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Energy Use and Emissions Comparison of Idling Reduction Options for Heavy-Duty Diesel Trucks

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ABSTRACT

Pollution and energy analyses of different idling reduction (IR) technologies have been limited to localized vehicle emissions and neglected upstream energy use and regional emissions. In light of increasing regulation and government incentives for IR, we analyzed the full-fuel-cycle effects of contemporary approaches. Our analysis incorporates direct impacts at the truck and upstream energy use and emissions estimates from the GREET model with published climate and vehicle operation data. We compared emissions, energy use, and proximity to urban populations for nine alternatives, including idling, electrified parking spaces, auxiliary power units, and several combinations of these. We compared effects for the United States and seven states: California, Florida, Illinois, New York, Texas, Virginia, and West Virginia. U.S.-average emissions impacts from all onboard IR options were found to be lower than those from a 2007-compliant idling truck. Total particulate emissions from electrified parking spaces were found to be greater than those from a 2007 truck, but such emissions generally occurred in areas with low population density. The lowest energy use, CO_2 emissions, and NO_x emissions are seen with a direct-fired heater combined with electrified parking spaces for cooling, and the lowest PM_{10} emissions were found with a direct-fired heater combined with an onboard device for cooling. As expected, state-to-state variations in climate and grid fuel mix influence the full-fuel-cycle impacts from IR technologies, and the most effective choice for one location may be less effective elsewhere. The many assumptions have a significant effect on the results. However, idling duration, which has considerable seasonal and spatial variation, affects the energy and emissions for any technology in direct proportion to the number of hours, but not the relative technology benefits, as long as the portion of heating and cooling time is held constant. Changes in the fraction of time spent heating or cooling do change the relative impacts.

BACKGROUND

Long-haul diesel trucks typically spend a substantial percentage of time idling while the driver takes mandatory rest periods (i.e., hours of driving and rest are mandated by law.). That amount of time varies considerably (Lutsey *et al.* 2004). Long-haul truck drivers may allow their engines to idle for a variety of reasons and under many different circumstances. Lutsey *et al.* (2004)

found climate control to be the most common reason cited by drivers for idling, and use of accessories and concerns about start-up were also cited. On-duty drivers of both long- and short-haul trucks may also tend to idle their engines during the workday while waiting to load or unload or while sitting in traffic, or they may idle their engines for other reasons related to their work or to vehicle operation and maintenance (Gaines *et al.* 2006).

Because of the adverse air-quality and public-health impacts of diesel exhaust from idling trucks, as well as increasing fuel costs, numerous idling reduction (IR) technologies are being implemented or demonstrated (EPRI and EPA 2006; ATRI 2006; EPA 2006a). Devices are available for stand-alone installation aboard the truck or use at wayside installations. Onboard devices can be used wherever and whenever the truck is stopped, but they add weight to the truck. Although the Energy Policy Act of 2005 permits a weight waiver, individual states are not compelled to grant this waiver. **Diesel-fired heaters** (DFHs) supply warm air to the cab/sleeper. An engine block heater can also be included. Fuel use and emissions by diesel heaters are very low, because they supply heat directly from a small combustion flame to a heat exchanger. Standard diesel fuel is used. Cab heaters can be coupled with air conditioners if the trucker's service area includes both cold winters and hot summers. **Thermal storage and battery-electric air conditioners** (storage cooling, or SC) are available. In either case, the energy to recharge the storage device is supplied by the truck's engine during operation. The engine uses a small quantity of extra diesel fuel for this, and the emissions from burning this fuel are on the highway, not at the truck stop or depot. **Auxiliary power units** (APUs) consist of a small diesel-fueled internal combustion engine that powers a generator to provide electricity and space conditioning. Fuel cell units are also being developed. Emissions are compliant with small engine standards, but California requires additional controls, such as a diesel particulate filter (DPF) for APUs on trucks built in 2007 or later. **Electrified truck parking spaces** (EPS) (also known as truck stop electrification) provide heating, cooling, and other services to parked vehicles. These fixed wayside systems add little or no weight to the truck and cause no local emissions, because no diesel fuel is consumed. There are, of course, upstream emissions from generating the electricity and producing and transporting the power plant fuel. "Single"-system EPS supplies services from equipment on the ground through a duct inserted into the cab window. "Dual"-system EPS allows the trucker to plug electrical equipment on the truck into a pedestal connected to the electric power grid.

Many public agencies are looking at ways to discourage or prohibit unnecessary idling. According to the American Transportation Research Institute, some type of idling restriction has been enacted in all or parts of 25 states as of July 2008 (ATRI 2008). Policy mechanisms favored by regulators to alleviate the impacts of truck idling include restrictions on idling time or proximity to certain facilities, such as schools (ATRI 2008). The California Air Resources Board (CARB) adopted a first-of-its-kind idling regulation that imposes a virtual ban on overnight idling within the state and sets strict new requirements for idling alternatives (CARB 2006). One compliance option is for diesel APUs to be equipped with a diesel particulate filter (DPF) or to be configured so that the APU exhaust is routed through the truck's main engine diesel particulate filter. Devices that comply with California regulations are now on the market, but no operating data are available.

Policy impact assessments to date have been based on localized truck tailpipe and IR device emissions. This analysis considers the full-fuel-cycle energy use and emissions, including the extraction and refining energy use and emissions associated with consumption of diesel fuel for onboard IR strategies and emissions from power plants (and their fuel supply chains) associated with electrified parking-space strategies.

