

# **Commercialization of Vehicular Fuel Cells**

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Washington Internships for Students of Engineering  
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## **ABOUT THE AUTHOR**

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Melony Anderson is currently a senior at the University of Delaware studying chemical engineering and serves as president of the student chapter of the American Institute of Chemical Engineers (AIChE). The research for this paper was conducted during the Washington Internships for Students of Engineering (WISE) program in the summer of 1999 and was sponsored by the AIChE.

## **THE WISE PROGRAM**

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The Washington Internships for Students of Engineering is a ten-week program for outstanding engineering students who have completed their junior year and have an interest in public policy, particularly the role that engineers play in the creation and implementation of technology-related public policy. Through frequent meetings and discussions with government officials, policy makers, lobbyists and other non-government individuals, the students receive a better understanding of how government works and what plays a role in the making of public policy. Each student also completes a paper that analyzes a specific engineering public policy issue of interest to the sponsoring society. For more information, contact WISE, Attn: Anne Hickox, 400 Commonwealth Drive, Warrendale, PA 14096-0001 or visit [www.wise-intern.org](http://www.wise-intern.org) on the World Wide Web.

## **ACKNOWLEDGEMENTS**

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## EXECUTIVE SUMMARY

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In the past decade, the United States has invested billions of dollars, through government, industry and academia, in energy research in the hopes of reducing the U.S. dependence on fossil fuels for energy, as well as reducing the emissions of carbon dioxide. One technology that has arisen out of this research is the fuel cell. Fuel cells have long been used by NASA to supply energy and water on space missions, but have only recently been seen as a potential substitute for the internal combustion engine, particularly in light-duty vehicles. Fuel cells are fuel flexible (they are capable of operating on a variety of fuels) and even fuel cells operating on gasoline are much more efficient than the internal combustion engine with much decreased emissions. Thus, the commercialization of fuel cell vehicles could mean a partial solution to the U.S.'s energy dependence problem, as well as reduce the amount of CO<sub>2</sub> released into the atmosphere.

Fuel cell vehicles are expected to enter the market in 2001. The first of these vehicles, however, will be extremely expensive and it is not likely that they will be commercially viable for several years after. If fuel cell vehicles are going to make a significant impact on fossil fuel dependence and environmental quality then they need to be widely used and accepted by the general public. Public acceptance is largely determined by economics. Fuel cell vehicles must be price-competitive with the internal combustion engine vehicles already on the market. The federal government's involvement in decreasing the cost of fuel cell vehicles for the consumer is one of the most important issues surrounding fuel cell commercialization.

The key players in this debate are divided into two groups: those who support government involvement in fuel cell development, and those who do not. Those who support the involvement are unified in the belief that federal funding and oversight are crucial to the introduction of fuel cells in the vehicular market. Those who do not support such involvement see it as "corporate welfare" and do not recognize the need for any government involvement.

Another important issue surrounding fuel cell vehicle commercialization is the type of fuel used in the vehicle. There are several alternatives, but the three in the current spotlight are hydrogen, methanol and gasoline. There are drawbacks and benefits to each type that affect the lives of the average citizen. Therefore, the federal government must make a decision whether or not to support a particular fuel for use in fuel cell vehicles, and if yes, which fuel.

The key players involved in this issue are the hydrogen, methanol and petroleum industries as well as environmental groups and consumers. Each of the first four groups has reasons for supporting a particular fuel. If the federal government does not single out a particular fuel for support, then the consumers will be the final determinants.

The benefits of commercializing fuel cell vehicles outweigh the economic drawbacks. The federal government should play a role in the commercialization, thus speeding up the process and making fuel cell vehicles a widely accepted alternative to the internal combustion engine. The federal government should provide incentives in the form of rebates and tax-credits to the purchasers of fuel cell vehicles. In addition, federal funding should go to the development of fuel cell

vehicles that operate on gasoline. Once gasoline-powered fuel cell vehicles are accepted in the market, the federal government should support the use of methanol as a fuel. Finally, the DOE's Hydrogen Program should continue researching the impact of converting to hydrogen as a primary fuel and energy source.

## **ISSUE DEFINITION**

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### **Overview**

Since the energy crisis in the 1970s, the federal government has taken an interest in technologies that could decrease the United States' dependence on fossil fuels for energy. With recent concerns about global warming and carbon dioxide (CO<sub>2</sub>) emissions, the government has also taken an interest in technologies that produce energy with less harmful emissions. In the last decade, fuel cells have arisen as a potential substitute for the internal combustion engine in the transportation sector. Fuel cells also have applications in the stationary power sector, and their progress in that area has been significant in the past decade. The benefits of fuel cells are increased efficiency, lower emissions, fuel flexibility, and quiet and continuous operation.<sup>1</sup> The main disadvantage of fuel cells, which has prevented them from entering the market, is cost. Present fuel cell technology is expensive, and until fuel cells are mass-produced their cost will preclude them from being a viable alternative to the internal combustion engine.

### **Issues regarding vehicular fuel cells**

This analysis covers two main issues related to vehicular fuel cell development. The first is the role of the government in the development of vehicular fuel cells for the commercial market. This paper will attempt to answer the questions:

- a) What is the government doing now and what has it done in the past?
- b) Should the government continue to be involved, now that most of the basic research has been done? And if so,
- c) What can the government do to ensure fuel cells become a viable commercial alternative to the internal combustion engine?

