1997: A-Class EV
Range: 125 miles
(>180 miles w/ 2004 battery)

2004: A-Class fuel cell vehicle
Range: 90 miles

CARB's Fuel Cell Detour on the Road to Zero Emission Vehicles

Alec Brooks
May 2, 2004

Summary

On April 20, 2004, California governor Arnold Schwarzenegger signed an executive order aimed at creating a network of 200 hydrogen refueling stations throughout the state by 2010. The goals for hydrogen powered transportation sound good on paper – zero emission vehicles propelled by hydrogen produced with clean renewable energy. It sounds almost too good. Is the governor's Hydrogen Highways program really the bold step that jump starts the future of transportation, or is it a monumental boondoggle that leads to a dead end? The conventional wisdom is that the former is true, but a growing body of analysis and evidence leads instead to the dead end conclusion.

The California Air Resources Board (CARB) has recently made a U-turn in their zero emission vehicle (ZEV) program just as everything was coming together. Battery electric vehicles had been improving rapidly and were almost universally loved by their drivers. Battery durability was shown to be better than expected and cost parity with conventional gasoline powered vehicles was clearly attainable.

By dithering on the ZEV mandate and putting all their chips on fuel cell vehicles, CARB has set back the development of practical zero emission vehicles by at least a decade. The current situation has much similarity to the California energy deregulation fiasco of the 1990s. This time, California is being led down the primrose path by automakers, with the promise of a future vehicle vision that on the face of it sounds great. In the 1990s, California was manipulated by energy companies; now it is the automakers' turn. By convincing CARB that fuel cell vehicles will be the ultimate future solution, they have bought ten or more years to avoid bringing real zero emission vehicles to market.

Support for fuel cell vehicles derives primarily from conventional wisdom and commonly accepted facts about these vehicles. These "facts" have been repeated so often that they have become generally accepted as the truth. But it turns out that many of the facts are not supported by the data; much of what is universally accepted about hydrogen and fuel cell vehicles is, in fact, wrong.

This article documents my long, and so far unsuccessful, effort to get CARB to pay attention to the real and serious issues with hydrogen and fuel cell vehicles rather than simply jumping to a conclusion. I felt that there needed to be real discussion and analysis of whether hydrogen powered vehicles were what the state really should strive for in the near term or even in the long term. What started out as my brief reply to CARB's reply to my original written comments has expanded into a very lengthy article. The length is needed to provide the relevant background, to give a detailed response to CARB's comments, and finally, to make recommendations as to what should be done to fix the mess CARB has made.

In condensed form, here are some of the key highlights of this story:

- The commonly held belief is that fuel cell vehicles will have two to three times the fuel economy of gasoline powered vehicles. But so far, fuel cell vehicles are losing. The mid-sized gasoline powered Toyota Prius gets 13 percent better EPA fuel economy than the subcompact Honda FCX fuel cell vehicle.

- Fuel cell vehicles are energy pigs. Fuel cell vehicles that operate on hydrogen made with electrolysis consume four times as much electricity per mile as similarly-sized battery electric vehicles.

- Battery electric vehicles powered by today's available battery technology can have twice as much driving range as current fuel cell vehicles.

- Fuel cell vehicles will inconvenience their drivers with more than ten times as much time devoted to refueling compared with battery electric or gasoline powered vehicles.

- CARB chairman Alan Lloyd effectively abandoned battery electric vehicles in response to auto company threats to pull out of the California Fuel Cell Partnership.

- As they were publicly trumpeting the arrival of the second generation EV1, General Motors privately vowed never to produce any more of them.

Introduction

For the last several years, CARB has grappled with amending the ZEV regulations to address multiple lawsuits brought by automakers. On January 9, 2004, the final regulations were published, along with the FSOR, or Final Statement of Reasons. The FSOR is a document in which CARB is required to note all substantive comments and recommendations submitted to them during designated comment periods, and to explain how that information was considered in the rulemaking process.

On February 20, CARB issued a supplement to the FSOR to the California Office of Administrative Law, the agency that is charged with making sure that state agencies like CARB follow the proper rulemaking procedures. The supplement covered two items: a request by Volkswagen for relief on a specific aspect of the regulation, and a response to comments that I had made at the December 2002 ZEV workshop (and subsequently submitted as written testimony prior to the March 2003 board meeting). CARB's official explanation of how this last minute response to my comments came into being is misleading if not outright false. The FSOR supplement itself is a slipshod job, and should be an embarrassment to CARB. This is the story of how CARB came to issue the response to my comments and what is wrong with what they said in it.

Background

I have been following the ZEV mandate since it was adopted at the November 1990 CARB meeting, at which I testified. In 1990 and 1991, I was a participant in the key design reviews for the EV1 as it was being developed at GM, and witnessed first-hand the trials and tribulations in getting that vehicle to market. The EV1 development team at GM was by and large incredibly dedicated to putting out a quality product. I leased an EV1 in 1996 on the first day they were available. The EV1 that I drove for more than three years had its share of glitches, but the overall experience was quite positive. I continued to closely follow GM's efforts (or lack thereof) to bring EVs to market, and CARB's seemingly continuous revisions to the ZEV program. I became very involved in the 2000 – 2002 review of the ZEV mandate. I testified at nearly every public workshop and board meeting and met several times with the chairman and senior staff.

By about 2000, it appeared that CARB had waffled so much on the mandate that car makers were emboldened to cancel their EV programs. Instead of EVs, they urged us to wait while they developed the silver bullet vehicle of the future, the fuel cell vehicle. It has been almost universally reported that fuel cell vehicles would be two, three, or even four times as efficient as conventional vehicles, and that making hydrogen with clean renewable electricity would finally end our oil imports and give us a wonderful and sustainable solution to our transportation needs.

In the 1990s, fuel cell vehicles started replacing battery EVs as the next big thing. Battery EVs were said to be a mature technology that wouldn't improve much more, and in small volume, they cost much more to produce than a conventional car. Fuel cell vehicles were touted as the solution to all the ills of battery electric vehicles. There would be no more range problems. They could refuel in a jiffy, and they would emit only pure water from the tailpipe. They sounded almost too good to be true.

My first exposure to fuel cell vehicles was in 1990 when I was contacted by "Dr." Roger Billings, the (self proclaimed) guru of hydrogen. He claimed that he had developed the first fuel cell vehicle with financial support from the Pennsylvania Energy Office. But his claims sounded suspect. I spoke with an official at the Pennsylvania Energy Office about the project and found that they couldn't actually say whether the vehicle was powered by a fuel cell or the batteries onboard. The 'fuel cell' in the vehicle was a shiny metal box with a few pipes and wires, but no evidence of a cooling system or other usual subsystems. This experience instilled in me a healthy skepticism about fuel cell vehicles that has served me well over time.

