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Alternative Fuel Vehicles

Which Shall Win the Race to Commercialization?

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I. Introduction

Alternative fuel vehicles (AFVs) are defined as those vehicles that run on fuel other than "traditional" petroleum fuels (petrol or diesel). The term also refers to vehicles that supplement traditional fuels with other sources of power, as in hybrid electric vehicles.

Historically, alternative fuel vehicles have been around for decades. Early developments were spurred by profit-seeking entrepreneurs—as in the case of the Stanley Motor Carriage Company's steam engine vehicles from 1902 to 1924—as well as by the demand for alternatives due to cost or limited access to petroleum. For instance, during World War II when petroleum was scarce, new innovations led to the use of wood gas to power cars with ordinary internal combustion engines. The range of possible fuels is extensive; from the 1930s to the 1950s, even charcoal was used to power cars in China (Wikipedia).

Today, a number of factors including environmental concerns, increasing oil demand, and rising oil production costs have triggered extensive research and development efforts for cleaner alternative fuels and advanced propulsion technologies. In recent years these efforts have finally begun to pay off. In fact, there are many AFVs already being marketed and sold to consumers around the world.

As the world moves further into the twenty-first century, alternative fuel vehicles are primed to become the dominant mode of personal transportation in the United States. The purpose of this project is to forecast which type (or types) of AFVs will have the most potential for commercial success in the U.S. over the next several decades. The development of these technologies will depend on a range of factors which must all be considered in a useful forecast. In order to accomplish this task, our research focused on answering the following questions:

- Economic – What will be the consumer costs, the effects of the technology on related markets, and the technology’s impact on the economy?
- Environmental – To what extent will the technology impact the environment through the reduction of pollution and waste?
- Technological – What will be the levels of vehicle safety, performance, and reliability? What will be the infrastructural requirements to support the technology and how expensive will they be? Furthermore, how complex or convenient will the technology be from a consumer standpoint?
- Government Support – How much government support will the alternative fuel technology receive in the form of subsidies, tariffs, tax incentives, etc.?

II. Research Methodology

Our research consisted of four different forecasting methods to home in on the technologies with the most potential for future mainstream adoption. We employed the following forecasting methods:

- Scanning
- General Survey
- Expert Interviews
- Relevance Tables

These methods were employed sequentially, and findings from each stage of the research were used as inputs for the following stage. The following sections discuss our research methods and the results of each stage in detail.

A. Scanning

We began our research with scanning. We perused news articles and websites, spoke with friends and relatives, and attended relevant conferences to identify the current leading automotive fuel technologies. Early in our research, we identified the term

“alternative fuel vehicle” as the one used by most government and industry organizations when referring to these technologies. Of the various technologies available, we found the following six to have the highest levels of R&D and commercialization:

- Biofuel – Biofuel vehicles have an internal combustion engine that is adapted to run on a type of fuel derived from biomass. The two leading types of biofuel are bio alcohol (an alcohol—most commonly ethanol—produced mainly from sugar and starch crops) and biodiesel (diesel made from vegetable oils, animal fats or recycled greases).
- Flex-fuel – Flex-fuel vehicles utilize a multi-fuel internal combustion engine that can run on different fuels—usually gasoline and biofuel—that are mixed into the same tank and burned as a blend in the combustion chamber. Flex fuel vehicles normally run on a mixture of either ethanol or methanol and gasoline
- Battery Electric – Battery electric vehicles (BEVs) are propelled by an electric motor which is powered by a large on-board battery unit. Current battery units have a limited capacity and must be frequently recharged at specialized charging stations. Charging stations can usually be installed in homes on a standard 120V or 240V setup. Electric vehicles do not require a tail pipe for exhaust and have negligible emissions.
- Hybrid Electric – Hybrid Electric Vehicles (HEVs) combine an internal combustion engine with an electric motor and a larger-than-normal car battery. Many current models use the internal combustion engine and regenerative braking technology to recharge the battery, but some newer models also have plug-in capabilities similar to pure BEVs. HEVs have a longer range

than pure BEVs and fewer emissions than a gasoline vehicle, but still use fossil fuels as an energy source.

- Hydrogen – Hydrogen vehicles use hydrogen gas as their primary fuel source, which produces no harmful emissions when burned. Hydrogen fuel can be produced domestically from methane and other fossil fuels, but also from alternative sources such as wind, solar, and nuclear power. Currently there are two implementations of a hydrogen vehicle: fuel cell vehicles, where hydrogen reacts with oxygen in a fuel cell to power an electric motor; and internal combustion engine vehicles, where a traditional combustion engine directly burns hydrogen fuel.
- Natural Gas – Natural gas vehicles use compressed natural gas (CNG) or liquefied natural gas (LNG) as their primary fuel source. Natural gas is a clean alternative to gasoline and is even cleaner than many currently available alternative fuel vehicles. Natural gas vehicles are powered by an internal combustion engine similar to gasoline engines, and existing gasoline engines can be converted to use compressed natural gas. The natural gas available in the United States is primarily produced in North America.

Table 1 provides a quick summary of each fuel type’s pros and cons.

Table 1: Fuel Type pros, cons, and price in relation to oil

Fuel Type	Pros	Cons
Biofuel	<ul style="list-style-type: none"> - Renewable energy source (reuse of materials) - Can be used in pure form or as additive - Fewer emissions than gasoline 	<ul style="list-style-type: none"> - Contributes to soil erosion, deforestation, increased water consumption - Less Fuel Efficient than gasoline - Strain on Food Supply Chain
Flex-fuel	<ul style="list-style-type: none"> - Environmentally Friendly - Tax Benefits - Fuel mixture as alternative to gas 	<ul style="list-style-type: none"> - Ethanol can cause corrosion and damage to the engine - Less fuel efficient than gasoline
Battery Electric	<ul style="list-style-type: none"> - Negligible emissions - Does not need gasoline - Easier upkeep 	<ul style="list-style-type: none"> - Batteries are expensive - Limited range - Long recharging times
Hybrid	<ul style="list-style-type: none"> - High fuel efficiency 	<ul style="list-style-type: none"> - High production cost



Electric	- Fewer emissions than pure gasoline	- Still needs gasoline
Hydrogen	- Environmentally Friendly - High Availability of hydrogen - Energy efficient - No harmful emissions, only water and small amount of heat	- High production cost - High maintenance cost - High flammability of hydrogen
Natural Gas	- High availability of natural gas deposits - Low cost of compressed natural gas - Low emissions - Low cost of maintenance	- High cost of vehicle production - Large fuel tanks needed - Low fuel efficiency - High flammability of natural gas

B. General Survey

From our scanning activities, we gathered an understanding of the leading alternative fuel vehicle technologies, their potential costs and benefits, and the challenges to their commercialization. Our next step was to attach social value to these technologies with a general survey. The objectives of our survey were threefold:

1. To understand general interest and public awareness of AFVs.
2. To gather opinions on how various factors influence consumer decisions for vehicles.
3. To gather opinions on the societal impacts of AFVs in general.