The second issue is whether or not the government should support one type of fuel for use in fuel cell vehicles, and if so, which fuel (hydrogen, methanol or gasoline).

### **Importance to the general public**

When they are commercialized, fuel cells - specifically vehicular fuel cells - have the potential to affect many aspects of public life. Chief among these effects are the economic and environmental outcomes of integrating fuel cells into the commercial vehicle market and the impact that will have on the United States' dependence on foreign oil.

### Economic

Fuel cell sales could reach \$3 billion by the year 2000, and if fuel cell vehicles replace just 20% of the internal combustion vehicles, a projected 800,000 jobs will be created.<sup>2</sup> In addition, the U.S. Department of Energy (DOE) estimates that a total of \$64 billion could be saved on motor fuel by the year 2030, assuming fuel cell vehicles hold a 24% cumulative market share of new

light-duty vehicles sold in the United States by the year 2030.<sup>3</sup> The DOE also estimates that the United States as a whole could save an additional \$23 billion by the year 2030 from the reduction of pollution and increased air quality.

### Environmental

Fuel cell vehicles will result in a reduction of emission of pollutants including non-methane organic gases (NMOG), nitrogen oxides (NOx), and carbon monoxide, as well as CO<sub>2</sub>. Assuming a cumulative 24% market share of light duty vehicles by the year 2030, fuel cell vehicles will be responsible for a 2300 million metric ton reduction in CO<sub>2</sub>, a 3.3 million metric ton reduction in NMOG and a 5.5 million metric ton reduction in NOx.<sup>4</sup>

### Foreign Oil Dependence

Fuel cell vehicles using non-petroleum based fuels like methanol or hydrogen could decrease the United States' consumption of oil by 6.3 billion barrels from 2000 through 2030.<sup>5</sup> Passenger vehicles alone currently consume 85% of the oil imports, about 6 million barrels every day.<sup>6</sup> Reducing U.S. dependence on foreign oil reduces trade deficits and increases economic, political and military security.<sup>7</sup>

## **BACKGROUND**

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### **Types of Fuel Cells**

A fuel cell is an electrochemical device that works in a manner similar to a battery, but requires no recharging or regeneration. It generally consists of two electrodes (an anode and a cathode) and an electrolyte. There are several different types of fuel cells being developed, including Phosphoric Acid, Solid Oxide, Molten Carbonate, Alkaline, Direct Methanol, Regenerative, and Proton Exchange Membrane.

#### Phosphoric Acid

This type of fuel cell is the most commercially developed and can be found in hospitals, airports, nursing homes, landfills and hotels. Phosphoric Acid fuel cells generate electricity at about 40% efficiency and operate at about 400 °F.<sup>8</sup>

#### Solid Oxide

The solid oxide fuel cell (SOFC) has an all solid state structure and operates at temperatures of about 1000 °C. They are most often used in big, high power applications, or in “combined cycle” systems with gas turbines. SOFC’s can achieve efficiencies of 60% at plant capacities as low as 250 kW.<sup>9</sup>

#### Molten Carbonate

Molten Carbonate fuel cells (MCFC) yield high fuel-to-electricity efficiencies and the ability to consume coal based fuels. The operating temperatures are about 1200 °F.<sup>10</sup>

#### Alkaline

This type of fuel cell was used on board the NASA Gemini and Apollo missions and is still used by NASA on its more recent space missions. The alkaline fuel cell uses alkaline potassium hydroxide as the electrolyte, but it too expensive to be used in commercial applications.<sup>11</sup>

#### Direct Methanol

This type of fuel cell does not use hydrogen as a fuel, but methanol. The anode catalyst draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. The direct methanol fuel cell is still being developed, but efficiencies of about 40% are expected.<sup>12</sup>

#### Regenerative

This is the youngest member of the fuel cell family, and is still in the basic research phase. It is a completely closed loop form of power generation in which

water is separated into hydrogen and oxygen by a solar-powered electrolyzer. The hydrogen and oxygen are fed into the fuel cell, which generates electricity. The water that is produced by the fuel cell is then recirculated back to the electrolyzer and the process begun again.<sup>13</sup>

### Proton Exchange Membrane

The Proton Exchange Membrane fuel cell (PEM), which is currently being used in the development of fuel cell vehicles, utilizes a platinum catalyst at the anode and a cellophane-like membrane between the electrodes.<sup>14</sup> They are the most attractive type of fuel cell for automotive applications because they are generally light weight and operate at moderate temperatures (less than 200 °F) thus requiring less start-up time. As the focus of this analysis is fuel cells for transportation, all future reference to fuel cells will refer to the PEM fuel cell.

