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# LETTERS

## Electric Cars and Lead

Lester B. Lave *et al.* (Policy Forum, 19 May, p. 993) recently assessed the overall rate at which lead waste is generated in the production and use of electric vehicles (EVs). Their analysis assumes that all lead wastes can be aggregated. They compare this rate of waste generation to the rate of lead waste generated by the use of leaded gasoline. This is a highly simplified analysis. A more complete analysis is complicated by many factors, such as the following.

■ The rates of lead emissions to the atmosphere in secondary lead smelting, as calculated by Lave *et al.* using standard Environmental Protection Agency (EPA) emission factors, are overstated. Although the EPA emission factors indicate that on the order of 1% of the lead processed in secondary smelters escapes to the atmosphere, for two smelters in Los Angeles (*1*), these emission rates are high by a factor of approximately 1000.

■ An analysis more favorable to EVs might focus only on air emissions from smelters. While it is tempting to assume that the lead leaving a secondary smelter as a solid (for example, battery casings) poses little risk if managed properly, the work of Behmanesh *et al.* (*2*) suggests that the situation is far more complex. They found that 80% of all lead sent to hazardous waste incinerators in the United States comes from battery casings from two secondary smelters. Some of this lead will undoubtedly leave the incinerators as air emissions.

■ Even the fate of lead emitted from vehicles running on leaded gas is complex. Friedlander and his coworkers (*3*) found that approximately 25% of the lead in leaded gas remains in the vehicle. Most of the rest is emitted as aerosol, and the exposure pattern for these emissions will be strongly influenced by the particle size distribution.

Comparing EV lead wastes to lead emitted by cars running leaded gas introduces many uncertainties. Lave *et al.*'s analysis approaches a worst-case scenario for EVs. Undoubtedly, best-case scenarios will be put forward that ignore the complex pathways and fates of lead wastes. Until a more complete assessment of this problem is put forward, it is premature to either brush aside the issue of lead wastes from EVs or to forecast the death of the EV by lead poisoning.

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### References

1. N. Steele, thesis, University of California, Los Angeles (1995).
2. N. Behmanesh *et al.*, *J. Air Waste Manage. Assoc.* **42**, 437 (1992).
3. S. K. Friedlander *et al.*, *Environ. Sci. Technol.* **8**, 448 (1975).

### Getting the lead out

General Motors' electric car, the Impact (below). An unusual number of letters were received about the 19 May Policy Forum "Environmental implications of electric cars." Most criticized the thesis of Lave *et al.* that "these vehicles do not deliver the promised environmental benefits" and would create more lead pollution than would comparable cars burning leaded gasoline. "Amazing," "absurd," and "the analysis . . . does not appropriately support its conclusions" were some of the comments.

Lave *et al.* incorrectly conclude that EVs are impractical and that their planned development may actually result in increased environmental pollution. These amazing conclusions result from errors of fact and incorrect assumptions regarding current and future EVs. Important factual errors include unreasonably high weight and low driving range for current lead-acid battery-powered EVs and incorrect estimates of toxic emissions produced by battery manufacturing.

More important, the authors incorrectly assume that future EVs will be powered by lead-acid batteries. Even if true, this would result by the year 2000 in only a 2% increase in the number of lead-acid batteries currently in use. However, this assumption disregards the economic, environmental, and technical significance of the new nickel-metal-hydride (NiMH) battery technology (*1*).

A Solectria EV with the roominess of a Ford Taurus powered by environmentally safe NiMH batteries produced by Ovonic Battery Company (Ovonic), a subsidiary of Energy Conversion Devices, set a record recently, traveling 238 miles on a single charge. The recyclable Ovonic NiMH battery can be charged to 60% of capacity in 15 minutes, lasts the lifetime of the car, provides acceleration from 0 to 60 miles per hour in less than 10 seconds, and operates in a temperature range of −30°C to 60°C. Fuel costs for NiMH-powered EVs are about 20% of those for conventional vehicles, and EVs will have much lower maintenance costs. The Ovonic NiMH EV battery is scheduled for production in 1996 by GM Ovonic L.L.C., a joint venture between Ovonic and General Motors.