The general survey consisted of 15 questions that addressed a host of vehicle-related as well as exogenous factors that may have an impact on personal opinions toward AFVs. The survey also included diagnostic questions so we could attain a better understanding of the demographics of our respondents. The following section discusses the results of our general survey and draws some basic inferences based on the data.

Survey Results

General demographics

A total of 100 respondents completed the general survey. Of the respondents, 54 percent were male and 46 percent were female. The majority of respondents—67 percent—were



age 34 or under. Most respondents were well educated, with 93 percent of the respondents claiming at least some level of college education. Additionally, 58 percent of respondents reported an income of at least \$50,000/year, and 20 percent reported an income of at least \$100,000/year.

Findings

We first asked respondents to identify the type of vehicle they use as their primary mode of transportation. Figure 1 shows the responses for each vehicle type as a percent of the total responses.

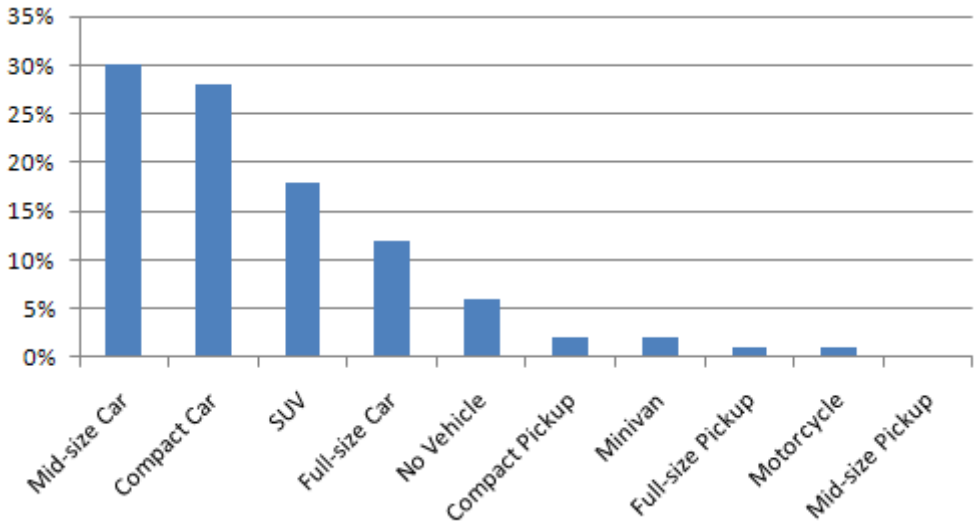


Figure 1: Vehicle type owned by respondents as share of total responses

58 percent of respondents indicated they own either a mid-size or compact car. Additionally, 18 percent of respondents own SUVs. In a supplementary text box, respondents added comments about their consumer choices. The responses seemed to indicate a dichotomy between a preference for fuel efficiency and low costs on one hand, and space, luxury, and comfort on the other.

Figure 2 shows the results for all respondents rating their familiarity with the surveyed AFV types.



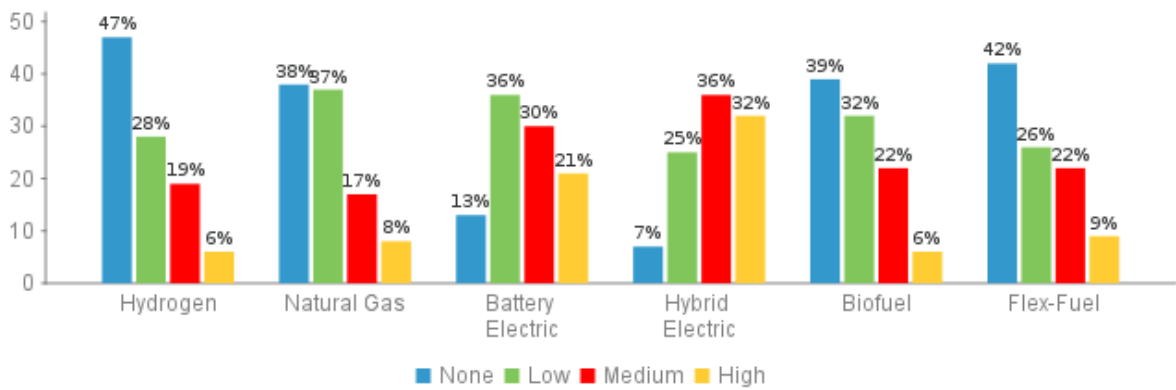


Figure 2: General familiarity of surveyed AFV types among all respondents.

Based on the responses, the public seems most aware of Hybrid Electric and Battery Electric vehicles. 68 percent of respondents reported either medium or high familiarity with Hybrid Electric vehicles, and 51 percent reported medium or high familiarity with Battery Electric vehicles.

Conversely, nearly half the respondents reported having no familiarity with Hydrogen vehicles, and only 6 percent reported high familiarity with this AFV type. Natural gas, biofuel, and flex-fuel vehicles also had relatively low levels of familiarity among all respondents.

Figure 3 shows the responses to the same question broken into two age groups: 34 and under, and 35 and older.