### **How Fuel Cells Work**

A fuel cell stack is a stack of bipolar electrode plates with membranes in between. A typical 50-kW stack contains about 25 bipolar plates. When a PEM fuel cell operates, hydrogen passes over the catalyst at the anode and is split into a proton and an electron. The proton then passes through, or exchanges through the membrane while the electron is utilized for electricity. Oxygen (from the air) passes over the cathode and combines with the hydrogen proton and electron to create water. When pure hydrogen is used as the fuel, the only products are heat, water and electricity.<sup>15</sup>

Hydrogen is the most abundant element on earth, but it is not easy to come by in its pure form. Therefore, many fuel cells systems incorporate a fuel reformer or fuel processor. The fuel reformer extracts the hydrogen from more common hydrocarbons like methanol, natural gas, petroleum or diesel. When using one of these fuels, the emissions from the fuel cell are still only water, heat and electricity. However, the emissions from the entire system include CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>x</sub>, carbon monoxide and particulates.<sup>16</sup>

### **History of Fuel Cells**

William Robert Grove built the first working fuel cell in 1839. The technology advanced somewhat over the next century, but fuel cells saw their first real use in the 1960s when NASA commissioned General Electric to build fuel cells for the Gemini and Apollo missions.<sup>17</sup> In the 1970s, DuPont introduced the Nafion<sup>®</sup> membrane for use in the PEM fuel cell. The Nafion<sup>®</sup> membrane is still the primary membrane used in PEM fuel cells today,<sup>18</sup> though membranes have been introduced by Dow Chemical and Ballard.

The oil shock of the 1970s prompted many companies and the federal government to investigate alternatives to fossil fuels. The replacement of internal combustion engines in light duty vehicles with fuel cells was considered as a potential means of making the United States less dependent on fossil fuels. The end of the oil embargo diminished the attention on alternate energy technologies,

though the research and development did not stop completely. Over the next 20 years, fuel cells were not widely publicized as a potential replacement for the internal combustion engine because they were far too expensive. The platinum catalyst, for example once cost about \$30,000 per fuel cell.<sup>19</sup> In the past several years, fuel cell developers like Ballard and International Fuel Cells made major advances in reducing the cost of the fuel cell. The cost of the platinum catalyst is now \$140 per fuel cell.<sup>20</sup> Just a few years ago, the fuel cell stack alone cost over \$5,000 per kilowatt. Thanks to the efforts of Ballard Power Systems, the bipolar plates now cost less than \$1 each, compared to a \$100 price tag a few years ago. The cost of the entire fuel cell system is now down to \$500 per kilowatt and is expected to be as low as \$50 per kilowatt once fuel cells are mass-produced.<sup>21</sup>

## **Fuel Cell Policy**

### The Department of Energy: Fuel Cell Program

The federal government, through the DOE serves several roles in fuel cell development. One role is as a source of funds. The government currently funds fuel cell research in the national laboratories, at several major universities, and in the private sector. The government invests approximately \$100 million per year in fuel cell research in five cabinet departments. The DOE is the key player in the development of fuel cells for transportation, spending about \$30 million per year. The government also participates in the Climate Change Fuel Cell Program. Under this program, the government supplies grants of up to \$1000/kilowatt to fuel cell purchasers, significantly decreasing the cost of the fuel cell and making them a more attractive alternate power source.<sup>22</sup>

The DOE also serves as coalition leader. In 1992, the United States Congress defined the government's role in the development of fuel cell vehicles with the Energy Policy Act (EPACT).<sup>23</sup> EPACT called for a "comprehensive program of research, development and demonstration of transportation fuel cells and related systems."<sup>24</sup>

In order to meet the goals of EPACT, the Department of Energy established the Fuel Cell Program, as a division of the Office of Advanced Automotive Technologies. The Fuel Cell Program is integrating the efforts of the automotive industry, fuel cell and fuel processor developers, national laboratories, universities and fuel suppliers in a customer-focused national program.

In cooperation with the U.S. Council for Automotive Research (USCAR), DoE formed the Fuel Cell Alliance to provide a "mechanism for obtaining industry consensus and recommendations for Program direction."<sup>25</sup> The Fuel Cell Alliance acts almost as a peer review board, allowing DoE to oversee the various fuel cell projects funded by the Fuel Cell Program. Fuel cell vehicles developed under this alliance are expected to enter the market in 2010.<sup>26</sup>

The shorter-term goals of the Fuel Cell Program are:

- By 2000 develop and validate fuel cell stack system technologies (50-kW net) that are:
  - Greater than 57% energy efficient at 25% peak power.
  - More than 100 times clear than EPA Tier 2 emissions.

- Capable of operating on hydrogen or hydrogen-rich fuel produced from gasoline, methanol, ethanol and natural gas.
- By 2004 develop and validate fuel-flexible fuel cell power system technologies that meet vehicle requirements in terms of:
  - Cost-competitive with internal combustion engines.
  - Performance, range, safety and reliability.<sup>27</sup>

#### Congress: Alternate Fuels Promotion Act

Recent legislation proposed in both the House and Senate could have major impacts on the commercialization of fuel cells. The Senate bill is S. 1003, proposed by Senators John D. Rockefeller, IV (D-WV) and Orrin Hatch (R-UT). The House version is H.R. 2252 and was proposed by Representative David Camp (R-MI). Both versions call for expanding legislation that governs tax credits given to purchasers of electric vehicles to cover alternate fuel vehicles, including fuel cell vehicles. In addition, the Alternate Fuels Promotion Act, as proposed would give tax credits to the sellers of alternate fuels.<sup>28</sup> S. 1003 was referred to the Senate Finance Committee and H.R. 2252 to the House Ways and Means Committee.

