EPA Truck OEM APU Prep Kit Design and Installation Project

FINAL REPORT

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Introduction

In October 2005 the NC Solar Center at NC State University (NCSC/NCSU) was awarded $500,000 from the U.S. Environmental Protection Agency (EPA) through a competitive solicitation for the *Truck OEM APU Prep Kit Design and Installation* project. The project concluded in August 2008. The purpose of the project was to develop and evaluate the effectiveness of mobile idle reduction technologies in long haul trucks.

There are 680,000 long-haul freight trucks with sleeper cabs in the United States[1]. Long-haul freight truck drivers need to take rest stops under the Federal Hours of Service (HOS) regulation in order to reduce driver fatigue[2]. During in-cab rest periods, drivers usually idle the base engines to power the heating, ventilating, and air conditioning (HVAC) system, and provide power for small appliances, such as refrigerators, and electrical outlets.

The average annual rest stops for long-haul truck are estimated to be from 1,460 to 1,800 hours, varying from 500 to 4,000 hours per truck[3]. Anti-idling strategies include mobile options, such as auxiliary power units (APUs), and stationary options, such as truck stop electrification (TSE)[4]. APUs are small diesel engine-generator sets that can supply power for electrical HVAC, and auxiliary loads. On-board TSE systems, referred to as shore-power (SP) systems, allow trucks to directly connect to a stationary source of electricity. An off-board TSE system provides electricity and HVAC via a module that fits in a truck window.

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[1] US Census Bureau. *2002 Economic Census: Vehicle Inventory and Use Survey-- Geographic Area Series-- United States: 2002*; EC02TV-US; U.S. Census Bureau: Washington, DC, December 2004.

[2] ATRI. *Idle Reduction Technology: Fleet Preferences Survey*; American Transportation Research Institute, Prepared for the New York State Energy Research and Development Authority, Albany, NY, February 2006.

[3] Lutsey, N.; Brodrick, C.-J.; Sperling, D.; Oglesby, C. Heavy-Duty Truck Idling Characteristics: Results from a Nationwide Truck Survey. *Trans. Res. Rec.* 2004, 1880, 29-38. Gaines, L.; Vyas, A.D.; Anderson., J.L. *Estimation of Fuel Use by Idling Commercial Trucks*; Paper No. 06-2567; Presented at the 85th Annual Meeting of the Transportation Research Board: Washington, DC, January 2006.

[4] SmartWay Transport Partnership, U.S. Environmental Protection Agency, Ann Arbor, MI, 2007. http://www.epa.gov/smartway/ (Accessed May 2008).

Acknowledgements

The NC State University's Truck OEM APU Prep Kit Design and Installation Project funded through the U.S Environmental Protection Agency's SmartWay program fostered a collaboration between Volvo Technology of America and university researchers that resulted in new methods to evaluate the "real world" usage and emissions reduction of auxiliary power units (APUs) to reduce base engine idling of long haul trucks. Another key result was Volvo's development and commercial introduction of 1) a shore powered AC HVAC for plug-in "hybrid" applications and 2) a fully mobile on-board APU- an AC HVAC system powered by an on-board 120 VAC diesel powered generator and 3) a Prep-Kit to facilitate the installation of APUs on new trucks . These results grew out of field demonstration whereby two fleets utilized two APU's for a real world evaluation of mobile idle reduction technology

The NC Solar Center at NC State University wishes to acknowledge the support of the U.S. Environmental Protection Agency's SmartWay program for funding the Truck OEM APU Prep Kit Design and Installation Project, particularly EPA project managers Mitch Greenberg, Paul Bubbosh and Mary Walsh.

The coordinator of this project, Anne Tazewell, Clean Transportation program manager at the NC Solar Center, is grateful for the collaboration with graduate students and the research leadership provided by Dr Chris Frey and Dr John Stone as well as Volvo's project team which includes Skip Yeakel, Chuck Villa, Randy Peck ,Johan Hultin and Bill Klodaski. Moreover, Volvo's industry partners including Bill Hathaway at Cummins, Lou Siegel at Dometic and the project team at Mechron Power Systems are to be acknowledged for their commitment to developing technologies to reduce fuel use and emissions of the long-haul trucking industry.

Project Summary

With $500,000 funding from the U.S. Environmental Protection Agency (EPA) the NC Solar Center at NC State University (NCSU) conducted a 34 month Truck OEM APU Prep Kit Design and Installation Project that began in October 2005 and concluded in August 2008. Goals for the project were to (1) evaluate in-use performance of the mobile idle-reduction technology (MIRT) by characterizing actual idle reduction times from an idling baseline provided by the fleet from existing trucks; (2) work with partners to evaluate fuel, maintenance, engine life savings, payback times, and user reactions; and (3) submit a final case study report to EPA at the conclusion of the study, and publicize the case study to the trucking industry to increase the knowledge, awareness, and lessons learned from the project.

Through a competitive solicitation to Truck Original Equipment Manufacturers (OEMs), Volvo Technology of America (VTA) was awarded a $350,254 subcontract to develop a Prep Kit to

facilitate MIRT installations, demonstrate auxiliary power units (APUs) in a minimum of twenty over the road trucks, track MIRT use, truck idling and driver acceptance. VTA collaborated with three principal technology providers to develop two APUs, APU-A and APU-B, that were utilized by two fleets, Fleet A and Fleet B. The twenty trucks participating in the field demonstration operated for over 2.8 million miles in 42 states during the sixteen month data collection period, which ranged from September 2006 to February 2008. From this field test and additional research conducted by NCSU, data was compiled to assess fuel displacement, cost saving and emissions benefits.

The Prep Kit designed by Volvo accommodated APU- A and APU- B, however due to the time requirements of the project; the Prep Kit was not utilized by the field study trucks. Nevertheless, the development of the Prep-Kit drove standardized mounting locations and methods assuring more secure MIRT installations and savings of an estimated 150 minutes in “prep time” per installation for the MIRT service provider. Through August 2008 Volvo had received 572 new truck orders for the Prep-Kit.

The APUs utilized by Volvo’s project partners were comprised of three components: an engine (2006 Kubota Z482 048 liter engine); a generator and a Heating Ventilation Air Conditioning (HVAC) system supplied by Dometic Environmental Corp that utilized a "split system" in that the evaporator and condenser are mounted separately. The fleets selected by Volvo for the field demonstration represent a wide spectrum of the company’s customer base. Fleet A had a self reported annual idling rate of 2,500 hours with single drivers utilizing Volvo’s largest black cabs while Fleet B utilized mid-size white cabs with team drivers that have a reported average annual idling time of 800 hours per truck from information provided to Volvo via truck dealerships.

Through August 2008 a total of 136 APUs had been ordered by new truck customers, in addition to the 20 trucks with APUs that participated in the field study and two additional trucks that were outfitted with APU- A and APU- B at the start of the project. VTNA has made a business decision to target primarily the AC/HVAC type MIRT systems. AC/HVAC refers to a HVAC system that can be used from a 120Vac power source while the vehicle is parked. The primary reason for this is the ability to operate the complete HVAC system from plug-in shore power, thus eliminating the need to run the diesel-powered generator set when shore power is available. Through August Volvo had received 4 orders for Dometic HVACs, a product that requires Shorepower.

A data acquisition system was installed by Volvo in each of the 20 trucks participating in the field test to determine idling hours and use of MIRT. The data acquisition system was comprised of four major components: electronic control units (ECUs), additional sensors, a data logging system, and Volvo Link^{TM}. NCSU researchers, Dr Chris Frey and graduate student Po-Yao Kuo tracked and interpreted data from the field test trucks. Fuel-based emission factors for the base and APU engines were estimated based on fuel properties and emissions measurements using a Portable Emission Measurement System (PEMS) by the NCSU team. Fuel use rates were also calculated for the base engine using ECU data, which for the field truck data vary depending on ambient temperature, and the APU which was calculated as a function of electrical load. Fleet A average fuel consumption rates varied from 0.47 to 0.65 gal/hr per truck or by 38%, over a range of temperatures. Fleet B average fuel consumption rates vary from 0.46 to 0.58 gal/hr, or by 26%. The two APUs have similar fuel consumption rates of 0.45 gal/hr at a load of approximately 3 kW. However, APU-A is more fuel efficient at higher load whereas APU-B is more fuel efficient at lower load. Although both APUs use the same engine, they operate at different RPM.

Drawn from the emission characterizations conducted by the NCSU team, the use of an APU instead of the base engines, if substituted 100% of the time for idling the base engine, leads to a 36 to 47 percent reduction in fuel use and emissions of carbon dioxide (CO_2) and sulfur (SO_2) under various loads as well as 80 to 90 percent reduction in nitrogen oxides (NO_x) emissions. Particulate matter (PM) emissions are reduced by 10 to 25 percent. There may also be significant reductions in emissions of HC and CO, but these data were typically below the PEMS detection limit and thus are not deemed to be statistically significant.

For Fleet A (mostly single drivers), the annual average idling for all stop durations and extended idling are 2,130 and 1,450 hours, respectively. The latter is comparable to literature estimates. For Fleet B (mostly team drivers), the averages are 770 and 250 hours, respectively. The proportion of APU usage during extended idling for single versus team drivers is estimated to be 67 and 28 percent, respectively.

For Fleet A, the use of anti-idling devices for all stop durations led to 72 to 416 gallons of avoided fuel use per year, which reduced fuel use by 8 to 28 percent. For Fleet B, average avoided fuel use during all stops and extended idling were -4 to 89 and -7 to 75 gallons per year, which is significantly less than for Fleet A. Negative values of avoided fuel use are attributed to a significant cumulative duration (e.g., over 270 hours per year for one truck) of double-dipping. Double-dipping refers to simultaneous usage of the APU and the base engine. Without double-dipping, avoided fuel use for all trucks would have been positive.

For all stop durations, avoided annual average fuel use and CO_2 emissions were 22 and 5 percent, respectively, for Fleets A and B. The differences in real world versus previously estimated avoided fuel use and emissions are because of differences in fuel use rates and emissions factors, lower hours of idle reduction activity, and double-dipping, which accounts for 0.1 to 29 percent of cumulative powered stop duration.

NO_x emissions for all stops were reduced by 47 and 12 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 70 to 90 percent. Avoided fuel use and emissions are only minor for team drivers because there are fewer rest stops and lower APU utilization rates than for single drivers.

Recommendations and observations from the field test include:

- Previous estimates and generalizations about idling activity and APU usage appear to be optimistic in that they assume that all trucks in the on road fleet would have similar performance. Although the sample of trucks in this study is not a nationally representative sample, the trucks observed here represent a proportion of those on the road. An accurate estimate of the national potential for avoided fuel use and emissions should take into account variability within the on road fleet and among APU systems.

