Truck Stop Electrification and Carbon Offsets

Issues Paper

Prepared for:
Climate Action Reserve

Photo: IdleAire

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1 Introduction and Key Conclusions

Truck stop electrification (TSE) is a commercially available technology that can reduce greenhouse gas emissions from extended idling of a heavy-duty vehicle by more than 90%. Rather than run the truck's main engine overnight to provide heat, air conditioning and accessory power, which tends to be a very inefficient source of energy for these purposes, truck stop electrification allows truckers to use grid power while parked at suitably equipped stops.

The potential scale is large. According to one estimate [*1*], 685 million gallons of fuel are consumed per year through overnight idling of trucks in the U.S., accounting for 7% of total fuel consumption of sleeper trucks. This equates to 7.0 million metric tons of CO_2 per year. Emissions from electricity use at truck stops, which must be deducted to determine net savings, are small in comparison. In one study, emissions from electricity use amounted to just 7% of the savings from reduced idling [*2*].

This paper provides an analysis of the potential to quantify emission reductions through developing a carbon offset protocol for truck stop electrification projects, focused on the U.S. voluntary and pre-compliance carbon market. It describes experience with the costs and emission impacts of TSE projects to date, and existing methodologies to quantify the emissions impacts of TSE. This is followed by an analysis of the key issues for a potential protocol, including development of the baseline scenario, demonstrating additionality, and ownership of emission reduction credits. The paper concludes by providing an order-of-magnitude estimate of the emission reduction potential.

The paper is based on an extensive literature review, coupled with informal conversations and in-depth interviews with staff at state agencies, carbon offset developers and equipment providers. The key conclusions of this paper are as follows:

- Emission reductions from truck stop electrification are relatively straightforward to quantify. The main areas of uncertainty relate to determining baseline emissions, specifically:
  - Determining the number of idling hours replaced by an hour of truck stop electrification usage.
  - Determining the appropriate idling emission factor.
  - Determining whether the baseline is idling the main engine or use of an auxiliary power unit (APU), particularly in states and local jurisdictions that prohibit idling. An APU is a device, usually diesel-powered, that can provide heat and power independently of the main engine.
- Truck stop electrification projects are likely to be additional, as few projects have been implemented in the absence of offset and/or grant funding. However, it may be difficult to determine the additionality of a project where substantial grant funding is also provided.
- The likely scale of emission reductions is difficult to determine; estimates range from 0.7 to about 5 million metric tons of CO_2 reduced per year.
- Transportation emissions would be capped from 2012 under the proposed American Clean Energy and Security Act. If this or similar legislation becomes law, it would preclude truck stop electrification and other transportation-sector offsets. Given a 3-12 month lead time to implement TSE projects, there would be little time to generate carbon offsets before cap-and-trade goes into effect.

2 Truck Stop Electrification

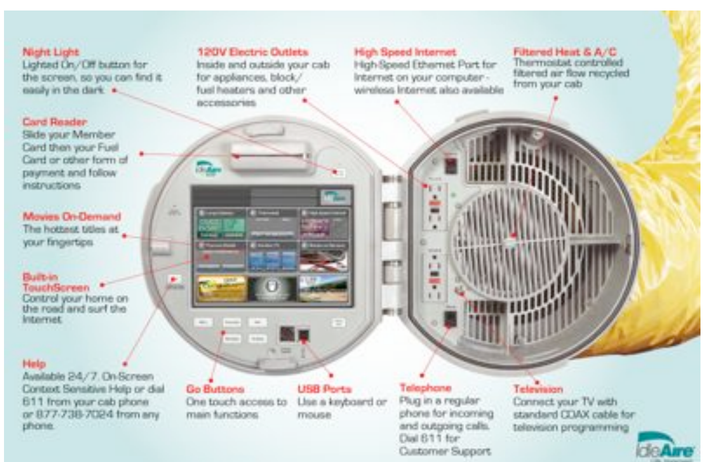
2.1 Background

Truck stop electrification replaces power from an idling diesel engine with grid-connected electric power, primarily for overnight and other extended stops. Long-haul truckers idle for considerable periods of time – between six and seven hours per day on average [*3*] – and effectively live out of their cabs for much of the year. Most drivers are subject to U.S. DOT hours-of-service regulations, which generally require a rest period of 10 consecutive hours after 11 hours of driving.[1]

Idling the main engine provides drivers with a source of "hotel power" for climate control and other accessory loads such as a television, microwave, coffee maker or refrigerator. Idling also helps to keep the engine and fuel warm and thus avoid start-up problems. It can also help truckers sleep through drowning out other noise [*3*].

Truck stop electrification systems fall into two main categories:

- **Off-board systems.** These systems provide heating and air conditioning directly to the cab of the truck via a flexible hose. They also provide electric power and entertainment (internet, telephone and cable television). Off-board systems require considerable capital investment on the part of the TSE provider to install, but only minimal investment by the truck owner. In the case of IdleAire, the dominant TSE provider, a $10 window adapter to accommodate the hose is the only retrofit required for truck owners. IdleAire currently charges $2.45-$2.89 per hour to use basic services; internet, on-demand movies and other services are extra.[2]



IdleAire off-board system and in-cab unit. The device on the left fits into the cab window
Photo: IdleAire

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[1] Even given less-than-perfect compliance with these regulations, drivers still rest for substantial periods of time. The precise U.S. DOT rules are somewhat complex. No driving may take place after 14 hours of duty time, until a driver has had a rest period of 10 consecutive hours. No more than 11 of these 14 duty hours may be spent driving. There are also limits on the amount of driving that may be undertaken in a seven- or eight-day period. See Federal Motor Carrier Safety Administration, "Interstate Truck Driver's Guide to Hours of Service," available at: http://www.fmcsa.dot.gov/rules-regulations/truck/driver/hos/fmcsa-guide-to-hos.PDF.

[2] See pricing list at http://www.idleaire.com/cms/IdleAire+Pricing/179.html, last accessed October 28, 2009.

- **On-board systems.** These systems, often known as shore power, simply provide a source of electrical power to the truck, similar to a plug-in for an RV or boat. They may offer internet and cable TV as well. On-board systems require some investment by truck owners for the on-board equipment. One option is to install an inverter to run on-board DC devices, which is usually offered as an option by the original equipment manufacturers (OEMs) of sleeper cabs. Alternatively (and much more cheaply), the driver can purchase standard 110-volt AC household appliances and run a heavy-duty extension lead through the cab window. The dominant provider, Shorepower, currently charges $1 per hour.

Shorepower system
Photo: The Climate Trust's Truck Stop Electrification Project

The infrastructure for on-board systems is significantly cheaper for the TSE provider to install (see below) and this technology may offer the greatest long-term potential. However, relatively few sleeper cabs have inverters installed. There is a "chicken-and-egg" problem as fleet owners are reluctant to invest in on-board equipment until there is a larger network of grid-connected spaces. Thus, off-board technology will be important for the short-to-medium term. Even if on-board systems more correctly align costs and benefits, as more of the capital costs are borne by truck owners who reap any fuel savings, the high up-front costs of on-board equipment mean that many truckers are reluctant to make the investment.

The $1-$3 hourly charges for truck stop electrification facilities may provide modest to zero cost savings to truckers compared to the cost of fuel for idling. Trucks burn 0.5 to 1 gallon of diesel per hour while idling (see Section 3.5.3), and maintenance savings amount to about 15 cents per hour of idling [*4*]. Thus, use of electrified truck stops may be largely driven by non-monetary factors such as driver comfort. In any case, the owner of emission reductions will almost certainly be the TSE technology provider, rather than the truck owner (Section 3.2). Thus, any fuel savings would not occur to the owner of the emission reductions and they are not relevant for determining additionality (Section 3.3).

Truck stop electrification is by no means the only option to reduce extended idling.[3] Others include:

- **Auxiliary power units (APUs)** are typically diesel powered, but run more efficiently than idling the truck's main engine. APUs could also be powered through fuel cells [*5*].
- **Battery systems** typically charge while the truck is running, and store enough power for overnight hotel loads. They provide greater storage capacity than the truck's own battery.

[3] EPA maintains a list of commercially available technologies at: http://www.epa.gov/otaq/smartway/transport/what-smartway/idling-reduction-available-tech.htm.

- **Diesel direct-fired heaters** are a relatively simply and cheap alternative, but do not provide power for air conditioning or other electrical loads.
- **Automatic shut-down/start-up systems** shut down the engine automatically, but start up as required to maintain cab temperature and battery charge. While they do not eliminate overnight idling, they can reduce idling time considerably.

A key advantage of these other anti-idling technologies is that they can reduce idling everywhere a truck is parked – not just in electrified truck parking spaces. However, the systems require a capital investment, and payback periods may be too long for many owners [*5*].