## **KEY CONFLICTS AND CONCERNS**

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Fuel cells have the potential to replace the internal combustion engine and yield higher efficiencies, lower emissions, greater fuel flexibility, and quieter and continuous operation.<sup>29</sup> These facts are not in dispute. Yet there are many conflicts associated with the development of vehicular fuel cells for the commercial market, despite the general acceptance of their potential for superiority.

### **Government Involvement**

The first, and perhaps most important issue surrounding fuel cell policy is the question about the government's involvement (particularly through the DOE) in the automotive industry's applied research to develop fuel cell vehicles for the commercial market. The most significant way that the DOE is involved is funding. Of the \$100 million the federal government invests in fuel cell research, about half is through the DOE's Fuel Cell Program. The department provides companies, including the major automobile manufacturers, with funds in order to develop fuel cells to the point where they can be used in cars and marketed for a profit. Many groups and individuals see this as a form of "corporate welfare." "Corporate welfare" can be defined as any government spending program that "provides unique benefits or advantages to specific companies or industries. It includes subsidies, grants, cut-rate insurance, low-interest loans and loan guarantees, trade restrictions, and other special privileges that confer benefits on targeted firms or industries."<sup>30</sup> For example, Senator John McCain (R-AZ) lists DOE funding for research into energy efficiency and renewable energies as a source of "pork" in the Energy and Water Appropriations for Fiscal Year 1999. Other groups like the Competitive Enterprise Institute, the CATO Institute and the Heritage Foundation also see the DOE's involvement as unnecessary and outside the national interest.<sup>31</sup>

Those who support the DOE's fuel cell program are, naturally, those who stand to benefit directly: the automobile manufacturers, fuel cell and fuel processor suppliers, and the universities and laboratories where some of the research is being done. In addition, there are groups like the Fuel Cell Commercialization Group, the National Hydrogen Association, and Fuel Cells 2000 who would like to see the DOE even more heavily involved in making fuel cell vehicles a cost-competitive product. They claim that funding the fuel cell program within the DOE is in the government's and in the nation's best interest.<sup>32</sup> In addition, those who support DoE's involvement like to point out that even though the "Big Three" automobile manufacturers (General Motors, Ford, DaimlerChrysler) are the ones most often in the news for fuel cell research, a majority of DOE's funding goes to small businesses like Arthur D. Little, Inc. and Plug Power.<sup>33</sup>

### **Expenditures and Benefits**

A conflict related to the debate over corporate welfare involves short-term expenditures versus long term economic benefits. Currently, fuel cells are

expensive, and no money is being made or will be made in the next five years by investing in fuel cell research and development. That is why automobile manufacturers claim that they need the DOE's funding to act as a catalyst for their own involvement.<sup>34</sup> This is also a reason that many criticize DOE's involvement as corporate welfare. However, the DOE has done studies that show that having fuel cells vehicles compete with internal combustion engine vehicles will result in benefits "to the entire domestic economy which include savings to consumers in the form of reduced expenditures for fuel." The money saved just by the reduction of consumption of motor fuel is estimated to total \$64 billion by 2030,<sup>35</sup> The fuel cell vehicle industry would also be a source of tens of thousands of jobs.<sup>36</sup>

## **Fuel Type**

Another key conflict is related to the type of fuel used in fuel cell vehicles. This is an issue of concern to policy makers because the type of fuel used in fuel cell vehicles has a direct impact on the lives of average citizens. There are environmental concerns with each type of fuel, as well as issues of national security, and energy security, not to mention the economic impact.

Currently, hydrogen and methanol fueled fuel cell vehicles are technically feasible and nearly ready for commercialization. However, hydrogen and methanol are not fuels readily available to the average consumer. Gasoline fuel cells would solve the fuel availability problem, but gasoline reformer technology has not yet progressed to the point of commercialization. The gasoline reformer is the limiting step in commercializing gasoline fuel cell vehicles. Using gasoline also greatly increases the emissions from the vehicle (though they have still been tested below the average emissions from internal combustion engines<sup>37</sup>). Another drawback to using gasoline is that it is a non-renewable energy source, and the U.S.'s dependence on a fossil fuel comprises national security and energy security. When the sources of fossil fuels are no longer available, gasoline powered fuel cell vehicles will face the same problems as internal combustion engine vehicles of today.

The current plan within the Fuel Cell Program is to develop fuel cells that are fuel flexible: i.e., they are capable of operating on a variety of fuels. The fuel cell itself operates on hydrogen, so the only changes that need to be made when converting to a different fuel are in the fuel processor, which abstracts the hydrogen from the fuel. This will make it easier to eventually convert to fuel cell vehicles that operate on pure hydrogen. First, fuel cells that operate on gasoline will enter the market. Eventually, the market will convert to natural gas or methanol fuel cells, and finally make the jump to hydrogen fuel.<sup>38</sup>

The key players within this conflict are the various fuel industries (hydrogen, methanol and petroleum) as well as some environmental groups and consumers. Some environmental groups, like the Rocky Mountain Institute, would like to see the jump directly to hydrogen,<sup>39</sup> with the DOE overseeing and providing funding for the development of a hydrogen distribution system.<sup>40</sup> Understandably, groups like the American Petroleum Institute and the American Methanol Institute would rather pursue other fuel choices. The key players within this conflict are the various fuel industries (hydrogen, methanol and petroleum)

as well as some environmental groups and consumers. Consumers are an important player because if the DOE does not support a particular fuel, it will be up to the market and the consumer to decide.

