Trading of Locomotive NO_x Emissions: A Potential Success Story

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ABSTRACT

New U.S. Environmental Protection Agency regulations are forcing locomotive manufacturers and railroads to reduce pollutant emissions from locomotive operation. All new locomotives must meet strict standards when they are built, and existing locomotives must comply when they are rebuilt. Emissions can be reduced either by adjusting combustion parameters, which incurs a fuel penalty, or by turning the diesel engine off when the train is not moving and would otherwise be idling. The latter reduces fuel consumption, but requires installation of a device — such as an auxiliary power unit (APU) — to ensure that the engine can be restarted in cold weather and to supply hotel loads for the crew. Without a financial incentive, capital-short railroads will opt to achieve compliance in the least costly way. However, if they have the option of selling emission credits from reducing emissions below regulated levels, it would be in their best interest to install additional equipment to minimize emissions. These credits could be purchased by businesses with compliance costs greater than either the cost of the credits or the fines they would have had to pay for non-compliance. The result is a financial benefit for both parties, and a net reduction in emissions, because the seller is emitting below regulated levels, and the buyer is no longer non-compliant. This paper describes a railroad as the potential seller, unable to consummate trades because of uncertainty in the regulatory environment, and estimates financial benefits and reductions in emissions and energy use that could be achieved if the barrier could be removed.

INTRODUCTION

Anyone who has spent much time driving on interstate highways in the United States knows that big rigs idle overnight while their drivers sleep. Ongoing work at Argonne National Laboratory for the U.S. Department of Energy (DOE) has estimated the energy wasted and air pollution impacts associated with this practice and outlined several possible technologies to reduce the impacts[1]. The National Energy Policy[2] singled out idling of heavy-duty trucks as a problem to be addressed. Similarly, but not as well-known, railroad locomotives are also idled overnight and part of the day as well. These are much larger engines (1,500–6,000 hp) than heavy duty truck engines and therefore produce larger impacts. Even though the engineers do not sleep in the locomotive cabs, the crew must remain in the cab while cars are changed or while the train waits (for up to 8 h) on sidings for other trains to pass. In addition, heating is required to keep the engine warm overnight and to make sure the engine starts, as with trucks, and to keep the water in the toilets from freezing. The technologies available to obviate the need to idle trucks could be applied to, or adapted for use in, locomotives as well. One company has already demonstrated auxiliary power units (APUs) on locomotives.

The impacts from locomotive idling are significant, both in terms of energy use and emissions, as well as in terms of dollars. For a switcher locomotive that idles 75% of the time, 27% of the fuel is consumed, and 25% of the NO_x emissions are produced at idle. The DOE's Office of Heavy Vehicle Technologies (OHVT) seeks to reduce energy consumption and emissions from locomotives. To this end, DOE sponsored the Workshop on Locomotive Emissions and System Efficiency in January 2001[3] to scope out the problem and created working groups that met to identify specific areas for research. The results of the working groups were summarized in a draft Railroad and Locomotive Technology Roadmap[4], which will be used to formulate a Multi-Year Program Plan. A solicitation for projects to support this plan has been published. The U.S. Environmental Protection Agency (EPA) requires that new or remanufactured locomotives meet a series of new standards, which become more stringent with time. Reduction of idling is one of the ways that locomotive emissions can be reduced to achieve compliance. Trading of emission credits could provide the incentive to reduce locomotive emissions early and to below regulated levels, yielding several benefits.

SUMMARY OF EMISSION REGULATIONS

The 1990 Clean Air Act Amendments mandated the EPA to establish emission standards for several previously unregulated non-road mobile sources, including locomotives. Unregulated locomotives were estimated to contribute almost 5% of the total nationwide emissions of NO_x, making them one of the largest remaining unregulated sources. Regulation of the remanufacturing process is included because locomotives are generally rebuilt several times during their very long service lives (typically 40 years or more).