- Using more generalized data APUs are not cost effective for trucks idling less than 4 hours daily, but an APU is recommended for trucks idling more than 7 hours daily. Using the 20 trucks in the demonstration field test as a specific sample, APUs require a 5 year or greater payback period for $4.50 or less fuel prices.
- Although there is still a net savings in fuel use when using an APU, field test trucks had relatively lower base engine fuel rates and APUs had relatively higher fuel use rates than is commonly assumed.
- As base engine emission standards become more stringent, the net emissions benefit of utilizing an APU will diminish although fuel use and CO_2 reduction benefits will remain
- Lower engine RPM, light cab color and smaller cab size can reduce emissions and fuel use when utilizing the base engine.
- During the course of the field test all trucks were observed to have run their base engines at the same time as the APU at one time or another, although not for long periods in most cases, which defeats the purpose of the MIRT. Simultaneous use of the APU and base engine should be discouraged or prevented (e.g., through a control interlock).
- APUs were used not only for extended idling but during shorter duration idling.
- Fleets that invest in MIRTs should provide driver training and incentives for consistent and optimal use.

In conclusion, by having Volvo begin to offer MIRTs as part of their product line, in addition to the Prep-Kit, customers will have confidence that the APU is of the same quality as all Volvo products. Having a truck OEM, such as Volvo including an APU as part of their product offering is a significant result of this project that will increase market acceptance for MIRTs. The results of this study will help target market niches (e.g., single drivers with high idle activity) where APU usage is most cost-effective and beneficial in terms of avoided fuel use and emissions. Moreover, methods developed by project researchers to track and analyze MIRT use, avoided fuel use and emissions can be adopted to evaluate other idle reduction technologies while adding to the body of “ real world” idle reduction technology and fleet evaluations.

Task 1: Develop ‘call for projects’ to select Truck OEM(s)

On October 24, 2005 the North Carolina Solar Center (NCSC) at North Carolina State University (NCSU) issued the “Truck Original Equipment Manufacturer/Mobile Idle Reduction Technology Prep Kit Design and Installation Project Request for Proposals”. The Request was distributed electronically to Original Equipment Manufacturers (OEMs) through Robert Clark of the Truck Manufactures Association. The close date for applications was December 5, 2005. Through the competitive bid process the NCSC received three proposals. A review committee (in consultation with EPA) selected Volvo Technology of America (VTA) based on their proposal to design a prep kit and demonstrate Mobile Idle Reduction Technologies (MIRTs) in at least twenty over the road sleeper trucks. On February 21, 2006 a subcontract for $350,254 was approved by NCSU and provided to Volvo.

The specific tasks heading for the sub-contract agreement are as follows:

- Design and develop MIRT prep-kit for heavy-duty diesel vehicles.

- Subcontract with technology and fleet project partners
- Determine idling times/patterns before installation of selected idle reduction technologies
- Install idle reduction technologies
- Monitor /Facilitate data collection
- OEM reports and meetings with NCSU project team members

The Volvo Group is a global leader in the manufacture of trucks, buses and construction equipment, drive systems for marine and industrial applications, aerospace components, and services. Volvo is the world's largest manufacturer of diesel engines, and second largest in terms of heavy-duty truck manufacturing. Volvo's products carry the brand names of Volvo Trucks, Mack Trucks, Renault Trucks, Volvo Buses, Volvo Construction Equipment, Volvo Penta, and Volvo Aero.

VTA is a unit of Volvo Technology Corporation and is headquartered in Greensboro, NC. VTA is an innovation company that researches, develops and integrates new technology, new product and business concepts for "hard" as well as "soft" products within the transport and vehicle industry. VTA participates in national and international projects in strategic areas and research programs. VTA frequently works in coordination with other Volvo companies, universities, research institutes, industry trade groups, governmental agencies and other companies. VTA's research, development and integration work is based on deep competence in a number of basic areas—e.g. transportation & telematics, human system integration, electronics & software, energy conversion & physics, mechanical structures & components, environment & chemistry, using methods such as systems engineering and simulation, multi-physical and chemical modeling. VTA develops functions, structures and technologies for soft products, transport systems, complete vehicles, powertrains, vehicle electronics, manufacturing, maintenance, etc.

The RFP and press announcement are posted on the NCSC's Clean Transportation's website at: http://www.engr.ncsu.edu/ncsc/transportation/MIRTproject.htm

Task 2: Select demonstration fleet(s) and commercially available APU technologies

Due to the nature of the OEM business and the close working relationship necessary between the OEM, selected fleets and MIRT technology vendors, Volvo took the lead in deciding whom it would work with on this project.

The two fleet partners selected by Volvo (based on truck ordering plans and interest) each agreed to have 10 auxiliary power units (APUs) installed as well as satellite based electronic tracking equipment to determine equipment usage. Although Volvo requested that fleets join EPA's voluntary SmartWay program, neither fleet signed up for the program. Requesting anonymity, the participating demonstration trucks were simply referred to as Fleet A and Fleet B in all tracking and reporting references. Following is a description of the two private fleets selected by Volvo to participate in this project.

- Fleet A: utilizes Volvo's largest sleeper cab (VN780). These are black cabs with predominantly single drivers and a self reported overall fleet average estimate of 2,500 annual idling hours per truck. The selected trucks were a good test bed for the northern tier as company is operated and headquartered in the northern mid west part of the U.S.

- Fleet B: utilizes Volvo's mid-size sleeper (VN 630) cab. These are white cabs with predominately team drivers that have a reported average annual idling time of 800 hours per truck from information provided to Volvo via truck dealerships. The fleet is based in the southern mid section of the U.S.

Due to the close and sensitive relationship between dealerships and participating fleets, the dealerships became the point of contact for VTA on this project. Several factors including business relationships, ordering lead time and technology compatibility were taken into consideration when Volvo dealers selected fleet partners.

Similar considerations were undertaken by Volvo when selecting the technology vendors. Three primary technology providers contributed to the development of two APUs, further referred to as APU A and APU B. These APUs are comprised of three components: an engine (2006 Kubota Z482 0.48 liter engine); a generator and a Heating Ventilation Air Conditioning (HVAC) system supplied by Dometic Environmental Corp that utilize a "split system" in that the evaporator and condenser are mounted separately (like a home air conditioner). The Kubota engines utilized by APU A and B are reported by the manufacturer to comply with the 2005 Tier II emission standards applicable to non-road engines.

VTNA has made a business decision to target primarily the AC/HVAC type MIRT systems. AC/HVAC refers to HVAC system that can be used from a 120Vac power source while the vehicle is parked. The primary reason for this is the ability to operate the complete HVAC system from plug-in shore power, thus eliminating the need to run the diesel-powered generator set when shore power is available. VTNA believes this to be the most environmentally friendly solution to idle reduction, as well as the best value for the customer. With an AC/HVAC type of MIRT the power can come from either a small diesel-powered generator set, converted from battery power via an inverter, or from plug-in shore power if it is available. The main benefit of this approach to idle reduction technology is the ability to operate from multiple power sources, including shore-power. However, a challenge to this approach is that depending on configuration, there could be a duplication of air conditioning equipment and it could be difficult to integrate into the vehicle. Through this project, VTNA was able to work through many of the potential challenges to this preferred type of system through experience gained from technology providers for APU- A and APU- B.

APU- A was sourced as a complete system from one company. It consists of a 6.0kW electrical generator wired in a 120/240 split-phase configuration. The engine used in APU A is rated at 10.9 hp @3,600 RPM and has a direct-driven 6 kW generator. The system employs a 120V-powered battery charger, so that battery-charge capability is available even when running from shore power. The HVAC system for APU-A has an "ECONO" mode setting that cycles the engine on and off based upon heating or cooling demand

APU- B is made up of components from several companies, assembled to work together as a system. APU B uses the same 2006 Kubota Z482 engine as APU A, but operates at 2,400 RPM for which the engine is rated at 7.4 hp. APU B has a belt driven 4.0kW electrical generator and the electrical power is routed through an APU / Shore Power transfer switch, which will allow automatic switching between the APU or the Shore Power, depending upon which is present. Vehicle battery charging is accomplished via a 12Vdc alternator installed on the APU. This does not provide for battery charging while running off of shore power (it requires that the APU be running).

The following table summarizes the Fleet vehicle and APU specifications.

Table 1: Truck and Auxiliary Power Unit Specifications

Fleet or APU Type	Specifications	Engine	Note
Fleet A	Volvo VNL 780 sleeper cab, 375 cubic feet	2006 VED12 (465 hp @ 1,800 RPM, 12.1 liters)	Black vehicle body; complies with EPA’s 2004 heavy duty diesel emissions requirements for diesel highway vehicles
Fleet B	Volvo VNM 630 sleeper cab, 200 cubic feet	2006 VED12 (435 hp @ 1,800 RPM, 12.1 liters)	White vehicle body; complies with EPA’s 2004 heavy duty diesel emissions requirements for diesel highway vehicles
APU-A	Direct-drive 6kW 120Vac generator; 14K BTU/hr HVAC system	2006 Kubota Z482 (10.9 hp @3,600 RPM, 0.48 liters)	ECONO mode in which APU cycles on and off to save fuel; complies with 2005 Tier II emission standards applicable to nonroad engines
APU-B	Belt-drive 4kW 120Vac generator; 14K BTU/hr HVAC system	2006 Kubota Z482 (7.4 hp @2,400 RPM, 0.48 liters)	Complies with 2005 Tier II emission standards applicable to nonroad engines

Trade media coverage of technology and fleet selection by Volvo included an article titled “*Volvo, N.C. State announce partners for MIRT tests*” in the July 15-31, 2006 issue of The Trucker. In addition a short article was published the same week in Transport Topics titled “*Volvo, N.C. State University to Test Technology Aimed at Reducing Idling*”.

Task 3: Develop contracts for OEM(s) to install selected idle reduction technologies

Based on the nature of OEM business relations, no formal contracts were signed between Volvo and technology provider companies. Although no subcontracts were developed, two privately owned fleets that conduct national operations agreed to field test 20 APUs – 10 by each fleet. Each fleet had 5 APU As and 5 APU Bs installed on new trucks they ordered from Volvo. Moreover, significant funds were leveraged by Volvo from fleet partners whom paid 1/3 toward the list price of each APU unit. In addition, technology providers contributed to product support at the Mid American Truck Show and Great American Truck Show in 2006 & 2007. The technology providers also agreed to support the products during the term of the field test. All totaled, over $860,000 in additional funds provided by Volvo and their partners were leveraged by this project.