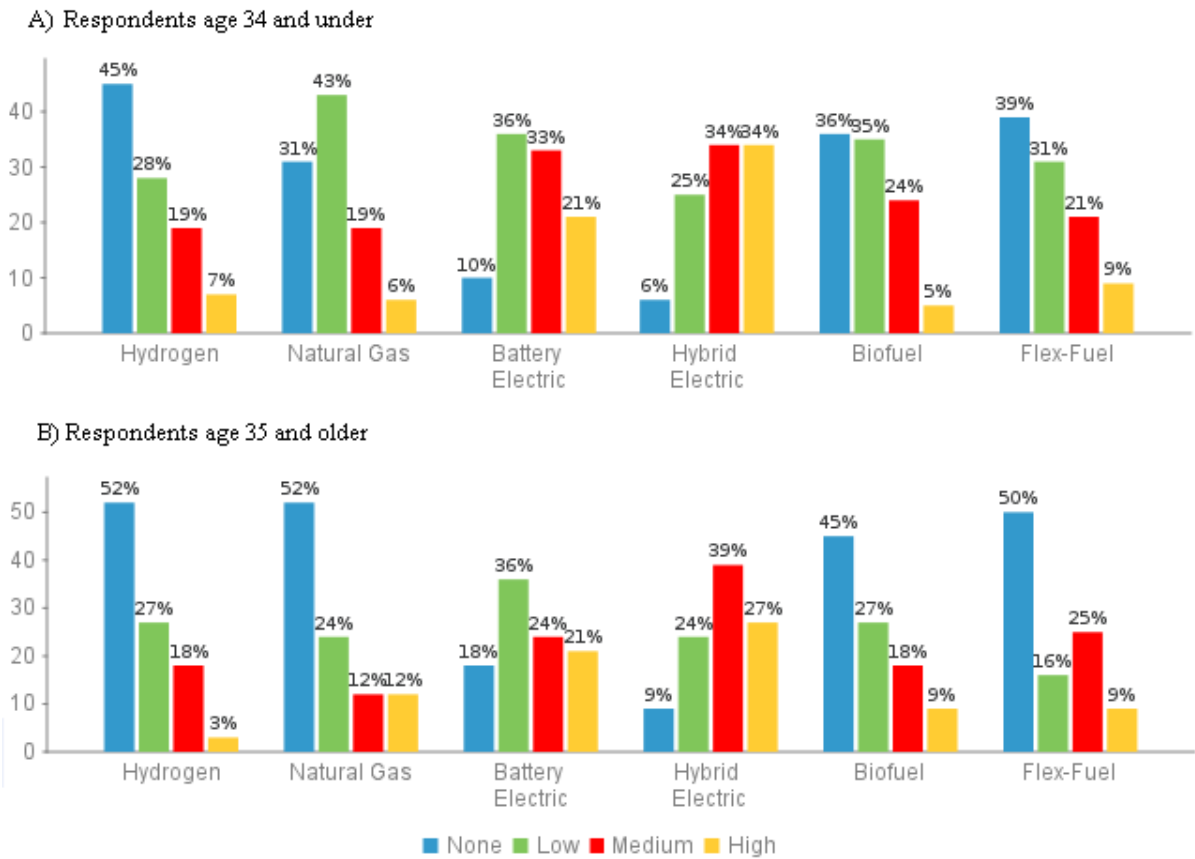


Figure 3: General familiarity of surveyed AFV types among respondents broken down by age

The results show that younger respondents report higher levels of familiarity with all AFV types than do older respondents. This trend is not surprising as younger generations tend to be more familiar with new technologies in general.

Respondents were also asked about their awareness of several AFV models currently on the market or near commercialization. Figure 4 shows the results to this question.



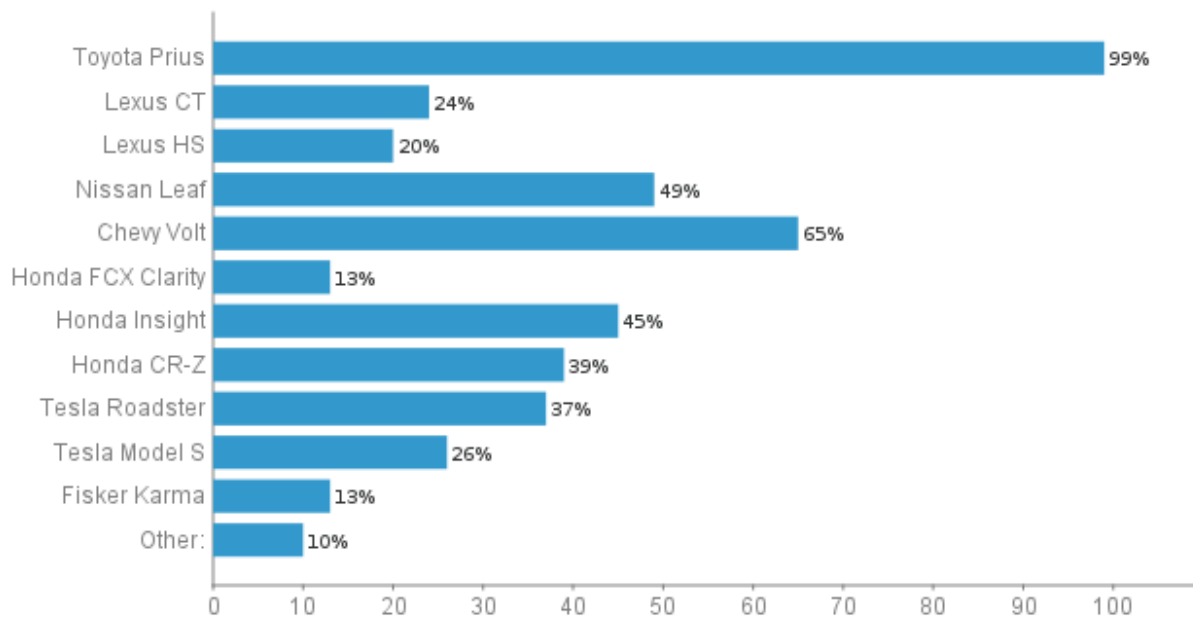


Figure 4: Respondent awareness of various AFV models

Unsurprisingly, the Toyota Prius had near universal recognition among all the respondents. However, other vehicle models did not fare as well, despite vast marketing campaigns and widespread publicity in mainstream publications. The Chevy Volt, for instance, has garnered accolades from many respected automobile publications, including the 2011 “Motor Trend Car of the Year Award” and Car and Driver Magazine’s “10 Best Cars” list for 2011. Yet, only 65 percent of respondents reported having heard of the Chevy Volt.

In agreement with the observations in Figure 3, younger viewers were more aware of the most popular AFV models. Even among respondents under age 35, however, only 71 percent were aware of the Chevy Volt. Only 53 percent of respondents over age 35 were aware of this vehicle model.

Figure 5 shows the amount of total respondents who reported owning an AFV.

Only 4 percent of respondents reported owning an AFV. The percentage of respondents who own AFVs did not vary significantly by age or reported level of income. If the



responses are broken down into two categories of respondents under age 35 and respondents over age 35, the ownership of AFVs remains around the 3-4 percent level. The same result is observed when responses are categorized by income levels below \$50,000/year and income levels above \$50,000/year.

Figure 6 shows the percentage of respondents who claimed a significant interest in purchasing an AFV at some point in their lives.

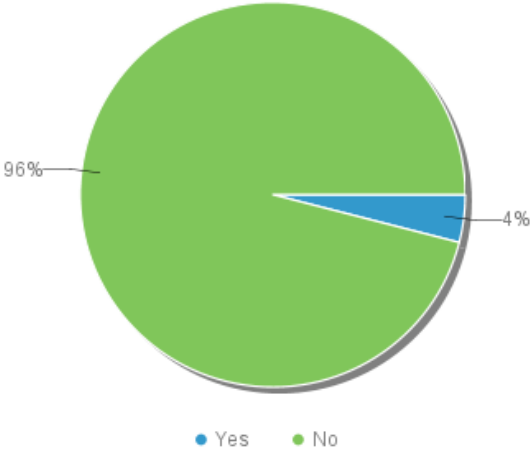


Figure 5: Respondent ownership of an AFV

The results show that over a third of respondents reported having seriously considered purchasing an AFV at some point. This is an interesting result when compared to the actual ownership of AFVs, which is much lower.