Emissions from diesel-powered locomotives have significant health and environmental effects. Nitrogen oxides (NO_x) are a major component of smog and acid rain, and they combine with hydrocarbons (HC) to form ground-level ozone, the primary constituent of smog. Ozone is highly reactive and damages lung tissue, causes congestion, and reduces lung capacity, in addition to damaging vegetation. Acid rain damages buildings and crops and degrades lakes and streams. NO_x also contributes to the formation of secondary particulate matter (PM), which causes headaches, eye and nasal irritation, chest pain, and lung inflammation. Environmental impacts of PM include reduced visibility and deterioration of buildings.

The EPA has promulgated emission standards for NO_x, HC, carbon monoxide (CO), and PM. The new standards are expected to achieve approximately a two-thirds reduction in NO_x

emissions (equivalent to reducing the number of passenger cars by over thirty million). HC and PM emissions will be reduced by 50%. One set of standards (Tier 0) applies when locomotives originally manufactured from 1973 through 2001 are rebuilt. Other standards (Tiers 1 and 2) must be met when locomotives are manufactured from 2002 through 2005 and later and when these are rebuilt. Separate standards apply for switcher (2,300 hp and below) and line-haul (over 2,300 hp) locomotives. The standards are shown in Table 1.

Table 1. Locomotive Emission Standards

	Emissions (g/bhp-hr)			
Tier and duty-cycle	**HC**	**CO**	**NO_x**	**PM**
Tier 0 line-haul duty-cycle	1.00	5.0	9.5	0.60
Tier 0 switch duty-cycle	2.10	8.0	14.0	0.72
Tier 1 line-haul duty-cycle	0.55	2.2	7.4	0.45
Tier 1 switch duty-cycle	1.20	2.5	11.0	0.54
Tier 2 line-haul duty-cycle	0.30	1.5	5.5	0.20
Tier 2 switch duty-cycle	0.60	2.4	8.1	0.24

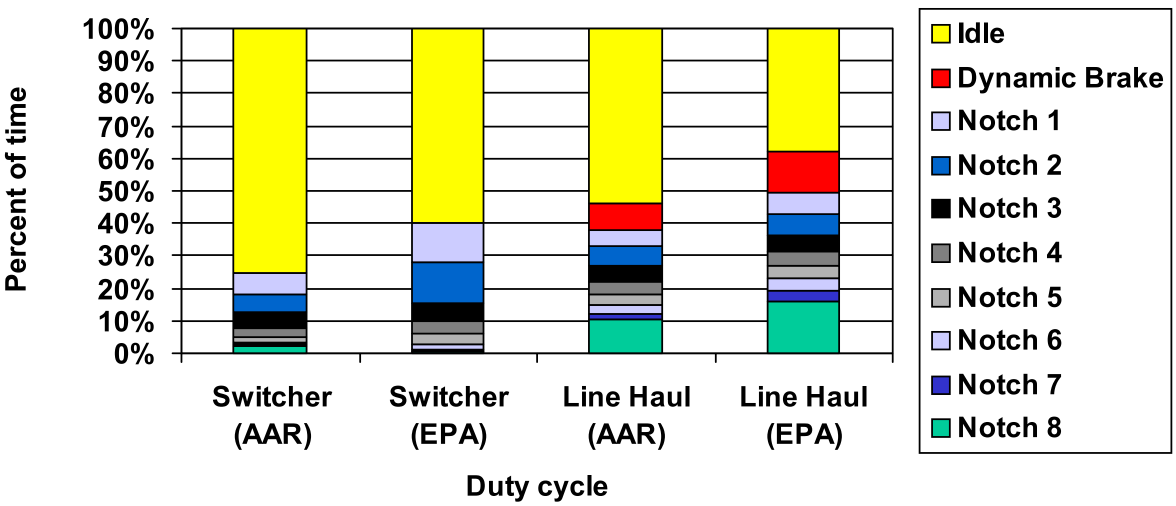
EPA has adopted averaging, banking, and trading (ABT) provisions to allow flexibility to meet overall emissions goals at the lowest cost, enabling more stringent standards than could be met if every engine had to comply. ABT is also designed to encourage early introduction of cleaner engines. (The source for this section is the EPA’s Final Emissions Standards for Locomotives[5].)