There are also non-technology based options to avoid extended idling. Drivers can sleep outside of the truck cab, e.g. in a motel, although at some cost. Alternatively, the use of team drivers allows one driver to sleep while the truck is on the road; this reduces idling emissions considerably [*6*].

Note that overnight idling is only a small part of total truck idling, which may also occur when loading and unloading, waiting in lines, or temporarily parked. While data are scarce, non-overnight idling may account for more than half of total truck idling [*1*]. Truck stop electrification may be suitable in some non-overnight idling locations (e.g. border crossings and highway rest areas that are used for shorter stops), but will usually be precluded by low demand at any individual location. The estimates for the potential scale of truck stop electrification, presented in Section 5, only consider overnight idling.

2.2 Existing Projects

There are currently two dominant providers of truck stop electrification systems. As of October 2009, IdleAire operated off-board systems at about 131 locations in the U.S. Shorepower (formerly Shurepower) provided power outlets for trucks to plug in at six locations, primarily in the Pacific Northwest. For both firms, each location has perhaps 25-50 electrified parking spaces. Limited data is available on occupancy rates, although anecdotal evidence suggests that occupancy has been lower than projected. A detailed survey of three IdleAire sites in Ohio and Indiana found that TSE spaces were used 26% of the time [*7*] – considerably below the 60% or more assumed in some grant proposals and projections of market potential. However, this may simply reflect usage at an early stage of market penetration.

Typically, IdleAire and Shorepower install and operate systems at truck stops or travel centers, which provide truck parking and other amenities such as showers and food service. They negotiate lease agreements with travel centers for a portion of the truck parking facility. Travel centers may receive a share of revenue, about 15% in some cases in the Northeast [*8*]. Truck stop electrification facilities can also be built and turned over to another company to operate, although this is unusual.

There are several other TSE providers included in U.S. EPA's list of commercially available anti-idling technologies, but none has achieved more than token deployment. CabAire and EnviroDock have both installed demonstration off-board systems in Connecticut and New York respectively.

Table 1 shows the growth in truck stop electrification facilities by state. There was rapid expansion from 2006 to 2007, but the number has stabilized since then. A significant expansion is likely in the next year due to the availability of federal stimulus funding, discussed below.

The number of TSE spaces per site is not available, but is typically 25-50. Below about 20 spaces per site, it is unclear whether TSE would be viable, particularly for off-board technologies. For purposes of verifying carbon offsets, emission reductions from multiple sites would likely be bundled into a single project. This has been the approach followed by all offset projects to date (Section 4).

Table 1 Truck Stop Electrification Sites by State

State	2006	2007	2008
AL	1	2	2
AR	2	6	6
AZ	–	4	4
CA	10	13	13
CO	–	1	1
FL	–	2	2
GA	4	5	5
IL	–	7	7
IN	–	4	4
KY	–	1	1
LA	1	2	3
MD	1	3	3
MI	–	1	2
MN	–	1	1
MO	–	3	3
MS	1	1	1
NC	1	2	2
ND	–	1	1
NE	–	1	1
NJ	1	3	3
NM	–	5	5
NV	–	1	1
NY	2	3	1
OH	–	10	11
OK	1	3	3
OR	–	5	5
PA	3	9	11
SC	1	1	1
TN	4	5	5
TX	12	19	22
UT	–	1	1
VA	1	2	2
WA	–	2	2
WV	–	1	1
Total	46	130	136

Source: NREL via Department of Energy Site Locator, www.afdc.energy.gov/afdc/locator/tse/, last accessed August 9, 2009.

The near-cessation of growth since 2007 is largely due to the financial difficulties experienced by IdleAire. After incurring losses of $60.2 million in 2006 and $93.4 million in 2007, IdleAire filed for Chapter 11 bankruptcy in 2008, citing debts of $303.6 million and assets of $210.9 million [*9*]. The company emerged from the bankruptcy proceedings under new ownership.

More limited financial data is available for Shorepower, but it has much lower revenue than IdleAire – a result of the less capital-intensive technology and smaller network. It reported revenue of $130,000 in 2007 and $89,000 in 2008.

2.3 Costs and Funding

The cost of installing truck stop electrification infrastructure varies depending on the type of technology. Off-board systems such as IdleAire typically cost between $10,000 and $20,000 per space to install. However, earlier IdleAire projections were that infrastructure costs would drop by 50 percent within five to seven years to $7,500 to $8,500 per parking space [*10*], likely due to economies of scale and refinements to the technology.

Current operating costs are not publicly available, but are typically covered by user revenue. The most complete data on IdleAire costs and revenues is provided in a 2005 evaluation of two demonstration projects in New York State [*11*]. This report estimates that an hourly service charge of more than $3 would be required to achieve break even, suggesting that such systems are not profitable in the absence of external funds (grants or carbon offsets). However, these calculations are sensitive to assumptions on capital costs, utilization rates and ancillary revenue (e.g. pay-per-view movies), and were derived based on demonstration projects that may not generalize to commercial experience.

EnviroDock, a more recent competitor, may have lower costs as the technology is simpler (TV and movies are not included) and locations can be unstaffed [*12*].

The installation of electrified outlets to provide external power to on-board systems generally costs from $4,500 to $8,500 per space [*13*]. Shorepower's current estimate is about $7,000 per space. However, this does not include costs to the truck owner or driver for any inverter or electrical equipment needed.

Expressing these capital costs in terms of cost per ton of emission reductions is highly sensitive to assumptions on facility utilization. Section 3.3 provides data from recent grant applications and market studies, which suggest that TSE lies in the range of $7-$30 per ton of CO_2 reduced. Alternatively, the capital cost per ton can be estimated directly. At 25% utilization, the capital cost per ton of CO_2 reduced is about $71. At 50% utilization, the capital cost is about $35 per ton. At 70% utilization, the capital cost is about $25 per ton.[4] As noted above, market studies often assume utilization of 60% or more, but in practice utilization to date appears to have been lower.

Given these high capital costs, almost all truck stop electrification facilities to date have been installed with the aid of government grants. In some cases, carbon offset funding has also been used (discussed in Section 4 below). Sources of state-level grant funding to date have included:

- **California:** Truck stop electrification is eligible under the Carl Moyer program to fund cleaner engines, equipment and emission reduction technologies, administered by the California Air Resources Board.[5] In 2005, CARB allocated $300,000 to IdleAire from the Carl Moyer program and a further $691,000 from its State Emissions Mitigation Program fund. A further $100,000 for the project came from U.S. EPA's National Transportation Idle Free Corridors Program.

[4] Assumptions: (i) Facility cost of $10,000, amortized over 20 years at 6% interest for an annualized cost of $872. (ii) Avoided fuel consumption of 0.5 gallons of diesel per hour of TSE utilization (see Section 3.5), or 5.1 kg of CO2 reduced per hour. (iii) Project emissions from electricity use are small and do not materially affect the cost per ton.

[5] Carl Moyer program information is available at: http://www.arb.ca.gov/msprog/moyer/moyer.htm

- **California:** Truck stop electrification is included in funding to the South Coast Air Quality Management District under the California Proposition 1B Goods Movement Emissions Reduction Program. However, specific TSE projects have yet to be funded.
- **California:** Truck stop electrification is included in the investment plan for the California Energy Commission's Alternative and Renewable Fuel and Vehicle Technology Program (AB118).[6] The investment plan is a guidance document that drives overall funding allocations; specific grant, loan or research programs would then direct resources to specific projects.
- **New York:** Several pilot programs, including IdleAire, Shorepower and EnviroDock systems, have been financed by the New York State Energy Research and Development Authority and New York Department of Transportation.[7]
- **Oregon:** Oregon's Business Energy Tax Credit Program and State Low Energy Loan Program have provided financing for Shorepower systems.

Two sources of federal funding have also been important for expansion of truck stop electrification facilities:

- **Congestion Mitigation and Air Quality (CMAQ):** Grants from this program, which is usually allocated by regional Metropolitan Planning Organizations, have funded facilities in Texas and Tennessee. For example, Knoxville, TN used $1 million in CMAQ funds to install 100 electrified spaces. CMAQ-funded installations are also planned in Massachusetts.
- **Diesel Emission Reduction Act (DERA) of 2006:** U.S. EPA administers various funding programs under DERA, and truck stop electrification is eligible for many of them. Funding is awarded both through competitive national programs, and through a non-competitive sub-allocation to states for their own grant programs.

These DERA programs were augmented by $300 million in stimulus (ARRA) funding in 2009, and most, if not all, truck stop electrification expansion over the next year would appear to depend at least partly on the stimulus. Typically, the award is made to a state agency that then conducts a competitive bidding process to select a private vendor. Precise details of investment costs and the share that is provided by grant funding are not available. However, given the amount of grant money per electrified parking space (a low of $8,800 to a high of $40,000 in these examples), it would appear that the vast majority of capital costs for stimulus-supported projects are publicly funded, making them less likely to depend on carbon offset revenues to go forward.