In addition to the 20 APUs that were field tested by Fleet A and Fleet B, a 21st truck owned by an independent owner operator utilized APU A for the duration of the field test and a 22nd truck (which was a Volvo marketing truck) utilized APU B. Reports from the marketing people who used the truck for 1 year (before it was sold) were very good.

Task 4: Design and develop APU prep-kit for over-the-road sleeper trucks

The goal of the Prep-Kit was to facilitate installation of MIRT units in the vehicles that Volvo Trucks North America (VTNA) produces to gain wider acceptance and adoption of the idle reduction units. As a result of this project, the Prep-Kit designed by VTNA is now an option specified at the time the vehicle is ordered. The components which make up the Prep-Kit are installed on the vehicle assembly line while the Mobile Idle Reduction Technology (MIRT) system itself is installed in the aftermarket, for various reasons as follows. With the number of variants in the trucks Volvo builds – wheelbase lengths, fuel tank sizes and locations, battery box locations, cabin interior options, etc. – it would not be possible to develop a cost effective Prep-Kit which covered every single component and task involved in the installation of a MIRT system. Combine this with the variations in available MIRT systems, and the number of ‘new parts’ would increase exponentially for the required electrical cabling, fuel line lengths, battery cable lengths etc.

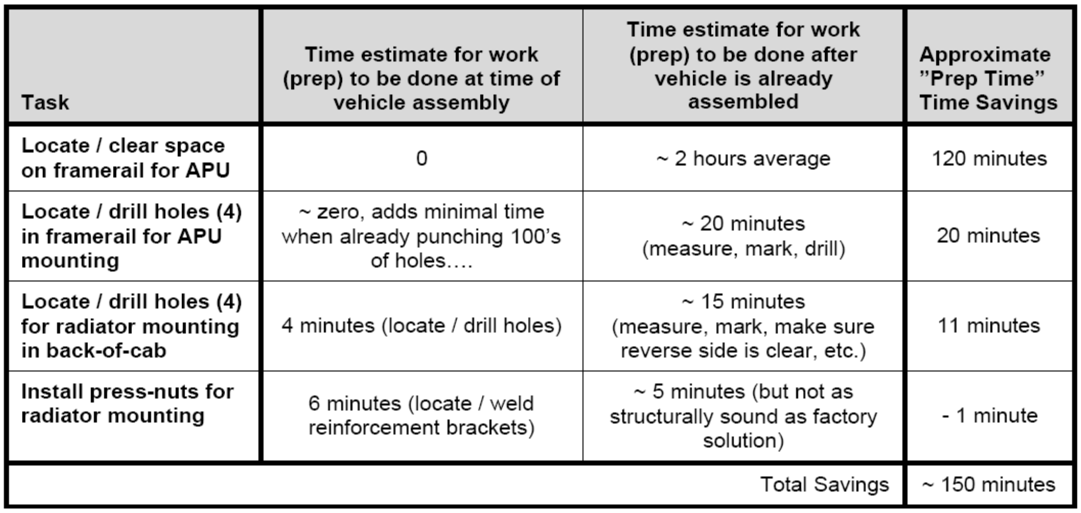
The Prep Kit was designed to accommodate APU A and APU B (and may be utilized by other APU technology providers after the truck is sold). However, there are impediments to the potential for multiple technology providers to utilize the Prep Kit and for Volvo to install MIRTs at the factory level, rather than through a after-market (post production) service which is the current method. Some of the reasons for this are as follows: VTNA’s supplier rules - in order for someone to ship product into a Volvo factory they have to be ISO certified, pass a Global purchasing committee 'screening', be visited by the company’s supplier quality assurance team, etc. To do this for one or two MIRT suppliers (let alone all) would be cost prohibitive. Another big consideration is warranty. If it's installed when it leaves the factory, Volvo is liable for the warranty. Installed in the aftermarket, the MIRT manufacturer is responsible. While offering a factory warranty for the MIRT system is certainly one of VTNA's goals, they don't yet have enough experience to take on this additional responsibility.

That said, the Prep-Kit developed by VTNA accomplishes easier installation by the after market service company by providing structural reinforcement, pre-drilled holes for component mounting, and holes for pass-thrus. In addition, selection of the Prep-Kit option when ordering a Volvo truck will drive restrictions in placement of other vehicle options to ensure sufficient free-space on the frame rails – eliminating the need to relocate frame-mounted components in order to accommodate the APU.

The development of the Prep-Kit drove standardized mounting locations and methods assuring a more secure installation with the intent of leading to fewer problems in the field. In addition to the modifications made to the vehicle in order to facilitate the MIRT installation, the selected MIRT system suppliers also designed several components specifically for installation in a Prep-Kit equipped Volvo Truck. In this way many of the Prep-Kit accommodations designed in the vehicle can be adapted to as many MIRT system suppliers as possible ("meeting in the middle" to accomplish the goal rather than one party bearing the entire burden).

Currently when a MIRT unit is installed in the aftermarket, a majority of the installation effort is spent on disassembly of the vehicle as well as relocation of already-mounted vehicle components in order to gain access for MIRT system mounting. With the VTNA designed Prep Kit, this impediment is removed, saving an estimated 150 minutes in "prep time" savings for the after market service provider. See Table 2 for an estimate of "prep time" time savings.

Table 2: Prep time savings estimated for VTNA Prep-Kit (Charles Villa, 2006)



Task	Time estimate for work (prep) to be done at time of vehicle assembly	Time estimate for work (prep) to be done after vehicle is already assembled	Approximate "Prep Time" Time Savings
Locate / clear space on framerail for APU	0	~ 2 hours average	120 minutes
Locate / drill holes (4) in framerail for APU mounting	~ zero, adds minimal time when already punching 100's of holes….	~ 20 minutes (measure, mark, drill)	20 minutes
Locate / drill holes (4) for radiator mounting in back-of-cab	4 minutes (locate / drill holes)	~ 15 minutes (measure, mark, make sure reverse side is clear, etc.)	11 minutes
Install press-nuts for radiator mounting	6 minutes (locate / weld reinforcement brackets)	~ 5 minutes (but not as structurally sound as factory solution)	- 1 minute
		Total Savings	~ 150 minutes

Note that the time estimates included above do not include actual installation of any of the MIRT components. They compare how long it takes to "prepare" for installation of the component. For example, clearing space (relocating components) on the frame rail must typically be done before even starting to mount the APU. With the Prep-Kit, this is already done when the aftermarket receives the vehicle – yet it “costs” no time on the vehicle assembly line since it is only a matter of preventing something being placed where it would only need to be moved again later. However, it should also be noted that although the time for locating / clearing space on the frame rail is shown as ‘zero’ for a Prep-Kit equipped vehicle if performed at the time of vehicle assembly, this may only be the case for the aftermarket company. In fact clearing space on the frame rail to accommodate MIRTs might cause additional time at order entry to work through the options / vehicle content which may be prevented due to option restrictions.

Due to the time needs of the field demonstration component of this project none of the 20 trucks utilizing APU A and APU B had the benefit of the Prep-Kit. However in 2007 VTNA began taking orders for the Prep Kit in new trucks and has continued with this product option in 2008. Moreover, this project leveraged over $260,000 from Volvo in product modifications related to the Prep-Kit as well as work efforts to add a data book option for the new product offering.

Below is the breakdown of orders received for the APU Kits through August 2008:

Code 82A-B1X Pre-Kit only (frame drillings and clear rail space):
- 2007 orders - 110 trucks
- 2008 orders - 462 trucks

In 2008 VTNA also began offering MIRTS as part of their product offering. These orders are in addition to (and a direct result of the experience gained through the 22 truck that field tested APU technology as part of this project).

Following is a breakdown of VTNA MIRT orders through August 2008:

Model 730/830/780/880 Dometic HVAC only - 4 trucks *(this product requires Shorepower)*
Model 630/670 APU B - 84 trucks
Model 730/830/780/880 APU B- 52 trucks

Therefore the 2008 orders with only the Prep Kit the total would be 326 (462-136=326) and the total number of APU’s sold to date are 140 (not including the 22 APU installed as part of the field test begun in 2006)

By having Volvo begin to offer MIRTs as part of their product line in addition to the Prep-Kit customers will have confidence that the APU is of the same quality as all Volvo products whether or not it is actually installed at the factory. Having a truck OEM, such as Volvo offering an APU as part of their product offering is a significant result of this project that will increase market acceptance for MIRTs.

Task 5: Install data logger to determine idling times/patterns before installation of selected idle reduction technologies

The study of idling times/patterns developed by the NC State University team lead by Dr Chris Frey, Professor in the Department of Civil, Construction, and Environmental Engineering, includes a field data collection component that was implemented by Volvo Technology of North

America and Volvo Trucks of North America. Volvo instrumented 20 shore-power (SP) capable long-haul Volvo trucks with data acquisition systems.

The driver logbooks were not available to the study team. Moreover due to the time constraints of the field test, it was not feasible to install the data loggers to determine idling times/patterns before the beginning of the field test. The pre MIRT installation idling estimates were provided to the NCSU research team by Volvo based on direct exchanges with the Fleet A and Fleet B. The pre field test annual idling estimate provided by Fleet A was 2,500 hours per year and for Fleet B it was 800 hours per year. The actual idling time for Fleet A, as determined through satellite monitoring system during the demonstration project period, was 2,130 hours annually Fleet B's actual idling was 770 hours annually.

In addition, Volvo was able to obtain idling duration information for non-MIRT-equipped Fleet-A and Fleet-B trucks that went into service about the same time as the 20 field test trucks, which supported the information above.

Volvo designed, installed, monitored, and maintained a data acquisition system for each of the 20 trucks participating in the field test. The data acquisition system was comprised of 4 major components: electronic control units (ECUs); additional sensors; a data logging system; and Volvo Link^{TM}, which transmits data from trucks to a central data repository via satellite. Each truck has electronic control units (ECUs) for the engine, climate control, lighting, and the instrument cluster. The ECUs provide data relevant to stop and idling activity, such as cumulative base engine idle hours. However, they do not provide enough data to fully quantify such activity. Therefore, Volvo designed and installed additional sensors that monitor additional data, such as electricity usage of APU and shore power (SP) systems, interior and exterior temperature. The data from the supplemental sensors are input to a data logging system. The data logging system, with a back-up battery, sampled inputs at 6-hour, 1-hour ,15-minute or 2 minute increments, depending on the parameter. The collected data from the ECUs and additional sensors were consolidated and periodically transmitted (every 6 hours for each truck) via the satellite-based VolvoLink system.

In order of priority, the following main goals were established for the data acquisition task in this project:

1. Determine fuel usage and duration by the main engine usage during idle operation
2. Determine fuel usage by the MIRT systems
3. Determine effectiveness of the MIRT systems at maintaining comfortable conditions
4. Detect and categorize specific idling situations / scenarios

The above goals supported an overall project goal to determine the effectiveness (energy use and space conditioning capacity) of various MIRT systems under different idling situations.