METHODOLOGY

An Excel spreadsheet was created to calculate annual urban and rural energy use and emissions from idling and IR technologies. Impacts include two contributions: one directly produced by operation of the cab comfort device on the truck and another upstream that is associated with supplying the fuel or energy to the device. Vehicle operations, energy data, and emissions data were used to estimate direct exhaust emissions and vehicle or device energy use. The second contribution is generally much smaller, except in the case of EPS, which only has upstream impacts. Upstream emissions and energy use, starting when the fuels are extracted from the ground, were estimated from the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) Model. GREET is a standard Excel model developed at Argonne (Brinkman *et al.* 2005) and used by over 9000 analysts worldwide. It is generally used to calculate well-to-wheels impacts for the full fuel cycle of a range of light vehicle types, with a variety of possible fuels. Therefore, it includes data on production and processing of diesel fuel, as well as impacts of electricity generation (including supplying the fuels), for several regions of the United States. These data were extracted from GREET and used in our spreadsheet model, to account for the upstream impacts of supplying cab comfort.

Fuel consumption and total emissions estimates of particulate matter (PM_{10}), nitrogen oxides (NO_x), and carbon dioxide (CO_2) for heating and cooling modes are presented for nine IR technology scenarios. The analysis considers the distinct electric grid profiles (including fuel mix and urban share of generation for each fuel) for five populous states (California, Florida, Illinois, New York, and Texas) and two less-populous states (Virginia and West Virginia), in addition to the U.S. average. Emissions of sulfur dioxide and secondary particulate formation are not discussed.

Truck Idling Characteristics

Total idling emissions and energy use are a function of duration. Idle duration must be divided into time used for heating, for cooling, and for non-climate-control accessories, because rates of emissions and energy use differ for each of these modes.

We assumed 7 hours per day and 300 days per year, for an annual average of 2100 idling hours. More research is needed to develop reliable average and location-specific estimates. Idling duration affects the magnitude of energy and emissions for any technology in direct proportion to the change in hours, but it does not affect the relative comparison of the technologies for a given state, as long as the portion of heating and cooling time is held constant.

For this analysis, it was thus assumed that the ratio of heating hours to cooling hours for each state would be consistent with the ratio reported by the National Oceanic and Atmospheric

Administration (NOAA 2000). For example, the percentage of total cabin-comfort hours spent on heating (or cooling) would be equal to the number of heating (or cooling) degree days divided by the sum of heating and cooling degree days for each state. This analysis assumes that all idling is used for either heating or cooling.

Geospatial Characteristics

The urban/rural distributions of emissions for the technologies differ because the emissions occur in different places. For APUs and heaters, emissions are primarily at the parking locations, with smaller components at the refineries and drilling sites. For storage cooling, emissions are wherever the truck is being driven when the device is being charged, as well as upstream for the fuel production. And for electrified parking spaces, emissions are at the power plants and along the supply chains of their fuels, which of course differ by fuel. The urban/rural distribution of parking locations and power plants differs by state as well.

A key factor in determining the health effects of emitted pollutants is population exposure. As a first approximation of exposure, we estimated the portion of stack and upstream emissions that occurs in areas of high population density. For the upstream emissions, GREET already reports the percentage of its calculated emissions that occurs in urban areas, on the basis of default or user-specified location profiles for power plants, mining operations, refineries, fuel storage facilities, and other upstream processes. For this analysis, GREET U.S.-average default values were used for all categories except power generation, for which state-specific profiles were used. The urban share of total generating capacity was developed by Solomon (2006) for each state by matching 2004 Energy Information Administration generator data from the EIA-860 (EIA 2006) database to the master list of urban ZIP codes (Census 2006). The generation mixes and urban and rural shares of plant capacities for the seven states are shown in Figure 1.

An inventory of truck parking facilities was compiled from on-line commercial databases, such as Dieselboss.com (2006), and state transportation agencies. These data were used to calculate the urban and rural shares of the direct impacts, which are greater than the upstream impacts, except for EPS, which has impacts upstream only. The urban share of truck parking spaces was 45% in California, 47% in Florida, 59% in Illinois, 41% in New York, and 51% in Texas, but only 25% in Virginia and 9% in West Virginia. These percentages imply lower population exposure per hour of operation in the less-populous states.

Vehicle and Device Parameters

To develop estimates for total annual impacts of idling and alternatives, emission and energy-use factors had to be obtained or estimated for each technology. The emission factors for the IR technologies were used to estimate local impacts, and fuel consumption values were combined with GREET outputs to incorporate upstream impacts.

Exhaust emissions and fuel consumption for idling, auxiliary power units, and direct-fired heaters were based on published test data whenever possible. The data for onboard idling reduction devices and 2001 trucks were measured by using 500-ppm diesel with heating and cooling loads. Values for 2007 trucks are based on assumptions and preliminary data (Storey 2007). No published measurements are available for 2007 engines or for devices running on 15-ppm ultra-low sulfur diesel fuel (ULSD). The analysis should be updated when these data

become available. Energy use for electrified parking spaces was based on data from a major service provider. For the special case of storage cooling, energy use was calculated on the basis of the energy storage capacity reported by manufacturers and efficiencies of the engine and charging system. The assumptions for vehicle and device parameters are summarized in Table 1. There are actually ranges for the different parameters because of (1) seasonal and other load variations and (2) differences among manufacturers and models; the numbers in the table are simply representative values that are considered to be a good starting point for calculations. Sensitivity to variation in these input parameters will be discussed later.

