ARE FUEL CELLS APPROPRIATE FOR CARS AND TRUCKS?

An AIChE Position Statement

Approved by
AIChE's Government Relations Committee

April 2003

Are Fuel Cells Appropriate for Cars And Trucks?

Fuel cells for transportation in automobiles and trucks have caught the public's and media's attention. The popular media have described them as offering promising potential long-term solutions to three major public policy concerns—greenhouse gas emissions, urban and regional air pollution, and US dependence on the world's exhaustible oil and gas reserves. President Bush, in his January 2003 State of the Union address, proposed significant new funding for federal programs to develop the technologies and infrastructure required to move toward a hydrogen-based energy system to provide the required hydrogen fuel for fuel cells in transportation.

The President has acknowledged that it will take several decades of research before it is likely that fuel cells and the hydrogen infrastructure will be economically viable for cars and trucks. Others have expressed concern, that, no matter how effective the research, economic viability is unlikely, barring some unforeseeable technological breakthroughs, and/or loss of access to world oil supplies. In addition, depending on the source of hydrogen and the design of the energy conversion systems, the use of transportation-based fuel cells may or may not result in a positive response in climate change and air pollution. Further, it could even result in an increased demand on fossil fuel based energy.

The American Institute of Chemical Engineers agrees that fuel cells for transportation and movement toward a hydrogen economy have promise and merit increased R&D attention. However, the US must not abandon R&D on conventional energy systems which clearly have more near-term promise in reducing energy use, pollution and greenhouse gas emissions. Fuel cells and hydrogen are not a panacea for car and truck transportation in the near term, and may never be.

Furthermore, AIChE supports continued R&D in conventional technologies and near-term alternative energy systems. Examples include electric and hybrid (an engine/battery combination with an electric drive train) vehicles, as a hedge against the long time frame for R&D needed to make transportation fuel cells viable. Attention must be paid to efficient technologies that have promise in the near term to reduce both greenhouse gas emissions and our dependence on oil while we are seeking technological breakthroughs for hydrogen fuel cells.

Chemical engineers have been working on fuel cell technologies for transportation and stationary generation of electricity for years; in fact, fuel cells have powered the space program since the 1960s. Clearly, for some specific systems and challenges, and even using current technologies, hydrogen powered fuel cells are the best solution to implement. For example, hydrogen and stationary fuel cells are an excellent backup for power grid failures, and also can provide electricity in areas where it is impossible or not desirable to run electric transmission lines. In the case of the space shuttle, fuel cells have been deemed the best solution and effective for providing the electricity to run the spacecraft instruments, life support and navigation systems.

However, for automobile and truck usage, the challenge is to design a fuel and power plant system that provides energy to hundreds of millions of automobiles, at low cost, in a reliable, safe, and convenient manner, and without using oil or producing any greenhouse gases or air pollution. A discussion of the various options for producing, storing, and distributing hydrogen can help to clarify the priorities for needed research.

Hydrogen and the Fuel Cell

Fuel cells operate best on pure hydrogen (H2). When they do so, they produce only water at the point of use. The impact of a fuel cell-based light duty vehicle fleet on the three underlying public policy concerns (greenhouse gas emissions, air pollution, dependence on oil) depends on certain assumptions about the feedstock for hydrogen and how and where hydrogen is produced.

<u>Sources of Hydrogen: Where do we get Hydrogen?</u>

Hydrogen is an energy carrier and does not occur naturally in the environment. Instead, it must be produced from other resources. The most likely resources are water, biomass, or fossil fuels (coal, petroleum or natural gas).

If the H2 is produced by electrolyzing water, and the electricity comes from nuclear or solar energy, biomass, or coal combined with carbon dioxide (CO2) sequestration, then no net CO2 (the primary greenhouse gas) would be emitted. Urban and regional air pollution would be reduced or perhaps eliminated. The US would eventually be independent of the world's limited oil and gas resources for transportation energy.

The chemical process of reforming hydrocarbon fuels such as natural gas, releases the H2 but also produces CO2 as well as pollutants contributing to urban and regional air pollution. In fact, unless sequestered in some way, as much CO2 is released in this process as burning it directly in a gasoline or diesel engine. Other important factors include costs and safety.

<u>Production of Hydrogen: How is Hydrogen made?</u>

Energy must be supplied to the source material to liberate the hydrogen. The only known routes to liberate hydrogen from a source are thermal decomposition, chemical decomposition, or, in the case of water as the source, electrolysis. Each of these processes is endothermic, which means energy must be put in to get hydrogen out. The net result is less energy out of the hydrogen than what was used to liberate it. This is also true of the current gasoline/diesel engine system, but in the case of hydrogen the losses are significantly greater (1).