Task 6: Monitor and analyze idling activity and emissions data

NC State University's Dr Chris Frey and graduate research assistant Po-Yao Kuo worked directly with Volvo to track and analyze data received from the 20 demonstration trucks to determine idling times and APU usage. NC State researchers also sampled the actual emissions of truck base engines and the selected APUs. This emissions analysis was used to determine the per hour truck emissions benefits of utilizing the APU over base engine idling on a straight comparison as well as the benefits based on the actual idling activity and recorded usage of the MIRT versus the base engine. Fuel use analysis was conducted to determine fuel use savings on a per hour of MIRT use versus base engine idling. For base engine fuel use, regression formulas were developed based on ambient temperature and engine speed provided by truck electronic control unit data. APU fuel use analysis was estimated based on bench scale measurements conducted by VTNA of fuel use versus electrical load and actual real-world electrical load as reported through the satellite tracking system.

Summary results of idling times, fuel consumption and emission characterizations generated through the collaborative effort of Volvo and NCSU researchers follow.

Idling times and APU usage

Most Fleet A trucks had a multimodal distribution of stop duration, with a peak in the frequency of very short duration stops and a second, lower, peak in the frequency of long duration stops. Most short duration stops had durations less than or equal to 3 hours. Most long duration stops had average estimated durations between 5 and 14 hours. An exception is that one Fleet A truck (Truck No. 6) had more stops with durations between 3 and 7 hours than those with durations between 7 and 14 hours.

Most Fleet B trucks had a unimodal distribution in which the highest frequency of stop durations was for short stops which were shorter than 5 hours.

For all 20 trucks, the distributions of stop activity with respect to stop scenarios of usage of the base engine, APU and shore-power and no power for stop durations ranged between 0.25 to 24 hours or more.

Seven Fleet-A trucks tended to use the APUs whereas the base engines were frequently used for 3 Fleet-A trucks. Seven Fleet-B trucks tended to use the base engines but the APUs were frequently used for 3 Fleet-B trucks for long duration stops. Single drivers prefer to use the APUs but team drivers prefer to idle the base engines.

Simultaneous use of the APU and base engine accounted for more than 25 hours of annual usage for 6 trucks. On-board shore-power system usage and simultaneous use of on-board shore-power and base engine were estimated to be less than 0.1 percent of time for all 20 trucks. There is no evidence that an off-board shore-power system (i.e. IdleAire) was used.

For Fleet A (mostly single drivers), the annual average idling for all stop durations and extended idling are 2,130 and 1,450 hours, respectively. The latter is comparable to literature estimates. For Fleet B (mostly team drivers), the averages are 770 and 250 hours, respectively. The proportion of APU usage during extended idling for single versus team drivers is estimated to be 67 and 28 percent, respectively.

Fuel Use

Base engine fuel use rates vary depending on ambient temperature and engine speed. Fuel use rates are typically high at high or low ambient temperatures and low at mild temperature. As engine RPM increases, fuel use rate increases. NCSU researchers developed regression equations for base engine idling fuel use rates versus ambient temperature and engine speed based on ECU data. Actual base engine fuel use at idle had previously been compared by VTNA to ECU-reported data, and was found to be accurate within ±5 % under all applicable conditions.

For each fleet, average fuel consumption rate varies with respect to ambient temperature. At a given ambient temperature, and particularly at high ambient temperatures, Fleet A trucks consume more fuel. The average fuel consumption rates vary from 0.47 to 0.65 gal/hr for Fleet A, or by 38%, over a range of temperatures. For Fleet B, the average fuel consumption rates vary from 0.46 to 0.58 gal/hr for Fleet B, or by 26%. The Fleet A trucks have higher fuel use rate even though they typically operate at lower RPM than for Fleet B. This is attributed to the larger heating and cooling load for the larger Fleet A cabs.

For both fleets, the variation in engine RPM at idle was found to be approximately independent of ambient temperature. This result is consistent with the expectation that drivers may choose an idle set point based on their preference.

Auxiliary Power Unit Engine Fuel Use

Fuel use rate for each APU was measured as a function of electrical load on the generator. Real-world APU fuel use rates were estimated based on electrical loads for each truck monitored by the data acquisition system.

The two APUs have a similar fuel consumption rate of 0.45 gal/hr at a load of approximately 3 kW. However, APU-A is more fuel efficient at higher load whereas APU-B is more fuel efficient at lower load. Although both APUs use the same engine, they operate at different RPM.

For APU-A, the distribution of electrical load is approximately bimodal, with one cluster of values representing loads of less than 1,000 W and another cluster with loads as high as 3,000 W or slightly higher. The latter most likely represent full load for the air conditioner, whereas the former likely represent loads impacted by the HVAC “ECONO” mode function. The average load for Fleet A was 800 W versus only 470 W for Fleet B. These loads correspond to fuel consumption rates of 0.31 and 0.30 gal/hr, respectively. The higher average load for Fleet A is attributed to: (a) larger cab size; (b) darker exterior color; and (c) a higher proportion of time (57 percent versus 47 percent) spent at temperatures of 20 ^{o}C or more.

For APU-B, there is a continuous rather than multimodal distribution of electrical load, with loads rarely exceeding 2,000 W for either fleet. The average electrical load for APU-B for Fleet A was 680 W versus 610 W for Fleet B. These correspond to fuel flow rates of 0.26 gal/hr for both fleets. As expected, Fleet A had a higher average load than Fleet B for APU B, but the relative difference is less than that for APU A. The Fleet B trucks with APU B had a larger proportion of time (29 percent versus 12 percent) spent at temperatures of less than 10 ^{o}C than the Fleet A trucks with APU B, which affects heating load.

Overall, there are larger differences in fuel use rates when comparing the two APUs than when comparing the two fleets. The main differences between APU-A versus APU-B are engine RPM, direct versus belt drive, and the “ECONO” mode function that is paired only with APU-A. There were also differences in the temperature distributions for each Fleet and APU combination.

Emissions

Fuel-based emission factors for the base and APU engines were estimated based on fuel properties and emissions measurements by NCSU using a Portable Emission Measurement System (PEMS). The PEMS used is an OEM-2100 Montana system. A base engine of the same make, model and horsepower as that for Fleet A trucks was tested with and without accessory load. The base engine for Fleet B has the same make and model but slightly lower horsepower because of the difference in timing and duration of fuel injection. Time-based emission factors are estimated based on fuel-based emission factors and fuel use rates. Because the opacity measured by the Montana PEMS provides only semi-quantitative values for PM concentrations, emission factors for PM were estimated by averaging data from published literature.

Two APU engine-generator sets were tested, corresponding to the systems used in the field trucks. Fuel-based emission factors were measured using PEMS. Mass per time emission factors were estimated using fuel consumption rate. PM emission factors were estimated based on literature data. Energy use rates for shore power (SP) systems are based on electricity consumed by the truck and the relationship between primary energy and electricity for power plants. Indirect emission factors from SP are based on energy consumed to generate electricity and total emissions for generating electricity.

In order to directly compare the energy use and emission rates between the base engine, APUs, and SP, two scenarios were developed. A “mild temperature” scenario is based on the energy use and emission rates typical of temperatures ranging from 10 ^{o}C to 20 ^{o}C, whereas a “high temperature” scenario is based on temperatures of 30 ^{o}C or more. The typical average load for the former is approximately 500 W, versus 2,000 W for the latter.

Since the base engine fuel-based emission factors are relatively insensitive to load, an average of these emission factors were used in combination with the observed base engine fuel use rates from the field study in order to estimate time-based emission rates. The APU emission rates are estimated for a given fuel flow based on curve fits for fuel-based emission rate versus fuel flow. Shorepower energy-based emission rates are a constant per unit of electricity consumed, regardless of load. The fuel or energy-based emission rates are multiplied by fuel or energy use rate to estimate time-based emissions rates.

Tables 3 to 5 provide summaries of fuel use and emission rates for APU engines and the truck base engine.

Table 3: APU-A Fuel Use and Emissions Rates

Electrical Load (kW)	Fuel Use (gal/hr)	NO (g/hr)	HC (g/hr)	CO (g/hr)	CO_2 (kg/hr)	PM (g/hr)
0	0.28	5.1	1.4	23.3	2.8	0.9
3	0.45	16.2	1.6	11.3	4.5	1.5

Table 4: APU-B Fuel Use and Emissions Rates

Electrical Load (kW)	Fuel Use (gal/hr)	NO (g/hr)	HC (g/hr)	CO (g/hr)	CO_2 (kg/hr)	PM (g/hr)
0	.22	11.2	1.4	7.5	2.3	0.7
3	0.45	24.7	0.8	5.7	4.6	1.5

Table 5: Base Engine Fuel Use and Emissions Rates

Fuel Use (gal/hr)	NO (g/hr)	HC (g/hr)	CO (g/hr)	CO_2 (kg/hr)	PM (g/hr)
0.45	69.2	2.7	12.8	4.6	1.1
0.60	92.2	3.6	17.1	6.1	1.4

The difference in NO and CO emissions rates between the APUs is attributed to differences in engine RPM and the direct vs. belt drive for the generators. The latter affects the mechanical efficiency from the APU to the generator.

Task 7: Install idle reduction technologies

The requirements of this project which necessitated the simultaneous development of the Prep Kit, APU- A and APU- B along with the production of new trucks on which the APUs were installed, prevented the utilization of the Prep Kit on the field test trucks.

In July 2006 a sales bulletin was sent to VTNA dealers announcing the Prep Kit and two months later, in October, the installation of 10 APUs- 5 of APU- A and 5 of APU- B were complete on Fleet A. Consequently Fleet A trucks were sending data to NCSU for analysis of APU usage and idling times by November 2006. By the end of February 2007 Fleet B field test trucks had 10 APU installed – 5 of APU A and 5 of APU B.

Both the 21st truck (owned by a private operator) and 22nd truck (owned by Volvo) were installed with APU- A and APU- B respectively.