Specific awards for truck stop electrification to date under the stimulus have included:

- $748,000 to Georgia Department of Natural Resources, to install a truck stop electrification station with 85 spaces
- $1.21 million to the Maine Turnpike Authority, to install truck stop electrification with 30 spots at a rest stop on I-95

[6] AB118 program information is available at: http://www.energy.ca.gov/ab118/index.html.
[7] For an example of a previous NYSERDA solicitation, see http://www.nyserda.org/Funding/784PON.html.

- $2 million to the Tennessee Department of Transportation for installation of 175 electrified spaces
- $22.2 million to nonprofit Cascade Sierra Solutions, of which $7.5 million will go to Shorepower for electrification of 50 truck stops. (The remainder of the funding will go to other anti-idling programs such as rebates on shorepower-capable equipment.)

Some states such as Arizona are also supporting truck stop electrification through their state sub-allocation of stimulus funding for diesel emission reductions.

2.4 Environmental Co-Benefits

Greenhouse gas emissions may be one of the smaller environmental benefits from TSE, with the health benefit from reductions in NOx and other criteria pollutants being far greater (at least when converted to dollar terms). There are also health and safety benefits to drivers. Studies have shown that truck stop electrification improves in-cab air quality [*14*], and drivers may also experience improved sleep and reduced vibration.

3 Issues for a U.S. Methodology

This section discusses some of the key issues related to quantifying emission reductions from truck stop electrification, and other factors that would affect a decision to pursue a Climate Action Reserve protocol for TSE. Section 4 describes how these issues have been resolved in specific methodologies to date.

3.1 Implications of Cap-and-Trade

The transportation sector is included under cap-and-trade legislation that has passed the U.S. House of Representatives and is pending in the U.S. Senate. Under the American Clean Energy and Security Act (Waxman-Markey), producers and importers of transportation fuels would be required to surrender carbon allowances based on the carbon content of the fuel they sell. This would go into effect as of 2012. A similar system would be implemented under the Western Climate Initiative, although this would likely be superseded by federal legislation.

A cap-and-trade system that extends to the transportation sector would preclude the possibility of any transportation-sector offsets. Otherwise, emission reductions would be double counted – once through the offset, and once as refiners or other regulated entities need to surrender fewer carbon allowances due to lower gasoline demand [*15*].

Note that a widely accepted truck stop electrification "offset" protocol would still have value under cap-and-trade. For example, it might be used to direct competitive grant funding for CO_2 reduction projects in capped sectors, or for Joint Implementation-style programs where regulated entities seek to fund alternative emission reduction projects.

Actual implementation of a truck stop electrification project usually takes three to six months, and possibly up to a year, according to IdleAire. Most construction is done off-site and so on-site assembly can proceed relatively rapidly. This 3-6 month period includes time to obtain local permits, but not securing a location or obtaining funding.

If an upstream cap-and-trade system begins in 2012, truck stop electrification projects may have just one year to generate carbon offsets. This assumes that a protocol is approved by the Climate Action Reserve in 2010, and infrastructure can be implemented that same year. Of course, passage of the American Clean Energy and Security Act is uncertain at this time. Even if the legislation is passed, it may not include the transportation sector under cap-and-trade.

3.2 Ownership and Double Counting

There are four potential owners of offsets generated by a truck stop electrification project:

- **Technology provider and installer** (e.g. IdleAire or Shorepower). These firms are the most logical owner of the offset credit. They undertake the capital investment and own and operate the electrification facility. Granting ownership to the TSE provider has been the practice in carbon offset projects from truck stop electrification to date.
- **Location owner** (e.g. the Travel Center or state government for public rest stops). These organizations have a weaker claim on any offsets, as their main role is usually to lease a portion of their parking facility. In order to prevent double counting, the lease agreement

between the location owner and TSE provider could include a contractual waiver to any claim over emission reduction credits by the location owner. This is explicitly stated in lease agreements used by both IdleAire and Shorepower.

- **Truck owner**. Large fleets may also have a claim to ownership of emission reductions, usually as a part of wider idle reduction programs. For example, the Ontario NOx emissions trading scheme allowed offsets from an idle reduction initiative by trucking firm J.B. Hunt, which measured idling hours before and after the implementation of a driver incentive program. Some of this idling may have been eliminated through use of TSE. The Climate Trust project (see Section 4) addressed this issue through requiring signs at TSE facilities stating that emission reductions belong to the Climate Trust. In order to avoid double counting, the Climate Action Reserve should not approve both a truck stop electrification protocol and a wider idling reduction protocol. This would avoid double counting within CAR, but would not preclude double counted offsets being registered elsewhere. Given the small number of idle reduction offset projects, the impact is likely to be negligible.
- **External funder**. As discussed in Section 2.3, most truck stop electrification facilities receive public funding for the installation of infrastructure. These funding agencies such as U.S. EPA and state agencies may have a claim to the offset credits. In these cases, ownership is best dealt with under the terms of the grant agreement. Some funders may welcome the sale of offsets as a form of matching funds. In one case, the funder preferred to retire the offsets as an 'atmospheric benefit'. For example, prohibitions on the generation or sale of mobile source emission reduction credits for NOx and PM were included in the 2002 funding agreement between IdleAire and the California Air Resources Board.

This discussion applies to double counting between carbon offset projects. There is also likely to be double counting with registry emissions by truck owners if trucking firms report their emissions to The Climate Registry, as use of TSE by their vehicles would reduce their reported emissions.

3.3 Additionality

There are several additionality tests that could be used for a truck stop electrification project:

- **Common practice test.** This could also be termed a performance standard, where the standard is simply to install and operate a truck stop electrification facility. Truck stop electrification is not common practice at present. Although it is difficult to estimate a precise figure for market penetration, only 136 TSE facilities existed in 2008 and their distribution was concentrated in California, Texas and the Mid-West (Table 1). (For comparison, in 1999 there were 3,382 commercial truck stops and travel plazas along interstates and other National Highway System routes with heavy truck traffic, plus 1,771 public rest areas [*16*][8].) The drawback to a common practice test, at least in the coming year, is that it may allow numerous non-additional projects to be verified as offsets, as many truck stop electrification facilities will proceed with the benefit of stimulus funding (see Section 2.3). On the other hand, some of the federal grants have requirements for matching funds (which carbon

[8] Note that not all of these commercial truck stops and travel plazas will be suitable for electrification, e.g. due to small size. Public rest areas tend to be used for shorter stops rather than overnight rest (due to lack of amenities and regulatory restrictions), and so fewer of these might be candidates for TSE.

offsets may be able to provide); hence, receipt of stimulus funding does not automatically mean a project will go ahead.

- **Financial barrier analysis.** This may be the most appropriate test for truck stop electrification projects, as carbon offset revenue is likely to account for a significant proportion of project funding. Even if the capital cost per ton of CO_2 reduced is in the $30 to $60 range (Section 2.3), this equates to offset funding (at $10/ton) amounting to 15-30% of project capital costs. In many cases, this will be enough to make a measurable difference to a project's Internal Rate of Return. In addition, low return on investment (in the absence of grant funding and/or offset revenue) appears to be the most significant barrier to more widespread deployment of TSE. Financial barrier analysis would also allow the verifier to consider any contribution from grant funding, which is highly project specific. However, in contrast to Climate Action Reserve practice to date, a financial barrier analysis test would require determination of additionality at the project level.

Both these additionality tests have been used in previous truck stop electrification offset projects. The Climate Trust/Shorepower project used financial barrier analysis. The American Carbon Registry/IdleAire protocol details several types of additionality test, but the common practice test was the one that the verifier focused on in practice, according to IdleAire.

The difference that carbon offset revenue makes to a project's feasibility, and thus the viability of a financial additionality test, can be illustrated through three examples:

- The Climate Trust purchased emission reductions at $4 per ton of CO_2, which it says equals "several thousand dollars" per electrified parking space over the course of the crediting period (The Climate Trust, personal communication). This is a significant proportion of the cost of electrified parking spaces for on-board systems ($4,500 to $8,500 per space, as noted in Section 2.3).
- Southern California Edison proposed Truck Stop Electrification to the California Air Resources Board as a voluntary early action measure to reduce greenhouse gas emissions. It estimated that a total of 672,000 metric tons of emission reductions were possible in and around California, at a cost of $7.48 per metric ton of CO_2 reduced. Thus, carbon offsets sold at $7.50 or more per ton (and purchased in a forward contract) could cover all of the capital costs of truck stop electrification at the more than 1,000 locations proposed by SCE.
- Connecticut's application for stimulus funding estimated that the capital cost amounted to $19-$32 per ton of CO_2 reduced, using the online EPA Diesel Emissions Quantifier to calculate benefits. The range reflects uncertainty in utilization rates; $19 per ton corresponds to 18 hours of daily use, and $32 per ton to 10.8 hours of daily use. In this instance, carbon offsets at $5-$10 per ton (and purchased in a forward contract) could cover up to half of the capital costs of truck stop electrification.