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**References**

1. S. R. Ovshinsky, M. A. Fetcenko, J. Ross, *Science* **260**, 176 (1993).

The analysis of Lave *et al.* does not appropriately support its conclusions. We have reviewed the just-released 1995 EPA AP-42 report for primary lead production (*1*) (not available when Lave *et al.*'s Policy Forum was written). The report states that there are no uncontrolled primary lead production facilities in the United States and that control efficiencies generally exceed 99%, not 90%, as indicated by Lave *et al.*

The high releases to the air quoted from the EPA Toxic Release Inventory (TRI) report (*2*) apply only to releases from onsite disposal at lead production and manufacturing facilities; a much larger quantity of lead wastes is transferred for off-site treatment and disposal.

On the basis of the authors' estimate that annual lead production is 1333 gigagrams, the lead amounts listed in the EPA TRI report imply that total lead releases to the environment are about 1.8% of production and, of these, about 3.5% are air emissions. So, overall emissions to air are 0.063% of total lead production or 8.2 milligrams per kilometer after correcting an apparent error in battery density of 38 watt-hours per kilogram rather than 18 watt-hours per kilogram.

In addition, human population exposure from the 22 milligrams-per-kilometer (primarily urban) roadside leaded gasoline emissions could be much greater than those that result from (primarily rural) on-site lead emissions of 8.2 milligrams per kilometer.

To conduct a correct comparative assessment of the environmental impacts of electric versus gasoline vehicles requires inclusion of all the important substances released to the environment from each type of vehicle, not just restricted to lead.

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**References**

1. *Metallurgical Industry Emissions Factors, AP-42* (Environmental Protection Agency, Durham, NC, 1995).
2. *U.S. Toxic Release Inventory 1992* (Technical Report EPA, 745-R-94-001, Office of Pollution Prevention and Toxics, Environmental Protection Agency, Washington, DC, 1994).

While it is useful to point out that there are environmental consequences of the use of EVs, the conclusions reached by Lave *et al.* are overstatements based on obsolete data and extremely pessimistic technology assumptions. At Argonne National Laboratory, we are completing an emissions examination for a total energy cycle analysis of electric and conventional vehicles that is part of a larger study being conducted by several national laboratories for the U.S. Department of Energy. Our findings lead to conclusions that are substantially different from those reported by Lave *et al.*

As a result of their assumptions, Lave *et al.* overestimate the air emissions by a factor of from 5 to 50, and the low energy density they use for their "available" case implies a quantity of lead use that is unreasonably high. In fact, lead production for batteries may actually result in an order of magnitude less emissions than the combustion of leaded gasoline. In any case, these emissions would cause far less human exposure, as they would be remote and away from the urban areas where EVs would be used.

Lave *et al.* also express the opinion that solid waste from lead mining, smelting, and recycling will find its way into the water supply of major cities and expose large populations to lead. While there are poorer data for solid wastes than for air emissions of lead, solid lead wastes from mining are essentially the same material as that initially present; the solid wastes from smelting, which are recycled, are primarily oxides and sulfates, which are more inert than the lead itself.

In examining the tradeoffs (including health and safety) among technologies, it is important to work from the best available data before eliminating any options. While it is important to take human health concerns seriously, better information is needed before sensational claims of damage to human health are made.

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We have serious reservations about the accuracy and completeness of Lave *et al.*'s study. Curiously, despite a wealth of recent and easily accessible data on current battery and electric vehicle performance, the study relies on outdated technical data on batteries and EVs. The study's "available technology" battery is already obsolete, and its "goal" technology battery is available now. The study assumes a vehicle energy consumption level three times higher than the General Motors Impact and inappropriately references the performance of a 15-year-old vehicle, the ETV-1.

The study overstates the potential increase in lead demand resulting from EVs. Realistically, the zero-emissions-vehicle requirement in California, Massachusetts, and New York would result in only a 1% increase in lead demand in 1998, and there is broad consensus that lead-acid batteries will only be used to power electric cars in the near-term.

The study also does not point out that starter batteries for conventional gasoline-powered vehicles are by far the primary consumer of lead. Those that are serious about minimizing the risks from lead may find it ironic that EVs are the key to developing a nontoxic substitute for the lead-acid battery.