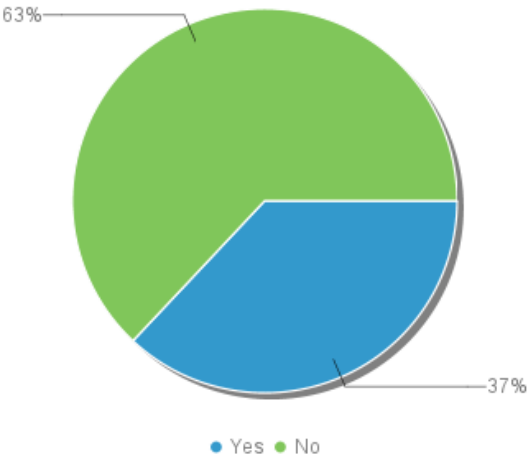


Figure 6: Respondents claiming they have seriously considered purchasing an AFV at some point.

Another interesting finding was the variance in the interest in purchasing an AFV by income level. Of respondents who reported an annual income of \$50,000 or less, 44 percent said they had seriously considered purchasing an AFV at some point. In respondents with an annual income over \$50,000, only 31 percent reported an interest in purchasing an AFV.

To better understand how people make their vehicle-purchasing decisions, respondents were asked to rate the importance of seventeen different vehicle-related factors when shopping for a new vehicle. Factors were rated in one of four categories: not at all

important, somewhat important, important, or very important. For each factor surveyed, Figure 7 shows the percentage of respondents that rated it as either “important” or “very important.”

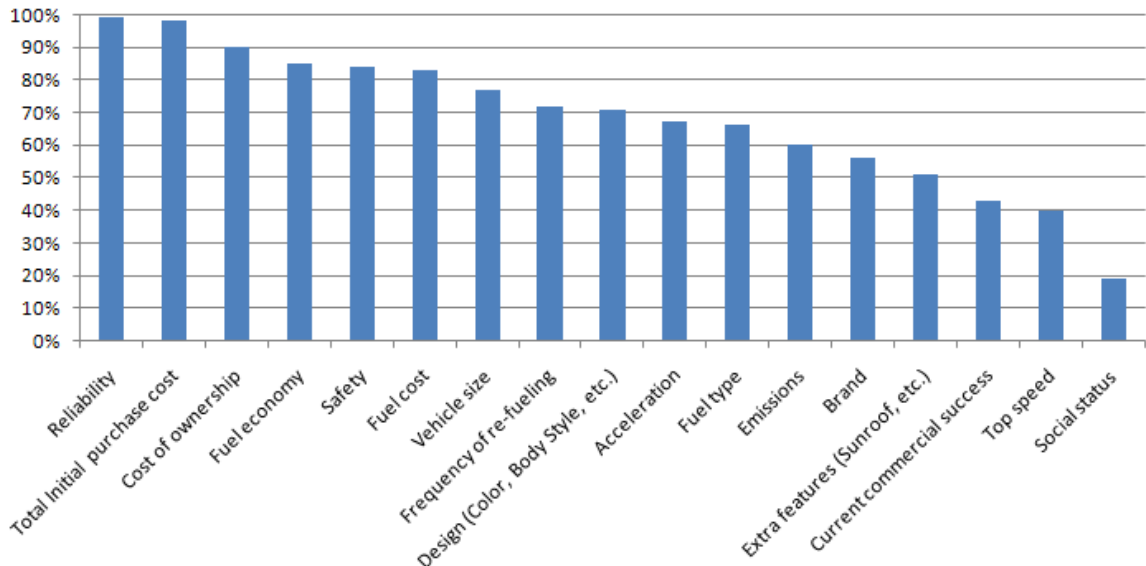


Figure 7: Percentage of respondents who rated the factors as either "important" or "very important" in their purchasing decisions.

Figure 7 indicates that nearly everyone believes that reliability and initial purchasing cost are important factors in their purchasing decisions. Non-performance factors such as brand name, social status, and current commercial success did not garner as much attention. One interesting note, however, is the lack of support for top speed as an important factor. This factor may be discounted in buying decisions due to speed limits and expectations of traffic congestion.

Of the vehicle-related factors listed above, respondents were also explicitly asked to rank the top three most important factors in their vehicle purchasing decisions. Figure 8 displays two methods of calculating the importance of each factor as rated by the respondents.



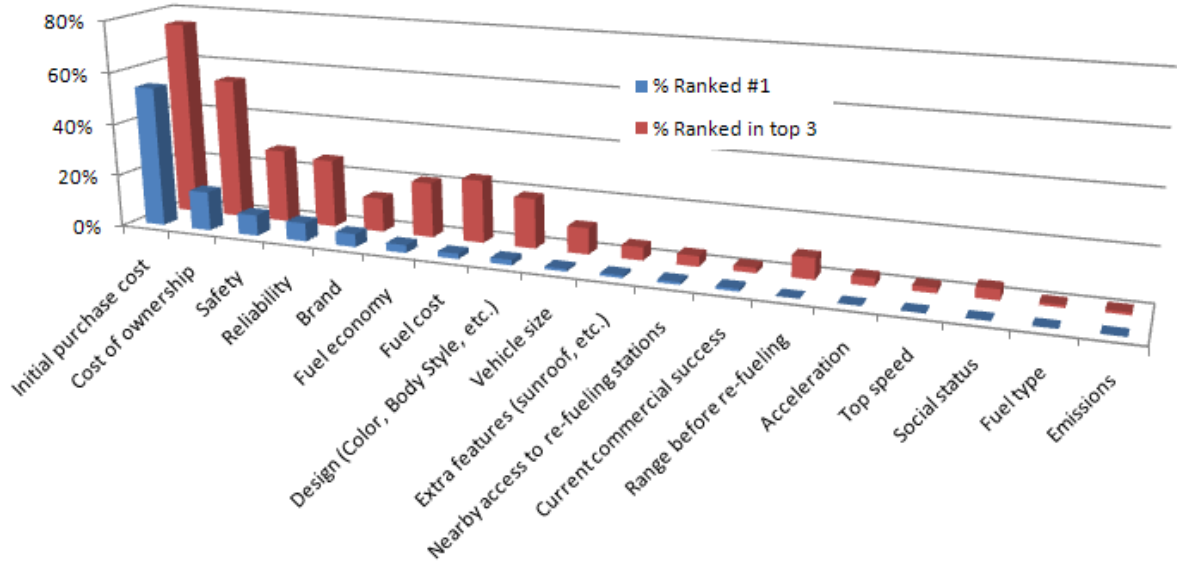


Figure 8: Percentage of respondents who ranked each factor as one of the top 3 most important factors in their vehicle purchasing decisions

In Figure 8, the blue bars represent the percentage of respondents who chose the factor as the number one most important factor in their vehicle purchasing decisions. The red bar is an aggregate value representing the percentage of respondents who chose the factor in any of the top three positions. From the data in this graph, as well as the results observed in Figure 6, the most important vehicle-related factors are clearly illustrated. Initial purchase cost, cost of ownership, safety, and reliability appear to be the most important factors.