More detailed financial information is not publicly available and so these calculations should be considered illustrative only.

Regulatory additionality is not relevant in the case of truck stop electrification. There are no regulations, existing or planned, that would mandate the installation of truck stop electrification equipment. There are numerous states and local jurisdictions with anti-idling regulations. However, these apply to truck drivers, not to TSE providers. Thus, anti-idling regulations primarily affect the choice of baseline (idling the truck's main engine or use of a non-idling technology such as an APU), and are discussed in Section 3.5 below.

Most TSE projects are likely to involve installation of electrification facilities at new locations. Potentially, service providers might seek to register offsets from existing locations that would otherwise be closed due to operating losses. Evaluating the additionality of such projects would be more challenging, but could be possible through analysis of site-level cost and revenue data.

3.4 Project Boundary

The project boundary for truck stop electrification is straightforward to determine. Most likely, it would include emissions from the truck's diesel engine (baseline emissions), and indirect emissions from electricity generation (project emissions).

Offset projects for greenhouse gas reductions to date have only included CO_2 in the project boundary. It would be straightforward to include N_2O and CH_4 as well, although this would introduce greater uncertainty regarding emission factors, and may also require the collection of additional data on truck age.

3.5 Baseline Quantification

There are three main areas of uncertainty regarding quantifying baseline emissions: determination of the baseline technology; determination of number of hours of idling eliminated; and emission factors. These are discussed in turn below.

3.5.1 Baseline Technology Selection

In most cases, idling of the truck's main engine is the most appropriate baseline for a truck stop electrification project. However, any protocol would also need to consider whether to include APUs in the baseline, which reduce greenhouse gas emissions by 11%-63% compared to idling [*17*]. Although there is little data, the market penetration of APUs appears to be driven largely by state and local regulations that prohibit truckers from idling. Thus, the most accurate baseline is likely to be regionally specific, taking into account these anti-idling regulations.

Baseline technology in states with no anti-idling regulations. In most of the U.S., there are no regulations prohibiting truck idling, and so APUs might be incorporated in one of three ways:

- Ignore the potential for APUs to be in the baseline, and assume that idling is the only alternative source of power. Given the very small share of APUs at present (about 5%)[9], and that APU-equipped trucks are less likely to use TSE facilities, this is unlikely to significantly inflate emission reductions in states with no anti-idling regulations.
- Discount any emission reductions by the share of APUs in the national fleet. This approach implicitly assumes that APUs are a zero emission technology, which will understate emission reductions.
- Calculate a separate baseline for the proportion of trucks equipped with APUs. This is the most complex option, and the additional transaction costs may not be warranted.

[9] EPA estimate in: www.cggc.duke.edu/environment/climatesolutions/greeneconomy_Ch3_AuxiliaryPowerUnits.pdf.

Baseline technology in states with anti-idling regulations. In parts of the U.S. with anti-idling regulations, it may still be possible to justify a baseline of idling the main engine, on the assumption that these regulations are patchily enforced, or that the truck would otherwise continue to a location where idling is permitted.[10] Note that many states did not claim emission reductions from anti-idling regulations in their State Implementation Plans (SIPs) under the Clean Air Act, due to concerns over enforcement. In addition, EPA's guidance on including idling emission reductions in SIPs specifically excludes regulatory measures such as anti-idling ordinances [*18*].

Alternatively, the baseline could assume the use of an APU in the baseline at electrified truck stops in locations where idling is restricted. While this will reduce the volume of emission reductions generated, APUs are still likely to have higher greenhouse gas emissions than an electrified alternative [*17*].

Sixteen states and a number of cities and counties have existing or pending anti-idling regulations, detailed in Table 2. In 2008, 30% of TSE facilities were located in these 16 states. Documentation of any local or state anti-idling regulations could be undertaken during the verification process. The American Transportation Research Institute publishes a regularly updated compendium of idling regulations.[11]

Table 2 States and Local Jurisdictions with Applicable Anti-Idling Regulations

State Regulations	Exemptions	% of Current U.S. TSE Facilities in State
California	-	10%
Connecticut	Cold weather (< 20°F)	0%
Delaware	Truck stop electrification not available	0%
Florida (from 9/30/2013)	-	1%
Georgia (proposed from 1/1/2012)	-	4%
Hawaii	-	0%
Massachusetts	-	0%
Nevada	-	1%
New Hampshire	Cold weather (< -10°F)	0%
New Jersey (from 4/30/2010)	-	2%
New York	Cold weather (< 25°F)	1%
North Carolina (from 5/1/2011)	-	1%
Pennsylvania (from 5/1/2010)	-	8%
Rhode Island (from 7/1/2010)	-	0%
Utah	-	1%
Virginia	-	1%

10 The latter assumption applies primarily for city-level anti-idling regulations, where truckers can easily continue to the next city that permits idling. It would be difficult to justify for state-level regulations, at least for large states.
11 American Transportation Research Institute, "Compendium of Idling Regulations," last updated August 2009. Available at: http://www.atri-online.org/index.php?option=com_content&view=article&id=164&Itemid=70

Local Regulations	Exemptions	
Aspen, CO	-	
Denver, CO	Cold weather (< 20°F for previous 24 hrs, or < 10°F)	
Washington, DC	-	
Atlanta, GA	-	
Minneapolis, MN	Outside residential areas or between 6 AM and 10 PM	
Owatonna, MN	Outside residential areas	
St. Cloud, MN	Certain streets only	
St Louis, MO	-	
Philadelphia, PA	-	
Texas (various cities)	Outside residential and certain other area Applies during ozone season only (Apr-Oct)	

Sources: American Transportation Research Institute (2008), "Compendium of Idling Regulations"; IdleAire, personal communication; various state and local websites. Data on TSE facility locations from Table 1.

Note: This list excludes many regulations that are not applicable to extended idling by sleeper cabs. Many states and cities, specifically exempt sleeper cabs or idling to comply with hours-of-service regulations; these are not shown in the table. Local regulations that are superseded by state-level regulations are also excluded.

3.5.2 Hours of Idling Eliminated

Monitoring data is readily available on the number of hours that each electrified truck parking space is used (Section 3.6). However, there may be difficulties in independently verifying this information, as hours of usage will normally be reported by the TSE provider from proprietary records.

Care should also be taken in distinguishing between billed hours and actual hours (for off-board systems) or hours during which power is consumed (for on-board systems). Billed hours will exclude system testing and maintenance, and capture periods when the engine would have idled but no power is being consumed (e.g. if a thermostat-controlled heater cycles off during the night). However, billed hours will also exclude periods of free promotional use. The Climate Trust methodology currently uses hours during which power is consumed, but plans to switch to billed hours as a more accurate measure.

One hour of use will generally correspond to less than one hour of avoided idling, for several reasons:

- **Prior idling behavior.** Drivers are likely to stay connected to an electrification facility for all or most of their period of rest. In the absence of an electrification facility, some drivers will idle all night, meaning that one hour of connection time replaces one hour of idling. Other drivers, however, will simply idle to warm up or cool down the cab and then switch off the engine. The number of idling hours depends on several factors, including outside temperature (which also affects engine speeds and thus emission factors, as discussed in Section 3.5.3); training; and employment status (owner operators who pay their own fuel bills are less likely to idle) [*3, 7*].
- **Double-dipping.** Some drivers will use both the electrification equipment and continue to idle (so-called double dipping), for example to warm up the cab more quickly. For APUs,

double dipping can occur for up to 29% of stop duration (i.e., both the APU and main engine are run at the same time) [*6*]. IdleAire has modified its technology to prevent double dipping from occurring.

- **Ancillary services.** Some drivers may not use electrification facilities to avoid idling, but rather to obtain cable TV, internet and other ancillary services.
- **Electric vehicles.** Electrified parking spaces may sometimes be used for electric vehicle charging rather than for truck parking.

Surveys have shown a range of reported values for idling behavior of between one hour and 10 hours per day. The American Truck Association estimates that 6 hours per day is typical [*1*]. Zietsman and Perkinson studied three truck stops in Texas, and found that trucks idle an average of 70% of the time parked [*7*], which equates to 7 hours during a 10-hour stop. Truck drivers in Lutsey et al.'s survey [*3*] reported an average 5.9 hours per day of idling and 4.1 hours per day stopped with the engine off. These figures confirm that idling only occurs during a portion of drivers' rest time. However, they cannot be directly translated into idling replacement by truck stop electrification, as drivers might choose not to use (and pay for) electrification during times when they would not otherwise idle.