At an EV industry conference in Atlanta in 1999, I saw a fuel cell vehicle up close for the first time – the Ford P2000. It was on display outside of the conferences' gala evening event. The engineers babysitting the car fired it up and had it 'idling'. It sounded like a lot of commotion – pumps, fans, blowers, etc, for a car that was, after all, just sitting there doing nothing. I asked the engineer with the car how much electricity (being produced by the fuel cell) was being used to run all those devices. The answer surprised me – it was 3 kilowatts! By contrast, the standby power of an EV is about a tenth as much. I knew that the average power requirement to drive a similar-sized EV over the EPA urban driving cycle was just 4 kW. Here was the fuel cell vehicle just sitting there using 3 kW! I asked about driving range, and at first got the stock answer – something like 100 miles. But I asked again about the city cycle range, and didn't get an answer, except an impression that it was a lot lower.

At the 2001 Environmental Vehicles Conference in Detroit, I test drove Ford's Focus FCV fuel cell vehicle. Again, I was struck by the cacophony of noises when the car was sitting there turned on but otherwise doing nothing. The engineer hosting the test drives confirmed that 3 kW number again. The driving experience was poor by comparison to what an EV driver might have come to expect. Accelerator pedal response was slow as the air pumps whined up to speed, and there was also an annoying lag when releasing the accelerator pedal; power continued to flow to the wheels for about a half-second after it was no longer being requested. I also got the sense from the test drive host that the range was not very good.

I also started to look at the fuel side of the picture. At present, most hydrogen is produced from natural gas, resulting in CO_2 emissions of about 12.5 kilograms per kilogram of hydrogen produced. For transportation applications it turns out that it will be more efficient and more practical to use natural gas directly in natural gas powered hybrid vehicles, rather than first converting the natural gas to hydrogen and then using the hydrogen in a fuel cell. The emissions of natural gas vehicles are so small that they are considered for practical purposes as clean as EVs, as evidenced by their allowance into California carpool lanes with a single occupant. The only other vehicles with this privilege are zero emission vehicles – battery and fuel cell powered. The long term goal often stated for hydrogen is to produce it by electrolysis, with renewable electricity, such as wind or solar. There are, of course, other uses for renewable electricity, such as offsetting coal or natural gas based electricity generation. So it is vitally important to understand how much electrical energy would be required to make hydrogen for fuel cell vehicles, and to compare that with the electricity requirements of battery electric vehicles.

I wanted to find out the efficiency of the electrolysis process that makes hydrogen by splitting water. At an industry conference, I went to the Stuart Energy Systems booth, where a prototype 'personal fueller' electrolysis device was on display. The idea was that you'd make hydrogen in your garage by connecting the personal fueller up to your 240V power and the water supply. I asked the company rep in the booth what the efficiency of the device was. I was assured that the personal fueller was extremely efficient, greater than 99 percent! I didn't believe it and decided to try a different approach. To avoid any confusion about what people defined as efficiency, I'd instead try to find out how much electricity, in kWh, was needed to produce and compress one kg of hydrogen (which is the energy equivalent of one gallon of gasoline).

I sent an email to Stuart Energy Systems asking for this information. It took three tries and 5 months to get the answer: 55 kWh. Subsequent data from Stuart's data sheets for their large "community fueler' product places the number at 63 kWh. This is a pretty big number. Other companies' electrolyzers are just as bad or even worse. Honda's electrolyzer installed at their research center in Torrance California consumes 64 kWh/kg, and Proton Energy's is up at 72 kWh/kg. If one kg of hydrogen is processed through a fuel cell at an average efficiency of 50 percent (a generous assumption given today's FCVs), the electricity you get back out will be 16.6 kWh, for a round trip efficiency of only 23 to 26 percent from the electricity consumed by the electrolyzer. Or put another way, you have to put in about four times as much energy as you get back out; three fourths of the input energy is wasted before any of the input energy reaches vehicle's drive motor! By contrast a lithium battery and good battery charger could return about 51 kWh of that same 63 kWh input, over three times as much energy back out for the same amount put in. So right away, an EV has a three fold energy advantage over an FCEV.

But there is more: a fuel cell is a one-way device; it produces electricity from hydrogen and oxygen. A battery is a two-way device, it can accept power as well as deliver it. This is a crucial difference. The power requirements for a vehicle are highly bi-directional. Positive power is needed to accelerate, go up hills, and maintain speed. Negative power is needed to slow down or go down hills. This negative power represents recoverable energy that can be used again to drive the vehicle. With conventional cars, the negative power is thrown away in the friction brakes or in engine braking. With battery electric vehicles, much of that energy is recaptured in the battery through regenerative braking. With fuel cell vehicles, since the fuel cell itself can't accept that energy, a separate energy buffer is sometimes employed. Honda uses a supercapacitor bank. Toyota uses a Prius battery pack. GM has nothing to absorb this energy; it is wasted as heat in the friction brakes. But the Honda and Toyota approaches are limited in the energy and power that can be reabsorbed, reducing the recapture of energy compared to battery electric vehicles.

The combination of the electrolyzer energy consumption numbers, the big difference in standby power, and the inferior regeneration energy capture all suggested to me that fuel cell vehicles would use many times more electricity per mile than battery electric vehicles.

I started to search for data on the actual fuel economy and driving range of fuel cell vehicles. I discovered that the data was usually given by vague statements, such as "range of up to 150 miles". Data for standardized test cycles or real world driving was never quoted. It seemed like it was a big secret. At the 2001 Michelin Challenge Bibendum, a competition for environmentally friendly vehicles, the participation of the fuel cell vehicles from the California Fuel Cell partnership came with the proviso that actual hydrogen consumption numbers and driving range would not be disclosed as part of the results. This seemed strange for a competition that was all about energy efficiency.

There were scattered bits of information that hinted of a range problem. In their "highlights of 2001" report, the California Fuel Cell Partnership touted 754 refueling events during the year, with 34,000 vehicle miles covered – an average of only about 45 miles between refuelings. In the Fuel Cell Partnership's "Rally Through the Valley" drive from Sacramento to Los Angeles, there were a lot of refueling stops. Some of these stops coincided with public events and test drives. But on the last day of the rally, the driving leg was from Bakersfield to Los Angeles with no events scheduled along the way. The vehicles were to travel directly to Griffith Park in Los Angeles for an afternoon test drive event. The distance from Bakersfield to Griffith park is just 105 miles, but there were <u>two</u> refueling stops along the way: one at the base of the Grapevine, and the other at Castaic. Driving range appeared to be a big problem but was being kept very quiet.