In addition to vehicle-related factors, the respondents were also asked to rate how eight exogenous factors might influence their vehicle purchasing decisions. This question was formulated in the same style as the question regarding the vehicle-related factors. Figure 9 shows the importance of each factor using the same method employed in Figure 7, with the bars representing the percentage of respondents who rated it as “important” or “very important.”



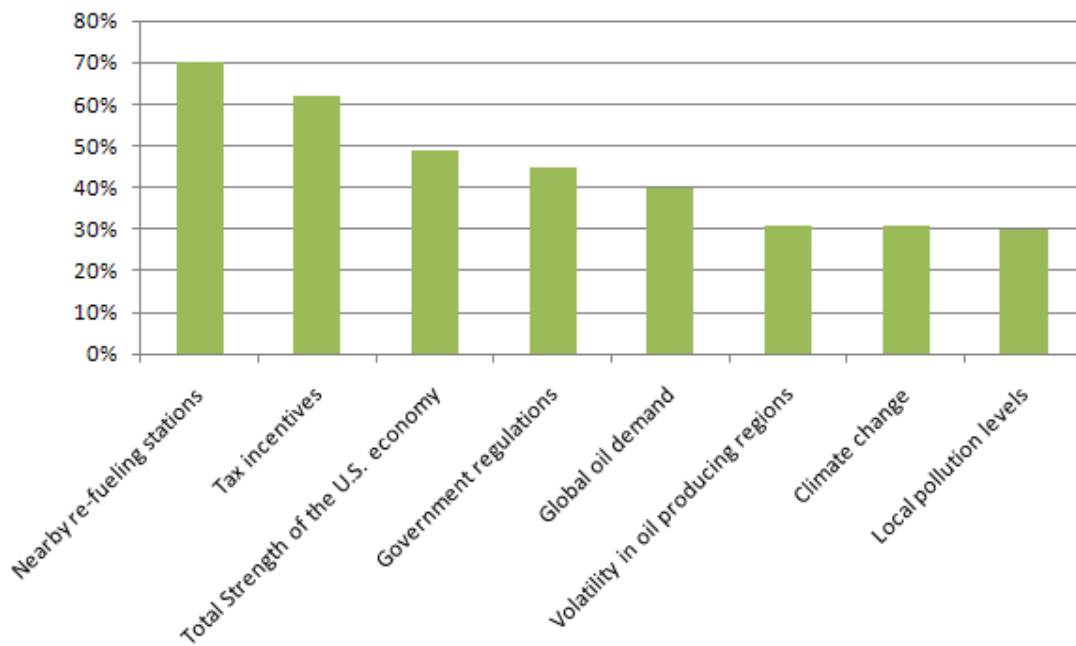


Figure 9: Percentage of respondents who rated the factors as either "important" or "very important" in their purchasing decisions.

The results displayed in Figure 9 indicate that issues of convenience and personal costs take precedence over geopolitical and environmental concerns. This observation is not entirely surprising, as those larger issues may seem too daunting and overwhelming to factor into a vehicle purchase decision. Nonetheless, the data supports the notion that there is a lack of progressive social and environmental idealism within our society. In general, the factors in this question were less important than the vehicle-related factors shown in Figures 7 and 8.

Other than information on consumer decisions, the survey also aimed to gather data on public opinion over the societal effects of AFVs. Respondents were asked to rate how the development of AFVs would affect seven national goals of major importance. Respondents could choose between one of five options: very negative, somewhat negative, neutral, positive, and very positive. Figure 10 shows the responses to this inquiry.



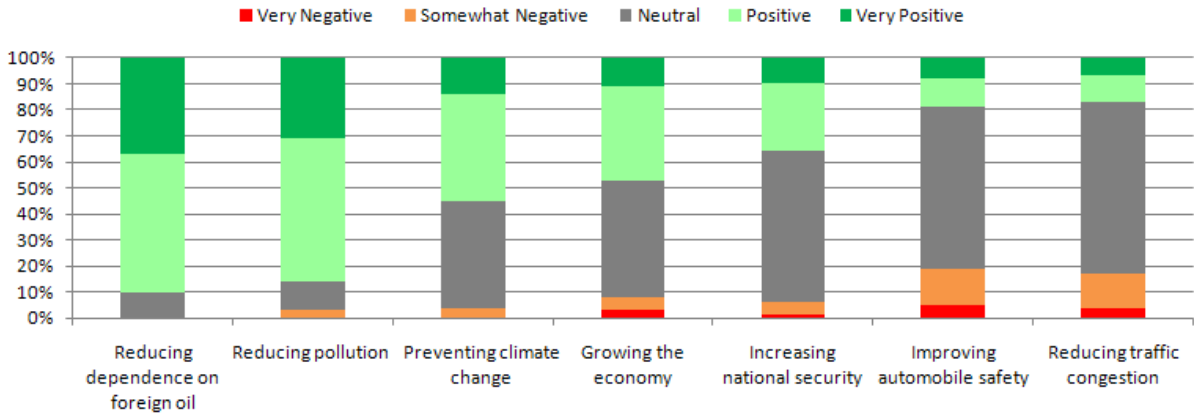


Figure 10: Respondent opinions on the effects of AFVs on various societal issues

Figure 10 displays the breakdown of opinions for each factor surveyed. The green areas represent positive opinions, while the red and orange areas represent negative opinions. The results show that the majority of the respondents believe that AFVs will have positive impacts on oil dependence and pollution levels. This response is interesting compared to the data observed in Figure 9 which suggests that these same factors do not have a great importance in vehicle purchasing decisions. Opinions on safety and traffic congestion issues were largely neutral with the respondents. However, in both of these issues nearly 20 percent of respondents believed that AFVs would have a *negative* impact. This data suggests possible apprehensions about the performance and reliability of AFVs.