METHODS OF COMPLIANCE

As new locomotives constitute only about 800 per year of the 20,000 units in service by the large Class I freight railroads[6], this paper concentrates on retrofits for existing locomotives, although the technology described could easily be installed on new locomotives as well. There are many ways that a railroad could retrofit its locomotives to make them compliant with the new EPA regulations. The first of these to be certified by the EPA is a kit sold by one of the locomotive manufacturers. It consists of (1) new nozzles designed to retard the injection timing and thus reduce NO_x emission and (2) appropriate control software. Unfortunately, installation of this kit causes a fuel penalty of 1–2% and requires a significant capital investment every two years.

To appreciate the second method, we must know a little bit about the operation of freight locomotives. Locomotives are operated in a series of discrete throttle settings, called notches, with Notch 8 corresponding to full power. There are also settings for idling and dynamic braking (during which the motors are used as generators to recover energy from the wheels as the train slows down). Both the EPA and the Association of American Railroads (AAR) have standard duty cycles to represent typical operations of both switcher locomotives in yards and line-haul locomotives that move freight. As can be seen in Figure 1, even line-haul locomotives spend almost 40% of their time idling (EPA cycle), and switchers may idle over 75% of the time. Actual practice differs with many factors.

Figure 1. Locomotive Duty Cycles



Why do these locomotives idle? Locomotives idle overnight and part of the day when they wait on sidings for other trains to pass, as well as at terminals. They idle to supply hotel load (space conditioning and electrical power for any crew that is aboard), to keep the engine and the fuel warm (antifreeze is generally not used, and the coolant must be dumped if there is the danger of a freeze), to make sure the engine starts, and to heat the water in the toilet (frozen toilets are an important cause of service loss). In addition, idling supplies power to maintain air brake pressure and to avoid time-consuming rechecks of the brakes. While these are real needs, they can be met with lower energy use and emissions than are caused by idling a 1,500-hp (or greater) diesel engine. If idling can be reduced, regulated emissions can also be reduced, with an energy savings rather than a penalty.

That is the idea behind APUs, one of several technologies already in use for long-haul trucks. One large railroad has formed a joint venture with an APU manufacturer and is currently installing APUs on its entire locomotive fleet[7]and is selling units to other carriers. The unit automatically shuts down the main engine and maintains the engine's coolant water and lubricating oil temperatures. It also supplies heat and air-conditioning to the cab[8]. Figure 2 provides a schematic of the new system, and Table 2 lists the equipment included. The APU, a 3 × 4 × 4-ft unit, is installed on skids behind the main engine. A photograph of a typical unit is shown in Figure 3.

The power for the APU is supplied by a 40-hp, turbocharged, mechanically injected Kubota 4-cylinder diesel engine. The oil change and maintenance occur at two-year intervals. The 12-V dc starting system is easily repaired. The useful life of the system is expected to be 7–10 years.