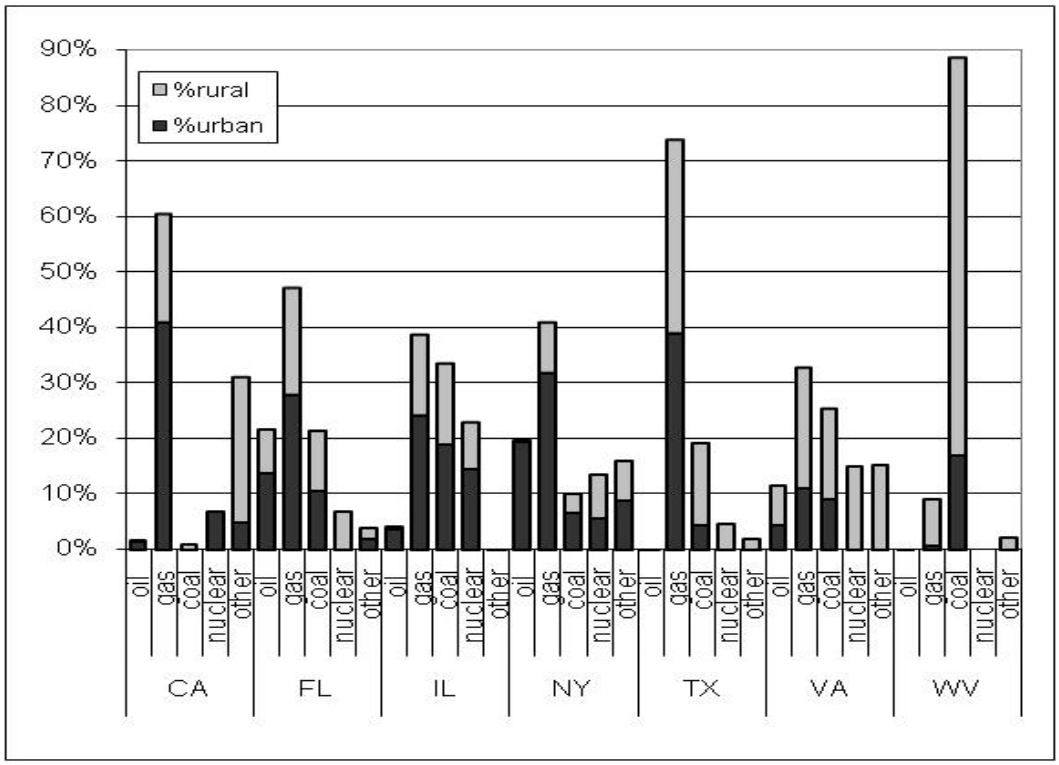

FIGURE 1. Distribution of power plant capacity by fuel type and urban or rural location for 7 states (adapted from Solomon 2006)

Technologies Included

We analyzed the following nine cab-comfort options:

1. Idling 2001-model truck.
2. Idling 2007-compliant truck.
3. Auxiliary power unit for heating and cooling.
4. Auxiliary power unit with diesel particulate filter for heating and cooling (APU/DPF).
5. Direct-fired heater/auxiliary power unit with diesel particulate filter for cooling (DFH+APU/DPF AC).
6. Direct-fired heater/auxiliary power unit for cooling (DFH+APU AC).
7. Direct-fired heater/storage cooling (DFH+SC).
8. Direct-fired heater/electrified parking spaces for cooling (DFH+EPS AC).
9. Electrified parking spaces for heating and cooling (EPS).

Several of these are novel combinations that have not been considered elsewhere. Although they are included here for analysis, the expense of some combined systems could prove prohibitive.

RESULTS

This section presents results of the analysis, on a full-fuel-cycle basis. State-specific results may include impacts from out-of-state fuel production and delivery. For California, impacts also include out-of-state power generation.

TABLE 1. Direct Emissions and Energy-Use for Cab Comfort Options

Technology	Setting	PM_{10} (g/h)	NO_x (g/h)	Diesel Fuel Use[e] (gal/h)
2001 Truck idling[a, b, c]	heating	3.74	156	0.77
	cooling	2.08	146	0.98
2007 Truck idling[a, b, d, f]	heating	0.14	133	0.53
	cooling	0.14	133	0.72
APU[d]	heating	0.72	9.1	0.23
	cooling	0.72	9.0	0.18
APU with diesel particulate filter[d,f]	heating	0.07	9.6	0.24
	cooling	0.10	9.5	0.19
Direct-fired heater[a]	heating	0.06	0.20	0.055
Battery electric cooling[g]	cooling	0.05	9.5(2001), 4.8 (2007)	0.10
Electrified parking space[h]	heating	1.6	1.6	NA
Electrified parking space[h]	cooling	0.86	0.86	NA

[a] Storey et al. (2003) data were used, because they reported on the widest range of pollutants. Results were reported for engine operation at 600 RPM and 1200 RPM.

[b] Fuel consumption is strongly dependent on accessory load and engine speed. Energy use was adjusted to 750 RPM for heating and 900 RPM for cooling to better represent real-world operation. Linear interpolation was based on an estimate developed in TMC RP1108 of fuel consumption as a function of idling speed and load (TMC 1995a). The adjusted estimates were verified with Storey (2007).