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Lave *et al.* conclude that a 1998 model electric car would release 60 times more lead per kilometer than a comparable car burning leaded gasoline. This is absurd. For example, every motor vehicle in operation in the United States today has at least one lead-acid battery. Assuming a battery lead mass of 11.8 kilograms, battery consumption of two batteries per vehicle life, and a vehicle lifetime of 165,000 kilometers, the authors' methodology would result in calculated battery lead per life-cycle kilometer of 0.143 grams per kilometer. This, in turn, would lead to the conclusion (again using the authors' methodology) that lead "releases" from a typical, gasoline-fueled automobile would be 5.7 milligrams per kilometer because of virgin production of lead, 2.9 because of recycling production, and 1.4 because of battery manufacture, for a total of 10.0 milligrams per kilometer, or nearly one-half the rate of tailpipe lead emissions estimated by the authors for gasoline vehicles fueled with leaded gasoline. The elimination of leaded gasoline from use in the United States only reduced tailpipe lead emissions, and not the hypothetical lead "releases" associated with lead-acid battery use. Consequently, if the authors were correct in their analysis, the maximum reductions in ambient lead levels resulting from the lead phase out could have been no greater than about 70%. In fact, long-term trends collected by the California Air Resources Board show reductions in ambient lead levels of well over 95% throughout California over the last 20 years (*1*, figure 6), demonstrating that the authors' estimates of lead "releases" from lead-acid battery use are substantially overstated.

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**References**

1. Sierra Research, *CVS News*, October 1993, p. 15.

The environmental hazard represented by half a ton of lead in each electric car soon to arrive at U.S. automobile showrooms merits creative attention. Lave *et al.* miss an opportunity to embed this small system of range-and-power batteries within the much larger system of more than 100 million lead-acid ignition batteries today found within cars with internal combustion engines. It would be desirable for the automobile industry to commit itself to steadily reducing the combined environmental hazard, by parallel investments in both systems.

It should be possible to secure agreement from all interested parties in favor of such a "cap" on the lead hazard from commerce in lead-acid batteries. Industry, government, and environmental-interest groups should all agree that a well-designed cap addresses population-averaged exposure rather than emissions and takes into account emissions to all media (air, water, and soils). There is an evident need to expand the monitoring of lead emissions from primary and secondary battery production facilities and to create cost curves for emissions reduction.

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Lave *et al.* argue that the use of EVs greatly increases lead emissions and, for that reason alone, "do not deliver the promised environmental benefits." First, the authors rely on archival data on lead usage and emissions and on precommercial technology (much of it from the 1980s) to specify battery and EV attributes. Imagine extrapolating emissions, energy use, and performance of gasoline cars from pre–Model T vintages. The authors' conservative approach to technological innovation with EVs is especially jarring given their exaggerated praise for "pollution controls [that] have lowered emissions from a controlled [gasoline] car by 98%" (actually, 75 to 90%).

Second, their focus on lead-acid batteries for EVs is misleading because the number of lead-acid batteries in EVs will probably never approach the number now used in gasoline cars. In most EVs (except perhaps very small "neighborhood" cars), lead-acid batteries will soon be superseded by more advanced batteries and other electricity storage and conversion devices (for example, ultracapacitors, flywheels, fuel cells, and hybridized powertrain designs). If they are not, EVs will never account for much. If the authors' concern is lead emissions, they should have focused on lead-acid battery use in gasoline cars, not EVs.

Third, the authors implicitly conclude, wrongly I would argue, that the presumed increase in lead emissions would outweigh other environmental benefits. Switching from internal combustion engines to electric drive creates the potential for vast energy and environmental improvements—reductions in greenhouse gas and air pollutant emissions, eliminated spills from storage tanks and tankers, no oil imports—improvements that swamp what is possible with any other behavioral or technological strategy.

It is always easy to find fault with new technologies. The question is not whether today's precommercial EVs do or don't improve the environment, but whether they can or would.

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*Response*: Reaction to our Policy Forum has been astonishing in terms of the level of attention, venom, and desire to defend EVs. Before getting to the details, we emphasize four points:

- Environmental problems are complicated; the obvious solutions often turn out to be much less beneficial than first appearances suggest. The life-cycle impacts of products and processes should be analyzed.
- We used the best data available, although the data are less than definitive. Consequently, we used a wide range of data. For environmental discharges, data on individual facilities are not substitutes for systematic life-cycle and mass balance data.
- We examined technologies available for 1998 vehicles, not proposed or hoped-for technologies.
- We examined total environmental discharges of lead, not just air emissions. Dismissing nonair discharges is inappropriate (*1*). Lead in water can expose people directly; lead in solid waste migrates gradually through weathering, leaving a legacy for future generations.

Allen suggests we produced a worst-case scenario. Actually, we omitted sources. Five to 7% of lead-acid batteries are not recycled; a similar fraction for EV batteries would more than double our estimated losses. Incineration of battery cases with resultant air emissions is also not in our calculations. The performance of the best facility in the industry says little about the average facility. Enclosing a facility can reduce air emissions, but the result may be toxic doses to workers. We agree that tracing discharges from their environmental fate and transport to human exposure is complicated.