Periodically throughout the field test various problems, mainly with data acquisition, were reported by VTNA to NC State. Following is a chronological list of issues encountered with either the APU technology or data acquisition

- Dec ’06 One Fleet A / APU A vehicle had data acquisition system problems for some time (vehicle-specific data being received, but no data from the MIRT). Tried troubleshooting the system “long distance” with the help of Fleet A, .
- Jan - Feb Two Fleet A / APU B vehicles lost communication altogether. Volvo worked with Fleet A to resolve long distance
- Mar ’07 Volvo sent technician to Fleet A to fix hardware that off- loads data and fixed one truck with bad connections
- Aug ‘ 07 Fleet A / APU B truck 446048 sidelined in Memphis for almost 1 week with what was thought to be APU problem, then blamed on HVAC system…Eventually solved by replacing the APU “Shorepower” transfer switch (a prototype part that Volvo made for the project)
- Call from Fleet B: Truck number 460722 with APU A developed HVAC problem. They wanted to service it themselves, but it requires special A/C test equipment (uses refrigerant like in a household system, not common in automotive). Eventually found dealer close by that had the needed equipment.
- Sept ’07 Call from Fleet B. Truck 460728 has developed problem with APU B. Put him in touch with technology provider hotline, they were able to fix over the phone.
- Fleet B Truck 460725 repaired (new Volvo Link ECU sent to Fleet B
- Oct ’07 VTNA visited Fleet B location and repaired data acquisition system on truck 460727 (replaced antenna cable) and 460728 (replaced Volvo Link ECU).
- Sept ’07 Sent replacement Volvo Link ECU to Fleet B location for truck 460720. (Truck back online as of Nov’-07)

Task 8: Monitor and interpret data to determine cost effectiveness, ROI, and emissions benefits.

Dr Chris Frey, Professor in the Department of Civil, Construction, and Environmental Engineering at NC State University and graduate research assistant Po-Yao Kyo interpreted idling activity and emissions data to determine the benefits of utilizing MIRTs based on the real world activity data generated through the field test. The twenty trucks participating in the field demonstration operated for over 2.8 million miles in 42 states during the sixteen month data collection period, which ranged from September 2006 to February 2008. From this field test and additional research conducted by NC State, data was compiled to assess fuel displacement, cost saving and emissions benefits. Dr. John R. Stone (NCSU Professor of Civil Engineering), Varshil Parikh and Soheil Sajjadi (Civil Engineering Graduate Students) conducted an APU Breakeven Analysis to determine the cost effectiveness of APUs using industry standard variables.

To garner driver feedback and determine driver acceptance, MIRT logs were placed in each of the field test trucks by Volvo, along with self-addressed, stamped, envelope to return first sheet completed with replenishment copies to follow as needed. However, no driver logs were received by Volvo. Therefore, we can only infer driver acceptance or lack thereof from direct data received through the Volvo Link satellite communication system that tracked actual APU use.

As a result of the information gathered through this project three journal papers have been prepared:

Frey, H.C., P.Y. Kuo, and C. Villa, "Methodology for Characterization of Long-Haul Truck Idling Activity under Real-World Conditions," *Transportation Research – Part D*, accepted for publication as of October 2008.

Frey, H.C., and P.Y. Kuo, "Real-world Energy Use & Emission Rates for Idling Long-Haul Trucks & Selected Idle Reduction Technologies" *Journal of the Air & Waste Management Association*, ready for submission.

Frey, H.C., P.Y. Kuo, and C. Villa, "Effects of Idle Reduction Technologies on Real World Fuel Use and Exhaust Emissions of Idling Long-Haul Trucks," *Environmental Science and Technology*, ready for submission.

Following is a list of related presentations/papers:

Frey, H.C., P.Y. Kuo, and C. Villa, "Methodology for Characterization of Long-Haul Truck Idling Activity under Real-World Conditions," Proceedings, 87th Annual Meeting of the Transportation Research Board, Washington, DC, January 13-17, 2008.

Frey, H.C., P.Y. Kuo, and C. Villa, "Measurement and Modeling of Fuel Use and Exhaust Emissions from Idling Long-Haul Freight Truck and Auxiliary Power Unit Engines," Paper No. 616, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

Frey, H.C. P.Y. Kuo, and C. Villa, "Measurement and Modeling of Fuel Use and Exhaust Emissions from Idling Long-Haul Freight Truck and Auxiliary Power Unit Engines," Presentation at 18th CRC On-Road Vehicle Emissions Workshop, San Diego, California, March 31-April 2, 2008

In addition to what was reported in Task 6, the following summarizes the research findings:

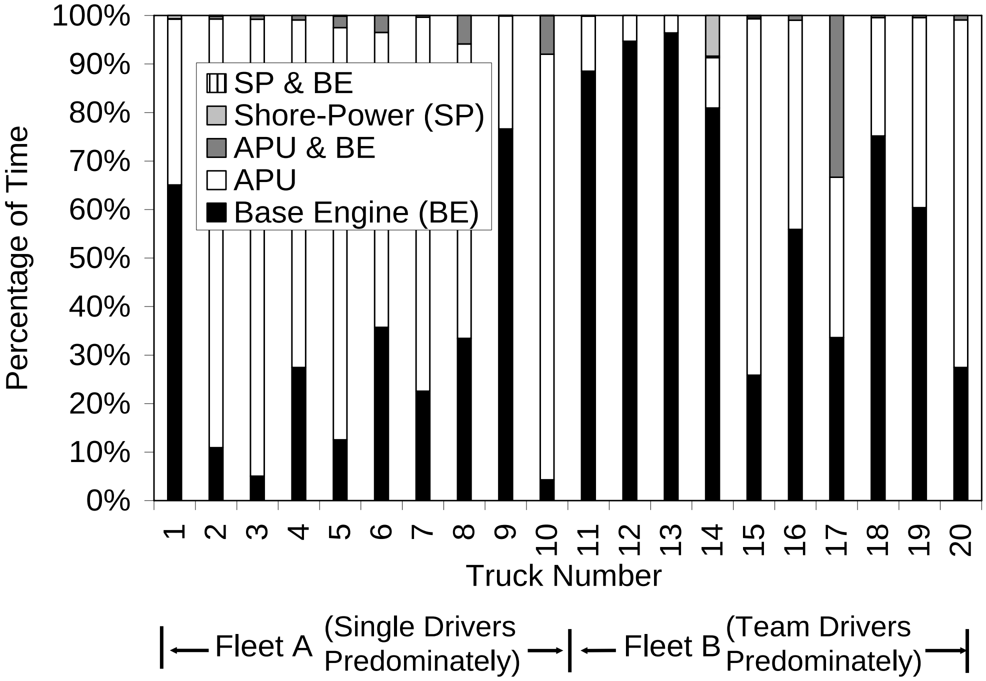
Idling Times

From direct monitoring of technology use it was observed that drivers made different choices regarding whether to meet their comfort needs using the base engine or the APU. Taking all stops into consideration that were recorded during the field demonstration study, drivers for three of the Fleet A trucks preferred to use the base engine during all stops, while drivers for seven of the Fleet A trucks tended to use the APU more often for such stops. One truck used the APU intensively even when the stop duration was less than 3 hours. For Fleet B, most trucks, except Truck No. 15, had a shorter overall APU usage duration than that for base engine idling.

Simultaneous use of APU and base engine was detected in 6 trucks, with those occurrences accounting more than 25 hours of annual usage per truck. The results imply that these types of activities may be significant during the test periods for some trucks, which cause negative impacts on fuel use savings for truck APUs.

Preferences regarding the source of power during idling for a given driver during all stops versus extended idling are similar. As illustrated in the figure below, drivers for eight of the Fleet A trucks preferred to use the APUs during extended idling, while drivers for eight of the Fleet B trucks tended to use the base engines more often for such stops.

Figure 1: Distribution of Time for Powered Stop Scenarios for Extended Idling for 20 Field Trucks ***(Frey, Kuo, and Villa, 2008)***



Emission Benefits

At mild temperature, 100% substitution of APU usage instead of the base engine would lead to an 80 to 90 percent reduction in NO_x emissions, 36 to 47 percent reduction in CO_2 emissions and fuel use, and 10 to 25 percent reduction in PM emissions. The estimated percent reductions in HC and CO emissions are based on average concentrations below detection limits. Thus, although data indicate a possible reduction in HC emissions, and a reduction in CO emissions for APU-B, they are not conclusive. On the other hand, the emission rates of HC and CO from diesel engines are typically low, and the pollutants of more substantial concern from such engines are typically NO_x, PM, and CO_2.

At high temperature, the estimated relative emissions reductions for the APU versus base engines are slightly lower than for the mild temperature case, but the magnitude of the emissions reductions is higher. For example, NO_x emissions would be lower by 78 to 88 percent, which is a slightly lower percentage than for the mild temperature case, but these reductions are with respect to a higher magnitude of base engine emissions of 92 g/hr versus 72 g/hr. Likewise, the reductions in CO_2 and PM emissions are similar on a relative basis but higher on an absolute basis.

The actual overall reductions in fuel use and emissions for the substitution of APUs instead of the base engine will be less than the estimates here, which are based on comparison of one hour of operation of each power source. **For example, the field data imply that the APU is used by single drivers for an average of 59% of idling and by team drivers for an average of only 25% of idling.** The actual reductions will depend on the portion of idling time for which the anti-idling devices are used, as well as the ambient conditions during which they are used. The high frequency of double-dipping for some trucks also defeats the purpose of the APU for reducing fuel consumption and emissions.

For the purposes of this project, the annualized reductions in total fuel use and emissions were quantified for each truck taking into account energy use and emission rates and real-world activity patterns. The annual average and range of avoided fuel use and emissions for all stop durations and extended idling are summarized in Table 6

For Fleet A, the use of anti-idling devices for all stop durations led to 72 to 416 gallons of avoided fuel use per year, which reduced fuel use by 8 to 28 percent. For extended idling, there were 46 to 388 gallons of avoided fuel use per year, with a fuel use reduction of 11 to 38 percent. For Fleet B, average avoided fuel use during all stops and extended idling were -4 to 89 and -7 to 75 gallons per year, which is significantly less than for Fleet A. Negative values of avoided fuel use are attributed to a significant cumulative duration (e.g., over 270 hours per year for one truck) of double-dipping. Without double-dipping, avoided fuel use for all trucks would have been positive.

For all stop durations, avoided annual average fuel use and CO_2 emissions were 22 and 5 percent, respectively, for Fleets A and B, which are significantly lower than literature estimates of 50 to 80 percent. The differences in real world versus previously estimated avoided fuel use and emissions are because of differences in fuel use rates and emissions factors, lower hours of idle reduction activity, and double-dipping, which accounts for 0.1 to 29 percent of cumulative powered stop duration.

NO_x emissions for all stops were reduced by 47 and 12 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 70 to 90 percent. Avoided fuel use and emissions are only minor for team drivers because there are fewer rest stops and lower APU utilization rates than for single drivers.