[c] Assumes 100% conventional diesel fuel (CD) containing 500-ppm sulfur.

[d] Assumes 100% ultra-low sulfur diesel (ULSD) containing 15-ppm sulfur.

[e] Fuel use in grams per hour was converted to gallons per hour by using GREET default values: (1) density 3167 g/gal and 3206 g/gal and (2) energy content 128,450 Btu/gal and 129,488 Btu/gal for CD and ULSD, respectively.

[f] Preliminary data (Storey 2007)

[g] Both battery electric cooling and storage cooling report total energy use of under 1 kWh to charge the storage medium for the night's cooling. Assuming efficiencies of 42% for the diesel engine, 60% for the alternator (Plummer 2008), and 75% for the battery and using the GREET default lower heating value of 129,488 Btu per gallon of ULSD, we found effective fuel consumption to be under 0.10 gallons per hour of air-conditioner operation. This is consistent with manufacturer estimates. The emissions are generated during normal truck operation and are assumed compliant with current EPA HDDE emission standards (EPA 2006b). The NO_x emissions dropped by a factor of 2 in 2007 and will be required to drop by a factor of 10 from 2001 levels by 2010. NO_x emissions for SC on 2001 and 2007 trucks are shown.

[h] Upstream emissions. Electric loads may vary widely, depending on equipment type and operating conditions. Estimates range up to 6 kW (DOE 2000; TMC 1995b; Brodrick et al. 2001; Venturi and Martin 2001). For this analysis, an average load of 1.6 kW for electric heating and 0.85 kW for electric cooling are used (Everhart 2004).

In Figure 2, which compares U.S. average emissions for the nine scenarios, we see that full-fuel-cycle emissions from onboard IR options are generally lower than those from idling trucks—in most cases, considerably lower. One exception is PM_{10} from EPS. In addition, although the direct PM_{10} emissions from the APU are greater than those from preliminary measurements of a 2007 truck that apparently performs beyond the new standards (see Table 1), the idling truck consumes more fuel, and the refinery emissions from processing that fuel almost make up for the small difference in tailpipe emissions. Among the idling-reduction options, the APU has the highest NO_x and CO_2 emissions (U.S. average case).

For the U.S. average case, the lowest total PM_{10} emissions are found with the heater and APU (for cooling) with filter. Total PM_{10} from electrified parking spaces (U.S. average case) is found to be greater than that from any option, except 2001-model truck idling. However, impacts from EPS occur entirely upstream; they will depend on the fuel mix for power generation and may not occur in populated areas. This will be an important point in later work when health effects are discussed.

Next, we examined annual total energy use per year for one truck, again for the U.S. average climate and power plant mix. All of the idling-reduction options use much less energy than does idling, with the least-efficient option still representing almost a three-fold reduction in fuel use. The energy used by all of the options, except the electrified parking space, is predominantly in

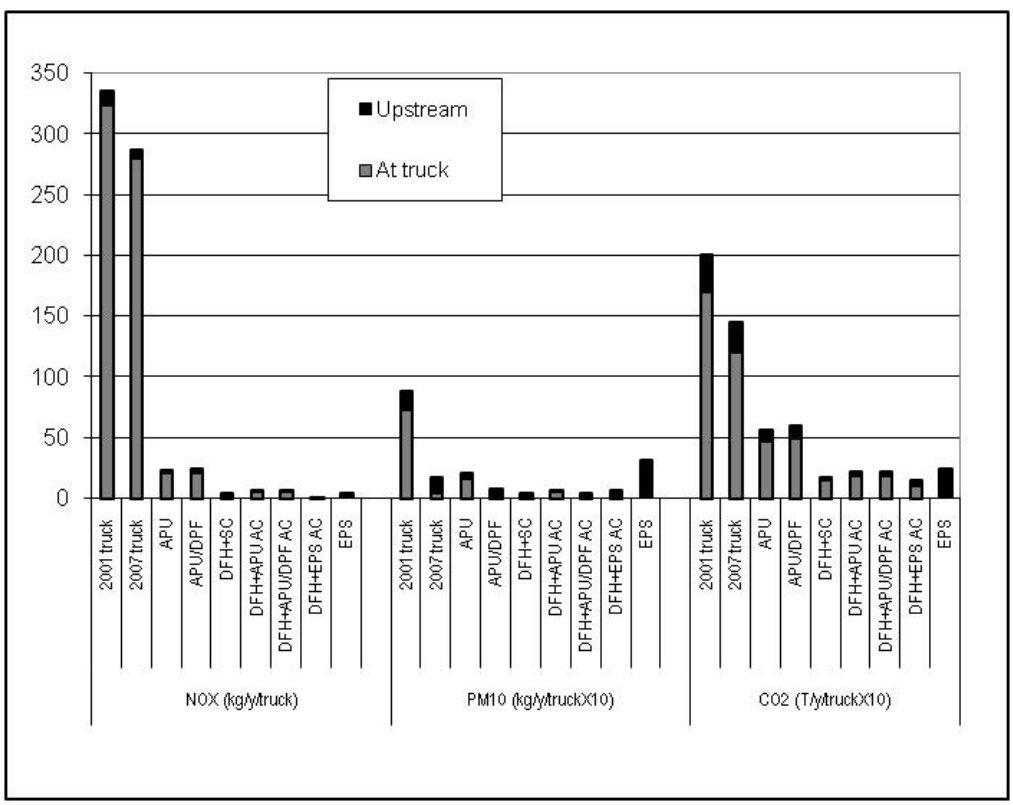

FIGURE 2. Full fuel-cycle NO_x, PM_{10}, and CO_2 emissions for nine scenarios (U.S. average)

the form of diesel fuel; that for the EPS depends on the fuel the local electric grid uses (see Figure 3). Thus, EPS is a means for substituting other fuels for petroleum. Of course, energy use and CO_2 emissions are tightly correlated, being directly proportional for all of the onboard options. Therefore, CO_2 will be used as a surrogate for energy use for the remainder of this discussion.