Figure 2. APU System for Freight Locomotive

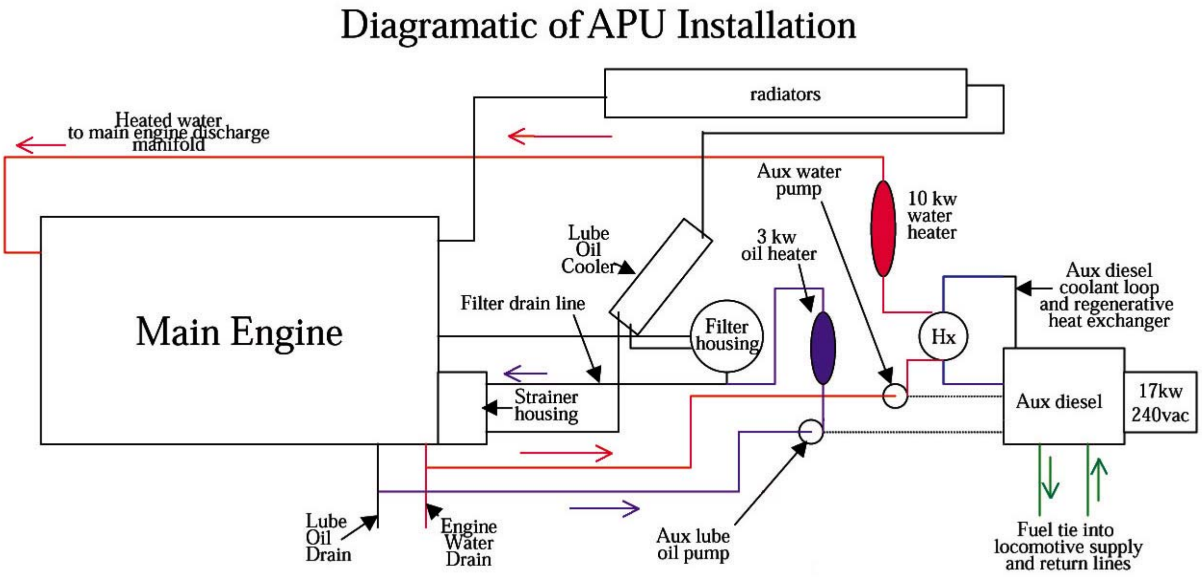


Table 2. Components of APU System

17-kVa auxiliary generator, 240/120V ac, single phase
9 kW of available water heat
6 kW of available oil heat
Cooling water thermostat
120-V lighting
240-V ac heaters (3 kW) for toilet compartment
240-V ac/70-V dc battery charger
Exterior floodlights, motion sensitive
Interior fluorescent lights, motion sensitive
36,000 BTU 240-V ac air conditioner
120-V ac outlets in engine room and cab

Figure 3. APU Installed on Locomotive

BENEFITS OF REDUCING IDLING

Reduction of idling reduces fuel and lubricating oil consumption, emissions, engine wear, and noise. A locomotive engine at idle consumes at least 3.5 gal/h of fuel, depending on load, while the APU uses approximately 0.5 gal/h. If installing an APU system reduced idling by 8 h/d, approximately 9,000 gal of fuel could be saved annually by just one locomotive. For switcher locomotives, savings of 10% of total fuel use are expected. Figure 4 shows how the fuel savings for a switcher locomotive increase with number of hours of idling displaced per day. Savings are less per locomotive for line-haul locomotives, which spend less time idling and more time at higher notches, where fuel consumption is high, but comparable in total because of their greater numbers. A careful estimate of potential savings from idling reduction in the entire Class I fleet gives a total of 230 million gal/yr, or 6.3% of their total fuel used[9]. Actual data from operation of the first locomotive