Regardless of the type of fuel, the source of that fuel is another area of concern. If the DOE supports a particular fuel, it must consider not only the supporters and opponents of such a fuel but the overall impact of converting to that fuel, both economically and environmentally. Methanol and hydrogen-fueled vehicles are cleaner, as far as CO<sub>2</sub> emissions are concerned, than gasoline-fueled vehicles. The process by which these fuels are produced, however, are not devoid of by-products, a significant number of which are harmful. The overall fuel production, distribution and utilization system must be considered, not just the how the fuel is used in the vehicle.

## **POLICY ALTERNATIVES**

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### **A. Policy alternatives to ensure commercialization of fuel cell vehicles.**

#### A-1. No involvement from the federal government; private industry as sole contributor

This alternative calls for the DOE to cease all funding of fuel cell development projects in the national laboratories, universities and specifically within private corporations. The development of fuel cell vehicles for the commercial market would be funded completely from the private sector.

#### *Effectiveness*

It is unclear what the specific effect this type of action would have on the fuel cell vehicle commercialization timeframe. If the automotive industry and fuel cell producing industry increase their own funding of the research and development projects to compensate for the loss of federal funding, then fuel cell vehicle development can proceed as planned. However, if funding is not increased then the expected introduction of fuel cell vehicles into the commercial market will be pushed back.

#### *Efficiency*

This action, if taken, will cost the federal government very little, if anything, as it involves the ceasing of federal funding. An effect however beyond economic will be the loss of government control over the fuel cell vehicle development projects. Currently, the DOE's Fuel Cell Program oversees the various federally funded projects and provides the means for a peer-review process. If these projects cease to receive federal funding, they will no longer have an incentive to agree to the oversight. In addition, the various companies will no longer have the incentive to work together in the Fuel Cell Alliance and fuel cell development could be pushed back even further, as each company will be working independently. Also, if the federal government is not involved in the development of fuel cell vehicles, then when they do become economically viable the market will be the determiner of the dominant technology. This could have good or bad consequences. There is no guarantee that the market will support the technically superior fuel cell vehicle. History reveals several cases of the market supporting a technologically inferior product.\*

#### *Equity*

By rescinding all funding to the development of fuel cell vehicles, technically the federal government would be treating all fuel cell vehicle developers equally. In actuality, this action would affect each company who invests time and money in fuel cell development differently. The major

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\* VHS vs. BetaMAX in the VCR market, DOS vs. Apple in the computer operating system markets

automobile companies (DaimlerChrysler, Ford, General Motors) accumulate huge profits and could replace the lost federal funds with their own funds with relative ease. The smaller companies (Plug Power, Energy Partners) however, rely more heavily on federal funds and would be at a huge disadvantage if forced to fund their projects alone. Should this action be taken, these smaller companies may not be able to compete with the larger, richer companies for market share.

Taking funding away from the Fuel Cell Program could have impacts on the average citizen. For one, it means the loss of jobs within the Fuel Cell Program and the abandonment of various projects across the country in national laboratories and universities. Additionally, if fuel cell commercialization is pushed back, they may not be available when fossil fuels really do run out, or when CO<sub>2</sub> emissions are of critical concern. Stopping the funding now could have extreme consequences in the near future.

### *Implementability*

This policy would be easy to implement as it would require only that Congress *not* appropriate funds for the Fuel Cell Program.

### A-2. Expansion of the Climate Change Fuel Cell Program

When fuel cell vehicles are ready for the commercial market, they will still be considerably more expensive than the internal combustion engine vehicles already on the market. Supporters of fuel cells should encourage the the federal government, by means of the DOE and the Fuel Cell Program to provide rebates to buyers of fuel cell vehicles in order to make them cost competitive with the internal combustion engine.

### *Effectiveness*

This program would be effective in making fuel cells a viable alternative to the internal combustion engine. Considering that the major disadvantage fuel cell vehicles are facing is still economic, this program could also speed up the introduction of fuel cell vehicles in the commercial market. This main problem with this program is that there is no way of knowing how long it will be required. As more fuel cell vehicles are produced, the cost of manufacturing them will decrease. The buy-down program will be required in some form as long as fuel cell vehicles are more expensive than their internal combustion counter parts.

### *Efficiency*

This alternative is not very efficient since it requires an unknown amount of funding over an unknown length of time.

### *Equity*

This alternative would treat all fuel cell producers and automobile manufacturers equally, as it would provide funds to the consumers, not to the

companies themselves. The costs of this alternative are related to the funding necessary for its implementation. By increasing funding to this program, it may be necessary to decrease funds in other areas that affect the average citizen.

### *Flexibility*

This program is also highly flexible, as it incorporates the changing cost of fuel cell vehicles and internal combustion vehicles. It provides only the amount of money necessary to make the fuel cell vehicle as attractive economically as the internal combustion vehicle. It is also flexible in that it does not necessarily require the complete elimination of the internal combustion engine. This alternative will allow the consumer to choose based on the technological merits of each system, rather than economics.