Stempel and Ovshinsky extol their product. Average drivers' experience would fall far short of the 238-mile EV world record range. Accelerating "from 0 to 60 miles per hour in less than 10 seconds" is incompatible with going 238 miles on one charge. The battery may operate at −30°C, but how much range and acceleration are available at that temperature? EV fuel costs are comparable to, not one-fifth of, a gasoline vehicle. Stempel and Ovshinsky do not discuss the environmental impacts of producing and recycling their batteries; nickel is carcinogenic and spent nickel-metal-hydride batteries are hazardous waste in California.

Gellings and Peck disregard nonair environmental discharges. We agree that most lead waste is transferred off site; that does not mean it disappears. Allen remarks that battery cases transferred off site are burned with substantial lead emissions. EPA's new AP-42 is consistent with our estimates of total environmental discharges. Gellings and Peck estimate that 8.2 milligrams per kilometer of lead goes to air; this is more than one-third of the lead emissions from burning leaded gasoline. In view of the health problems associated with leaded gasoline, this level is unacceptable. Finally, we agree that EVs should be compared to gasoline-powered vehicles.

We look forward to reading the study by Gaines and Wang when it is completed and has passed peer review. Lead ore is mined at great depths, away from the water table. In contrast, smelter waste is often exposed to weathering.

Gellings and Peck, Gaines and Wang, and Hwang complain about our range of battery energy densities. However, the low end of our battery technology range can be purchased in auto supply stores; the upper end of the range is not yet available. Is it "unreasonable" to use the low-end battery in an EV? Perhaps. What battery energy density–vehicle range makes an EV attractive?

Hwang also asserts our vehicle energy efficiency is too low. However, the GM Impact, under ideal conditions, is not indicative of the range of 1998 vehicles (including light trucks and minivans) in actual driving conditions. We agree with Hwang that current lead-acid batteries are the major use of lead and the major contributor to lead in the environment.

Rubinstein and Austin assert our estimates are "absurd." However, contrary to their assumption, virgin lead is not recycled before being made into batteries. Thus, instead of 10 milligrams per kilometer of lead being discharged, they should have calculated that 7.1 milligrams per kilometer is discharged for virgin lead and 4.3 milligrams per kilometer for recycled lead. As roughly two-thirds of lead is recycled, discharges are 5 milligrams per kilometer, of which 17% is emitted into air: 0.9 milligrams per kilometer. As leaded gasoline resulted in roughly 22 milligrams per kilometer of air emissions, the correct figure is 4% of air emissions. Lead in solid waste migrates slowly, contributing little to current air emissions. Contrary to their conclusion, the data are consistent with a 96% decrease in lead air emissions.

Socolow seeks a middle ground. If current lead discharges are not acceptable, setting a cap at this level is not acceptable.

Sperling and others suggest that forcing the introduction of EVs in 1998 will push the technology and quickly lead to satisfactory vehicles. Technology forcing has worked in some cases (for example, vinyl chloride monomer) and not worked well in others (for example, passive automobile seat belts). New technologies should not be embraced without systematic economic and environmental analysis; see (2, 3) for recent EV studies. The 1998 mandate means that automobile and battery manufacturers must spend hundreds of millions of dollars on current battery technology: lead-acid, nickel-cadmium, and nickel-metal-hydride. These batteries would require up to 1000 pounds of toxic metals in each EV. Heroic efforts would be required to smelt and recycle these metals without significant environmental discharges. Forcing lead-acid or other available technology (and the associated recharging infrastructure) is not attractive compared to pushing advanced technologies such as fuel cells. Research and development should focus on promising technologies that do not require the processing of large quantities of toxic materials.

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**References**

1. R. Renner, *Environ. Safety Technol.* **29**, 256 (1995).
2. F. Kreith, P. Norton, D. Potestio, *Transp. Q.* **49** (no. 2), 5 (Spring 1995).
3. V. Bevc, *Natl. Reg. Res. Inst. Q. Bull.* **16**, 21 (1995).

**Corrections and Clarifications**

In the Research News article "Controversy: Is KS really caused by new herpesvirus?" by Jon Cohen (30 June, p. 1847), the quote from Susan Krown of the Memorial Sloan Kettering Cancer Center was incorrect. The quote should have read, "I think we all need to be treatment activists to move the field forward."