The last question in our general survey asked respondents to rank their appeal to six major AFV technologies. Figure 11 shows the appeal of each AFV type using three methods of calculation.



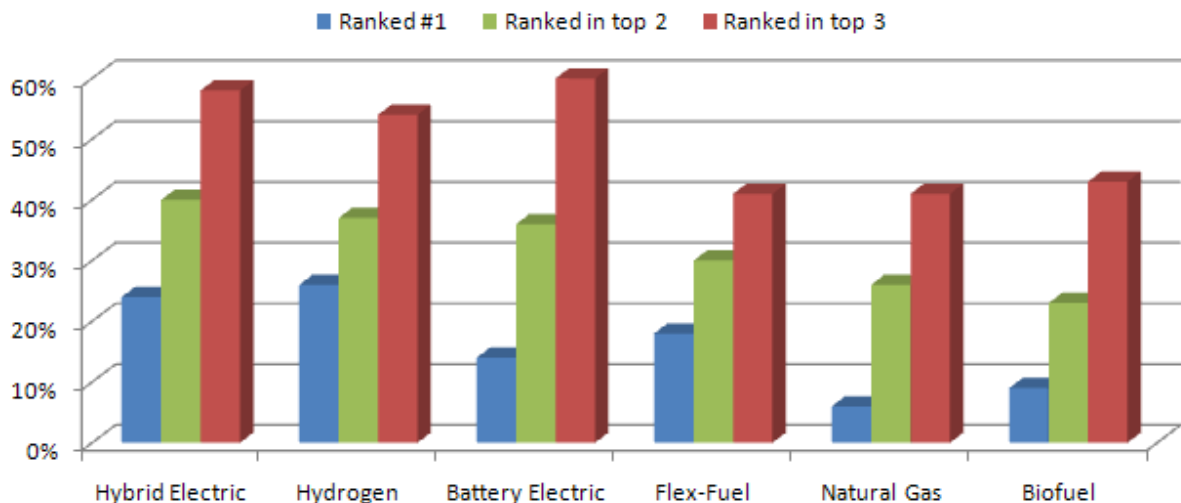


Figure 11: Overall appeal of each AFV type to all respondents

In Figure 11, the blue bars represent the percentage of respondents who chose each AFV type as the most appealing to them. The green bars represent the percentage of respondents who put it in the top two, and the red bars indicate the percentage of respondents putting the AFV in the top three. The data indicates that from the general responses, the most popular AFV technologies are Hybrid Electric, Hydrogen, and Battery Electric.

C. Expert Interviews and Relevance Matrices

After analyzing a total of 100 responses to our general survey, we were able to determine the general public's views and opinions of alternative fuel vehicles. The next step was to build the interview questions for our subject matter experts based on the general survey results. The goal of the subject major expert interviews was to determine the viewpoints of the experts in regard to alternative fuel vehicles. The interview consisted of 7 questions that were designed to build upon one another as the interview progressed.

Another aspect included in the interview was the addition of two relevance matrices that included data that was determined based on the survey results. The first relevance matrix

was build based on the top four factors in making purchasing decisions determined from the survey results. With this matrix we wanted the experts to rate how important they felt that each factor would be in determining the success of alternative fuel vehicles.

The second relevance matrix was also built based on the top four factors in making purchasing decisions but also included the top three alternative fuel vehicle technologies that were determined from the survey results. With this matrix the experts were asked to rate the strength of each factor for each alternative fuel vehicle technology. With the interview questions and relevance matrices we planned to compare the subject matter experts' results with the general survey results to see if there was a general consensus or disagreement between the two. See the appendix for our interview template and for the profiles of the subject matter experts who participated in the interviews.

Interview Results

We conducted interviews with six subject matter experts from various sectors including academia, forecasting & future studies, government, and the alternative fuel vehicle industry. There were some similarities and differences in their responses to the survey questions, which you can see below.

The first question asked which alternative fuel type would be the most successful in the long run. The response to this question varied with three stating the electric, one stating biofuel, one stating hydrogen/fuel cells, and one stating it would be a mix of the electric for short ranges and hybrid or hydrogen/fuel cell for long distances. With these responses the majority of the experts' picture the electric car as being the most successful vehicle in the future with hydrogen fuel and hybrid tied for second.



The second question asked what aspects of the selected alternative fuel technology from the previous question gives it the edge over the other competing fuel technologies. The majority of experts stated that they believe their chosen technology has the edge because of its high efficiency rates and because there are various ways to generate the fuel source. For the electric choice it was stated that the elimination of dependence on foreign countries for energy, the abundance of electric infrastructure that can be utilized, low cost of electricity, and it being a clean technology were important aspects of the technology. For the hydrogen/fuel cell choice it was stated that because its only byproduct is water vapor, this was an important aspect of technology giving it the edge. The expert that chose biofuels stated that the aspects that give this option the edge is that there is plenty of fuel available, it has already been implemented, and because of the experience with biofuels in Latin America.

The third question asked what are the main benefits and challenges to the development for their chosen technology. The experts who chose the electric car stated that the main benefits were the various ways to generate and capture the power source, being able to avoid increasing cost of oil and its long term risk, and that it will allow for energy independence. In a few of the responses it was stated that the power for the electric car can be generated using solar panels on the roof of the car and from solar cells imbedded in the surface of car, which can act similarly to batteries with capabilities to capture and store energy. The challenges for the electric choice would be getting the solar cell onto the car in the proper shape and being able to paint over them, upfront vehicles cost due to batteries, the current capacity limitations of batteries, range limitations, and the amount of time it takes to fully charge the batteries. For the hydrogen/fuel cell choice it was stated that the benefit is the abundant availability of hydrogen, the large amount of water from

which hydrogen can be extracted, and the ability to convert solar power to hydrogen. The challenges for hydrogen/fuel cells are the high cost to produce and maintain the cars, challenges in developing the infrastructure, and ability to gain public and government support. It was also stated that if we are able to lower the cost of the materials to develop fuel cell vehicles through the use of nanotechnologies, the industry would reach an important turning point. For those who chose biofuels, it was stated that the main benefit, as well as the main challenge, would be the ability to eliminate the use of fossil fuels as a source of energy.

The fourth question asked will there be room for other competing alternative fuel technologies or will society settle with just one winner. All but one expert stated there would be room for other technologies. Of these it was stated that several technologies would also be a part of the market for competition purposes and to allow the consumer the option to choose. The natural gas car was mentioned by most of the experts as being one of the competing technologies that will still be around. One expert believed in Pickens Plan which states that various technologies will be used in various parts of the transportation industry. For example, the electric car and hybrid would dominate the average consumer vehicles whereas natural gas would flourish in public vehicles like buses as well as with large commercial vehicles such as semis and dump trucks. Most believed that gasoline would still remain an energy source in the future but will just have a smaller share in the energy market. A few experts believed that the electric and hybrid would coexist in the future, each having a defined role in transportation system. The one response that stated there would not be any room for other technologies believed that electric was going to be the future and that everything would be shaped around that choice.