In late 2002, the EPA came through with official fuel economy test data for the Honda FCX fuel cell vehicle. The EPA fuel economy guide for the 2003 model year listed only two zero emission vehicles. One was the battery electric Toyota RAV4EV, and the other was the Honda FCX fuel cell vehicle. These vehicles are about the same size and utility, although the FCX has only two doors, and is about 200 pounds heavier than the RAV4EV. At last, here was the data for an apples-to-apples comparison of the energy consumption of fuel cell and battery electric vehicles tested over the same driving cycles. The published results confirmed what I had expected. The FCX was rated at 50 miles per kg of hydrogen (combined city / highway), and the RAV4 EV was rated at 30 kWh / 100 miles, or 0.30 kWh/mile. With the electrolyzer energy consumption number that I had at the time – 60 kWh/kg – the FCX would need 1.20 kWh of electricity (to produce hydrogen) per mile. This is fully <u>four</u> times as much as the RAV4EV's 0.30 kWh/mile. To put this into perspective, this is the same ratio as between a Hummer and a Honda Civic! (But unlike the comparison of the Hummer to the Civic, in this case the vehicles are about the same size. The fuel cell vehicle was an energy pig!)

As I read more and more gushing articles about fuel cell vehicles, it became apparent to me that I had never seen these basic energy comparisons with battery electric vehicles expressed anywhere. Every time fuel cell vehicles were mentioned, it had always just been accepted as fact that they were going to be wonderfully efficient.

In 2000, the energy efficiency guru Amory Lovins came to AC Propulsion, where I was working at the time, for a short visit. At the end of the visit, I drove him to the Los Angeles airport in a prototype 4-door electric vehicle. It wasn't a particularly lightweight vehicle, having a large liquid-cooled nickel-metal-hydride battery pack. The trip was on the freeway in heavy traffic with lots of speedups and slowdowns. Lovins was very interested in the digital displays in the vehicle that tracked battery Amp-hours and kiloWatt-hours (kWh). The displays showed both net values and cumulative energy captured by regenerative braking. In AC Propulsion's electric vehicles, virtually all vehicle slowing in normal driving is accomplished with regeneration, leading to large amounts of energy returned back to the battery.

During the drive Lovins confidently told me all about his fuel-cell-powered hypercar concept, and rattled off a string of very optimistic efficiency numbers which he multiplied together to get an astounding overall efficiency. In addition to his efficiency numbers all being on the high side of reasonable, he had forgotten to include the difference between the higher and lower heating value of hydrogen, a common mistake. The higher heating value represents the energy of the hydrogen-oxygen reaction if the water byproduct of the hydrogen-oxygen reaction is accounted for as condensed liquid water. The lower heating value is the energy of the reaction if the water is in the vapor state. The difference between the two is the heat of vaporization of the product water. Electrolyzers often have efficiency quoted relative to the higher heating value of the hydrogen produced, while fuel cell efficiencies are usually referenced to the lower heating value. The difference between the two for hydrogen is about 15%.

After dropping Lovins off at the airport, I drove home and recharged the car overnight on my separately-metered EV charging circuit. The data displays in the car had indicated 201 Wh/mile DC energy consumption over the 80.8-mile trip. Energy recovered from regenerative braking tallied up at 5.27 kWh, or 65 Wh/mile; without regeneration, the energy consumption would have been 32 percent higher. The energy used to recharge the vehicle back up to full was 26.5 kWh at the AC meter, or 328 Wh/mile. The inefficient liquid-cooled battery resulted in quite a bit of extra energy consumption compared to the DC value, but still, 328 Wh/mile is a respectable number for a four door EV. A lithium-battery-powered vehicle of similar capability would have used only about 250 Wh/mile AC on the same trip. I sent Lovins a follow up email to note that with the amount of hydrogen that could be produced with that same 26.5 kWh of electricity, his futuristic hypercar concept, even if it was as efficient as he claimed it would be, would not have been able to travel as far as the here-and-now EV.

In the summer of 2003, I attended the Future Car Congress in Washington DC, sponsored by the Department of Energy and the Society of Automotive Engineers. In the keynote session, Toyota's fuel cell vehicle executive engineer Norihiko Nakamura candidly summed up the cost problem facing fuel cell vehicles:

> "If a certain level of mass production can be achieved the cost should be dropped drastically. But a great amount of effort is needed to bring the cost to even *two to three times* that of a standard vehicle." (emphasis added)

The Future Car Congress had a ride and drive event to provide the opportunity to drive a variety of vehicles, including hybrids, fuel cell vehicles, a battery electric, and a diesel. During the course of the day, only the fuel cell vehicles had to leave the ride and drive to go refuel. Not even the battery electric RAV4EV had to go recharge.

At the September 7, 2000 CARB meeting, the board strongly reaffirmed their commitment to the ZEV program. The board directed the staff to work out the details and bring back a new ZEV rule for a vote in January 2001. At the January meeting, the board actually boosted the number of ZEVs that would have been required under the staff proposal, and approved new rules that would require thousands of battery EVs starting in 2003. In these new rules, CARB started to show a favoritism to fuel cell vehicles. In the early years of the new proposed rules, battery electric vehicles were to be awarded with 8 or 12 ZEV credits, while fuel cell vehicles would receive a whopping 40 ZEV credits. This seemed backwards, given all the apparent disadvantages of fuel cell vehicles compared to battery electric vehicles. It seemed very premature to declare that fuel cell vehicles were preferable over battery electric vehicles. There should be analysis, discussion, and informed debate as to whether fuel cell vehicles were even a good thing to strive for, even in the long term.

A subsequent set of proposed changes also included an "alternate compliance path" which would allow automakers to meet all of their pure ZEV requirements by producing just a small number of fuel cell vehicles for demonstration programs. These vehicles would not even have to be sold in California. (In fact, they wouldn't have to be sold at all – just placed for a limited amount of time in demonstration programs). This was a depressing turn. Here was CARB planning to put all their chips on fuel cell vehicles – vehicles that used four times the energy of battery electrics when the hydrogen is produced by electrolysis, had lower range than battery electrics with current technology, and didn't appear to have any hope of ever being cheaper to manufacture than battery electric vehicles. It defied logic that they were going down this path. Maybe they didn't know the real numbers.

In order to stimulate discussion of the relative merits of fuel cell and battery electric vehicles, I decided to make a detailed presentation comparing the two vehicle types at the CARB public workshop on December 5, 2002. The purpose of the workshop was for CARB to capture public feedback on their proposed new ZEV rule structure. I prepared a written document to go with my presentation. It was long – I expected it would take 25 minutes to present, which is much longer than is typically allotted. The workshop was well attended by CARB staff and representatives from the automakers and many EV drivers. Board Chairman Alan Lloyd was present. The organization of the workshop was a little informal, with no assigned order of speakers. I knew from attending past workshops that the attendance tails off as the day goes on. I secured a speaking slot in mid morning, and launched into my presentation hoping that I wouldn't be cut off for going on too long. I stuck to reading from my prepared text and went along at a fast clip and got all the way through. The response from the audience was very positive, even from Tom Cackette, deputy executive officer of CARB, who happened to be sitting next to me in the hearing room. I later got several very complimentary emails from people that that seen the webcast or read the online printed copy.