Figure 4. Fuel Savings as a Function of Idling Hours Displaced

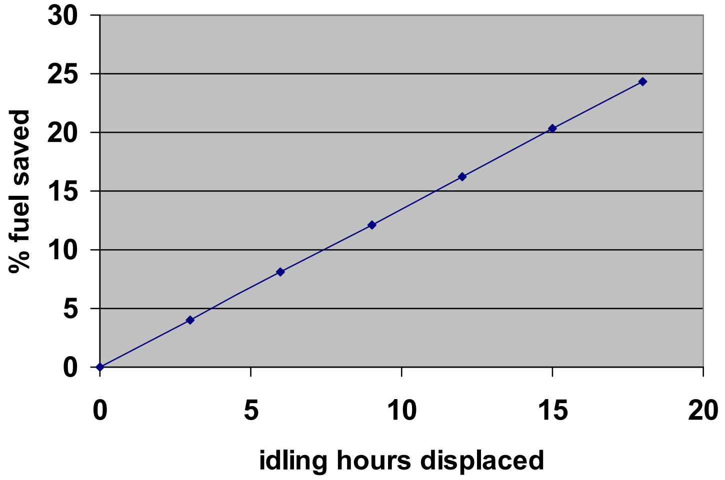
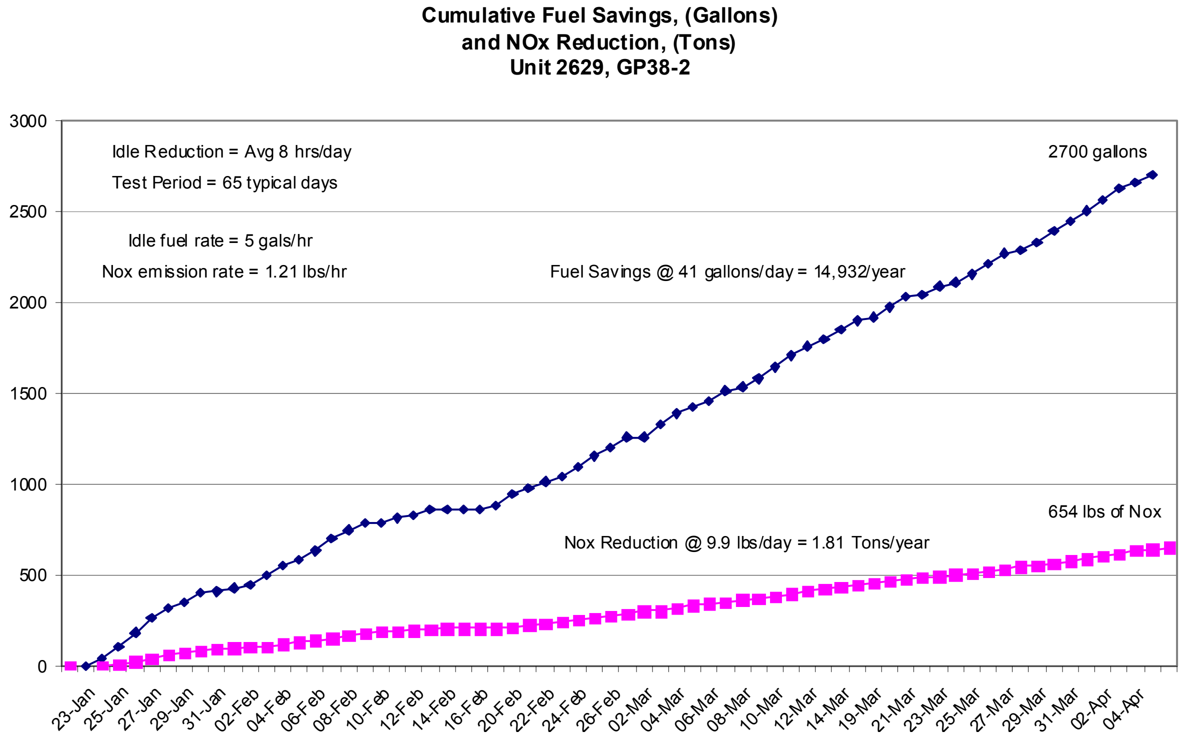


Figure 5. Data from CSX Locomotive 2629



equipped with an APU are shown in Figure 5[10]. Consumption of oil during idling is quite high because engine operation is not optimal. Approximately 0.1 gal of oil are consumed per gallon of fuel burned at idle; therefore, an annual savings of about 1,000 gal of oil per locomotive is also achieved by reducing idling. Engine wear is also believed to be high during idling, leading to more frequent overhauls, but no definitive data are available to quantify this. It is believed that reducing idling could eliminate one engine rebuild, which costs $125,000, over the engine's lifetime. The APU supplies power at 120 or 240 V, allowing standard household appliances, such as air-conditioning, to be used at lower cost and higher reliability than current equipment.

Emissions of NO_x, HC, CO, and PM are also all significantly reduced by over 80% by operation with an APU, compared to operation with the main locomotive engine idling[11]. Test results from Southwest Research Institute are shown in Table 3. Noise reduction is another important benefit, especially in cities. One demonstration of idling reduction is currently planned in the city of Chicago; the city's participation is primarily motivated by noise reduction[12]. Table 4 shows how significantly noise is reduced in the vicinity of a locomotive with an APU in operation.

