COMMENTARY

Hydrogen as a Transportation Fuel

In their recent article in *Environment*, Marc W. Jensen and Marc Ross bring an overdue dose of realism to the debate on hydrogen as a transportation fuel by stressing the importance of a refueling infrastructure.[1] They are correct that gasoline- and methanol-powered fuel cell vehicles are problematic, but their article, like much of the current discussion of hydrogen, is misleading because it focuses uncritically on near-term applications of fuel cells in automobiles.[2] This error comes about by backing into the issue of hydrogen after asking, *How might automotive technologies evolve to solve pollution and climate problems?*

In answering this question, Jensen and Ross are over-optimistic about fuel cells. A close examination of the entire fuel cycle reveals that fuel cells may have little or no environmental or efficiency advantages over advanced internal combustion engines.[3] In addition, fuel cells are extremely expensive and will likely remain so for a long time. Currently, fuel cells are more than 10 times the cost of comparable engines. Moreover, the outcome of the horse-race between the two technologies matters little because solving climate and oil import woes depends much more on shifting transportation fuels than it does on the technologies that use them.

However, shifting transportation fuels is difficult, so insights into technological change will be critical to successful introduction. New technologies typically enter tiny niche markets before diffusing into general use.[4] Diffusion is fueled by a virtual circle in which technological learning in response to experience and growing investment drives costs down and thus opens market opportunities.[5] However, because of insufficient consumer demand, environmental technologies do not follow this pattern unaided.[6] Thus, the correct question to ask about hydrogen is, *Into what niches can government most easily introduce hydrogen as a transportation fuel?* The answer requires minimizing hydrogen's disadvantages (high costs and storage difficulties) in three areas: vehicle design, refueling infrastructure, and institutional capability.

Into what niches can government most easily introduce hydrogen as a transportation fuel?

Beginning with the vehicles themselves, the low energy density of hydrogen makes it very difficult to design hydrogen-fueled cars that have adequate storage space and acceleration.[7] Vehicles for which size and speed are less important constraints thus will be more easily adapted to hydrogen. The extra expense of hydrogen technologies will be less important in vehicles that are used more intensively and have longer lifetimes. And learning-by-doing will be maximized where the vehicles are manufactured in small numbers of near-custom designs, not through mass production.

The cost of building an acceptable hydrogen refueling infrastructure may be minimized by focusing on vehicles that fuel at a centralized facility within a small region or at a small number of widely disbursed sites, instead of trying to figure out how to provide hydrogen for automobile users who demand ubiquitous gasoline retailing nationwide.[8] Many heavy-

duty vehicles (such as transit buses, long-haul trucks, trains, and ships) are fueled at centralized sites. These sites will tend to be larger than gasoline retail outlets, thereby gaining economies of scale that are important in hydrogen production.[9]

Finally, it is easier to introduce new technologies where institutional factors are most favorable to managing technological change. These include ensuring proper safety precautions, adequate maintenance, and user training, which will be easier in work settings with professional crews.

All these factors point toward introducing hydrogen as a transportation fuel into heavy-duty fleet vehicles—not into your grandparent's car.

In addition, consider where clean (but expensive) hydrogen propulsion would have the greatest air pollution benefits. Existing diesel-powered freight vehicles are dirty, and relatively modest requirements for cleaner heavy-duty freight vehicles are only now being eased in after decades of regulating automobile emissions down to nearly zero. For instance, marine fuels can contain as much as 2,000 times more sulfur per gallon than the new clean gasoline formulation recently introduced in Southern California by ARCO, making international shipping a major air pollution problem in coastal Northern Europe, California, and Texas.[10]

So what is the straightforward way to introduce hydrogen as a transportation fuel? Nations with significant international maritime freight operations and serious interests in controlling carbon dioxide (CO_2) emissions (e.g., Germany, Japan, or the Netherlands) could construct and operate a small fleet of hydrogen-fueled cargo ships. These would use large internal combustion engines, which are just as efficient as fuel cells.[11] As experience is gained, hydrogen technologies (perhaps including fuel cells) could next be used by heavy-duty freight vehicles—such as rail and long-haul trucks—at the port. This would set up the potential to develop a sparse but adequate network of hydrogen refueling sites at truckstops across the country, finally setting the stage for hydrogen-fueled automobiles should this emerge as a cost-effective choice for a climate-friendly energy system.

This process would require successive government actions over several decades. Such a timetable is not only realistic but desirable—energy systems change over the course of time and an incremental approach would maximize learning-by-doing.[12]

It is erroneous to assume that hydrogen-powered fuel cell vehicles are the best way to introduce hydrogen into the transportation system or that they are the ultimate automotive design. In the long-term, a desirable future energy system may feature different fuels for different modes. Perhaps heavy-duty vehicles will use hydrogen fuel cells while light-duty vehicles burn biofuels (e.g., ethanol) in ultra-clean internal combustion engines. In the near-term, these observations suggest a major change in the current directions of CO_2 mitigation research and development. The existing emphasis on the development of fuel cell vehicles that use gasoline or other fossil fuels and on hydrogen in passenger vehicles is misplaced. Resources currently being spent on the introduction of hydrogen into the transportation system should be shifted to heavy-duty freight applications, and thoughts of hydrogen as a transportation fuel for the general public should be deferred for a least a decade.

ILLUSTRATION BY BOB SCHOCHET

"I made my millions in oil. Cleaning it off beaches!"

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We appreciate the response from Alex Farrell and David W. Keith in regard to our article in the September 2000 issue of *Environment*. Farrell and Keith propose a realistic and technically sound strategy for introducing hydrogen as a fuel for maritime transportation systems and eventually for heavy-duty freight vehicles. Hydrogen use in these applications would certainly displace more harmful air emissions on a per-mile basis than in passenger vehicles, which have more strictly regulated emissions. This is a straightforward answer to the question of how to introduce hydrogen as a transportation fuel. There are a wide variety of older solutions to this appealing question.[1] For example, more than 20 years ago our colleague Lawrence Jones proposed a technically sound strategy for introducing hydrogen fuel into aviation systems. Jones proposed beginning this transition by providing hydrogen fuel to a significant number of airplanes with dedicated routes between two carefully chosen airports. From this initial linkage, an expanding network of airports could provide hydrogen fuel to a succession of dedicated airline routes across the country and eventually around the world. This strategy, which is perhaps slightly closer to being realized today than it was 20 years ago, is similar to Farrell and Keith's in that it would dramatically reduce relatively unregulated emissions and would require a large amount of government intervention.

Farrell and Keith propose a realistic and technically sound strategy for introducing hydrogen as a fuel for maritime transportation systems and eventually for heavy-duty freight vehicles.

The question our article addressed was much more specific than the general introduction of hydrogen as a transportation fuel or even how automotive systems might evolve (or atrophy, for that matter) to solve pollution and climate problems. Our goal was to describe barriers and propose potential solutions to the challenge of providing fuel for fuel cell vehicles. Other than an admittedly optimistic view that fuel cells may one day be implemented in an environmentally benign and cost-effective manner, we see few inconsistencies between our proposals and those of Farrell and Keith. Their comments are well taken. And praise for hydrogen as a general transportation fuel is certainly a welcome addition to our article.

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