A recording of the presentation is online at
http://www.socalev.com/Sounds/CARB-AM08.mp3
and the written version titled "Perspectives on Fuel Cell and Battery Electric Vehicles" is at:
http://www.arb.ca.gov/msprog/zevprog/2003rule/2003rule.htm

The main points of my presentation were:

- Fuel cell vehicles have significant range problems. Battery EVs with modern batteries can easily have twice the driving range of fuel cell vehicles.

- Fuel cell vehicles fuelled by hydrogen made by electrolysis will use four times as much electricity per mile as a similar-sized battery electric vehicle.

- Using natural gas to make hydrogen for fuel cell vehicles will consume as much or more natural gas per mile as just burning the natural gas directly in a ICE hybrid vehicle. The higher energy per unit volume of natural gas would provide more than twice the driving range as a fuel cell vehicle given equal tank volume and pressure.

- CARB’s electric vehicle cost assumptions were wrong. New cost data was presented for lithium ion and sodium nickel chloride batteries. The Prius was cited as an example of what a battery EV would cost to manufacture in volume.

- CARB was not being realistic about the cost challenges facing fuel cell vehicles. It was noted that Toyota said they’d have to work very hard to get the cost of a fuel cell vehicle down to double or triple that of a conventional car.

After the presentation I felt that maybe I had made a difference and that CARB would pay attention to what I had said. Previously, Alan Lloyd and some of the CARB executive staff had sought out my ideas and advice on changes they were considering for the mandate. But the only follow up I had from CARB was from their staff attorney who asked me why I thought their approach with multiple categories of ZEVS was an invitation to another lawsuit. But I heard nothing about any of the rest of what I had said. I had expected at least some follow up questions. But there was just nothing. At a subsequent fuel cell vehicle event, I asked a CARB staffer whether CARB was going to acknowledge my comments and respond. I was told that I’d have to wait for the final statement of reasons document at the end of the rulemaking process. I was told that CARB was required to respond in that document.

In December 2003 I inquired about the response to my testimony as part of an email to Analisa Bevan, heat of CARB’s ZEV section:

> Dear Analisa,
>
> Attached is an article about the Tokyo Motor Show from the Dec 03 issue of SAE Automotive Engineering. After the initial section about fuel cell vehicles, note the section on page 3 titled "EV resurgence?". It appears that the Japanese automakers are quietly working behind the scenes on advanced-battery EVs, which are likely to be a cost effective and better range and energy efficiency alternative to fuel cell vehicles.
>
> On another subject, just over a year ago I gave a presentation at the December 5 ZEV workshop which set forth new information and perspectives on the relative energy efficiencies of fuel cell and battery electric vehicles, that EVs could have GREATER range than fuel cell vehicles, and that, based on the Prius, CARB's assumption on the "EV cost penalty" was wrong. Since then, Toyota has introduced the 2004 Prius which is even more "EV-like" than the previous one, and AC Propulsion has demonstrated 300 miles of EV range with lithium ion batteries. Is CARB ever going to acknowledge or comment on these issues that I raised in my testimony? I get the sense that they were "swept under the rug". I received quite a bit of favorable feedback from people that had seen the presentation or downloaded it from the web (http://www.arb.ca.gov/msprog/zevprog/2003rule/1202wkshp/brooks.pdf).
>
> best regards,

Alec Brooks

I quickly got a response, not from Bevan, but from the executive officer, Catherine Witherspoon:

> Alec- We have a duty to respond to all substantive testimony in our final statement of reasons on the regulations, so yes, there will be a response to the specific points you raised. However, we don't typically write reply letters to every witness that appears at our regulatory hearings, for obvious reasons. But if you want a direct response, staff would be happy to draft one to you in the New Year. Just let me know.
>
> Catherine Witherspoon

Again I was assured that CARB would respond to my comments in the final statement of reasons. By this time the final statement of reasons (FSOR) was due out in only a month, so I decided to wait to see what they said in it. When the FSOR came out in early January, I discovered that CARB had cherry picked a few summary quotes from my comments for their response, and had ignored every single one of the real issues that I had raised. I called the California Office of Administrative Law (OAL) which had 45 days to review and approve the ZEV rulemaking file. I wanted to let them know that CARB had failed to respond as they were required to. I was told by the OAL "reference attorney" that they could not investigate complaints such as mine. All they do is review the rulemaking file, which was huge – over 1000 pages – to see whether in their judgment CARB had followed the rules. I knew that with such a large volume of documents and no knowledge about any specific complaints, the review of the rulemaking file would no doubt result in an approval. The reference attorney went on to tell me that my only recourse after the OAL approved the rulemaking was to file a lawsuit. It appeared that my only realistic recourse was to call this oversight to CARB's attention directly to see if they would right the wrong. Here is the message I sent to the senior staff and chairman:

> **From:** Alec Brooks
> **Date:** Wed Jan 21, 2004 11:41:12 PM US/Pacific
> **To:** cwithers@arb.ca.gov
> **Cc:** abevan@arb.ca.gov, alloyd@arb.ca.gov, tcackett@arb.ca.gov, ktschogl@arb.ca.gov, jmartin@arb.ca.gov, djohnsto@arb.ca.gov
> **Subject:** ZEV FSOR did not address the issues that I raised
>
> Dear Catherine,
>
> After receiving your Dec 22 reply to my inquiry (below), I decided to wait to see how my testimony was addressed in the FSOR. Now that the FSOR is out, I have to say that I am irked (to put it mildly) that NONE of the substantive testimony I provided has been addressed! It is true that my testimony is referenced three times in the FSOR, but these are references to my concluding recommendations, not to the substantive testimony I gave that was the basis of the recommendations. I believe that this testimony was extremely relevant to the ZEV mandate, and provided a perspective that was unique. By not responding to my substantive testimony, I believe that CARB has violated the provisions of the California Administrative Procedure Act.

I feel that the information I provided was "swept under the rug" by CARB because it provided clear reasons to slow down and take a second look at whether fuel cell vehicles were really what we wanted in the state. (Similarly, it was shocking to me to see how presentation of other new information, such as the EPRI battery report, was systematically cut short during the public testimony at the March 2003 meeting).

So yes, I will take you up on your offer of a direct response. Here are a few of the areas that I would be interested in hearing CARB's take on:

Fuel cell vehicles have a range problem. Has CARB checked this out?

Using electricity to make hydrogen to power a fuel cell vehicle takes too much electricity - no one will want a vehicle that uses $9.00 worth of electricity to travel 40 miles! The Honda FCX fuelled by hydrogen produced by electrolysis takes fully four times as much electricity per mile as the battery electric Toyota RAV4EV. This is too big a difference to ignore! If we want to use renewable energy to make hydrogen, it will take four times as much land area/resource use as compared to charging battery electric vehicles.

Making hydrogen for a fuel cell vehicle from natural gas also makes no sense; because of the losses in the conversion process, it is better to make a natural gas powered hybrid vehicle and use the natural gas directly. The natural gas hybrid version would use less natural gas than would the fuel cell version, and would have 2-3 times the range using the same compressed gas tanks.