Comment: Is this true of steam-methane reforming??? It's true of water electrolysis by first principles, but it's not intuitively obvious that the H2 heating value is less than the net energy applied to a steam-methane reformer. The statement says (to me) "…less energy out of the hydrogen than what was used (= the net energy applied?) to liberate the hydrogen." This could be true for reforming. I haven't studied the energy balance for reforming. We should just be very sure this is correct.

<u>Distribution/Point-of-Use of Hydrogen: Where do we make the Hydrogen?</u>

Hydrogen must be readily available for a fuel cell to work, similar to having gasoline available for a car engine to work. Either a supply of hydrogen can be stored on the vehicle (similar to having a gasoline tank on a conventional car), or a source of hydrogen can be stored on the car where hydrogen is liberated from the source as needed. If hydrogen is stored on the car, it must be stored under high pressure which gives rise to safety concerns (1). If other materials (chemicals) are stored on the car, then the hydrogen can be liberated by a chemical reaction on demand. Chemicals that can liberate hydrogen include conventional gasoline, ethanol, methanol, water, and chemical hydrides. For on-board liberation, energy must be available at the vehicle to liberate the hydrogen from the chemical.

Scenarios to Consider

A number of paths may be used to deliver hydrogen for use in fuel cells in cars and trucks. Analysis of these scenarios provides insight on their overall effects on the important criteria of greenhouse gas emissions, urban air pollution, and dependence on the world's oil. In addition to these public policy criteria, economics, safety, and timeline for implementation are also important. Four general hypothetical scenarios (although there are many others) help illustrate the importance and tradeoffs among the multiple impacts of using hydrogen in fuel cells for transportation.

Scenario 1: *Fossil fuels (includes gasoline, diesel, natural gas, or alternatives derived from fossil fuels such as methanol from coal or natural gas) are the source of the hydrogen. The fuel is carried onboard the vehicle. An onboard chemical reactor or reformer produces the hydrogen as needed.*

This scenario has the shortest time frame. It gets fuel cell vehicles into use and takes advantage of the existing infrastructure for fuel supply and delivery. The presence of fuel cell vehicles, compared to current conventional vehicles, has no significant effect on greenhouse gas emissions, urban air pollutant emissions, oil dependence, or transportation safety hazards (1,2). It does, however, increase costs because the onboard reformer and the fuel cell make the vehicle and the fuel more expensive than the conventional vehicle/fuel system they replace.

Scenario 2: *Conventional or alternative fuel is produced and delivered to the fuel marketing area as it is now. In the marketing area (such as a "gasoline" station), hydrogen is produced from the conventional or alternative fuel by catalytic reforming and delivered under pressure to hydrogen tanks on the fuel cell vehicle.*

In this scenario, the presence of fuel cell vehicles has no significant effect on greenhouse gas emissions or oil dependence. Urban air pollutant emissions may be reduced; that would depend on the reformer emission control system effectiveness compared to that of the onboard converter used in the first scenario. Fuel costs will increase because hydrogen must not only be produced but also compressed. Vehicle costs may or may not increase; the onboard reformer from Scenario 1 would not be needed, but storing hydrogen onboard under pressure to provide the necessary vehicle range would increase the overall cost. Since hydrogen under pressure is more hazardous than current conventional or alternative fuels, major safety concerns must also be addressed. These will significantly increase cost (3). Alternatively, the hydrogen could be stored in some solid form such as a chemical hydride, which would minimize the safety concerns, but add cost, complexity, and additional energy inefficiencies.

Scenario 3: *Electricity is produced from nuclear or renewable energy or from coal with CO2 sequestration, transmitted conventionally to the marketing areas, where it is used to produce hydrogen from water by electrolysis and delivered under high pressure to hydrogen tanks on the fuel cell vehicles.*

In this scenario, greenhouse gas emissions, urban air pollutant emissions, and oil dependence significantly decrease over the current internal combustion engine. Electricity generation will be more expensive, and the transition period will be long. There will be additional electricity transmission costs because energy now being moved as conventional fuels will be moved by newly constructed transmission lines. Local infrastructure, vehicle costs, and safety issues will be similar to those in the second scenario.