Table 6: Absolute Amount of Avoided Energy Use and Emissions During All Stops and Extended Idling for Actual versus Base Engine Scenarios on a Per Truck Basis *(Frey, Kuo, and Villa, 2008)*

Fleet	APU	Stop Activity Range		Avoided Energy Use (gal eq./yr)	Avoided CO$_2$ Emissions (kg/yr)	Avoided NOx Emissions (kg/yr)	Avoided HC Emissions[c] (g/yr)	Avoided CO Emissions[c] (g/yr)	Avoided PM Emissions (g/yr)
A	APU-A	All Stop Durations[a]	Average	241	2460	89	*2000*	*-5600*	190
			Range	72 to 374	737 to 3830	25 to 142	*603 to 3140*	*-10000 to -970*	67 to 265
		Extended Idling[b]	Average	194	1990	72	*1620*	*-4700*	149
			Range	46 to 273	472 to 2790	17 to 100	*401 to 2250*	*-7500 to -880*	34 to 218
	APU-B	All Stop Durations[a]	Average	281	2850	78	*2120*	*8540*	335
			Range	115 to 416	1170 to 4230	29 to 106	*784 to 3190*	*3240 to 13200*	166 to 576
		Extended Idling[b]	Average	237	2400	66	*1790*	*7200*	280
			Range	96 to 388	979 to 3940	24 to 99	*657 to 2970*	*2710 to 12300*	140 to 539
B	APU-A	All Stop Durations[a]	Average	20	202	8	*168*	*-950*	9
			Range	1 to 89	10 to 910	1 to 35	*16 to 735*	*-3900 to 4*	-3 to 53
		Extended Idling[b]	Average	17	171	7	*138*	*-690*	11
			Range	1 to 75	6 to 773	0 to 30	*4 to 627*	*-3300 to 42*	0 to 45
	APU-B	All Stop Durations[a]	Average	30	299	11	*246*	*860*	4
			Range	-4 to 71	-43 to 723	1 to 20	*32 to 560*	*-200 to 2240*	-140 to 86
		Extended Idling[b]	Average	10	99	5	*95*	*272*	-15
			Range	-7 to 31	-68 to 314	1 to 12	*22 to 225*	*-270 to 900*	-140 to 37

[a] All stop durations: Annual sum of all hours of the combination of the duration of base engine idle, APU usage and shore-power usage.

[b] Extended Idling: Annual sum of all hours of the combination of the duration of base engine idle, APU usage and shore-power usage excluding stops shorter than 7 hours.

[c] For numbers that are italicized, the estimates are based on average exhaust concentrations from measurements below the detection limits of 20 ppm for HC and 200 ppm for CO. For these numbers, there is less confidence in the stability of the mean values.

Compared to the base engine, shore-power will produce larger reductions in emissions than can be achieved with APUs, on both a relative and absolute basis. For the high temperature scenario, SP consumes 74 percent less energy and produces 79 percent lower CO$_2$ emissions, while achieving NO$_x$ reductions of 98 percent and PM reductions of 75 percent. The disadvantage of SP is that it leads to higher emissions of SO$_2$. When compared to APUs rather than the base engine, SP has substantial reductions in energy use and emissions, except for SO$_2$.

Cost Effectiveness

Dr. John R. Stone (NCSU Professor of Civil Engineering), Varshil Parikh and Soheil Sajjadi (Civil Engineering Graduate Students) conducted an APU Breakeven Analysis to determine the cost effectiveness of APUs. As reported, the payback time period calculation takes several variables into account. There are variables that are truck related, APU related, and general. Tables 7-9 show assumed constant values of the variables in their respective categories. It is noted that costs of trucks and APUs vary, that life cycle times vary and that maintenance costs vary with use. However, the assumed values and resulting calculations for breakeven time will demonstrate the relative cost effectiveness of using APUs to replace engine idling at different fuel cost and idle duration scenarios.

Table 7: Assumed Values of Truck Related Variables

Variable	**Value**
Truck price	$100,000
Truck life cycle	10 years
Truck salvage value	$10,000
Annual maintenance cost for truck without APU	$1000
Fuel consumption rate	0.47 gal/hr

Table 8: Assumed Values of APU Related Variables

Variable	**Value**
APU price	$8,400
APU life cycle	5 years
APU salvage value	$100
Annual Maintenance cost for truck with APU	$460
Fuel consumption rate	0.25 gal/hr

Table 9: General Variables

Variable	**Value**
Operating days per year	261
Annual Investment rate	14%
Rate of interest	6%

Major variables affecting the break even point of an APU investment are average truck idling time per day and fuel cost. An idling time range of one hour to 10 hours and a range of diesel fuel costs from $3 to $5 per gallon define different scenarios for break even point (payback period) in this analysis. Other scenarios were tested during the analysis including idling at different temperatures and varying the electrical load on the APU. In both cases fuel consumption rates for the truck and the APU changed. However, the payback period, which is a function of total annual savings provided in calculation methodology section, did not change significantly in the temperature and load scenarios. Thus, the payback time period is not sensitive to temperature and electrical load on the APU, but rather payback is sensitive to idling time and fuel cost.

Table 10 shows results for different scenarios of idling time and fuel cost. For a constant idle time per day, increasing fuel cost will decrease payback period. For a constant fuel cost, increasing daily idle time decreases payback period significantly. Other scenarios of fuel cost and idle time can be chosen depending on expected future operations.

Table 10: Payback Period Times in Years for Different Scenarios

	Fuel Cost / Gallon					
Idling Time	$3.00	$3.50	$4.00	$4.50	$5.00	$5.50
1.0 hours/day	11.8	11.3	10.9	10.5	10.2	9.8
2.0	9.5	8.9	8.4	7.9	7.5	7.2
5.5	5.6	5.1	4.7	4.3	4	3.7
8.0	4.4	3.9	3.5	3.2	3	2.7

A similar analysis of payback period was conducted by Frey and Kuo based on the real world activity data for each of the 20 trucks. For $4.50 per gallon or lower diesel fuel price, no truck would have positive net cost savings because the reduction in fuel cost is not enough to offset leveled capital cost and non-fuel O & M cost, even if the latter are at the low end of their possible ranges. With zero discount rate, a net cost savings is estimated for six Fleet A trucks for high fuel price ($8.00 per gallon) and low APU capital cost ($8,500), and only for one Fleet A truck for high fuel price and high APU capital cost ($13,000). With a discount rate of 10 percent, only 3 Fleet A trucks have net cost savings if fuel price is high and capital cost is low. Payback periods range from longer than 5 years to no payback period (no net discounted savings) for $4.50 per gallon or cheaper fuel Payback periods of 3 to 5 years are associated with only six trucks for which the annual fuel savings was 275 gallons or more if there is low APU capital cost, no discount rate and $8 per gallon fuel. As discount rate increases, the payback periods increase.

Table 11: Sensitivity Analysis for Net Cost Savings per Unit of Energy Use Reduction with Discount Rate of Zero for All Stop Durations for All Trucks (Frey & Kuo)

Fleet	APU	Truck No.	APU Annual Fuel Saving (gal/yr)	Net Savings per Unit of Energy Use Reduction ($/gal)											
				Diesel Fuel Price ($/gal) 2.56				Diesel Fuel Price ($/gal) 4.50				Diesel Fuel Price ($/gal) 8.00			
				APU Capital 8,500		APU Capital 13,000		APU Capital 8,500		APU Capital 13,000		APU Capital 8,500		APU Capital 13,000	
				APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600	APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600	APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600	APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600	APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600	APU O & M Cost ($/yr) 400	APU O & M Cost ($/yr) 600
A	APU-A	1	63	-1940	-2140	-2840	-3040	-1820	-2020	-2720	-2920	-1600	-1800	-2500	-2700
		2	278	-1390	-1590	-2290	-2490	-849	-1050	-1750	-1950	**+123**	-77	-777	-977
		3	366	-1160	-1360	-2060	-2260	-452	-652	-1350	-1550	**+830**	**+630**	-70	-270
		4	164	-1680	-1880	-2580	-2780	-1360	-1560	-2260	-2460	-786	-986	-1690	-1890
		5	298	-1340	-1540	-2240	-2440	-760	-960	-1660	-1860	**+282**	**+82**	-618	-818
	APU-B	6	367	-1160	-1360	-2060	-2260	-446	-646	-1350	-1550	**+840**	**+640**	-60	-260
		7	416	-1040	-1240	-1940	-2140	-228	-428	-1130	-1330	**+1230**	**+1030**	**+328**	**+128**
		8	197	-1600	-1800	-2500	-2700	-1210	-1410	-2110	-2310	-523	-723	-1420	-1620
		9	114	-1810	-2010	-2710	-2910	-1590	-1790	-2490	-2690	-1190	-1390	-2090	-2290
		10	307	-1310	-1510	-2210	-2410	-720	-920	-1620	-1820	**+353**	**153.4**	-547	-747
B	APU-A	11	4	-2090	-2290	-2990	-3190	-2080	-2280	-2980	-3180	-2060	-2260	-2960	-3160
		12	1	-2100	-2300	-3000	-3200	-2090	-2290	-2990	-3190	-2090	-2290	-2990	-3190
		13	1	-2100	-2300	-3000	-3200	-2100	-2300	-3000	-3200	-2090	-2290	-2990	-3190
		14	1	-2100	-2300	-3000	-3200	-2100	-2300	-3000	-3200	-2090	-2290	-2990	-3190
		15	89	-1870	-2070	-2770	-2970	-1700	-1900	-2600	-2800	-1390	-1590	-2290	-2490
	APU-B	16	71	-1920	-2120	-2820	-3020	-1780	-1980	-2680	-2880	-1530	-1730	-2430	-2630
		17	-4	-2110	-2310	-3010	-3210	-2120	-2320	-3020	-3220	-2130	-2330	-3030	-3230
		18	6	-2090	-2290	-2990	-3190	-2070	-2270	-2970	-3170	-2050	-2250	-2950	-3150
		19	3	-2090	-2290	-2990	-3190	-2080	-2280	-2980	-3180	-2070	-2270	-2970	-3170
		20	71	-1920	-2120	-2820	-3020	-1780	-1980	-2680	-2880	-1530	-1730	-2430	-2630

Noted in the preceding table is the annual fuel savings derived from the use of APU in place of base engine idling for the 20 field trucks. The annual fuel gallon savings ranges from -4 gals of (from simultaneous use of base engine and APU) to 416 gallons annual savings with an overall average for the 20 trucks of 141 gallons saved annually. If actual APU usage had been higher for the 20 field trucks (as the result of incentives and /or driver training or all 20 trucks operating with single drivers) than payback periods would be reduced.

Conclusions and Recommendations

Differences in base engine speeds, ambient weather conditions, accessory loads, or combinations of these, as applicable, can have significant effects on energy use and emissions rates for the base engines, APUs and SP systems. Through this field test, new methods have been developed for estimating fuel or energy use rates and emission factors taking into account variations of key factors in real-world conditions.