### *Implementability*

This program could be implemented easily as it already has a counterpart in the stationary fuel cell market.<sup>41</sup> It would be only a matter of expanding that program to incorporate fuel cell vehicles.

### A-3. Tax-credits through the Alternate Fuels Promotion Act<sup>†</sup>

The promoters of fuel cells should support the Alternate Fuels Promotion Act (S. 1003, H.R. 2252) specifically section 101, which extends the electric vehicle tax credit.

### *Effectiveness*

This type of legislation will increase the tax credit given to purchasers of electric vehicles and alternate energy technology vehicles. Currently, the credit is 10% of the purchase price, up to \$4000. The new legislation will allow current policy to remain in place until 2010 and provide an additional \$5000 credit to an electric vehicle that meets extended range requirements.<sup>42</sup> This kind of incentive could be enough to encourage buyers to purchase fuel cell vehicles. However, it is unlikely that it will be enough to combat the large price differential between fuel cell vehicles and internal combustion vehicles in the introductory stages.

### *Efficiency*

This alternative will cost the federal government less than the buy-down program, but will have less of an effect on the fuel cell vehicle market. The incentive is not large enough to make fuel cell vehicles competitive with internal combustion engines for most buyers.

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<sup>†</sup> Introduced in the Senate by Senators John D. Rockefeller, IV and Orrin Hatch. Introduced in the House by Representative David Camp

### *Equity*

This alternative treats all fuel cell vehicle manufacturers equally, just as the previous alternative. However, it does not treat all vehicle manufacturers equally as it provides an incentive to buyers of alternate fuel vehicles only.

### *Flexibility*

This program is fairly flexible because it works on percentages. It would provide credits based on the price of the vehicle. It does have an upper limit of \$4000 however, so it cannot be considered as completely flexible.

### *Implementability*

This program would be very easy to implement, as there is a similar program already in place. The passage of the Alternate Fuels Promotion Act is all that is required to begin the program.

### A-4. Government purchase of fuel cell vehicles fleets

Under the Energy Policy Act of 1992, 75% of federally acquired fleet vehicles are required to be alternate fuel vehicles in 1999 and thereafter.<sup>43</sup> The federal government should purchase fuel cell vehicles, when they are available, that operate on methanol or hydrogen.

### *Effectiveness*

The alternative would be effective in increasing the likelihood that fuel cell vehicles could compete with internal combustion engine vehicles. By agreeing to purchase large quantities of fuel cell vehicles, the federal government solves the initial economic problem associated with commercialization of fuel cell vehicles. This alternative would allow automobile manufacturers to sell competitively priced fuel cell vehicles to the general public, after the government fleet purchases.

### *Efficiency*

This alternative is efficient in that it decreases the cost of fuel cell vehicles very quickly and allows them to enter the consumer market faster. However, it requires a great deal of funding as the number of vehicles purchased by the federal government would have to be large, and each vehicle would be very expensive, compared to the internal combustion engine.

### *Equity*

This program has the potential to be favorable to some and unfavorable to many. If the federal government purchases fuel cell vehicles from only one manufacturer, that manufacturer stands to receive almost all of the benefits of this alternative while other manufacturers receive none. In addition, this alternative does not consider the other alternate-fuel vehicle technologies that may be available.

### *Flexibility*

This alternative has the potential to be very flexible. Of the 75% of fleet vehicles required to be alternate fuel vehicles, the federal government could purchase all fuel cell vehicles or only a small percentage. The greatest effect on fuel cell vehicle commercialization, however, would come from the greatest percentage.

### *Implementability*

This alternative is very hard to implement, as evidenced by the fact that the government has yet to meet the requirements for the purchase of alternate fuel vehicles. Once fuel cell vehicles are available, however, it may be easier for the federal government to meet the requirements of the Energy Policy Act.

## **B. Alternatives regarding the type of fuel to be used in fuel cell vehicles**

### B-1. Hydrogen

#### *Fuel Efficiency and System Size*

Fuel cell vehicles operating on hydrogen are highly efficient. The DOE, partnered with Ford Motor Company developed a hydrogen fuel cell system with a fuel economy two to three times the fuel economy of a typical internal combustion engine.<sup>44</sup> The system developed weighs 300 pounds and has a volume of eight cubic feet.

#### *Environmental*

The fuel cell vehicle operating on pure hydrogen emits only water vapor, heat and electricity. The process by which hydrogen is produced, however, is not without harmful emissions (see below).

#### *Fuel Reformers and Start-up*

Since hydrogen is supplied to the fuel cell vehicle directly, there is no need for a fuel reformer. This is a major advantage, as one of the largest problems with fuel reformers is their slow start-up. Fuel reformers require certain temperatures and pressures that take time to achieve. The lack of a fuel reformer makes the hydrogen fuel cell vehicle quick and easy to start up.

#### *Fuel Storage: Range and Safety*

Since the hydrogen is not reformed on the vehicle, it must be stored on board. There are several methods for storing hydrogen: gaseous, liquid, slush and metal hydride. Because of its low density, it is difficult to store enough gaseous hydrogen on a vehicle to go more than 100 miles.<sup>45</sup> This is a major disadvantage, but according to DaimlerChrysler, the 75-hp NECar 4, which is a hydrogen fuel cell vehicle based on a compact Mercedes Benz model, can travel nearly 280 miles before refueling. The hydrogen on the NECar 4 is stored cryogenically (liquid).