Table 3. Results of Emission Reduction Tests[11]

Pollutant	**Idling Emissions (g/h)**	**APU Emissions (g/h)**	**Reduction (%)**
NO_x	605	53	91
HC	76	4.3	94
CO	150	6.1	96
PM	16.4	2.6	84

Table 4. Noise Reduction with APU (db)

Distance	Locomotive Shutdown	Idle	High Idle Notch 3	APU Unloaded	APU Loaded
100 ft Forward	42.0–45.0 / 44.0	55.5–56.5	65.0–66.0 / 65.8	47.0–48.5 / 48.0	49.5–51.5 / 51.0
150 ft Forward	42.0–45.0 / 44.0	53.5–54.5	63.0–64.5 / 64.0	49.0–50.5	45.5–47.0 / 46.8
100 ft Crew Side	40.0–55.0 / 48.0	64.0–66.0	71.0–73.0 / 72.5	54.0–56.0 / 55.0	55.0–57.0 / 56.0
150 ft Crew Side	41.0–50.0 / 48.0	59.0–61.0	67.0–68.5 / 68.0	51.5–53.5 / 53.0	51.0–55.0 / 54.0
100 ft Rearward	40.0–45.0 / 44.0	57.0–58.5	67.0–68.0 / 67.5	47.5–49.0 / 48.5	49.5–51.0 / 50.5
150 ft Rearward	38.0–44.0 / 42.0	54.0–55.0	64.0–65.0 / 64.5	44.5–45.5 / 45.0	47.0–48.5 / 48.0
100 ft Engineer Side	42.0–46.0 / 45.0	62.0–63.0	72.0–73.0 / 72.5	49.5–51.0 / 50.5	50.5–52.0 / 51.8
150 ft Engineer Side	42.0–45.0 / 44.0	57.5–58.5	67.5–68.5 / 68.0	46.0–47.5 / 47.0	48.0–49.0 / 48.5

WHY TRADING EMISSION CREDITS IS KEY

Railroads are short of capital, and operate at very slim margins. Therefore, unless there is a clear incentive to do otherwise, they will achieve compliance with emission regulations with the least possible investment and as late as possible. When an engine is rebuilt and must be retrofitted with devices to reduce emissions, the owner will install the most inexpensive system, unless another system offers a very attractive return on investment, which means under a two-year payback for the railroads. The payback period for an APU depends on the fuel cost and on the actual duty cycle of the unit in question, with the payback period decreasing as idling time that can be replaced increases. If the system costs $25,000 and reduces annual fuel use by 8,000 gallons, the payback period is 4–5 years (assuming fuel at $0.90/gal and discounting future earnings). With this relatively unattractive payback, a company with a severe lack of capital might need to install a $15,000 kit, even though it incurs an operating cost penalty and additional costs every two years.

If, however, a financial incentive is created for emission reductions below regulated levels, either by reducing emissions to Tier 0 levels before the unit is rebuilt or by over-complying afterwards, the picture changes, and several benefits accrue. If over-compliance is achieved by idling reduction, fuel and lubricating oil consumption are significantly reduced. As a result, not only are NO_x emissions reduced (these are the key pollutants in the standards), but so are emissions of CO_2, CO, HC, and PM. In addition, noise levels in the vicinity of the yards are also drastically reduced.

An incentive for emission reductions can be created by allowing a company that reduces emissions beyond what is required by law to trade or sell emission reduction credits to other companies whose costs to reduce their own emissions to compliant levels exceed the cost of purchasing credits. This creates a new income stream for the seller, and in the case of railroads, that is a rare and very welcome occurrence. Emission trading is already commercial for nitrogen oxides. Note that trading of credits for a specific pollutant may not actually reduce its total emissions, but it will allow compliance at lower cost. Emissions are reduced if (1) fewer credits are granted than the reductions achieved by the over-compliant seller or (2) the buyer would otherwise have been non-compliant and paying fines. With few exceptions, trading has been among stationary sources, and locomotives are considered mobile sources, even though the switchers' operation is confined to a small area. However, in the Houston area, a demonstration project is being instituted to allow mobile-stationary trading and improve air quality in that non-attainment area while still enabling industrial expansion.