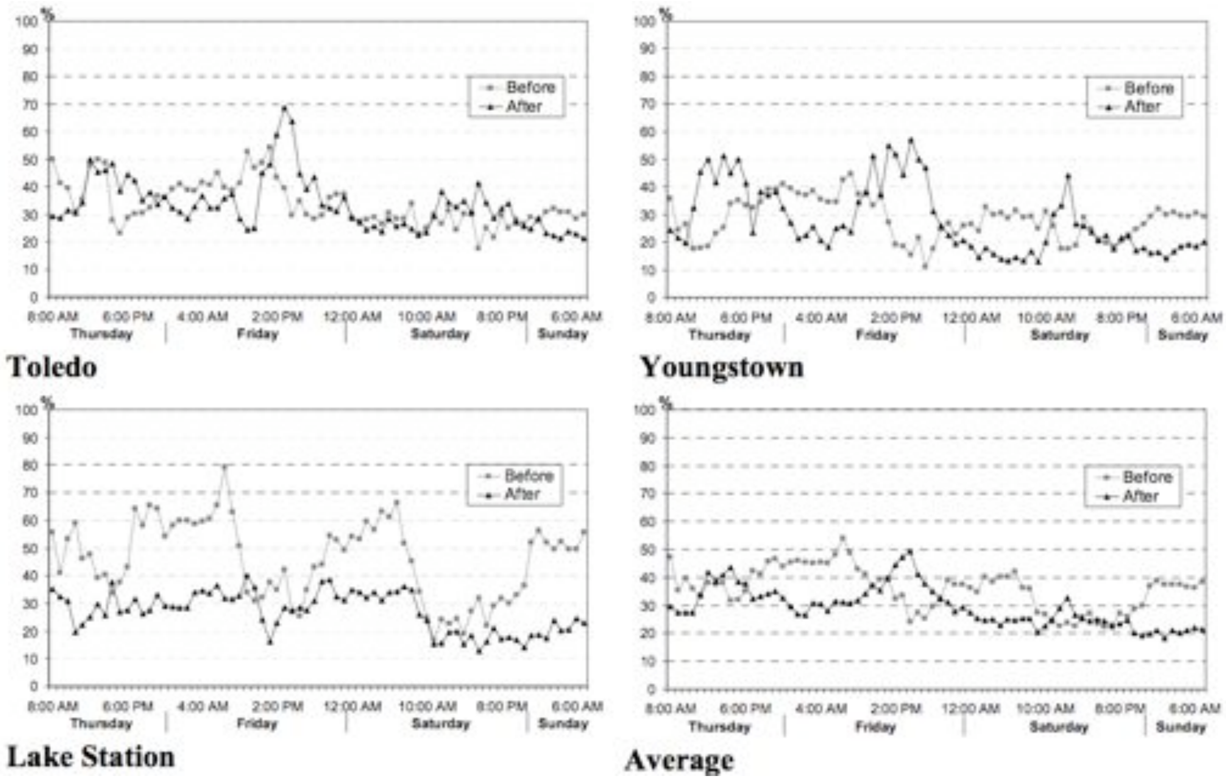
A truck stop electrification protocol could take two approaches to determining the number of idling hours avoided per hour of truck stop electrification use. First, the protocol could require before and after surveys to determine changes in idling behavior at each location (or a sample of locations), with care taken to avoid the effects of seasonal variations in idling. One study by the Texas Transportation Institute (TTI) uses this approach [*7*].

Second, a default value could be determined from the literature. The main source that examines this issue in detail is the TTI study, which conducted surveys at three locations in Ohio and Indiana before and after the installation of truck stop electrification equipment [*7*]. Hourly counts were performed of the percentage of trucks idling. The average idle rate was 36.0% before installation and 29.6% after installation, with an average of 25.7% of trucks using the electrification facilities (note that electrification equipment was only installed at about one-third of truck parking spaces).

While a more complex model would take into account temperature and other differences between the before and after surveys (which took place a year apart), the TTI data suggest that one hour of TSE utilization translates into about one quarter hour of avoided idling.[12] However, generalizing from these survey results may considerably underestimate the impact of TSE at other locations. Two of the three sites had average temperatures in the 60s, where drivers could maintain a comfortable temperature without idling (the surveys were conducted in September). At the third site, Lake Station, temperatures were in the 40s and 50s and much greater reductions in idling were achieved (Figure 1).

[12] Calculated as (0.360-0.297) / 0.257

Figure 1 Idling Rates Before and After TSE Installation



Source: [*7*]

3.5.3 Emission Factors

The emission factor is used to determine the quantity of emissions savings per hour of avoided idling. This section focuses on CO_2 emissions, but emission factors could also be applied for CH_4 and N_2O if these gases are included within the project boundary.

CO_2 emissions are proportional to fuel consumption, and so CO_2 emissions per hour of idling can be either measured directly or determined through estimating fuel consumption rates. One gallon of diesel contains 2,778 grams of carbon or 10,186 grams of CO_2, assuming complete combustion,[13] although there may be modest differences between summer and winter blends.

There is considerable variation in emission factors or fuel consumption rates reported in the literature. Two factors are particularly important:

- **Engine speed (RPM).** A typical pre-set idling engine speed is 600 RPM. However, drivers may increase the engine speed to run heavy accessory loads such as air conditioning, maintain engine temperature, or reduce noise and vibration [*3*]. Hence, RPMs are often higher during hot (or cold) weather. Based on a survey of truck drivers, Lutsey et al. [*3*] report that RPMs range from 500 to more than 1,300 with an average of 870; the distribution is shown in Figure 2. Fuel consumption and CO_2 emissions increase

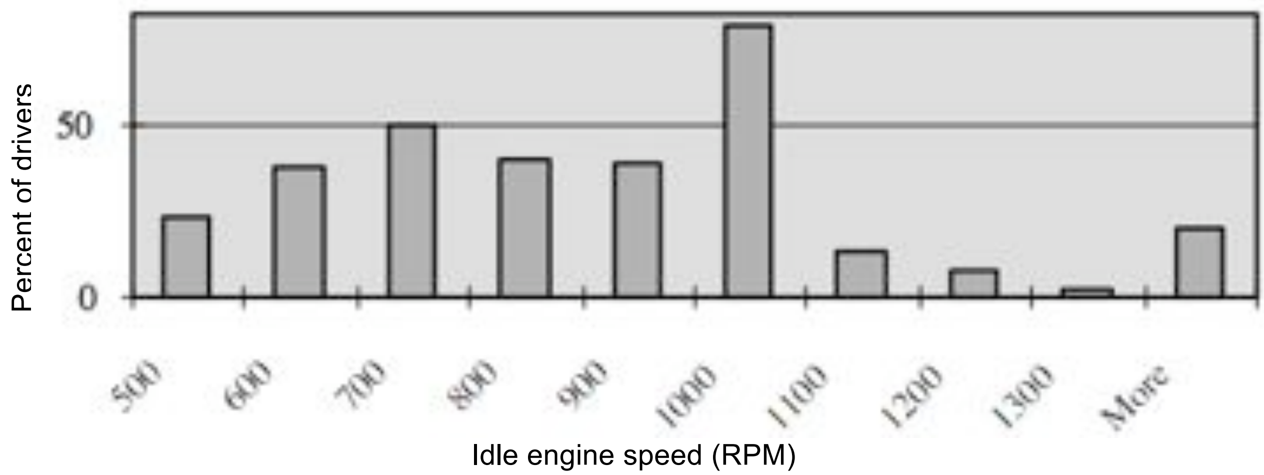
[13] U.S. EPA: www.epa.gov/OMS/climate/420f05001.htm

approximately linearly with the idle engine speed (RPM). Doubling RPM approximately doubles fuel consumption per hour.

- **Accessory load.** Holding RPM constant, fuel consumption and CO_2 emissions increase with accessory loads – for example, if the air conditioning is turned on [*19*]. A related impact is the color of the truck cab (black absorbs more heat) and interior volume, which affect heating and cooling needs [*17*].

Idling fuel consumption is relatively stable across truck model years. Although criteria pollutant emissions per idling hour have declined substantially, CO_2 has not [*19*]. Thus, no data are required on the age of trucks using a TSE facility, unless CH_4 and N_2O were to be included in the project boundary.

Figure 2 Idle Engine Speed Among Surveyed Drivers



Source: [*3*]

One gallon an hour is the most often-cited value for idling fuel consumption, stemming from a 1995 Truck Maintenance Council study cited by Argonne National Laboratory [*4*]. However, most other studies suggest lower values, in some cases considerably so. These are summarized in Table 3. In some cases, studies report a single fuel consumption rate. In others, fuel consumption is a function of RPM.