If liquid hydrogen is subjected to a vacuum it will evaporate with a subsequent cooling of the liquid mass to cause the temperature to fall below the freezing point of -259.2 C and solid hydrogen will be produced. The resulting mixture of liquid and solid hydrogen is called "slush".<sup>46</sup> This is an even more efficient way of storing hydrogen, though it is an expensive process.

Metal hydride storage involves the storage of hydrogen in the interatomic spaces of granular metals. This is an efficient and safe way of storing hydrogen, but the metals are often expensive and heavy.<sup>47</sup>

Studies have been done by Ford Motor Company that indicate storing hydrogen on board a vehicle is actually safer than storing gasoline for two major reasons. One, the tanks used to store hydrogen (carbon fiber wrapped composite storage tanks) are capable of withstanding greater impacts than the vehicle itself.

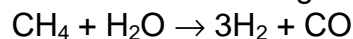
Two, hydrogen disperses much faster than gasoline because it is lighter and more buoyant. In the event of a crash and a leak in the hydrogen storage tank, the hydrogen would dissipate into the atmosphere rather than collecting in a pool near the vehicle as gasoline would.<sup>48</sup>

### *Cost*

Hydrogen is expensive compared to gasoline. The average price of gasoline is 80 cents per gallon,<sup>49</sup> while the average cost of hydrogen is about \$2.40 per gasoline-equivalent gallon.<sup>50</sup> The Alternate Fuels Promotion Act, if passed, will provide a \$0.50 per gasoline-equivalent gallon tax credit to sellers of clean-burning fuels like hydrogen. This would reduce the cost of hydrogen, perhaps enough to make it comparable with gasoline.

### *Infrastructure and Availability*

There is currently very little infrastructure for the distribution of hydrogen fuel. Hydrogen is an extremely abundant element, but it is not readily available to the average consumer. There are several ways to produce hydrogen, all of which have environmental and economic disadvantages. The major process is chemical, an example of which is steam reforming:



One disadvantage of this process is the production of carbon monoxide (CO). CO is a colorless, odorless, poisonous gas. Another major disadvantage is the cost of creating a hydrogen infrastructure. A hydrogen fueling station was recently completed in Munich, Germany and cost the German government approximately US \$18.7 million.<sup>51</sup>

## B-2. Methanol

### *Efficiency and System Size*

Methanol fuel cell vehicles will achieve a fuel efficiency of at least 38%, compared to the internal combustion engine average fuel efficiency of 19%.<sup>52</sup>

### *Environmental*

DaimlerChrysler's methanol fuel cell vehicle, NECar 3, demonstrated no NO<sub>x</sub> emissions and no carbon monoxide emissions. Hydrocarbon emissions were 0.0005 mg per mile. Fuel cell CO<sub>2</sub> emissions will be less than half the emissions from an internal combustion engine operating on gasoline.<sup>53</sup>

### *Fuel Reformer and Start-up*

The methanol fuel reformers use a process known as steam reforming to split the methanol molecule and yield hydrogen for the fuel cell. This process requires an operating temperature of about 400 °C. This is a relatively low temperature, but start-up still requires several minutes. In addition, the reformer

adds to the overall size and weight of the system, putting restrictions on the size of the car itself.

#### *Fuel Storage: Range and Safety*

Toyota's prototype methanol fuel cell vehicle, based on the RAV4 demonstrates a range of 310 miles. Methanol is also considered to be safer than gasoline. 180,000 vehicle fires occur each year where gasoline is the first material to ignite. This could be reduced to 18,000 if methanol were used as a fuel instead.<sup>54</sup>

#### *Cost*

The average cost of methanol from 1978 to 1998 is about \$0.48 per gallon, compared to the average pre-tax wholesale price of gasoline over the same period of \$0.66 per gallon. However, methanol has less energy per gallon than gasoline, so the cost of methanol is about 47% higher than gasoline per unit of energy. Since a methanol fuel cell is more efficient than the internal combustion engine running on gasoline, the cost of methanol fuel per mile is about 27% lower than the average cost of gasoline per mile.<sup>55</sup>

#### *Infrastructure and Availability*

California already has a network of 50 public methanol fueling stations and an additional 50 operated by private or public fleets. The cost of converting a gasoline station to methanol is estimated at \$50,000 per station. Using this number, 10% of the gasoline stations in the United States could be converted for \$1 billion. If these stations are targeting in the three states where zero emission vehicles will be required to be made available in 2003 (California, New York, Massachusetts) then this number would be reduced to \$500 million. The American Methanol Institute and the methanol industry are willing contributors to the development of a methanol distribution infrastructure, and they estimate that there is enough time to develop the infrastructure before methanol fuel cell vehicles hit the market.<sup>56</sup>

### B-3. Gasoline

#### *Efficiency and System Size*

The DOE recently completed a cost-shared project with Arthur D. Little, Inc. and Plug Power to create a fuel flexible fuel cell system, capable a running on gasoline, methanol, ethanol or hydrogen.<sup>57</sup> The resulting system, when using gasoline, demonstrated the potential to double fuel economy compared to the internal combustion engine.<sup>58</sup>