Toyota's Norihiko Nakamura is on record about fuel cell vehicles saying that a "great deal of effort is needed to bring the cost to even two to three times that of a standard vehicle". Has CARB checked with Toyota on whether Toyota really believes cost effective fuel cell vehicles are possible? CARB seems to think that automakers are saying that they think they can make a business case for fuel cell vehicles. I keep up on this field and haven't heard it quite this way from automakers. Larry Burns says "GM wants to be the first company to sell a million fuel cell vehicles". This isn't saying much. More telling are the recent remarks of Bob Lutz of GM, who is on the product side of the house. He said there was no business case for hybrids because their small extra cost can't be justified by the fuel savings. With fuel cell vehicles, you can't even tout fuel cost savings, so according to Lutz's logic, there is no way GM would ever see a business case for fuel cell vehicles. And GMs recent reclaiming of operational EV1s from willing customers and CRUSHING them (http://ev1-club.power.net/archive/031219/jpg/after2.htm) should give your a healthy skepticism about GM's commitment to bringing fuel cell vehicles to market beyond a few demo programs.

The driving range of battery electric vehicles is and will be GREATER than for fuel cell vehicles if the comparison is made on a level playing field i.e. what is available now in 2004 in each case; not comparing a hypothetical 2020 fuel cell vehicle to a ten year old existing electric vehicle. With lithium batteries available today at the same price per kWh as Panasonic lead acid EV batteries, a battery electric version of any of the fuel cell vehicles out there will have twice the driving range. (I recently remembered that about nine years ago, Daimler had developed a very nice sodium nickel chloride powered Mercedes A-class EV. Now they have a fuel cell powered A-class. Guess what? The rated range of the EV version was 250 km, and that of the fuel cell version: 150 km! This is progress?

CARBs cost data relating to producing electric vehicles is WRONG. In my testimony, I showed how Toyota could produce an EV Prius at the same cost as the hybrid Prius. I have made this point to CARB many times over several years and it has been consistently ignored. Why?

The battery report commissioned by CARB did not adequately address all types of batteries. The battery expert hired by CARB was a specialist in hybrid vehicle batteries and he did not adequately cover all the types of batteries for EVs. The EPRI report that was squelched at the March 03 meeting had some very positive news about NiMh batteries. The manufacturer of the Zebra Sodium Nickel Chloride battery published a paper at EVS20 showing the inherent low cost of this battery technology, and how it could achieve cost parity with gasoline in volume production. These batteries are proven to be durable; that nine year old Mercedes A-class EV is still reportedly running fine.

Several of you were at my Dec. 5 2002 presentation. An audio recording of it is online at
http://www.socalev.com/Sounds/CARB-AM08.mp3

My written submittal for Dec 5, 2003 workshop is at:
http://www.arb.ca.gov/msprog/zevprog/2003rule/2003rule.htm

I look forward to CARB's detailed response to these issues.

Thank you,

Alec Brooks

Catherine Witherspoon wrote back to say that CARB would send me a response by February 20. The response took the form of a cover letter and a supplement to the FSOR, which was also provided to the OAL on February 20. On the surface, the supplement appears to respond in detail and did apparently satisfy the OAL; they put their stamp of approval on the new regulations a few days later. But the supplement was a disingenuous and slipshod piece of work that merits a detailed response. Below is the supplement, with my comments indented. (Note that in CARB's quotation/summary of my original testimony, the use of "we" refers to AC Propulsion, where I was employed at the time).

State of California
Environmental Protection Agency
AIR RESOURCES BOARD

Supplement to the Final Statement of Reasons for Rulemaking,
Including Summary of Comments and Agency Responses

THE 2003 AMENDMENTS TO THE CALIFORNIA
ZERO EMISSION VEHICLE PROGRAM REGULATIONS

Public Hearing Dates: March 27-28 & April 24, 2003
Agenda Item No.: 03-02-4

One of the persons who submitted written and oral comments at the March 27-28, 2003 hearing of the Air Resources Board (ARB or Board) was Alec N. Brooks. Mr. Brooks has worked in the area of zero emission vehicles (ZEVs) for 16 years and has followed the ZEV mandate since it was originally adopted in a 1990-1991 rulemaking. At the hearing, Mr. Brooks submitted a document entitled “Comments relating to ZEV mandate for CARB Board meeting March 27, 2003.” Attached to this March 27, 2003 document was another document titled “Perspectives on Fuel Cell and Battery Electric Vehicles, [by] Alec N. Brooks, Presented at the CARB ZEV Workshop December 5, 2002.” After the Final Statement of Reasons (FSOR) was issued on January 9, 2004 and posted on the ARB’s website, Mr. Brooks expressed his concern to the ARB that the FSOR did not address the issues raised in his December 2002 workshop comments. The FSOR did summarize and respond to issues raised by Mr. Brooks’s 3-page March 27, 2003 “Comments” document.

> Not quite the truth – one of the three summarized comments in the FSOR was straight out of my December 2002 testimony, which was submitted in March 2003 as part of the same MS Word file that had the March 27 “comments” document. Here is CARBs summary of my December 2002 testimony, verbatim from the original FSOR:
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> > *<u>42. Comment</u>: The ZEV mandate should not single out fuel cell vehicles for extra large credits and should not provide credit for fuel cell infrastructure. Fuel cell and battery ZEVs should be on equal footing. (Brooks)*
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> This was what CARB deemed an appropriate summary of 12 pages of detailed testimony that contained a lot of new and relevant information.

The ARB concluded that although Mr. Brooks’s December 2002 workshop comments were originally presented before the “45-day” hearing notice was published January 10, 2003, those comments should have been addressed in the FSOR because Mr. Brooks resubmitted them as part of his March 27, 2003 presentation. Accordingly, this Supplement to the FSOR summarizes and responds to the December 2002 workshop comments of Mr. Brooks.

> This is a complete misrepresentation. CARB tries to spin it as if they didn’t initially realize they were obligated to respond to the December 22 section of the March 27 comments. Yet, as shown above, they actually <u>did</u> respond to a ludicrously abbreviated version of that specific testimony. They got caught ignoring substantial testimony, and are now trying to make it sound like an oversight.
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> When CARB submitted the rulemaking case files to the OAL in January, they had to certify under penalty of perjury that the rulemaking record was complete and closed. They did this knowing full well that they had failed to respond to my testimony. When the supplement was filed with the OAL on February 20, CARB included a new

> certification of the rulemaking record, presumably certifying again under penalty of perjury that the rulemaking record was really complete this time. In my view, it is still incomplete, as they have still failed to address the key points that I raised.

Preliminarily, it is important to note that the recommendations submitted by Mr. Brooks and other battery electric vehicle (EV) advocates prompted the Board to include significant modifications designed to promote the continued development of battery EVs. These modifications include allowing battery EVs to meet half of the alternative compliance path (see Section II.B.1.(c)(iii) of the FSOR, p. 21) and providing additional credits to existing battery EVs to promote their continued use (see Section II.B.10 of the FSOR, p.34.) In addition, the regulation provides equal credit for all pure ZEV technologies beginning in model year 2012.

