Letter to the Editor

Seager,T. P. 1998. **Geo Metro versus EV-1: The Effect of System Boundaries on Analysis.** Letter to the editor regarding Socolow and Thomas's (Winter 1997) "The Industrial Ecology of Lead and Electric Vehicles," *Journal of Industrial Ecology* 1(1): 13–36; and L. B. Lave and colleagues' (Spring 1997) "Clean Recycling of Lead-Acid Batteries for Electric Vehicles: A Reply to Socolow and Thomas," *Journal of Industrial Ecology* 1(2): 33–37.

The exchange between Lave, et al. and Socolow & Thomas in the Winter and Spring 1997 issues is ample evidence that the potential environmental impact of electric vehicles is poorly understood. The separate conclusions drawn by each researcher depend entirely upon the underlying assumptions of the analysis (in this case, the point of debate focuses on whether our economy will successfully produce and recycle the lead for electric vehicle batteries without increasing harmful lead emissions to the environment -- Socolow argues that it can, but Lave is less sanguine). The potential environmental impacts can be characterized in a myriad of ways: greenhouse gas, uncombusted hydrocarbons, NOx emissions, etc., and Lave is justifiably credited with expanding the debate to include material flows beyond 'tailpipe' comparisons, but inevitably a formidable challenge to any of the present analyses can be mounted on the basis of some disagreement with the underlying assumptions.

Lave and colleagues sidestep much of this criticism by focusing attention on the only electric vehicle in mass-production, the General Motors EV-1 (which is a lead-acid battery car with a regenerative braking system) as something of a proxy for current electric vehicle technology. They choose the Geo Metro as a point of comparison for internal combustion technology, as the Metro is likely to be used in approximately the same fashion as the EV-1 (commuting, delivery of small packages over short distances, etc.). The choice of specific vehicles successfully narrows the ground rules of the debate, but the problem of characterizing "impacts" still remains as thus far no holistic study of electric vehicles has been undertaken and no holistic measure of environmental impact has been devised. It is possible, for example, that even if Lave's conclusions are correct, other environmental benefits of switching from internal combustion to electric vehicles may be so overwhelming as to justify electric vehicle production despite increased lead contamination risks. I will not argue that position here (or elsewhere), but the debate is of increasing urgency, especially in New York State where the 2% zero-emissions-vehicle requirement originally enacted in California (but postponed there and in other northeastern states) takes effect in 1998. To date, we have no methodology to provide us with a holistic assessment without invoking subjective, questionable "impact" determinations (see J.W. Owens, this journal, winter 1997 and related on-line discussion).

Lacking such holistic, objective measures, we may follow Lave's approach and expand the analysis of electric cars piecemeal. Consider, for example, the impact of electric cars upon fossil fuel consumption. The GM-EV-1 is rated by the EPA as requiring 30kW-hr/100 miles of city driving. The Geo Metro is rated at 44 miles to the gallon under identical driving conditions. If one considers gasoline to be 2660 grams of octane (C8H18), a simple thermodynamic calculation considering the free energy of formation of octane

(5211kJ/mole) shows that the Metro requires 2760 kJ/mile of fossil fuel (i.e., chemical energy) per mile. The EV-1 requires 1080 kJ/mile of electrical energy. The lower energy requirements are largely due to the improved aerodynamics and regenerative braking system in the EV-1, which weighs about 1100 lbs. more than the Metro (2900 lbs. to 1829 lbs. curb weight, respectively). However, if one considers the fossil fuel required to deliver 1080kJ/mile of electricity to the EV-1 batteries, the analysis changes. Assuming that only 40% of the chemical energy of fossil fuels used in electricity generation is converted to useful electricity, the fossil fuel requirement of the EV-1 is 2700 kJ/mile, almost exactly the same as the Metro.

It is interesting to note two other important distinctions: the Metro has greater interior space and cargo capacity, and the EV-1 achieves an equivalent fossil fuel demand only by employing regenerative braking technology, carbon-fiber body panels, advanced aerodynamics, an aluminum frame, and other energy saving technologies that could presumably be employed (at least in part) to the benefit of an internal combustion powered vehicle as well.

From this "back of the envelope" comparison, one could conclude that the greatest potential for reduction of vehicular fossil fuel demands and consequent economic and environmental benefits (whatever they are) lies in extending the life and efficiency of internal combustion vehicle technologies, and applying the energy saving technologies employed in the design of the EV-1 to vehicles with internal combustion engines.

As we have seen with other studies, the underlying assumptions are essential to the conclusions herein. One could endeavor to include some "efficiency factor" in the distillation of gasoline from crude oil. The figure of 40% efficiency for electricity generation and transportation may also be subject to scrutiny, and is likely to be found to be too high in many cases. Most importantly, the assumption that electricity is generated exclusively from fossil fuels may be called into question. Should the electricity be generated by solar, hydro or nuclear power the analysis could change in dramatic, unexpected ways.

The most important conclusions drawn to date have not provided holistic answers to the questions raised by electric vehicles, but instead have served to remind us that there is always a danger to oversimplifying systems problems by drawing the boundaries of the system too narrowly. The analysis provided by Lave and others serves to expand the boundaries of our discussion in heretofore unimagined or under examined ways. It is not clear that the challenges of systems analysis are understood (or acknowledged) by the legislators who have enacted electric vehicle requirements, and the researchers who raise these issues in substantive ways are to be commended for bring it to our attention.

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