The fifth question asked when the chosen technology would enter mainstream, adopted by 30% of the industrialized world. The range for the responses was within the next 10 to 20 years. One expert stated that the adoption of the electric car maybe delayed due to the complexities in battery technologies compared to other technologies. Another expert believed that the technologies would arrive in waves with electric and biofuels coming first and then fuel cells arriving later. One expert believed that it would depend on external factors that affect the development of the technologies, such as breakthroughs that can speed things up, or natural disasters like the Japanese earthquake and tsunami, which can have a negative effect on the advancement of the technologies as focus is shifted to other pressing matters. One expert believed that it would depend on the growth rate in China because he believed that China would be the focal point for alternative fuel vehicles due to their current economic position and the growth of the automobile industry in the country.

The sixth question asked what would be the main issues that will drive mainstream adoption of alternative fuel vehicles. The responses to the question were broad. Most mentioned that the increased cost of oil, climate change, and other environmental impacts would be the major issues that will drive mainstream adoption. Other issues that were mentioned included the needed to stop using fossil fuels, need to refurbish an aging national energy infrastructure, the growth of China's alternative fuel market, government fees for carbon emissions, the effects of external factors from the previous question, and potential competition between biofuels and the human populations' need for food and water as the population grows. It was also mentioned that in the United States a major issue would be having a national energy plan with an implementation policy that is both supported and executed.

The seventh question asked what would be the main issues that may hinder mainstream adoption. The top issue stated by experts was the price of oil; if it drops and remains low, the development and adoption of alternative fuel vehicles may be stalled or dramatically slowed. Other issues mentioned positive climate change, aging transportation system, not being able to lower the cost of purchasing and maintaining alternative fuel vehicles, natural disasters, the ratio between alternative fuel cost and consumption, and the need for upgrades to the electrical grid and systems. Governments were also mentioned as an issue by a few experts being that they have the ability to support the changes and if they don't, mainstream adoption would be affected. In the United States it was mentioned that the lack of a national energy plan was a major issue that would affect adoption.

	Reliability	Initial Purchase Cost	Cost of Ownership	Safety
Importance:	8.7	6.83	6.75	7.6

Figure 12: Average ratings for the importance of the top factors.

Figure 12 shows the experts' average ratings for the importance of the top four most important factors in making purchasing decisions of alternative fuel vehicles that were determined by the general survey results. These numbers were rated from 1-10 with 1 being the least important and 10 being the most important. The numbers show the averages between the six experts that filled out the relevance matrix.

These results show that amongst the subject matter experts, reliability is the most important factor followed by safety, initial purchase cost, and cost of ownership. It's important to note that the most important factor for the experts matches the most important factor for the surveyed general public, reliability, but the remaining results for the experts do not match the results of the surveyed general public which ranked the remaining factoring in the following order, initial purchase cost, cost of ownership, and then safety.



	Reliability	Initial Purchase Cost	Cost of Ownership	Safety
Hydrogen/Fuel Cell	5.5	2.3	2.3	5
Battery electric	6.9	7.3	6.7	7.7
Hybrid Electric	8.2	7.3	7.1	7.8

Figure 13: Average ratings for the strength of the top factors for each of the top alternative fuel vehicle types.

Figure 13 shows the experts' average ratings for the strength of the top four most important factors for each of the top alternative vehicle types, both determined by the general survey results. These numbers were rated from 1-10 with 1 being the weakest and 10 being the strongest. The numbers show the averages between the six experts that filled out the relevance matrix.

These results show that on average the hybrid electric vehicles is the strongest and the hydrogen/fuel cell is the weakest for all the factors. It was mentioned by one expert that the fact that hybrid electric vehicles have been on the market for the last 10 years and success of such models as the Toyota Prius is why this technology was rated so high. The same expert also mentioned that the electric car was rated relatively high because it was viewed in a similar light as the hybrid and there are widely known examples on the market, such as the Chevrolet Volt and the Nissan Leaf, which are available for public consumption and provide the ability to measure these factors.

A few experts mentioned that the reason the hydrogen/fuel cell rated so low is mainly due to the lack of presence in the market place and the known high cost of owning and maintaining vehicles such as the Honda FCX Clarity, which is only currently offered via a lease program in select markets. Furthermore, there is the common perception of flammable gas stored in a hydrogen vehicle just waiting to explode upon impact.



III. Overall Conclusions

The results of the general survey imply that the leading alternative fuel vehicle types for future commercialization will be hybrid electric, hydrogen, and battery electric. Of the three, the ultimate leader will be based on the vehicle's product design and the manufacturer's marketing and sales strategy. This conclusion is supported by the leading factors that influence vehicle purchases according to survey responders, which are initial purchase cost, cost of ownership, reliability, and safety. Product design influences a vehicle's overall costs and performance (reliability and safety). This conclusion is also supported by our assessment that marketing is very important, because the most highly recognized alternative fuel vehicles were the Toyota Prius and Chevy Volt. These two cars were promoted heavily before and during their tenure on the automobile market. Lastly, although survey responders agreed that alternative fuel vehicles will help reduce pollution, "going green" was not a priority in determining whether or not they or anyone else would purchase an automobile. In fact, fuel type and emissions were ranked lower in comparison to all other factors in influencing automobile purchases. This leads us to believe that although having alternative fuel is important as a cost savings factor (fuel economy), improving the environment is a very low priority when it comes to the average person's reason for purchasing an automobile.

The results of the expert interviews provided an in depth look at what could be the leading alternative fuel vehicles for commercialization. The experts generally agreed with survey responders, but also included biofuels as a potential leader along with hybrid electric, hydrogen, and battery electric. As previously noted, the experts ranked the top factors for making alternative vehicle purchase decisions differently from the survey responders. For the experts, reliability led safety, initial purchase cost, and cost of

ownership. These results varied from the general survey responders, whose ranking order was reliability, initial purchase cost, ownership cost, and safety. The difference may be due to the expert interviewers' focus being on the technology itself. The expert interviewers, unlike the general survey responders, focused on the technology's complexity, the renewability of the technology's fuel source, and impact on the environment in determining which of the alternative fuel vehicle technologies would be leaders in the commercialization of alternative fuels for automobiles.

