means of energy storage should be investigated and exploited where possible.
- Increased use of capacitors rather than batteries for energy storage

G. INCREASE IN TRAILER CARGO CARRYING CAPACITY

It is well known that an effective way of increasing HD vehicle energy efficiency is by increasing the carrying capacity of the truck or trailer. Incremental gains in cubic capacity or weight carrying capability have been shown to be safe and effective methods to improve performance as measured in ton-miles per gallon of diesel fuel burned or other energy equivalents. Although there are many statutory limitations on larger or heavier trucks, there are means to increase the ability of a trailer to carry cargo within current limits.

Weight Reduction

A very straightforward way to allow trailers to carry more payload weight is to make them lighter in terms of tare weight. Most trailers van or box type trailers are already aluminum intensive, but some of the trailer is made from steel and other materials such as wood are sometimes employed as well. Aluminum is used in trailer design and construction due to its excellent combination of properties, specifically relatively high strength and stiffness, resistance to corrosion and reasonably low cost. Aluminum is also highly recyclable making it an ideal material for many types of trailers.

Steel is used for trailer components requiring higher strength and stiffness than aluminum typically affords. Trailer axles, upper couplers, rear frames and floor crossmembers in certain parts of van trailers are typically made of high strength low alloy (HSLA) steels. Steel allows these portions of the trailer to be strong and stiff at lower costs than other materials would make possible.

Volume or Cubic Capacity Increase

Many trailer loads are not weight limited but are in fact limited by the cubic capacity of the trailer. Simply put the trailer "cubes out" before the trailer "weighs out." Trailer dimensions are limited by both Federal and State highway regulations, and local laws sometimes limit the sizes of trailers as well. Length, width and overall (in service) height are all regulated by a patchwork of laws that are seemingly based on infrastructure limitations. Larger trailers in terms of longer, wider or taller trailers are probably not a practical consideration in the immediate future as both legislative changes and infrastructure improvements would need to be coordinated for this to happen. We view this as unlikely. One area that has been only partially exploited is lowering the floor in the trailer to increase its cubic capacity. Drop frame or drop floor trailers exist, but these have limitations in terms of forklift loading and in interfacing many loading docks.

Improvements in cargo carrying capacity are a well-known method of improving transportation efficiency of HD vehicles. Goals for capacity improvement are listed below. This list is certainly not exhaustive and should only serve to encourage development of more ideas for improvement.

Goals:

- Reduce weight thru the use of lighter weight materials such as aluminum and high strength, high stiffness composite materials in lieu of steel.
- Improve the cubic capacity of the trailer such as by lowering the floor and preserving the ability of the trailer to be forklift loaded or perhaps loaded by other means. Develop suspension systems or other means to allow the trailer to continue to interface with existing loading docks in a practical manner.

H. REGULATORY IMPACTS

We must not minimize or overlook the impact of governmental regulations. As stated earlier, EPA/NHTSA has announced the Phase 2 Greenhouse Gas Emissions (GHG2) final rule which for the first time will impose federal regulations on truck trailer OEMs. The proposed legislation mandates features to reduce energy consumption for many types of trailers used in heavy duty operations.

We also have existing regulations that seem to go against logic and physics. For example, CARB requires side skirts on all trailers. However, side skirts have *little or no positive impact* when used in certain low-speed operations such as in-city pickup and delivery (P&D) processes. Requiring skirts on P&D trailers seems to us to have little, if any, benefit and may actually result in a net *inrcease* in use of energy.

Those who may require a list of the upcoming GHG2 regulations review the EPA website:

https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-commercial-trucks#regulations

This site covers the light- and heavy-duty final rules that go into effect in 2018 with implications out to and beyond 2025.

Goals:

To foster increased choices to comply with existing and upcoming government regulations such as CARB and GHG2, to some extent through testing and education of regulators (as in skirts on P&D trailers).

The American Transportation Research Institute (ATRI) recently published *Cost of Congestion to the Trucking Industry:2017 Update* which, along with several other ATRI documents, cover topics such as the road environment, including the effects of traffic conditions, hours-of-service rules, wait times at warehouses, dead heading, lost time looking for parking, etc. TMC encourages ATA to continue their efforts of educating federal and state regulators as they consider designs for new and improved highways as those efforts relate to improving net miles per trailer per year. TMC also encourages ATA's ongoing efforts as they relate to the use of longer combination vehicles. While not the solution for every lane or market or operator, they are an opportunity that deserves some attention within the topic of this paper.

SUMMARY

Many opportunities exist for improving the energy efficiency of heavy duty commercial vehicles and combination vehicles such as tractor-trailer units continue to improve due to voluntary efforts and regulatory pressures. Trailers have benefitted from fuel savings technologies for a number of years, but continued improvement is needed in the future. Trailer technologies represent a large percentage of the energy reduction potential for long haul HD commercial trucks going forward. In addition, energy efficiency improvements through operating technologies such as autonomous operation and truck platooning must be fully explored.

Trailer aerodynamic improvements represent an underutilized method of reducing energy consumption and significant improvements in the penetration rates of cost justified aero systems for trailers is needed. Aero improvements for trailers have been known for many years, but only within the past decade or so have commercial devices and systems been widely available. In many ways aero systems for trailers are still in their infancy and future trailers should utilize these improvements whenever cost justification allows.

Trailer tires continue to improve and LRR tires are available for many applications. Development of LRR tires for additional applications must continue but technological improvements to improve wear and damage resistance of trailer tires in general should also be the focus of tire manufacturers.

Insulation and refrigeration technologies used in and for trailers must continue to evolve and progress. Improvements in these areas of CT trailers have long been evolutionary as opposed to revolutionary and technological improvements in insulation and refrigeration for trailers would be a great benefit.

Energy harvesting technologies for trailers need continued development and commercialization to allow these relatively untapped sources of solar and braking energy to be better exploited. Static electricity from the trailer body created by air friction may be able to be harvested in the future as well.

Finally, load carrying capacity improvements for trailers represent a well-known source of improvement in energy utilization per ton mile of cargo carried. Innovation in this area faces challenges in terms of infrastructure and is bounded by regulation, but this remains a very viable means of enhancement. With some careful consideration and innovation, perhaps this relatively low-tech method may soon offer a boost to the industry.

Finally, TMC must mention SAE J3016 and the various levels of automated vehicle operation, which will certainly impact trailer design. TMC's Future Truck Committee is specifically discussing an auto tractor/trailer coupling technology currently being adopted in the European Market under the ISO 13044-2 global standard. The potential that market penetration of safety automation technology in the automotive fleet may have secondary benefits to the commercial vehicle fleet safety, improving car-to-truck spacing and perhaps netting higher average highway speeds, less inefficient use of braking and acceleration. ❑