The next two figures break out heating and cooling options separately so that we can better understand why the aggregated results come out as they do. The figures further distinguish the truck and upstream contributions. Figure 4 shows emissions for the individual heating options, except idling, with the U.S. average number of days requiring heating and the U.S. average power generation mix. Again, the APU produces the greatest NO_x emissions. The EPS produces the greatest PM_{10} emissions for the U.S. average grid mix, but these emissions will be seen to vary considerably by state, on the basis of the electricity generation mix. Furthermore, all emissions occur upstream—none occur at the parking location, where emission reductions can therefore be documented for regulatory compliance. The most striking finding is that emissions from the direct-fired heater are the lowest by far of all the options. This is in large part because producing heat directly is much more efficient than converting to electricity and then using resistance heating. Thus, scenarios that include a heater generally produce fewer emissions than others. This advantage is most pronounced in the states with the most heating degree days. However, a heater supplies no electricity. Electricity for other accessories can be supplied in small quantities by batteries or by an APU. One commercially available device actually combines an APU with a heater. Use of an APU or a battery pack for accessory power may reduce the efficiency benefits of the heater.

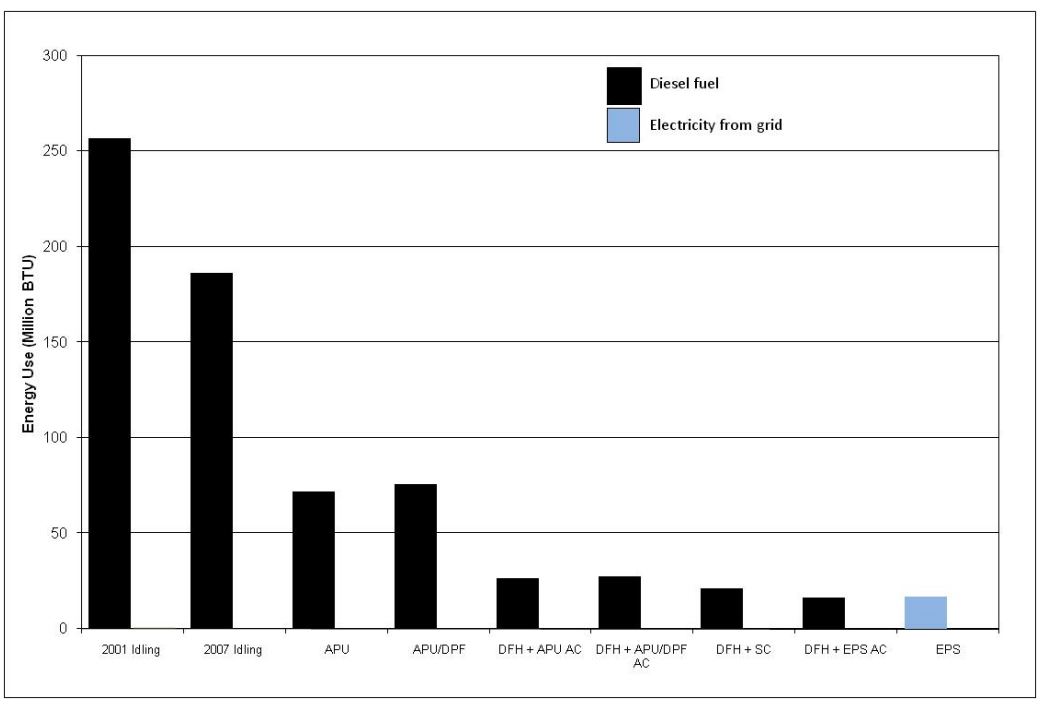

FIGURE 3. Annual energy use for 2100 h of cab comfort, U.S. average climate and grid mix