As with all advanced technologies, there is a tremendous uncertainty in the pace of development and technological breakthroughs. The far-reaching nature of the ZEV program has both pushed technology and created the need for mid-course changes. The Board's focus on fuel cell vehicles represents the long-term commitment to commercially viable pure ZEVs.

> How does CARB know that they should be focusing on fuel cell vehicles as the best ZEV solution? What evidence do they have of commercial viability? How to they rationalize selecting a ZEV technology that uses four times as much electricity as ZEVs that have already been successfully deployed? The best evidence CARB could cite in the FSOR was this: "Manufacturers appear to believe there is a business case for fuel cell development". That is exactly what the auto manufacturers want CARB to think – that they <u>appear</u> to think there is a business case. This "appearance" is being used as an excuse to let them continue in the near term without making any real ZEVs or increasing fuel economy. "Just be patient – we have this great new technology that will solve all the problems, just free us up from doing anything real now so we can work unfettered toward the holy grail."

The Board will rely on an Independent Expert Review Panel to assess the progress made in pursuing this goal, and will have the opportunity to make further adjustments as necessary.

S-1. <u>Comment</u>: It appears that CARB has effectively given up on battery EVs, and is placing a high risk bet that fuel cell vehicles will in fact become practical in the future. While this may happen, it is not at all certain. First – what about driving range and efficiency of fuel cell vehicles – where is the data? There was recently a rally for fuel cell vehicles driving down Highway 1 between Monterey and Santa Barbara, a distance of 250 miles. There were <u>four</u> refueling stops set up along the way. The California Fuel Cell Partnership 2001 highlights showed 754 hydrogen refueling events for the 34,000 miles covered by the fuel cell vehicle fleet, or about 45 miles on average between refuelings. Actual range and hydrogen consumption data are very closely held, but there are some indications that might indicate that there are problems with range and efficiency. (Alec Brooks)

Agency Response: As noted in the comment, the range of current prototype fuel cell vehicles is closely guarded and would appear to be below that needed for commercialization. ARB acknowledges that storing adequate amounts for hydrogen as compressed gas is technically very difficult because of the large volume required. Research and development efforts are ongoing to resolve this issue with promising work in a variety of storage technologies including metal hydride, nanotube, and liquid storage. Additionally, relatively short range is mitigated by fast fueling, making hydrogen fuel cell vehicles more attractive. The Independent Expert Review Panel will evaluate this issue as part of its review and suggest changes if necessary.

> So CARB does acknowledge the range problem of fuel cell vehicles. But why is it such a secret what these vehicles can really do in real world driving? Surely CARB must know the data from their close ties with the California Fuel Cell Partnership. Why not 'open the books and let the sun shine in'? CARB should spell out the details of the 'promising work' on the other hydrogen storage technologies they cite. Liquid hydrogen storage has been tried and rejected as too impractical, and has even worse energy efficiency than gaseous hydrogen. Metal hydrides are so heavy that the end result is no better than lithium batteries for energy storage. Finally, the belief that fast fuelling makes a short range hydrogen vehicle more attractive than a longer range EV doesn't hold up. Fast refueling is relative. With normal usage of an EV, a driver spends on the order of 15 seconds every day plugging and unplugging – about the same as plugging in a cell phone. If the vehicle is driven 40 miles a day, then the effective personal inconvenience time associated with recharging is one minute for every 160 miles covered, or 160 miles/minute. A Prius refueling at a gas station recovers range at twice that rate, but with the overhead of the transaction and stopping at the gas station, the overall rate is about the same as an EV.
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> But the story is far worse with the 'fast fuelling' fuel cell vehicle. First of all, with fast fuelling, you don't get a full tank of hydrogen because of the temperature rise in the hydrogen caused by the fast fuelling. You can only fill the tank all the way up with a 'slow fill', which takes as long as recharging an EV. Unlike an EV that can be recharged at home every day, with a fuel cell vehicle you'd have to go well out of your way every 120 miles or so to find a hydrogen fuelling station and then wait 5-10 minutes for that partially-full "fast fill". At a Toyota event for the new Prius, I talked to Greg Kelly, president and CEO of Orthodyne Electronics in Irvine, about his experiences as a daily driver of Toyota's FCHV fuel cell vehicle. He said he filled up every two or three days, and it took just over 10 minutes. I asked what the farthest he had driven on a tank was. The answer: about 120 miles. So with extra travel time to go to a fuelling station of, say, only 5 minutes and a refuel time of 10 minutes, we have 15 minutes of personal inconvenience time for every 120 miles traveled, a rate of only 8 miles per minute, 15 times worse than an EV or Prius! Would people put up with a car that took so much time and effort to keep fueled? It is hard to see how CARB rationalizes that a low range

vehicle with slow refueling relative to a gasoline car could be more desirable than an EV with more range and that can be recharged at home at a fraction of the cost.

S-2. Comment: The range problem might be overcome by a future hydrogen storage breakthrough that would allow enough hydrogen on board to match the range of what drivers are used to. But what about fuel economy? How much hydrogen do fuel cell vehicles consume per mile traveled? This is a more important metric than how efficient a fuel cell stack is at a particular operating point. Mr. Norihiko Nakamura, Toyota Executive Advisory Engineer for fuel cell development, said at the 2002 Future Car Congress that the best fuel economy that fuel cell vehicles can achieve is about 62 miles per kilogram of hydrogen (or about 62 miles per gallon equivalent). But today's hybrid vehicles, the Honda Civic and Toyota Prius, essentially match these numbers with 57 and 58 miles per gallon uncorrected combined EPA ratings. A benefit of the CNG hybrid version is that the driving range would be a whole lot better. Even though it uses on-board fuel energy at a 42 mile per gallon equivalent rate vs. 64 for the fuel cell vehicle, the same tanks would hold about 3.2 times more energy in natural gas as compared to hydrogen. This would yield a driving range that would be 2.1 times greater, or about 400 miles. (Alec Brooks)

Agency Response: Fuel cell vehicles offer zero-direct emissions as well as higher vehicle efficiency as noted in the comment. Unlike the hybrid vehicles mentioned, fuel cell vehicle emissions will not deteriorate over time. While the requirements for partial ZEV allowance vehicles (PZEVs) ensure that the vehicles have an emissions warranty for 15 years or 150,000 miles, the vehicle is ultimately susceptible to becoming a gross polluter if not maintained after this period.