In addition to the physical characteristics of the base engine and APU, driver behavior plays an important role in the effectiveness of MIRTs to reduce base engine idling. Team drivers generally do not use an APU because the idling time is low, and thus APUs are not cost effective for team-driven trucks. For trucks operated by single-drivers, APUs are used in the field both for long duration rest stops and for some shorter stops that are likely to be during loading or unloading of the truck. The APUs were cost-effective for those drivers who most actively used the APUs. The idling activity patterns were similar for the single drivers regardless of whether they preferred to use the base engine or the APU. Thus, the results imply that if drivers who otherwise are not using the APU can be encouraged or required to use the APUs (which can include long duration rest stops as well as shorter stops), the payback period will decrease to acceptable levels. Fleets should closely analyze their needs to assess the value of purchasing MIRTs and once idle reduction technology has been adopted insure usage by providing training and incentives for use.

Base engine fuel rates lower and APU fuel rates higher than anticipated

Most drivers for Fleets A and B tended to idle the base engines at low RPM of approximately 600 and 690 RPM, respectively, with average base engine fuel use rates of 0.46 to 0.65 gal/hr, depending on variations in ambient the temperature. These are much lower than typically reported values of 0.8 to 1 gal/hr. The estimated average APU fuel use rates typically ranged from 0.24 to 0.41 gal/hr, depending on variations in electrical load impacted by ambient temperature, which are higher than the typically reported values of approximately 0.2 gal/hr. Thus, the magnitudes of reduction in fuel use for the APUs are lower than the other reported values, and APUs may be not as an attractive idle reduction option here as prior studies imply.

The base engine and APU fuel use rates during cold and hot weather cases are generally higher than those during mild weather cases, which are similar to the trends reported in literature. The base and APU engines for Fleet A tend to consume more fuel than those for Fleet B by 8% for the base engine and by 4 to 7% for the APUs. Higher fuel use rates for Fleet A are attributed to higher accessory loads for cooling and heating because of the cab size and, in the case of cooling load, exterior temperature. The APU electrical load is influenced by factors such as “ECONO” model of the HVAC system.

Emissions

The use of APU instead of base engines could lead to potential reductions of 36 to 47 percent in fuel use and emissions of CO_2 and SO_2 under various loads, assuming 100% substitution of the APU for the base engine during all idling. Of course, the actual achievable reduction in practice will depend on the proportion of idling time during which the APU is used instead of the base engine. In the case of the observed fleets, these reductions were 22 percent for Fleet A and only 5 percent for Fleet B. The 80 to 90 percent potential reductions in NO_x emissions are more substantial. PM emissions potentially can be reduced by a modest but significant 10 to 25 percent. There may also be significant reductions in emissions of HC and CO, but these data were typically below the PEMS detection limit and thus are not deemed to be statistically significant.

The use of SP instead of the base engine can lead to potential reductions of 75 to 93 percent in energy use and CO_2 emissions. Except for SO_2, the reductions in emissions of other pollutants are much larger for SP than for APU usage when compared to the base engine.

The overall reductions in fuel use and emissions for the substitution of either APUs or SP instead of the base engine will be less than the estimates here, which are based on comparison of one hour of operation of each power source. For example, the field data imply that the APU is used by single drivers for an average of 59% of idling and by team drivers for an average of only 25% of idling. The actual reductions will depend on the portion of idling time for which the anti-idling devices are used, as well as the ambient conditions during which they are used.

The wide ranges of variability in base engine fuel use rates imply the importance of accounting for variability in engine speed and ambient temperature.

Effects on engine RPM, load size, cab color and size

The user-setting for base engine idle RPM is shown to have a significant effect on base engine fuel use during idle. A key implication is that the base engine idle RPM should be set as low as possible in order to conserve fuel. When purchasing trucks, owners should consider the choice of exterior color and cab size, with a preference for lighter and smaller, respectively, given their influence on idle fuel consumption. Measures to reduce base engine fuel use will reduce the economic attractiveness of APUs, since they will reduce the potential reduction in fuel use achievable with APUs.

The two APUs compared in this study used the same engine but have different efficiencies as a result of the RPM setting and integration with the generator. Since APU loads were found to be typically less than 3 kW, the configuration for APU-B will typically be more fuel efficient than that for APU-A. For example, percentage reductions in fuel use for APU B versus APU A at 500 W, 1,000 W and 2,000 W are 17, 13 and 4 percent, respectively. Thus, appropriate matching of APU characteristics to expected load patterns can help in reducing fuel consumption.

APUs, fuel economy and increasing emission standards

On average, fuel use rates for the APU engines are lower than those for the base engines, leading to a net reduction in fuel use. However, the field trucks have relatively low base engine idle fuel use rates compared to those reported elsewhere, whereas the APU engine fuel use rates are higher than assumed in most other studies. Therefore, the fuel use savings and emissions reductions that would be projected from these results will typically be lower than those based on other sources.

The high frequency of double-dipping for some trucks defeats the purpose of the APU for reducing fuel consumption and emissions. Double-dipping should be discouraged (or prevented, via an interlock) in order to achieve the fuel use and emissions reductions that are possible if the APU is used instead of the base engine.

As new base engines that are subject to increasingly stringent emissions standards enter the on road fleet, the relative advantage of APUs or SP may be decreased with respect to emission rates, especially for NO_x and PM. However, the advantages with respect to reduced fuel use and CO_2 emissions are likely to remain. Additional data would be useful regarding the idle emission rates of newer base engines. Furthermore, the effect of alternative fuels such as B20 biodiesel on both base and APU engine emissions should be assessed.

Some states, such as California, will not allow the use of APUs without advanced emission control devices. However, trucks often stop at locations that are not served by SP or other types of TSE. Thus, for trucks that spend most of their operation time outside of the currently limited number of states or localities where APU use is not allowed, APUs may still be an idle reduction technology worth considering, given their portability and applicability at any location other than those excluded by law or regulation.

The estimated real-world fuel use rates and emissions factors were used to quantify avoided fuel use and emissions in the real-world conditions for the observed Fleets A and B, and to assess the cost effectiveness of idle reduction using APUs. The methods developed here are recommended for the measurements and certification of the APU fuel use rates versus electrical load in order to have a direct comparison among various APUs. The methods developed here can be adopted to assess other idle reduction options, such as off-board TSE and direct fire heaters.

Payback most sensitive to idling time, APU usage and fuel cost

The break-even point (payback period time) is highly sensitive to APU usage, idling time and fuel cost. If the estimated APU lifecycle is about 5 years and assuming that fuel price does not change significantly from $4.60/gallon, using an APU is not cost effective for trucks idling less than 4 hours daily, but an APU is highly recommended for trucks idling more than 7 hours daily.

For a constant idling time per day, payback period is not highly sensitive to temperature or electrical load on APU because payback time is function of total annual saving and changing those conditions will affect both sides of this formula leaving the total annual savings variable with no significant change: (Total annual savings =Annual cost of truck without APU – Annual cost of truck with APU).

Payback period time calculations have multiple variables which can change significantly from case to case. Thus, a good approach to estimating payback period is to apply a range of reasonable values such as APU cost, the cost of fuel, and other values in a "what if" sensitivity analysis.

For an assumed combination of values as shown in Table 10 with an APU cost of $8400 the payback period is 3.2 years. These more generalized values are within the range of the values used by Frey and Kuo in the sensitivity analyses conducted on the 20 field trucks except that the Table 10 APU cost ($8400) is at the lower extreme of the Table 11 range ($8500-$13000) and the annual fuel use saving rates were significantly less for the 20 field test trucks. If the APU cost increases to $13000 (the highest APU cost in Table 11), if fuel costs $4.50/gallon, and if truckers idle eight hours per day (using an APU instead of base engine), then the payback period is five years. Therefore the results of the more generalized sensitivity analysis conducted by Dr Stone are consistent with results of Frey and Kuo analysis on the real world usage conducted through the 20 field trucks. Moreover if the 20 field trucks had higher avoided fuel use rates (by using the APU more rather than idling the base engine), the payback rates would be reduced significantly and would bring field test payback periods more in line with the generalized sensitivity analyses represented in Table 10

Task 9: Extrapolate potential benefits (fuel savings and emission reductions) from more wide spread use of selected technologies

Dr. John R. Stone (NCSU Professor of Civil Engineering), Julie Bjornstadt (UNC Department of City and Regional Planning Graduate Student), and Soheil Sajjadi (NCSU Civil Engineering Graduate Student) conducted a case study to extrapolate the potential benefits in fuel savings and emissions reductions from a single vehicle to trucks passing through an urban area.

Mecklenburg County North Carolina Case Study

NCDOT conducted truck traffic counts in 2006 in Mecklenburg County outside Charlotte and estimated 13,986 daily Federal Highway Administration (FHWA) class 9[5] sleeper-cab tractor trailers on I-77 and 18,614 daily tractor trailers on I-85. The number of truck stops in Mecklenburg County on or near I-77 and I-85 and their number of spaces in the fall of 2007 were 59 on I-77 and 70 spaces on I-85.

For the case study “what if” analysis the number of long haul trucks stopping within the county was estimated using assumed percentages that define several scenarios ranging from 5% to 20% stopping (1,630 to 6,520 trucks per day). These numbers are beyond the Mecklenburg County truck stop capacity which is129 spaces or 310 equivalent spaces assuming 10-hour rest periods and 100% occupancy. Thus, more spaces would have to be constructed inside or outside Mecklenburg County to accommodate the assumed truckers stopping to rest. In any event the scenarios give a feasible “what if” range to determine if idle reduction technologies for trucks impact air quality and Mecklenburg non-attainment status.

The estimated fuel and emissions rates are given by Table 11. Rates for the conventional engine and for APU are taken from Task 6 results for this study. Equivalent rates for shore power (TSE) which receives power from a remote electrical plant are taken from Stodolsky (2000). The average value of these estimated emissions and consumption rates has been used for calculations.

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[5] This research uses FHWA Vehicle Class Scheme F. It includes all vehicle types – class 1 motorcycles to class 13 multi-trailer trucks. The FHWA class 9 category only includes five-axle tractor trailer vehicles that often include sleeper cabs. Truck manufacturers used another scheme based on weight - GVWR. Class 8 in the weight scheme includes FHWA classes 8 through 13 and some of the vehicles in FHWA classes 4 through 7 depending on weight.