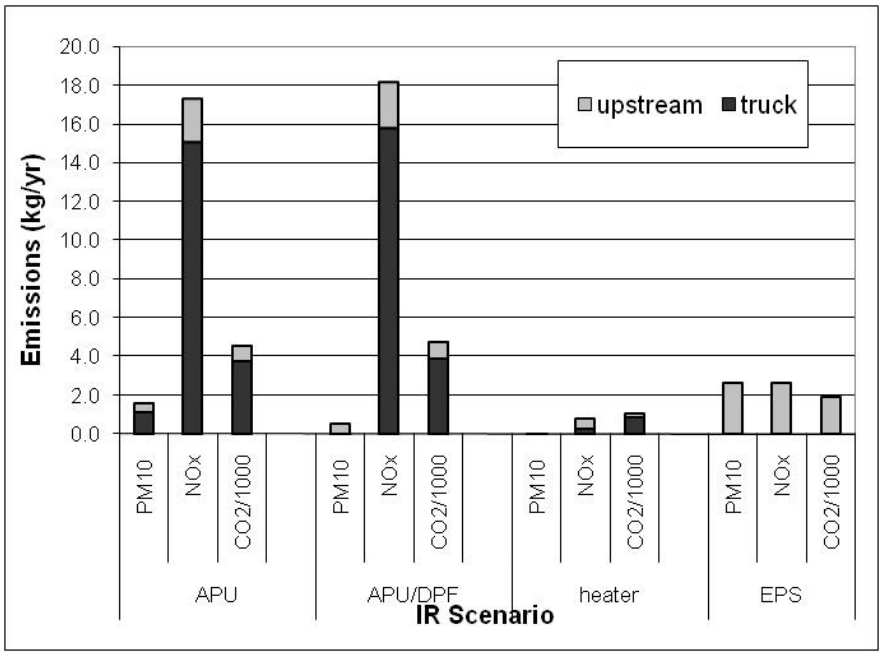

FIGURE 4. Heater emissions for U.S. average heating demand

Figure 5 shows emissions from air-conditioning options. APUs produce the most NO_x, but still much less than that produced from idling (see Figure 2). Emissions from storage cooling (shown for installation on a 2007 truck) are produced during vehicle installation and will decrease by about a factor of about 5 when these devices are installed on trucks meeting 2010 standards. Idling emissions are also expected to decrease at that time. Until then, EPS cooling has the lowest NO_x and CO_2 emissions, but storage cooling has the lowest PM_{10} emissions. Per-year tailpipe NO_x from APU cooling is lower than that from APU heating, even though per-hour cooling emissions are higher (see Table 1). The reason for this difference is that the U.S. average number of heating degree-days greatly exceeds the number of cooling degree-days. As for the heating case, the EPS produces the most PM_{10} on a full-fuel-cycle basis. But because there is no very low NO_x option for cooling, cooling via the EPS produces the lowest NO_x of the available technologies. Storage cooling produces little PM_{10}, because the battery is charged or the thermal storage medium is cooled by the truck engine, which is assumed to meet the stringent 2007 truck PM standards. Neither storage cooling nor electrified parking spaces produce emissions at the parking site. The emissions from storage cooling occur on the road, and those from electrified parking spaces occur at upstream locations.

Next, we compare results for different states. There are three main differences among the states. The first difference is the distribution of truck stops (affecting onboard options) and power plants (affecting EPS) between urban and rural areas. That will be very significant in any analysis of health impacts. The second difference is the mix of electricity generation, and the third is the balance of heating and cooling degree days, which impacts the mix of heat and air-conditioning required. Figures 6 and 7 illustrate that the interactions of these factors are complex. In all states, the APU shows the highest NO_x and CO_2 emissions of the IR options, and those that supply AC with an APU are almost as high in states with high cooling loads.