> CARB is too focused on direct tailpipe emissions. On a total fuel cycle basis, the US DOE GREET model shows that hydrogen production produces 12.5 kilograms of CO_2 per kilogram of hydrogen produced from natural gas at a refueling station, and 11.5 grams of urban NO_x. So with a fuel cell vehicle that gets, generously, 50 miles per kilogram of hydrogen, the CO_2 emissions are 250 grams/mile and NO_x 0.23 grams/mile. For hydrogen made with electricity, with the average mix of California electricity generation, these numbers are much higher at 548 grams/mile CO_2 and 0.53 g/mi NO_x. By contrast, on a total fuel cycle basis, a hypothetical 50 mpg natural gas SULEV hybrid vehicle would produce only 157 grams/mile CO_2, and 0.11 grams/mile NO_x – far lower than the hydrogen version. Even a gasoline-powered 50 mpg SULEV is better than either mode of making hydrogen for fuel cell vehicles, with emissions of just at 212 g/mi CO_2 and 0.12 g/mi NO_x (again on a full fuel cycle basis). CARB is saying that a fuel cell vehicle is preferable to a SULEV CNG vehicle, even though it has NO_x emissions that are 2 to 4 times greater, and CO_2 emissions that are 1.6 to 3 times greater.
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> Natural gas powered SULEVS are about as clean as they come for ICE powered vehicles. As ILEVs, (inherently low emission vehicles) they are considered clean enough to merit solo carpool lane access in California.

S-3. Comment: The popular long-term vision for fuel cell vehicles is that the hydrogen would be made by electrolysis with renewable electricity. The flaw in this argument is that it is not fair to claim the cleanest form of electricity generation to a particular type of load, leaving the dirtier electricity generation to everyone else. Calculations of the upstream emissions associated with recharging battery electric vehicles are usually based on the average power mix; not by singling out the cleanest electricity just for battery EVs. All forms of generation involve some form of impact; there is always something about any form of generation that someone won't like. (Alec Brooks)

Agency Response: ARB has always based its estimates of upstream emissions from battery EVs on marginal emissions in the South Coast Air Basin. Under the assumptions used most recently by the California Energy Commission, electricity produced for battery EVs would come from extremely clean natural gas turbines. ARB would use the same process for determining the upstream emissions from fuel cell vehicles. And, like electricity, the ability to obtain hydrogen from clean renewable sources makes it especially attractive as a transportation fuel.

> It is good to see that CARB intends to evaluate upstream emissions from electrolysis using the same emissions factors that they use for EVs. They will of course find that fuel cell vehicles powered by hydrogen made with electrolysis have four times the pollution and CO_2 emissions as EVs. But curiously, in the last sentence of their response, they fall into the same trap that they said immediately before that they wouldn't – they say that the hydrogen can be made from clean renewable sources. But those same clean renewable resources can also be used for other purposes. If renewable electricity is diverted to make hydrogen, other non-renewable powerplants will have to make up for the diverted power. Another way to look at it: if the renewable energy slated to make hydrogen was instead used to charge EVs (or plug-in hybrids), only 25% of it would be needed to provide the same number of miles of travel; the other 75% of the energy would be freed up to offset combustion-based generation and prevent the associated emissions.
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> It is interesting to calculate the in-basin emissions from the "extremely clean natural gas turbines" that CARB says would be making the electricity to make the hydrogen. The California Energy Commission cites the best powerplant NOx emissions available (or Best Available Control Technology, or BACT) as 0.078 pounds per megawatt hour of generation. Converted to different units, the value is 0.0354 grams/kWh. Making and compressing hydrogen takes 63 kWh per kilogram of hydrogen, so the associated emissions are 63 x 0.0354 = 2.23 grams of NOx per kg of hydrogen produced. An efficient fuel cell vehicle will travel 50 miles per kg of hydrogen, resulting in 2.23/50 = 0.045 grams per mile of in-basin NOx emissions. This is greater than the SULEV NOx standard of 0.020 grams/mile for gasoline powered vehicles! And this is for the very best powerplant; the average power generation in California emits 12 times as much NOx as the BACT level. A similar sized battery electric vehicle, which uses only one quarter of the electricity per mile, would result in 0.011 grams of NOx per mile, convincingly below the SULEV standard.

S-4. Comment: Making hydrogen with electricity is very inefficient. Compared with battery electric vehicles, electricity consumption will be from 3 to 6 times higher per mile. (Alec Brooks)

Agency Response: The Board agrees that the cost-effective and clean production of hydrogen and the efficient use of that hydrogen in the fuel cell vehicle are critical to improving any adverse impacts from fuel cell vehicles. Research is ongoing worldwide to develop efficient and clean techniques for hydrogen production.

> This is a particularly evasive response. They are saying that they agree with something that I did not say. When confronted with clear evidence that electricity consumption will be four times higher with fuel cell vehicles this is all they can say? Do they think it is OK to use this much energy? And what is this "critical to improving any adverse impacts from fuel cell vehicles". Fuel cell vehicles are supposedly being developed to prevent adverse impacts, not cause them! Another curious aspect of all of this is greenhouse gas emissions. CARB is on the hook to implement AB 1493, which requires that they develop regulations to limit greenhouse gas emissions from passenger cars. Yet here they are pursuing a ZEV strategy that has four times the greenhouse gas emissions of battery EVs. In fact, the 548 grams/mile greenhouse gas emissions from making hydrogen for a 50 miles/kg fuel cell vehicle is the same as for gasoline powered vehicle that gets only 19 mpg! CARB is breaking the same law that they are charged with implementing!

S-5. Comment: Making hydrogen for a fuel cell vehicle from natural gas also makes no sense due to the losses in the conversion process. It is better to make a natural gas powered hybrid vehicle and use the natural gas directly. When hydrogen is produced from natural gas, fuel cell vehicles can, at best, only match the fuel economy of a comparable natural gas hybrid vehicle, and will have less than half the driving range for given tank volume and pressure. (Alec Brooks)

Agency Response: The primary focus of the ZEV program is the commercialization of a pure ZEV for use in urban centers not meeting air quality standards. The ZEV program acknowledges the environmental benefits of other technologies such as natural gas vehicles and has provided incentives to encourage their development as part of the ZEV program. As discussed in the response to Comment 2, the ZEV regulation is focused on air quality. Fuel cell vehicles provide zero tailpipe emissions where compressed natural gas hybrids do not.

> If the hydrogen is produced from natural gas at refueling stations, which by definition have to be located in those same urban areas where the vehicles drive, there are associated emissions that are just as local as a vehicles' tailpipe. As noted previously, the urban NOx emissions from making hydrogen from natural gas for a 50 m/kg fuel cell vehicle would be 0.23 g/mile, which is about 12 times higher than the SULEV NOx tailpipe standard.

S-6. Comment: And finally, there is the cost issue. If there are concerns that battery electric vehicles are too expensive to manufacture, there should be even greater concerns about fuel cell vehicles. (Alec Brooks)

Agency Response: ARB agrees that significant cost reductions are needed before fuel cell vehicles are able to compete in the marketplace. Automakers worldwide are now developing components and subsystems that have the potential for being mass-produced at low cost. The staged approach of the alternative compliance path is designed to address the relative cost of each stage of development. Time is needed to determine if the cost targets for commercialization can be met. Finally, the Independent Expert Review Panel will closely evaluate this issue as part of the Panel's review.