TEXAS SETS A GOOD EXAMPLE

The city of Houston is the site of the nation's first major locomotive APU demonstration project. The Texas Natural Resource Conservation Commission (TNRCC) is currently funding installation of APUs on two switcher locomotives in the Houston, Texas, non-attainment area. Southwest Research Institute will monitor the one-year project. Another project is planned for Chicago, which is particularly interested because of the potential for noise reduction, with funding from the city and the EPA. The Chicago project will retrofit seven locomotives with

APUs and will be the first to include line-haul locomotives as well as switchers. The city of Baltimore will receive funding from DOE for its own 70 locomotive APU project. The objective of the Houston project is to demonstrate both emission reductions and a system for trading emission reduction credits. This system is intended to serve as a model for other states, with California being next, and then potentially for national implementation of a uniform standard for railroad emission trading.

Under the Texas regulations, switcher locomotives are assumed to operate in the rail yard under the EPA duty cycle. The further assumption is made that after the main engine idles for 10 minutes, it turns off automatically and the APU starts up. To estimate the emissions from the APU, which change with load, Houston weather data were used to calculate that the air-conditioning would be required 75% of the time and heat 25%. Emissions will also be estimated for line-haul locomotives, but this is more difficult. Since a road locomotive moves from place to place, a global positioning system (GPS)(a $2K black box to enable position tracking) is required to record actual location and duty cycle data to enable correlation of emissions with the air quality districts in which they took place.

Emission reductions from both switchers and line-haul locomotives will be eligible to provide mobile source credits, which can then be traded to stationary sources on the open market. These are called MDERCs (mobile discrete emission reduction credits) and currently sell for $4,000–6,000 per ton in the Houston area. After each quarter of operation, the locomotive's location will be confirmed and the APU inspected. The locomotive operator will then apply to the state for credits, which can be traded forever. Note that 10% (or more) of the credits must be retired as an environmental contribution, so that the trading does result in a net total reduction in emissions of the traded commodity. (Credits for the two state-funded APU locomotives will be retired.) Credits can be generated in a non-attainment zone and traded anywhere, but credits cannot be generated in an attainment area and sold in a non-attainment area. Credits generated outside the ozone season may not be used during the ozone season, but they do represent real reductions in emissions. It has been estimated that installation of APUs on 400 locomotives would reduce Houston's NO_x load by approximately 7.2 t/y, or about 25% of the quantity required by the State Implementation Plan (SIP), to bring the area into compliance with the Clean Air Act. Only NO_x trading is included at this time, but particulate credits may be banked, and trading is foreseen after 2007, when particulates must be included in the SIPs. Further information on the Texas program can be found at the TNRCC website[13].

CONCLUSIONS

Installation of APUs on locomotives reduces environmental impacts and provides a potential new income stream for the railroads. However, the relatively low payback period and the industry's lack of capital impede rapid installation. Emission credit trading could accelerate introduction and result in reduced noise, emissions, and energy use. But national rule-making is expected to take at least another year. This protracted process may be impeding a win-win situation. Note that for this potential incentive to continue to produce benefits, these reductions should not be included in the SIPs.

Just as study of trucks led to applications to the railroads, we see extensions of the concept of idling reduction to other modes of transport as well. Although APUs might not always be the optimum technology to apply, there are significant opportunities for reduction of energy use (especially in the form of petroleum) and emissions from idling vehicles. City buses and sightseeing buses both idle for extended periods, often in areas where noise and air quality are particularly important. Similarly, barges on our inland waterways idle and produce impacts. Ocean-going ships idle to supply hotel loads in port, but they could use shore power; the environmental impacts are especially severe because of the high sulfur content of the fuels the ships use. The Port of Los Angeles has already enabled emission credit trading for ships (as well as trucks) under its Regional Clean Air Incentive Market (RECLAIM).[14, 15]

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