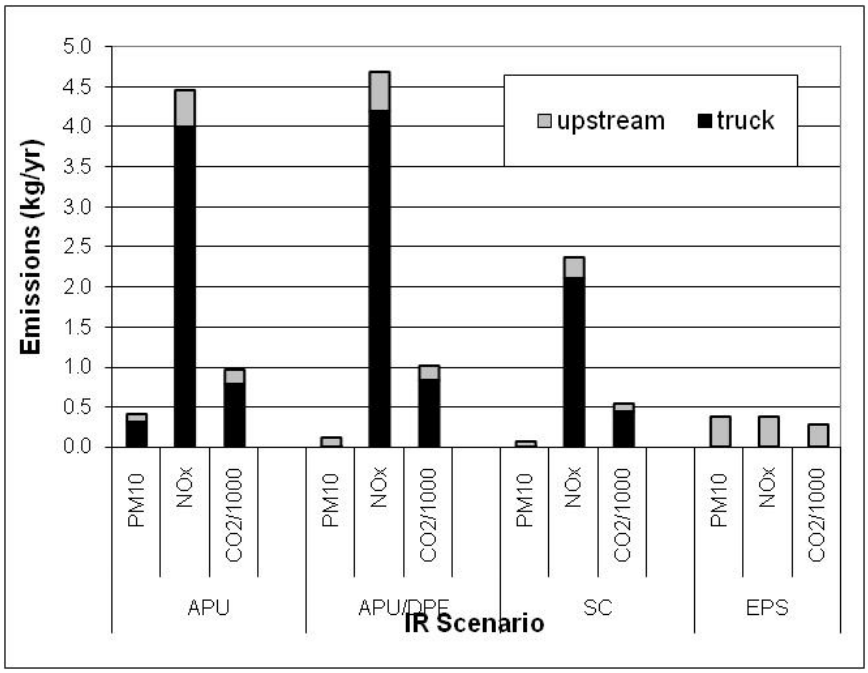

FIGURE 5. Air-conditioning emissions for U.S. average cooling demand

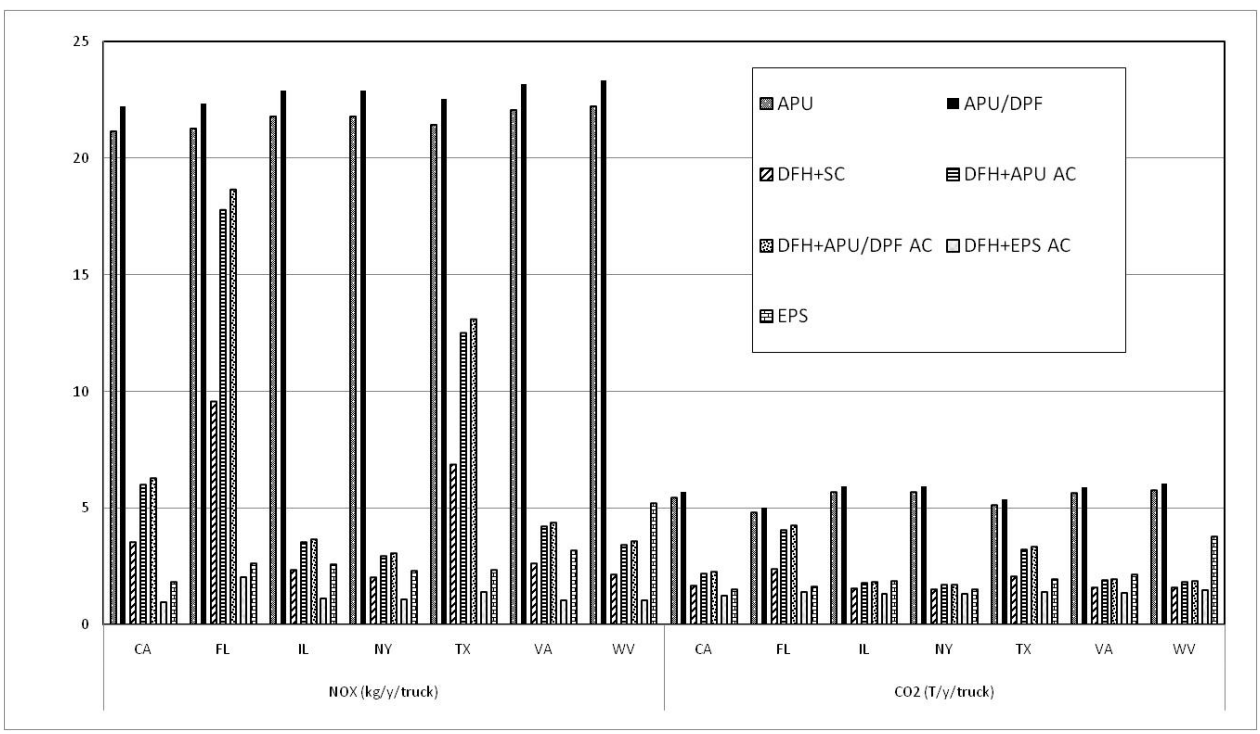

FIGURE 6. NO_x and CO_2 emissions for seven scenarios for seven states

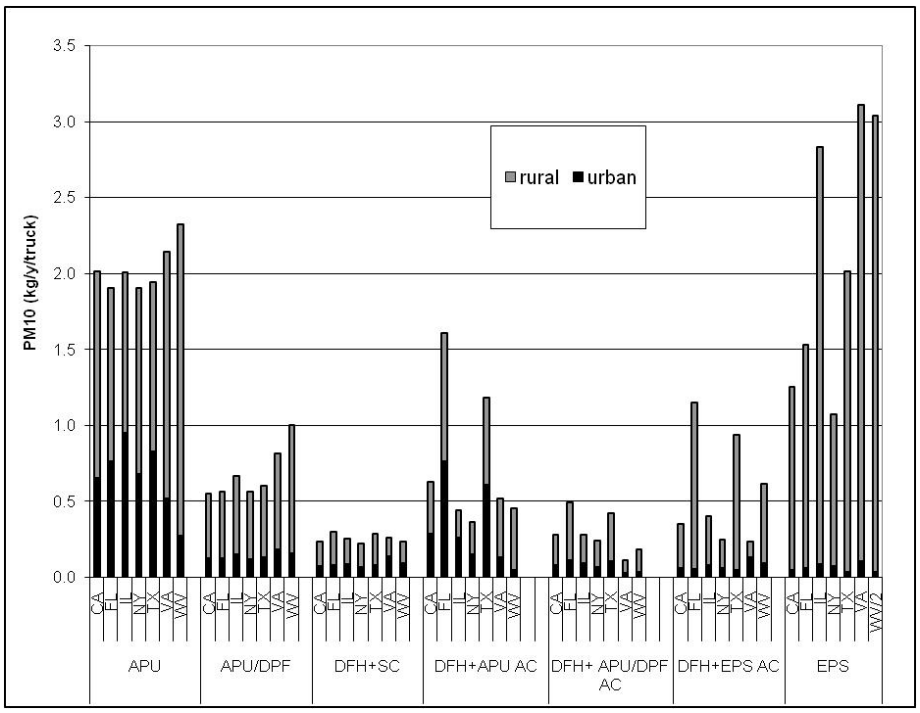

FIGURE 7. PM_{10} emissions in urban and rural areas for seven scenarios

Emissions of NO_x and CO_2 for the other options are all similarly low, with the exception of EPS in West Virginia, because of the heavy reliance on coal there for electricity generation. State-to-state variation for PM_{10} is significant for electrification scenarios, suggesting that individual state grid mix significantly influences the emissions benefits associated with electrified parking spaces. Illinois, Virginia, and West Virginia, with the highest reliance on coal of the states examined (see Figure 1), show the highest PM_{10} emission rates from EPS. The importance of the electricity generation mix can be explained by examining the data in Table 2, which shows how emissions per kWh of electricity vary among the states studied—from California, with a high percentage of power generated by using natural gas and hydro, to West Virginia, which relies almost entirely on coal. Note that the West Virginia PM_{10} emissions for EPS in Figure 7 have been divided by two to fit on the graph. These results illustrate that a single strategy will not necessarily yield the lowest energy use and emissions of all pollutants (NO_x, PM_{10}, and CO_2) everywhere.