Table 3 Reported Emission Factors for Extended Idle

Study or Source	Method	Test Conditions	Fuel Use (gallons/hr)
TMC 1995, cited in [*4*]	Not reported in [*4*]	1000 RPM	1
EPA 2002 [*20*]	Laboratory test	Vehicles at 2-4 RPM levels with varying accessory loads	Range: 0.39-1.65 Low (600-800) RPM mean: 0.58 High (1000-1200) RPM mean: 1.18
Brodrick et al. 2002 [*21*]	On-road test	600 RPM, no A/C 600 RPM with A/C 1050 RPM with A/C	0.39 0.52 0.88 Note that higher rates were observed with longer idle periods
Storey et al. 2003, cited in [*19*]	Not reported in [*19*]	600 RPM	0.46
Pekula et al. 2003, cited in [*19*]	Not reported in [*19*]	600 RPM	0.4
Lutsey et al. 2004 [*3*]	Driver survey to determine RPM; data on RPM-fuel use relationship from [*20*]	N/A	Mean: 0.85 90% confidence limits: 0.5-1.5
Lutsey et al. 2005 [*5*]	Simulation based on ADVISOR model	N/A	Mean: 0.92 90% confidence limits: 0.5-1.48
Khan et al. 2006 [*19*]	Laboratory test*	600 RPM	No A/C: 0.47 With A/C: 0.59 At 1100 RPM, fuel use increases by 165%
Frey et al. 2009 [*6, 17*]	20 in-service trucks monitored for more than one year**	Fleet A mean: 601 RPM Fleet B mean: 700 RPM	Fleet A mean: 0.55 95% range: 0.40-0.63 Fleet B mean: 0.51 95% range: 0.25-1.00

* Values for electronic fuel injection vehicles. Values for mechanical fuel injection are ~2% lower.

** Two fleets were observed. Higher fuel use for Fleet A is attributed to darker exterior paint (which increased cooling loads) and higher interior volumes (which increased cooling and heating loads).

The considerable variation in fuel consumption rates between different studies is mainly attributable to differences in engine idling speeds used by drivers. Three broad options are possible for a Climate Action Reserve protocol:

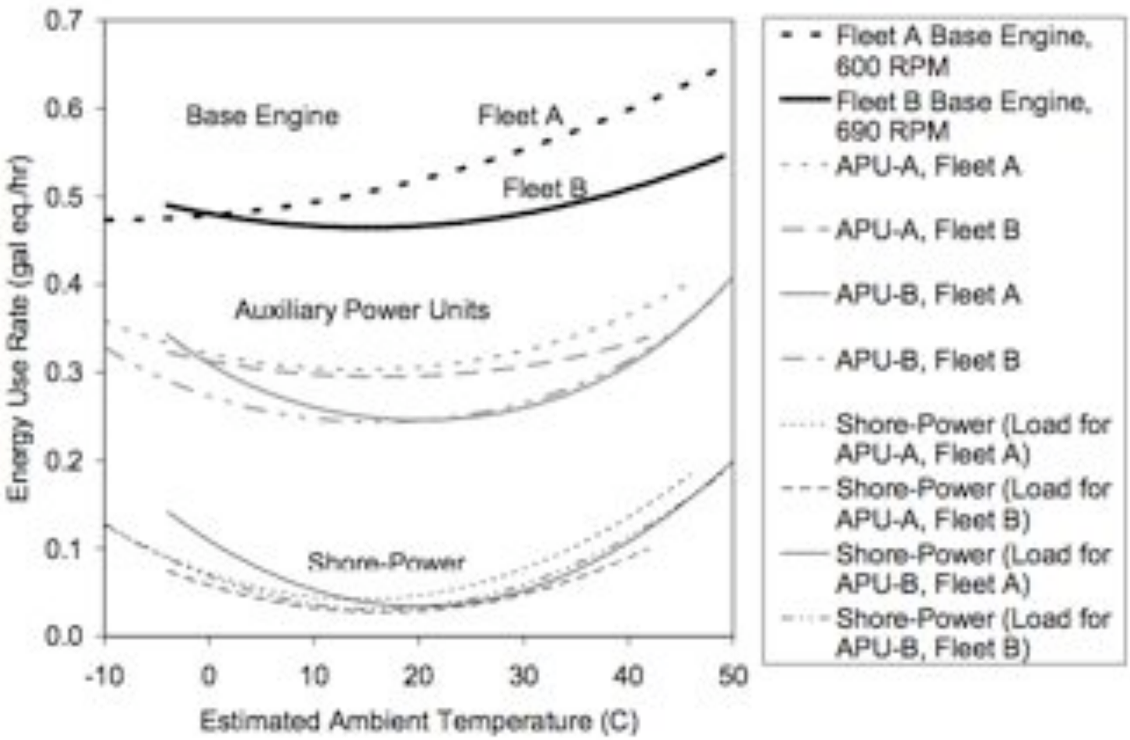
- **Use a default value from the literature.** In this instance, the fuel consumption rates of 0.51-0.55 gallons per hour observed by Frey et al. [*17*] would appear to be the most suitable, as they are both conservative and derived from real-world observations rather than laboratory tests.
- **Require or allow use of a temperature-dependent function**. As both RPM and fuel consumption at a given RPM increase with accessory loads, data on ambient temperature could be used to estimate fuel consumption rates. This is similar to the approach used by CARB in the EMFAC2007 model (Table 4). The recent Frey et al. study [*17*] could be used for this purpose, as shown in Figure 3.
- **Require or allow driver surveys**. As variations in fuel consumption rates are largely due to variations in RPM, a driver survey could be used to determine engine idle speeds at truck stop electrification locations. This is similar to the approach used by Lutsey et al. [*3*]. Surveys could either be undertaken before TSE installation, or after installation using a sample of drivers who do not use the TSE facilities.

Table 4 **EMFAC2007 Idle Emission Factors for Heavy Heavy-Duty Trucks**

Rate	Emission factor (gr CO_2 / hr)	Equivalent diesel consumption rate (gallons/hr)
Low RPM	4,640	0.46
High RPM (winter)	8,350	0.82
High RPM (summer)	10,670	1.05

Source: [*22*], derived from test data reported in [*19*]. Winter is Oct-Feb; summer is Mar-Sep. The actual emission factor is a weighted average of the low (61%) and high (39%) idle rates.

Figure 3 Effect of Ambient Temperature on Fuel Consumption Rates



Source: [*6*]

3.6 Project Emissions Quantification

Project emissions are straightforward to quantify for truck stop electrification. The only project emissions relate to the electric power consumed.

Electricity consumption is usually monitored directly in real-time at the site level by service providers such as IdleAire or Shorepower, or can be determined from utility bills. In the latter case, complexities are introduced as a single bill may encompass the entire truck stop, including food service facilities and showers as well as electrified truck stops.

The main issue related to project emissions is the choice of the emission factor for electric power. eGRID factors reported by U.S. EPA are used by the two most recent TSE offset projects (Table 5).

eGRID emission factors represent the average emissions per unit (e.g. tons of CO_2 per MWh) from electricity generation in a given subregion. This approach has several advantages for TSE:

- Simplicity and low verification costs
- Consistency with The Climate Registry General Reporting Protocol
- Avoiding the potential for gaming by project developers, e.g. through seeking the most advantageous emission factor
- Conservativeness. Most power for truck stop electrification is used at night and occupancy peaks at around 1 AM [*7*]. Thus, eGRID is likely to provide a conservative measure of project emissions; at night, marginal emissions from electricity consumption may be close to zero if there is a source of baseload power that cannot be easily fired down.

Moreover, project emissions for TSE are likely to be very small in relation to baseline emissions. In the case of the initial IdleAire project, emissions from electricity use were about 7% of avoided emissions from idling – i.e., the project reduced emissions by 93% [*2*]. Thus, the choice of emission factor may make little practical difference to the volume of reductions, and a simple, conservative approach may be preferred.

Two more complex options could incorporate generator-specific data to develop a more precise emission factor:

- The "combined margin" approach could be used as in the Clean Development Mechanism "Tool to calculate baseline, project and/or leakage emissions from electricity consumption"[14] (see also [*23*]). The combined margin is a weighted average of the "operating margin" (the emission factor from existing generation capacity) and "build margin" (the emission factor from plants that would otherwise have been built to satisfy demand). Four different options are available for calculating the operating margin under the CDM, including the simple generation-weighted average, and more complex options making use of grid dispatch data.
- A TSE-specific emission factor could be developed based on emissions from the marginal generator at the times when TSE power is used. This would require additional verification effort (determining time of usage as well as total usage), and the calculation of separate emission factors for different times of day.

3.7 Leakage

With the possible exception of lifecycle emissions, leakage emissions from truck stop electrification are likely to be minimal, or else considered beyond the scope of a Climate Action Reserve protocol. Any increased use of air conditioning, heating, television or other amenities as a result of TSE would be captured under project emissions. The main potential leakages are:

- Additional distance driven to access TSE facilities as drivers detour from the highway. This is likely to be negligible or nil, as TSE facilities are usually located at existing travel centers close to freeway interchanges.