### *Environmental*

The emissions from the DOE's gasoline-powered fuel cell are 50% less the emissions from a gasoline-powered internal combustion engine. However, they are not as low as the emissions from either the methanol fuel cell vehicle or the hydrogen fuel cell vehicle.<sup>59</sup>

### *Fuel Reformer and Start-up*

The gasoline reformer requires a temperature of about 700°C, which takes a considerable amount of time to achieve (about 10 minutes).<sup>60</sup>

### *Fuel Storage: Range and Safety*

The fuel storage necessary for a fuel cell vehicle using gasoline is the same system used for the internal combustion engine. Because the fuel cell is more efficient than the internal combustion engine, however, the range of the fuel cell vehicle is greater. As far as safety is concerned, both methanol and hydrogen have been deemed safer than gasoline as a fuel, but research is still being done to increase the safety of gasoline storage.

### *Cost*

The average cost of gasoline per gallon is obviously the same whether the vehicle uses a fuel cell or an internal combustion engine. Since fuel cells are more efficient, the average cost of gasoline per mile will be considerably lower with the fuel cell than with the internal combustion engine.

### *Infrastructure and Availability*

The use of gasoline as a fuel in fuel cell vehicles solves the problem of the fuel availability. However, fossil fuels are not a renewable energy source and at some point they will run out. The American Petroleum Institute suggests that this will not become a reality for a very long time.<sup>61</sup>

## FUEL ALTERNATIVE COMPARISON

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	<i>Hydrogen</i> <sup>62</sup>	<i>Methanol</i> <sup>63</sup>	<i>Gasoline</i> <sup>64</sup>
<i>Fuel Economy (Compared to internal combustion engine)</i>	2-3 times better	2 times better	2 times better
<i>Environmental (Vehicular CO<sub>2</sub> Emissions compared to internal combustion engine)</i>	0	<1/2	1/2
<i>Reformer/Start-up (temperature required)</i>	N/A	400°C	700°C
<i>Range (miles before refueling)</i>	100	310	Data not yet available
<i>Cost (compared to average cost of gasoline on an energy basis)</i>	200-300% higher	47% higher	N/A
<i>Infrastructure/ Availability (cost per station)</i>	\$18 million	\$50,000 (to convert from gasoline)	N/A

## RECOMMENDATIONS

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The recommendations that extend from this analysis are related to some of the questions posed at the start. Namely, should the government be involved in the development of fuel cell vehicles for the commercial market, and if yes, how? In addition, what type of fuel should the government support for use in fuel cell vehicles (hydrogen, methanol or gasoline)?

### Encourage Commercialization

The government should be involved in fuel cell vehicle commercialization in several ways. First, the Climate Change Fuel Cell Program should be expanded to cover vehicular fuel cells. I recommend this program above all other alternatives because it has the potential to be very effective, it is relatively easy to implement and it solves the short-term problem without creating long-term effects.

The expansion of the Climate Change Fuel Cell Program is an effective alternative in that it will help compensate for the initially high cost of fuel cell vehicles by providing funds to the purchasers, thus providing an incentive for buying the better technology. This program will be easy to implement, as well since it is already in place for stationary fuel cells. In addition, this program can be designed in such a way that it will eventually make it self obsolete. By providing rebates based on the price differential between fuel cell vehicles and internal combustion engine vehicles, the Climate Change Fuel Cell Program for vehicles would no longer be needed when fuel cell vehicles are economically competitive with internal combustion engine vehicles.

In addition to expanding the Climate Change Fuel Cell Program, Congress should pass a bill that extends the electric vehicle tax credit. This has already been proposed in section 101 of the Alternate Fuels Promotion Act. If the Alternate Fuels Promotion Act fails to be enacted into public law, then the tax-credit extension should be incorporated into it's own bill, or another bill, and passed separately.

### Type of Fuel

I recommend the use of gasoline in fuel cell vehicles *initially*. The public is too accustomed to gasoline powered vehicles, and fuel cell vehicles will be even more difficult to commercialize if they run on a fuel that is not widely distributed or familiar to the consumer.

During the first years of commercialization, I recommend that the DOE, with help from the methanol industry begin the conversion of gasoline fueling stations to methanol fueling stations. Several developers of fuel cell vehicles have singled out methanol as the most promising fuel,<sup>65</sup> and there are environmental benefits to converting away from fossil fuels. The benefits are in addition to the benefits to the national security and energy security of the U.S. When methanol is more widely available, fuel cell vehicles operating on methanol will have a much better chance of being competitive in the market.

Finally, the Department of Energy should continue its hydrogen research program and begin researching the impact of converting to a hydrogen infrastructure, economically and environmentally.

## ENDNOTES

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- <sup>30</sup> Stansel, Dean and Stephen Moore. “Federal Aid to Dependent Corporations: Clinton and Congress Fail to Eliminate Business Subsidies.” A report for the CATO Institute, 1.
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- <sup>32</sup> Interview with Bernadette Geyer, Executive Director, Fuel Cells 2000. June 18, 1999
- <sup>33</sup> Ibid
- <sup>34</sup> Interview with Karen I. Miller, coordinator for National Hydrogen Association and Robert L. Mauro, Executive Vice President of National Hydrogen Association. June 11, 1999
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