Overall, our study shows that four alternative fuel vehicle types will become leaders in the commercialization of alternative fuels for vehicles. The order will be hybrid electric, followed by battery electric and hydrogen fuel cell, and trailed by biofuel. One has already shown itself as a clear leader in the US, which is the hybrid electric vehicle. This is because the technology has been able to advance enough for mass production to reduce costs so that the average consumer can afford to purchase the vehicle. In addition, this is due to marketing and Toyota's brand equity. As other technologies advance and become low enough in cost for mass production (and receive the proper government and infrastructural support) they will likely become the next competitors to the hybrid electric vehicle. The next competitor will likely be battery electric followed by hydrogen fuel cell, based on that assumption. As additional alternative fuel vehicles enter the market, differentiation will also emerge as a competitive factor. By this we mean that the alternative vehicle manufacturers will apply the technology to different uses and vehicle types as a means of influencing customer purchases.

Lastly, although the various alternative fuel vehicle technologies will emerge commercially over the upcoming decades, consumer acceptance can be increased through initiatives to increase the awareness of these vehicle fuel types, the importance of

reducing pollution, and the importance of reducing our reliance on gasoline as an energy source. The average automotive consumer who is placing a high level of importance on overall cost, reliability, and safety should distinctly include fuel cost and fuel performance as an ultimate impact on his or her future automotive purchasing decision. Fuel cost and performance should be promoted, and the consumer educated so that consumer demand will help push the direction of alternative fuel vehicle commercialization.



IV. Appendix

A. General Survey Questions

The following is the general survey built electronically and emailed to our general audience for response:

General Survey Introduction

The term "alternative fuel vehicle" (AFV) generally refers to any type of vehicle that does not rely solely on "traditional" fuels (gasoline and diesel) to provide locomotion. There are a number of AFV options currently available throughout the world, with several more set to enter the marketplace in the coming years.

The objective of this survey is to assess the general public's knowledge and opinion of AFVs by gathering information about the following:

- (a) General awareness of the current leading alternative fuel technologies.
- (b) Opinions on the societal impacts of AFVs.
- (c) Opinions on how different factors influence consumer decisions for vehicles.

Please complete the following questions:

1. **What is your age?** Under 18, 18-24, 25-34, 35-44, 45-54, 55-64, 65 or Above, or Prefer Not to Answer
2. **What is your gender?** Male, Female
3. **What is your highest completed level of education?** High School, Bachelor's degree, Master's degree, PhD/Doctorate, or Other, please specify:
4. **What is your annual income?** Under \$20,000, \$20,000 - \$30,000, \$30,000 - \$40,000, \$40,000 - \$50,000, \$50,000 - \$75,000, \$75,000 - \$100,000, \$100,000 - \$150,000, \$150,000 or more, or Prefer Not to Answer
5. **Please select the option from the dropdown list that most closely matches your primary vehicle type.** Compact, Mid-Size, Full-Size, Compact Pick-Up, Mid-Size Pick-Up, Full-Size Pick-Up, SUV, Minivan, Motorcycle, or No Vehicle
6. **Can you provide a short explanation of why you chose this vehicle type?**
7. **Have you ever seriously considered purchasing an AFV?** Yes or No
8. **Do you currently own an AFV?** Yes (Please state the make/model) or No
9. **Please rate (None, Low, Medium, or High) your familiarity with the following AFV types.** Hydrogen Natural Gas Battery Electric Hybrid Electric Biofuel Flex-Fuel
10. **Which of the following dedicated AFV models are you aware of?** Toyota Prius, Lexus CT, Lexus HS, Nissan Leaf, Chevy Volt, Honda FCX Clarity, Honda Insight, Honda CR-Z, Tesla Roadster, Tesla Model S, Fisker Karma, or Other, please specify:

11. **In your opinion, what affect will the development of AFVs have on achieving the following national goals?** Rank as Very Negative, Somewhat Negative, Neutral, Positive, or Very Positive. Reducing pollution, Reducing dependence on foreign oil, Increasing national security, Preventing climate change, Reducing traffic congestion Improving automobile safety, or Growing the economy
12. **As a consumer, please rate how the following vehicle-related factors might influence your vehicle purchasing decision.** Rank as Not at all Important, Somewhat Important, Important, or Very Important: Initial purchase cost, Cost of ownership (maintenance, repairs, insurance, etc.), Brand, , Current commercial success, Social status, Design (Color, Body Style, etc.), Vehicle size, Extra features (sunroof, 4 wheel drive, etc.), Fuel cost, Fuel type, Fuel economy, Safety, Acceleration, Top speed, Frequency of re-fueling, Reliability, and Emissions.
13. **Of the factors listed above, which would you consider to be the top three most important in determining consumer choices?**
14. **Please rate how the following other factors might influence your vehicle purchasing decision.** Rank as Not at all Important, Somewhat Important, Important, or Very Important: Strength of the U.S. economy, Global oil demand, Volatility in oil producing regions, Local pollution levels, Climate change, Nearby re-fueling stations, Government regulations, or Tax incentives
15. **Please rank the following AFV types based on which is the most appealing to you.** Rank in order of 1 through 6: Hydrogen, Natural Gas, Battery Electric, Hybrid Electric, Biofuel, and Flex-Fuel

B. Expert Interview Template

The following are the interview questions and relevance matrix used for the Expert Interview research:

1. **Which alternative fuel type do you think will be the most successful in the long run?**
2. **What aspects about this technology give it an edge over the other competing technologies?**
3. **What are the main benefits and challenges to the development of this technology?**
4. **Will there be room for other competing technologies, or will society settle on a single winner?**
5. **When do you expect this technology to hit the mainstream (30% industrialized world adoption)?**
6. **What will be the main issue or issues that will drive mainstream adoption?**



7. What will be the main issue or issues that that may hinder mainstream adoption?

Relevance Matrix:

Rate importance of factor (1 -10 scale), 1 being the least important and 10 being the most important

	Reliability	Initial Purchase Cost	Cost of Ownership	Safety
Importance:				

Rate strength of AFV in each factor category (1 – 10 scale) 1 being the weakest and 10 being the strongest

	Reliability	Initial Purchase Cost	Cost of Ownership	Safety
Hydrogen/Fuel Cell				
Battery Electric				
Hybrid Electric				

C. Interviewed Expert Profiles

Name	Company	Title
Charles Smith	California Energy Commission	Energy Specialist
Steven Cunningham	Deloitte Consulting Federal Sector / Simmons & Company International	Consultant
William Halal	The George Washington University / TechCast	Information Systems Technology Management Professor / President
Jonathan Peck	Institute for Alternative Futures	President & Senior Futurist
John Petersen	The Arlington Institute	Founder & President
Robert Rycroft	The George Washington University	International Science & Technology Policy and Energy Policy Professor



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