[14] Available at cdm.unfccc.int.

- Lifecycle emissions from TSE infrastructure. This includes the manufacture and assembly of off-board systems, and any equipment purchased (e.g. inverter) to enable use of plug-in facilities.
- Well-to-tank (upstream) emissions for diesel fuel. Emissions from petroleum extraction, refining and transportation are not included in the emission factors reported here. Inclusion of this positive leakage would increase emission reductions by about 14%.[15]

Lifecycle emissions have not been included for any truck stop electrification offset project to date. There is little data on these lifecycle emissions, which include manufacture of the off-board HVAC system, and transport to the TSE facility for assembly. For on-board (shore power) TSE, the manufacture of on-board electric appliances might also be considered as part of lifecycle emissions. A practical approach would be to ignore these emissions, on the assumption that they are outweighed by the upstream emission savings from reduced diesel fuel consumption. However, further effort would be needed to verify this assumption prior to adoption of a Climate Action Reserve protocol.

3.8 Monitoring Requirements and Scientific Uncertainty

Table 4 summarizes likely monitoring requirements for a truck stop electrification project, based on the analysis in Sections 3.5 through 3.7.

Table 4 Potential Monitoring Requirements

Data	Required?	Likely Source	Uncertainty	Comments
Hours Utilized	Required	Direct monitoring by service provider	Low	
Average % of hours idling (before and after TSE installation)	Potentially optional	Survey	Depends on sampling procedure	Used to determine hours of idling replaced per hour of TSE utilization Default value could be used instead
Local anti-idling regulations	Likely required	American Transportation Research Institute	Low	
Ambient temperature	Optional	Third-party data	Low	Used to estimate temperature-dependent emission factor Default value could be used instead
Average idle speed	Optional	Survey	Depends on sampling procedure	Used to estimate RPM-dependent emission factor Default value could be used instead
Electricity consumption	Required	Direct monitoring by service provider	Low	

3.9 Permanence

Emission reductions from truck stop electrification are permanent. As with any project that reduces fossil fuel consumption, there is no risk of reversals in that these emissions would be subsequently released into the atmosphere.

[15] According to approved CDM methodology AM0031 for Bus Rapid Transit.

In the transportation context, there may be some confusion with the term "permanence," as this is often used to refer to the permanence of modal shifts. For example, there is some uncertainty whether behavior changes prompted by the introduction of TSE are permanent. This issue can best be addressed through project monitoring, and is more properly termed "years of effectiveness" rather than "permanence." However, even if the *behavior change* is temporary, the *emission reductions* are permanent – emissions avoided during a project's first year are not released to the atmosphere.

3.10 Scope

Truck stop electrification is just one type of anti-idling mitigation measure that might be covered in a Climate Action Reserve Protocol. Some others that might be considered for the same or a separate protocol are:

- **Auxiliary power units (APUs).** The use of APUs will result in substantial emission reductions, and can reduce idling in locations that are not equipped with TSE facilities. They do pose greater monitoring challenges, as the equipment is mounted on a large number of trucks rather than at fixed locations. There is also uncertainty about fuel consumption and emission factors from APUs, although data do exist to allow these to be estimated [*17*].
- **Driver idle-reduction incentives.** Driver training and experience and fleet policy (e.g. fuel economy bonuses) do lead to reductions in idling [*3*]. Tradable emission reductions from at least one fleet have been generated for the Ontario NOx program, using remote monitoring of idling hours before and after program implementation. Care would need to be taken to avoid double counting with any emission reductions from TSE. Also, given that the project owner would be the fleet, which would typically profit from reduced fuel consumption, additionality may be challenging to demonstrate.
- **Non-truck idling.** Both locomotives and ships idle for considerable periods of time, and shorepower systems can provide a low-emission alternative. The main issue here would be to determine appropriate emission factors per hour of idling.

4 Existing Methodologies

This section reviews existing methodologies or protocols that have been developed for truck stop electrification and similar projects, including those for NOx as well as greenhouse gases. The methodologies are summarized in Table 5. With the exception of the South Coast Air District Rule, most of these can be classed as "one-off" methodologies in the sense that they were designed around a single project. They may or may not be adapted for similar projects in the future.

Note that the methodologies listed here tend to generate greater volumes of emission reductions than might be warranted by recent research. For example, they tend to assume high fuel consumption rates of ~1 gallon per hour, and in some cases assume that each hour of TSE utilization displaces one hour of idling.

Some methodological precedent is also available from U.S. EPA, which provides guidance on quantifying the impact of anti-idling technologies for the purposes of air quality conformity [*18*]. This states that agencies should simply multiply actual hours of TSE use by the emission factor to determine the reductions. Monitoring is "the number of hours the idle reduction technology operated while the main truck engine did not idle, recorded by a non-resettable meter, data logger, or computerized data acquisition system capable of recording total hours operated on each truck." EPA also requires surveys to determine historic idling activity at a location, and in the absence of a suitable explanation (e.g. weather), will cap emission reductions at historic idling levels.

Note that for truck stop electrification, EPA's guidance does not require consideration of project emissions as these are assumed to be accounted for separately in air quality plans.

A similar methodology is provided by EPA for using truck stop electrification as a mobile source emission reduction credit (offset) under New Source Review [*24*]. In California, the South Coast Air Quality Management District adopted Rule 1613, which provided for the generation of offsets from TSE for New Source Review. However, it was not approved by U.S. EPA for State Implementation Plan purposes – partly due to a perceived lack of conservatism, and perhaps partly due to more general skepticism on the part of U.S. EPA towards mobile-to-stationary trading.

The South Coast Air Quality Management District subsequently adopted Rule 1634 as one of four credit-generating protocols for the RECLAIM NOx trading program. These were put in place rapidly during the California electricity crisis in response to rapid price increases and a shortage of credits. The protocol was never used, as RECLAIM credit prices subsequently came down making TSE projects less economic, and has now sunset.

Native Energy has also purchased carbon offsets for fuel-efficient truck fleets from Cascade Sierra Solution. This project includes idle-reduction technologies such as APUs, as well as aerodynamic modifications and other efficiency improvements. The methodology is not specific to anti-idling, however.[16]

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[16] For details, see http://www.nativeenergy.com/pages/cascade_sierra_solutions_trucking_efficiency_project/477.php

Table 5 Methodologies Developed for Truck Stop Electrification

Registry/ Developer	Gases	Project(s)	Monitoring	Calculation of Baseline Emissions	Emission Factor (Electricity)	Availability and Notes
Climate Trust	CO_2	Shorepower installation at 8 sites	• Hours of utilization • Power consumption	• Assumes 1 hr utilization reduces 1 hr idling • Discounts from this to account for double dipping; use of facility for EV charging; and for trucks not idling in baseline scenario • No discount for interactions with other anti-idling measures (e.g. APUs); assumes that truckers would not plug in if they have an alternative • Assumes idle fuel consumption of 1 gallon/hr from [*4*]	eGRID	Proprietary methodology; not publicly available.
American Carbon Registry	CO_2	IdleAire installation at 124 sites	• Hours of utilization • Power consumption	Temperature-dependent emission factor derived from [*20*]:** • Average monthly lows 50°F – 70°F: 5,805 gr CO_2/hr (assumes low RPM) • Average monthly lows <50°F or >70°F: 11,815 gr CO_2/hr (assumes high RPM) Assumes 1 hr utilization replaces 1hr of idling	eGRID	Publicly available at: www.americancarbonregistry.org/ carbon-registry/projects/idleaire
Chicago Climate Exchange	CO_2	IdleAire installation at 24 sites	• Hours of utilization • Power consumption	• Assumes 1 hr utilization replaces 1hr of idling • Assumes idle fuel consumption of 1 gallon/hr from [*4*]	State-level grid factors from EIA***	Proprietary methodology; not publicly available. Intended as one-off "proof of concept" for IdleAire. Emission reductions donated to Clinton Global Initiative
South Coast AQMD Rule 1634 (RECLAIM)*	NOx	Not used and now sunset	• Hours of utilization and location, date, time, truck operator and truck license number • Power consumption	• Default emission factor of 80.8 gr NOx per hour of utilization • Project applicants could propose and justify alternative	N/A	Publicly available at: www.aqmd.gov/rules/ reg/reg16/r1634.pdf Ineligible projects included: • Projects receiving public air quality funding • Projects required under law or regulation • APU-equipped trucks • Projects charging an hourly fee of less than $1
Ontario Emissions Trading System	NOx	JB Hunt driver incentives for idle reduction	• Moving and idling time for each truck before and after incentive program	• % of time spent idling in baseline determined from 'before' data • Baseline emissions calculated using 'after' data on moving minutes and baseline idle %	N/A	Publicly available at: http://www.oetr.on.ca/oetr/uploads %5CNIC%5C118%5C2004B%5C118_ 2004B_protocol.pdf Verification report available at: www.ghgworks.com/pdf/ JBHTJBTVerificationReport.pdf

* See South Coast AQMD, Rule 1634, adopted in 2001. The District also had a similar, earlier Rule to allow TSE facilities to generate MSERCs (Rule 1613, adopted in 1997).