TABLE 2. Full Fuel-Cycle Emissions for Electricity Generation (g/kWh)

State	NO_x	PM_{10}	CO_2
California	0.145	0.018	152
Florida	0.793	0.474	621
Illinois	0.322	0.472	307
New York	0.361	0.150	259
Texas	0.618	0.650	630
Virginia	0.447	0.510	395
West Virginia	1.217	1.852	1157

Finally, we examine PM_{10} and the distribution of impacts between urban and rural locations. The presumption is that emissions in urban locations result in higher population exposures to harmful pollutants than do rural emissions. On a state-specific basis, PM_{10} from electrified parking spaces is significantly less in states with non-coal power, because the main source of these PM_{10} emissions is the production and transport of coal[1]. Therefore, for California and New York—each with relatively low percentages of coal in its electrical generation mix (see Figure 1)—PM_{10} emissions from electrified parking spaces are lower than those from 2007-model truck idling; for Florida, Illinois, Texas, Virginia, and West Virginia, they are higher. If the mix of power generation shifts away from coal toward natural gas, nuclear power, or other technologies, these PM_{10} emissions will be reduced. Again, we see that these emissions are predominantly rural and therefore do not result in significant population exposure. With the exception of idling trucks and APUs without filters, rural emissions are much greater than urban emissions. The reason for that exception is that about 83% of the truck's or APU's full fuel-cycle emissions occur at truck stops, which are often located in urban areas.

Emissions of NO_x (for which the urban/rural distribution is not shown) uniformly exhibit large urban components, with no significant differences among technologies or states, although EPS may offer some of the lowest NO_x in urban settings. The distribution of CO_2 emissions between urban and rural areas was not addressed, because this is a global rather than local pollutant.

VARIABILITY AND SENSITIVITY

The results shown should not be construed as providing exact estimates of emissions that would result from operation of IR devices. Rather, they are indicative of the relative merits of the device types and demonstrate how the benefits depend on key variables. There are two main types of uncertainties in the results. First, there are additional factors that influence energy use and emissions. There are many manufacturers and models of the different devices, each with slightly different features and performance, which may vary with age and intensity of use. Drivers may choose different temperature settings, and some may stop during the day, when air-conditioning loads would be higher. Insufficient data were available to model the way in which the impacts of the devices vary with such factors. In addition to actual variations, some of the data were, of course, subject to considerable uncertainty. For instance, the 2007 truck emissions estimates were from a small number of unpublished preliminary data points. Because there are very few points for each parameter and no information on what the distributions might be, formal uncertainty analysis, such as Monte Carlo analysis, was judged to be inappropriate. Some of the parameters were better known, such as the grid mix and relative heating and cooling intensities of the states. And of course, emissions at the parking location, for both EPS and SC, are exactly zero.

However, the major conclusions are robust to the levels of uncertainty in the energy and emissions data, which we estimate to be accurate to about 20%. Thus, it is appropriate to conclude that full fuel-cycle energy use and emissions from all of the IR options are significantly lower than those from an idling truck, with the exception of PM_{10} from a 2007-compliant truck.

[1] Note: that the PM associated with coal are primarily coarse PM.

Similarly, it is correct to conclude that heaters are the lowest-impact heating device and APUs the highest impact for both heating and cooling. However, attempting to rank non-APU options for cab comfort in Illinois or New York on the basis of CO_2 emissions would be inappropriate.

CONCLUSIONS

Several factors have been shown to influence the impacts from idling-reduction technologies, and the most effective choices for one location may be less effective elsewhere. For instance, climate affects the optimum technology choice, because locations with high heating loads can rely on direct-fired heaters, but locations with high cooling demands will see a much lower benefit from heaters.

It is important to consider the full-fuel-cycle impacts during any technology comparison, because upstream impacts can significantly alter the relative positions of the options. For example, electrified parking spaces have no impacts at their locations, and this may provide a considerable advantage to states seeking to guarantee reduced emissions in non-attainment areas. However, there are emissions produced elsewhere, most notably from coal production in rural areas, and these should be included in a systematic evaluation. Total benefits from electrification are therefore lowest for states that rely heavily on coal for their electricity generation.

These results should be updated when reliable measurements of actual emissions from idling 2007-model trucks and trucks and auxiliary equipment using ultra-low sulfur diesel fuel become available. This is especially true for anticipated NO_x-emissions reductions.

Choices among idling-reduction options will be made on the basis of many factors in addition to emissions and fuel use. One factor is the effectiveness of the technology; if the system's performance is not satisfactory, it will not receive widespread market acceptance. A second factor is cost. Buyers will make trade-offs between cost and performance, and agencies subsidizing or providing loans for idling-reduction equipment will need to evaluate the cost-effectiveness and financial case (being addressed in complementary work by the authors) of each technology. Cost-effectiveness depends not only on full-fuel-cycle emissions, but on the population exposure to these emissions, which is the next important subject required in the analysis.

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