Table 12: Estimated Emissions and Fuel Consumption by Technology

Technology	*Fuel Consumption (gal/hr)*	*VOC (g/hr) (ref 2)*	*CO (g/hr)*	*PM_{10} (g/hr)*	*NOx (g/hr)*	*CO_2 (g/hr)*
Conventional Idling[1]	0.45 - 0.60	12.6	12.8- 17.1	1.1 - 1.4	69.2 - 92.2	4.6 - 6.1
Auxiliary Power Units[1]	0.22 -0.45	0.45	5.7 - 23.3	0.7 -1.5	5.7 - 15.84 5.1 -24.7	2.3 - 4.6
Shore Power[2]	0.29	0.05	0.48	0.03	6.04	3.01

[1] Task 6 and Frey, H.C., P.Y. Kuo, and C. Villa, "Measurement and Modeling of Fuel Use and Exhaust Emissions from Idling Long-Haul Freight Truck and Auxiliary Power Unit Engines," Paper No. 616, Proceedings, 101st Annual Meeting of the Air & Waste Management Association, Portland, OR, June 24-27, 2008.

[2] Stodolsky, Frank, Linda Gaines, and Anant Vyas. *Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks.* Report ANL/ESD-43. Center for Transportation Research, Argonne National Laboratory, U.S. Department of Energy, June 2000.

Results

The Mecklenburg County case study estimated the amount of emissions and fuel that could be saved assuming alternative scenarios of idling trucks. In Table ZZ the data in the first scenario illustrate how much fuel per day would be used if 5% of the truck drivers (1,630 trucks per day) passing through Mecklenburg County on I-85 and I-77 stopped to rest. If they idled their engines for 8 hours of their 10 hour rest period they would consume a total of 7,302 gallons of fuel. If they used APUs they would use 4,434 gallons, or shore power 3782 gallons. APU and shore power daily fuel savings for the 5% scenario are 2.868 gallons and 3,520 gallons, respectively.

Table 13: Scenarios for Daily Estimated Emissions and Fuel Consumption

% of Passing Trucks Stop for Idling	*Idling Reduction Technology*	*Fuel (gal/day)*	*VOC (g/day)*	*CO (g/day)*	*PM_{10} (g/day)*	*NOx (g/day)*	*CO_2 (kg/day)*
5%	Conventional	7302	164304	194948	16952	1044113	70416
	APU	4434	5868	189080	14344	167564	45640
	Shore power	3782	652	6259	391	78762	39250
10%	Conventional	14605	328608	389896	33904	2088226	140832
	APU	8867	11736	378160	28688	335128	91280
	Shore power	7563	1304	12518	782	157523	78501
15%	Conventional	21907	492912	584844	50856	3132338	211248
	APU	13301	17604	567240	43032	502692	136920
	Shore power	11345	1956	18778	1174	236285	117751
20%	Conventional	29210	657216	779792	67808	4176451	281664
	APU	17734	23472	756320	57376	670256	182560
	Shore power	15126	2608	25037	1565	315046	157002

Conclusions

Both shore power (TSE) and APU significantly reduce emissions and fuel consumption, and they are economically viable (Task 8). Each system outweighs the other system in one aspect or another – availability, cost, weight, etc. APUs shift the cost to the truck owner, they are mobile, and they can be used anywhere including ports and terminals and ad hoc rest stops on exits, highway shoulders, and public rest areas. APUs may be best for existing truck stops and ad hoc stops. Shore power may be best for large truck stops especially in states which follow California's policy of banning long term diesel idling. It is recommended that APUs be used in the short term while shore is not widespread. Shore power appears to be the most beneficial long-term solution in terms of fuel savings and emissions reductions.

Mecklenburg County is a non-attainment area for ozone and the NC Division of Air Quality has proposed regulations effective May 2011 to limit extended idling for trucks weighing more than 10,000 pounds. Also according to an October 4, 2006, public hearing if facilities (presumably including trucks) have the potential to emit 100 tons per year or more of VOC or NOx they must comply with rules for Reasonable Available Control Technology (VOC RACT 15A MCAC 02D .0902 and NOx RACT 15A NCAC02D .1402). The 5% scenario for 1,630 trucks stopping and idling would produce about 1 ton/day NOx and 0.2 ton/day VOC, or about 300 tons/year NOx and 60 tons/ year VOC (allowing for reduced weekend and holiday traffic). Thus, if 5% (of fewer) of the trucks on I-85 and I-77 stopped, rested, and idled in the Mecklenburg non-attainment area, they should be required have idle reduction technology. This is consistent with the proposed NCDAQ proposal to limit idling of all diesel trucks.

Task 10: Submit reports to EPA and publicize summary

Based on the analysis conducted by NC State University's Dr Chris Frey and Po-Yao Kyo on 20 field demonstration trucks outfitted by Volvo with APU and satellite based electronic tracking devices the following conclusions and " lessons learned" have been reached. A project summary and lesson's learned case study will be distributed to trade media and posted under projects at www.cleantransportation.org along with a 10 minute video about the project developed by Volvo.

Previous avoided fuel use rates and emissions benefits from APUs may be optimistic

Avoided annual average fuel use and CO2 emissions for all stops are 22 and 5 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 50 to 80 percent. Based on literature values for national idle base engine and APU fuel use rates, national average annual avoided fuel use could be as high as 480 to 770 million gallons per year. Based on results from single drivers, the national annual avoided fuel use would be projected at only 130 million gallons. The projected reduction in fuel use for team drivers is far lower; however, the proportion of on road trucks that have team drivers is not known. Thus, the EPA reported estimates appear to be optimistic in that they assume that all trucks in the on road fleet would have similar performance. Conversely, the sample of trucks in this study is not a nationally representative sample. However, the trucks observed here represent a proportion of those on the road. An accurate estimate of the national potential for avoided fuel use and emissions should take into account variability within the on road fleet and among APU systems.
Avoided annual average NO emissions for all stops are 46 and 14 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 70 to 90 percent. Based on literature estimates, national avoided NO_x and PM emissions could be 130,000 to 160,000 and -1,000 (an increase) to 4,800 tons per year, respectively. Based on results from the single driver trucks, the estimated national annual avoided NO_x and PM emissions are 42,000 and 130 tons, respectively. Fuel use rates and emission rates of NOx, HC and CO_2 for the APUs are generally lower than those for the base engine.

Thus, both the avoided emissions as well as fuel use are sensitive to truck and APU characteristics, as well as driver behavior. Previous studies estimated fuel use and emissions without accurate estimates for real-world idle reduction hours, fuel use and emission rates, and double-dipping activities and their impacts. The differences in real world versus previously estimated avoided fuel use and emissions is because of differences in fuel use rates and emissions factors, and lower idle reduction activity

With more stringent regulated emissions standards, APU benefits are reduced and costs increased although CO_2 and avoided fuel use benefits remain

As new base engines that are subject to increasingly stringent emissions standards enter the on road fleet, the relative advantage of APUs may be decreased with respect to emission rates, especially for NO_x and PM. However, the advantages with respect to reduced fuel use and CO_2 emissions are likely to remain. New APUs in California need to control PM emissions by routing APU exhaust through the truck PM filter or installing an extra APU PM filter after 2008. These new emission standards are likely to increase the cost of APUs.

Incentive programs needed to encourage low RPM, high APU use and reduce double dipping

In order to reduce energy use and emissions for APU-equipped trucks operated by single drivers, driver incentive programs should be developed to encourage low base engine RPM and high APU utilization levels and discourage double-dipping. During the 18 month field test six trucks had 25 hours or more of activity in which the base engine and APU were operating simultaneously, which increases fuel use and emissions. The trucks operated by team drivers should consider other idle reduction options because it is almost impossible for them to have net cost saving for the use of the APU.

New methods developed through this project can be applied to additional idle reduction technology

Although the shore power (SP) facilities are currently unavailable at most truck stop locations, further geospatial analysis is recommended for identifying suitable SP facility spots. The cost effectiveness of the SP facilities for the chosen spots should be estimated based on the measured electrical loads for the APU because they are indicative of the loads that could be supplied by SP if such facilities had been available. Methods developed by the NCSU project team can be used for quantifying activity patterns and avoided fuel use and emissions for additional trucks and extended to include other types of anti-idling methods.

Payback periods may not justify APU use unless APU use and fuel costs are high

The economics of APUs are sensitive to the annual avoided fuel use. Many studies appear to use high values for base engine fuel use (e.g. 1.0 gal/hr) and low values for APU fuel use (e.g. 0.2 gal/hr), combined with assumed but uncertain hours of substitution of APU usage for that of the base engine, which leads to estimated payback periods of 1.4 to 4.3 years[6].

Sensitivity analyses for net cost savings per unit of energy use reduction and payback periods for each of the 20 trucks are based on actual fuel use and emission rates and activity patterns, using discount rates of 0 to 10 percent, fuel price of $2.56 to $8.00 per gallon, APU capital cost of $8,500 to $13,000, and annual APU non-fuel O&M cost of $400 to $600.

For $4.50 per gallon or lower diesel fuel price, no truck has positive net cost savings because the reduction in fuel cost is not enough to offset levelized capital cost or non-fuel operations and maintenance (O & M) cost, even if the latter are at the low end of their ranges. With discount rate of zero, a net cost savings is estimated for six Fleet A trucks for high fuel price ($8.00 per gallon) and low APU capital cost ($8,500), and only for one Fleet A truck for high fuel price and high APU capital cost ($13,000). With discount rate of 10 percent, only three trucks have net cost savings for high fuel price and low capital cost.

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[6] Stodolsky, F.; Gaines, L.; Vyas, A. *Analysis of Technology Options to Reduce the Fuel Consumption of Idling Trucks*. ANL/ESD-43; Prepared by Argonne National Laboratory for U.S. Department of Energy: Washington, DC, June, 2000

Payback periods for all trucks range from longer than 5 years to no payback period (no net discounted savings) for fuel price of $4.50 per gallon and lower. For low APU capital cost, no discount rate and $8 per gallon fuel price, only six trucks have payback periods shorter than 5 years and the shortest of these is 3 years. As discount rate increases, the payback periods increase.

Payback times are significantly reduced with greater APU use. A more generalized sensitivity analysis concludes that with an APU cost of $8,400 and 8 hours daily APU instead of base engine idling that payback can be expected in 3.5 years. The field data derived from the 20 trucks imply that the APU is used by single drivers for an average of 59% of idling and by team drivers for an average of only 25% of idling. Therefore this lack of APU use instead of base engine idling significantly impacts the payback times for APUs in the field test and underscores the need for driver incentives and training.

APUs used for short and long duration stops, however total rest stops are less than typically estimated

Trucks with single drivers have significantly more and longer stops than trucks with team driver, however the total idling time for rest stops is less than typically estimated. APUs are used for both short and long duration stops

Rate of APU use varies within fleets and between fleets that employ single versus team drivers

With fleet purchases of APUs the field study demonstrated that driver preference for APU versus base engine varies. It can be assumed that individual owner operators that purchase APUs will have a higher percentage of usage and therefore a quicker/better rate of return on the investment. Single drivers have a greater APU use rate than team drivers.