** 5,805 gr CO_2 is equivalent to 0.56 gallons of diesel. 11,815 gr CO_2 is equivalent to 1.14 gallons of diesel.

*** "Updated State-Level Greenhouse Gas Emission Coefficients for Electricity Generation 1998-2000." Energy Information Administration, April 2002. Available at: http://www.eia.doe.gov/pub/oiaf/1605/cdrom/pdf/e-supdoc.pdf

5 Emission Reduction Opportunities

This section provides order-of-magnitude estimates of the emission reduction potential of truck stop electrification projects in the United States, based on a combination of the literature and the assumptions developed earlier in this paper. The estimates range from a reduction of 0.7 to 24.9 million metric tons of CO_2 per year; however, a range of 0.7 (10-15% of U.S. emissions) to 5 million metric tons (70-100% of emissions) is more realistic.

5.1 Full U.S. Market Penetration

Full market penetration of TSE is unrealistic even in the long run as it ignores (i) trucks that continue to idle; and (ii) competing anti-idling technologies such as APUs. However, this scenario is useful to consider as it provides an upper bound on potential emission reductions.

There are two general methods to estimate a full market penetration scenario. The first is based on the amount of idling by trucks, and assumes that TSE can replace all overnight idling by sleeper trucks. The second is based on the number of truck stop facilities, and estimates penetration in terms of the number of equipped truck stops.

Gaines et al. [*1*] is the most comprehensive example of the first type of analysis. They use data from the 2002 Vehicle Inventory and Use Survey to identify sleeper trucks that travel beyond a given radius from their home base, and thus are likely to idle overnight. For this population of trucks, they assume 6 hours per day per truck of overnight idling, 300 days per year; and idle fuel consumption of 0.8 gallons per hour. Overnight idling according to these estimates consumes 685 million gallons of diesel per year or 7.0 million metric tons of CO_2. Applying a more conservative fuel consumption rate of 0.53 gallons per hour (see Section 3.5.3) yields a **total potential of 454 million gallons of diesel per year or 4.6 million metric tons of CO_2 per year.** Note that this only includes overnight idling, and does not consider the potential of TSE to displace daytime idling during shorter stops.

Zietsman et al. [*7*] provide an example the second type of analysis, using truck stop penetration rates. Based on their before and after surveys in Indiana and Ohio (discussed in Section 3.5.2), they find that TSE reduces fuel consumption by an average 61,000 gallons and CO_2 emissions by 767 tons per truck stop per year. On average, there were 67 electrified parking spaces per truck stop. Applying these reductions to all 1,000 truck stops that have 100 or more truck parking spaces, TSE could reduce CO_2 emissions by 767,000 tons [*7*] or **696,000 metric tons per year**.

Note that these figures from Zietsman et al. assume an idling fuel consumption rate of 0.92 gallons per hour and so may overestimate emissions reductions. However, the three surveyed sites also include two truck stops with mild September temperatures where little idling occurred in the "before" surveys, and also ignore the potential at the ~3,500 smaller truck stops (fewer than 100 spaces) and public rest areas [*16*]. This would underestimate emission reductions.

On a per-location basis, the Zietsman et al. estimates are comparable to the volume of emission reductions generated by existing carbon offset protocols. IdleAire generated 48,412 metric tons of verified emission reductions for the American Carbon Registry in the first half of 2007, from projects at 124 truck stops.[17] This equates to 781 metric tons per location per year.

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[17] Environmental Resources Trust, Project Verification Statement 1 Jan 2003 – 30 June 2007.

5.2 California Studies

Two estimates of partial market penetration have been developed for California only. In practice, the assumptions for partial market penetration are relatively aggressive and so the results are comparable to the "full market penetration" studies discussed in the previous section.

TIAX [*25*] estimates market growth and potential of TSE in California through 2020 under two scenarios – "expected" and "achievable". Even the "expected" scenario is aggressive; due primarily to anti-idling regulations, it assumes that nearly half of truck parking spaces are electrified by 2020. In the "achievable" scenario, 98% electrification is assumed by 2020. The estimates of emission reductions are shown in Table 6. Baseline emission factors assume full penetration of APUs in California by 2010, with an APU fuel consumption rate of 0.208 gallons per hour.

Table 6 TIAX Estimates of TSE Penetration in California

	Expected		Achievable	
Year	**No. of electrified spaces**	**CO_2 displacement (tons/yr)**	**No. of electrified spaces**	**CO_2 displacement (tons/yr)**
2002	<200		<200	
2010	8,000-10,000	90,000-120,000	16,000-20,000	180,000-230,000
2015	10,000-14,000	130,000-180,000	22,000-28,000	280,000-350,000
2020	14,000-19,000	200,000-270,000	30,000-40,000	430,000-570,000

Source: [*25*]. Note: units are short tons.

The California Energy Commission developed two scenarios [*10*] based on analysis of Shorepower and IdleAire business plans (note that this analysis preceded IdleAire's bankruptcy filing):

- **Business-as-usual:** 250 new electrified spaces per year in California, which would reduce diesel demand in California by 62 million gallons in 2025. This is equivalent to 0.6 million metric tons of CO_2 per year.
- **Aggressive:** 1,000 new electrified spaces a year from 2005 through 2015, with 90% of truck parking spaces electrified by 2025. This assumes significant cost reductions, and that all eligible heavy vehicles take advantage of technology. This expansion would reduce diesel demand by 300 million gallons or 3 million metric tons of CO_2 in California in 2025.

It is unclear how best to scale the California estimates up to the entire U.S. There is no authoritative data on truck idling by state. Assuming that TSE potential is proportional to population, the figures above could be increased by a factor of 8.3. This yields a range for the entire U.S. as follows:

- TIAX: 1.5 to 4.3 million metric tons/yr in 2020
- CEC: 5.0 to 24.9 million metric tons/yr in 2015. However, given the estimate that overnight idling accounts for 7.0 million metric tons of CO_2/yr in the U.S. [*1*], this upper estimate has to be considered as unrealistic.

Based on the difficulty in determining the magnitude of emission reductions, the best estimate of the emission reduction potential of truck stop electrification projects in the United States ranges from 0.7 to 5 million metric tons of CO_2 per year.

6 Conclusions

Emission reductions from truck stop electrification are relatively straightforward to quantify. The main areas of uncertainty relate to determining baseline emissions, specifically:

- Determining the number of idling hours replaced by one hour of truck stop electrification usage. One option is to require a survey to determine the proportion of time that trucks idle when parked at a given rest stop, before and after truck stop electrification implementation. Alternatively, a conservative default factor from the literature could be applied, e.g. that one hour of TSE usage equates to 0.25 hours of avoided idling.
- Determining the appropriate idling emission factor. The simplest approach is to use a conservative default factor based on idle fuel consumption of 0.51-0.55 gallons of diesel per hour. Alternatively, a temperature-dependent emission factor could account for higher engine speeds (RPM) during hot or cold weather, when accessory loads are higher. The third option is to require or allow surveys of driver RPM settings.
- Determining whether the baseline is idling the main engine or use of an auxiliary power unit (APU), particularly in states and local jurisdictions that prohibit idling. A protocol could use regionally specific baselines that assumes APU use in locations where idling is prohibited.

Truck stop electrification projects are likely to be additional, as few projects have been implemented in the absence of offset and/or grant funding. A common practice test would be simple to administer, as TSE is not currently common practice. However, a common practice test would give offset credit to non-additional projects that are fully funded through state or federal grant programs, such as the Congestion Mitigation Air Quality Improvement (CMAQ) program. Thus, TSE may require a project-level determination of additionality based on Internal Rate of Return or financial barrier analysis.

Estimates of the capital cost per ton of emission reductions from truck stop electrification are highly sensitive to assumptions about utilization (hours per day), as well as the baseline emission uncertainties discussed above. The likely range is about \$7 to \$70 per ton of CO_2 reduced. The higher cost estimate assumes just 25% utilization and uses more conservative emission factors. Even at the higher end of the range, however, carbon offset revenue could make a measurable difference to a project's Internal Rate of Return. Operating costs are covered by user revenue.

The likely scale of emission reductions is difficult to determine. Estimates range from 0.7 to about 5 million metric tons of CO_2 reduced per year, as there is considerably uncertainty about both market penetration and overall market size.

Transportation emissions would be capped from 2012 under the proposed American Clean Energy and Security Act. If this or similar legislation becomes law, it would preclude truck stop electrification and other transportation-sector offsets. Given a 3-12 month lead time to implement TSE projects, there would be little time to generate carbon offsets before cap-and-trade goes into effect.

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