Scenario 4: *Electricity is produced as in the third scenario. Hydrogen is produced by electrolysis of water at the generating sites, or by coal gasification with CO2 sequestration, transmitted by pipeline to the marketing area (approaching the so-called "hydrogen economy"), and delivered under high pressure to hydrogen tanks on the fuel cell vehicles.*

In this scenario, the time frame could be similar to that in the third scenario. Greenhouse gas emissions, urban air pollutant emissions, and oil dependence significantly decrease, as in the third scenario. Electricity will be more expensive, as in the third scenario. Hydrogen production may be a bit less expensive than in the third scenario due to economies of scale. Hydrogen transmission costs, however, will be higher than electricity and natural gas transmission costs. Hydrogen transmission by pipeline will require more compression capacity and require major improvements in pipeline materials and integrity compared to natural gas transmission. Safety concerns will be extended to the design and operation of the transmission system and to storage of large amounts of hydrogen in the marketing areas. Vehicle costs will be the same as in the second and third scenarios.

Summary

These scenarios point to some of the impacts of fuel cell vehicles on public policy concerns. They also identify key areas where research and development might, if successful, reduce costs, improve performance, and address safety issues.

The two scenarios using fossil fuels as the hydrogen source (Scenarios 1 and 2) indicate that fuel cells in motor vehicles, in and of themselves, won't have any effect on the public policy goals under which this initiative is proceeding. They would, however, result in increased costs and increased safety concerns.

The other two scenarios (Scenarios 3 and 4), which would meet the policy criteria, will require fundamental changes in the United States' national infrastructure. For example, much current electricity generation capacity would need to be replaced or upgraded to include CO2 sequestration. Natural gas pipelines would need to be upgraded in the fourth scenario or replaced with an expanded electricity transmission system. The timeframes are long and the costs substantial – by some estimates, immense.

R&D Needs Identified

The Department of Energy (4) has identified R&D needs for the hydrogen/fuel cell system for transportation to meet the policy concerns of reduced greenhouse gases, improved urban and regional air quality, and reduced use of oil. These R&D priorities include improvements in fuel cells, H2 generation, storage, distribution and safety-related technologies, nuclear and renewable electricity generation (including biomass), and CO2 sequestration.

Without technology breakthroughs, the transition to a hydrogen economy will simply not occur. To match the performance, cost, and safety of future advanced technology internal combustion engines with lower emissions and higher fuel economy poses a tremendous challenge for such R&D. To commit to a hydrogen/fuel cell vehicle future now, to the exclusion of research to improve internal combustion engines and fuels would be a major risk to the nation.

If however, it were necessary to totally abandon the internal combustion engine, it is still not apparent that the hydrogen/fuel cell system would be the most viable solution. Reasons that could cause elimination of the internal combustion engine could include unforeseeable limits on or availability of the world's oil and gas resource base, or some sharp ramp-up in the dangers associated with global climate change. Use of electricity directly for vehicle propulsion is at least as viable as the hydrogen/fuel cell system.

Thus, continued R&D in a number of areas outside of hydrogen/fuel cells is important. Research should continue on improvements in conventional vehicles and fuels, CO2 sequestration for electricity generation from coal, and lightweight electricity storage. Breakthroughs in these areas would make the hybrid electric car even less dependent on gasoline or diesel fuel and could make an acceptable (in terms of range and performance) all-electric car a reality. Such an electric or electric/hybrid would go a long way toward meeting the public policy concerns of reduced greenhouse gases, improved urban and regional air quality, and reduced use of oil. This would also provide even more time for R&D on the tremendous technical challenges associated with the fuel cell vehicle and the hydrogen economy.

Finally, safety issues involving wide availability and use of hydrogen as a fuel merit significant research and development efforts.

In conclusion, Are Fuel Cells Appropriate for Cars and Trucks? The answer is: In the long term, "Maybe."

References

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(2) Weiss, M.A., J.B. Heywood, A. Schafer, & V.K. Natarajan, "Comparative Assessment of Fuel Cell Cars," Massachusetts Institute of Technology Laboratory of Energy and the Environment Publication No. LFEE 2003-001 RP. February, 2003.

(3) Shinnar, R., “The Hydrogen Economy, Fuel Cells, and Hydrogen Fueled Cars A Technical Evaluation,” City College of New York, March 13, 2002, publication under review.

(4) “National Hydrogen Energy Roadmap,” U.S. Department of Energy, November 2002.

Chemical Engineers Represent a Key Resource to Provide Technology

AIChE, founded in 1908, is a professional association of more than 50,000 chemical engineers worldwide. AIChE fosters and disseminates chemical engineering knowledge, supports the professional and personal growth of its members, and applies the expertise of its members to address societal needs and improve the quality of life.

Chemical engineers are creative problem solvers who perform research and develop processes and products utilizing the principles of engineering, physics, chemistry, biology, and mathematics. They play key roles in such diverse industries as energy, chemicals, biotechnology, food, electronics, and pharmaceuticals. Chemical engineers are also leaders in environmental health, safety, and sustainability. They endeavor to improve the quality of life for people the world over.