> Where is CARB's evidence of the potential for low cost manufacturing of fuel cell vehicles? Toyota has said pretty much the opposite – only after a great deal of work will they be able to produce a fuel cell vehicle for two to three times the cost of a conventional vehicle. CARB's statement that "time is needed to determine if the cost targets for commercialization can be met" sounds like it was written by the Alliance of Auto Manufacturers. What they are really saying is: we'll give automakers what they want: 10 or 20 years to do some demo programs with fuel cell vehicles before they come back and tell us they cost too much. In the meantime they don't have to do anything with ZEVs that actually work and can be placed with real drivers. The same kind of language is in the DOE's hydrogen roadmap: David Garman, assistant secretary EERE, DOE, to Congress March 2003:
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>> *"The Plan identifies specific technology goals and milestones that would accelerate hydrogen and fuel cell development to enable an industry commercialization decision by 2015."*
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> This is giving the auto industry what they want: "Give us relief from doing anything that will be useful in the near term so we can devote all our resources to this great future technology". In exchange for making a few fuel cell vehicles they won't need to worry about more stringent fuel economy standards and making zero emission vehicles for real customers.

S-7. Comment: There has been some disappointment expressed by members of the Board that battery technology for electric vehicles hasn't progressed nearly as much as had been hoped. The reality is that battery technology has progressed significantly in the last decade. But vehicle manufacturers haven't been applying that technology in new products. (Alec Brooks)

Agency Response: The near-term focus of the ZEV program has been on battery EVs. While technically mature and well suited from a performance standpoint for many applications, battery EVs face severe cost challenges. As noted in the FSOR, ARB contracted with Dr. Anderman Menahem to determine if recent improvements in battery technology were significant enough to change this fundamentally issue. While ARB does not dispute that improvements have occurred during the last decade, the Board has found that the technology is still not ready for widespread commercialization. See the response to Comment 1 and Section II.B.1 of the FSOR.

> "Battery EVs face severe cost challenges"? There are certainly some cost issues for early low volume EVs. But how can they say EVs have severe cost challenges when they are promoting fuel cell vehicles? If CARB says EVs have severe cost challenges, they will have to think up a whole new superlative to describe the cost challenges of fuel cell vehicles. (Maybe they could use: "super-ultra-severe" cost challenges?) Toyota doesn't see a pathway to make fuel vehicles that are less than double to triple the cost of conventional vehicles. The hydrogen fuel will cost anywhere from $5.00 to $10.00 per kilogram, good for 50 miles or so. (An EV uses about $1.30 in electricity to go 50 miles). And CARB says EVs have <u>severe</u> cost challenges?
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> You can tell by CARB's stated purpose of the contract with Dr. Anderman that they knew in advance what result they wanted: "to determine if recent improvements in battery technology were significant enough to change this fundamentally (sic) issue".
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> At a Washington D.C. conference in January 2004, Alan Lloyd had this to say about battery electric vehicles:
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> > *"And again, people said to me recently, well, you gave up on battery electrics too early. You haven't seen the recent advances in nickel, uh, on lithium ion batteries. And we say, well, we have a technology review coming up in a few years. If, in fact, your predictions come true, then clearly the auto companies are going to be looking at that as a viable option as well."*
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> Lloyd slipped up by starting to mention nickel metal hydride batteries. He <u>had</u> in fact seen the data on the exceptional durability these batteries had shown in operation in the Toyota RAV4 EV. A March 2003 EPRI report, "Advanced Batteries for Electric-Drive Vehicles", described how nickel metal hydride batteries were lasting longer in EV use than CARB had been assuming:
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> > *"This study concludes that NiMH batteries from the top manufacturers appear to significantly exceed previous projections by ARB staff for cycle life and durability. It is highly probable that NiMH batteries can be designed, using current technologies, to meet the vehicle lifetime requirements of full-function battery EVs, city EVs, and plug-in HEVs. This significant development could mean that only one battery pack per vehicle is required for the life of that vehicle, not two as previously projected."*
> >
> > *"This new information on NiMH battery life indicates that the cost-effectiveness of many types of electric-drive vehicles has improved and can lead to life cycle cost parity of BEVs and PHEVs with conventional vehicles."*

One of the principal investigators for this report was Dr. Fritz Kalhammer, who was also the leader of the battery technology advisory panel that produced the 2000 battery report for CARB. The EPRI report should have been seen by CARB as new and important information. But CARB wanted nothing of it. At the March 2003 board meeting Alan Lloyd gave automakers as much time as they wanted to testify. But when Lou Browning went up to present the results of the new EPRI battery study, he was brusquely told by Lloyd he had only three minutes to make his presention. Menachem Anderman, CARB's paid consultant, was allowed 15 minutes earlier in the day. Lloyd's treatment of the two of them presents a stark contrast:

> ***DR. ANDERMAN: Fifteen minutes, I was told.***
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> ***CHAIRPERSON LLOYD: Well, I'm not going to disagree with staff if they told you 15 minutes.***

The staff had arranged in advance with Lou Browning that he would have 10 minutes:

> ***CHAIRPERSON LLOYD: Dr. Browning, again, I've read your conclusions. I would appreciate if you could summarize this in three minutes.***
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> ***DR. BROWNING: In three? Oh, okay.***
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> ***CHAIRPERSON LLOYD: Well, because the way I read the conclusion is very similar to Dr. Frank's.***
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> ***DR. BROWNING: I thought I had 10.***

Lloyd was clearly in no mood to hear anything positive about batteries.

CARB is saying with regard to batteries: "the technology is still not ready for widespread commercialization". But batteries <u>are</u> ready for initial commercialization, leading to higher volume over time. Does CARB believe that fuel cell vehicles will suddenly show up one day ready for mass commercialization, without having gone through a period of higher cost early commercialization? Why does CARB say that to be viable at all, batteries have to already be ready for mass commercialization? It should be noted that we are not talking about immediate mass commercialization for either fuel cell or battery electric vehicles. Instead there will be a gradual ramp up of volume.

<u>S-8. Comment</u>: It is interesting to look at what kinds of battery vehicles we could have had by now and to compare them with fuel cell vehicles. Three specific battery types that compare favorably to fuel cell vehicles include lead acid, sodium nickel chloride and lithium ion. (Alec Brooks)

<u>Agency Response</u>: ARB contracted with Dr. Anderman to review the status of those battery technologies currently used in battery EVs and which are at a stage of development where it would be possible to produce them in larger quantities if cost targets are met. While Dr. Anderman has more recently focused on issues related to

battery chemistries used in hybrid EVs, he has extensive experience as a consultant in development assessment and application of battery technologies. This experience included participation on the Battery Technical Advisory Panel of 2000.

Throughout the ZEV program's history, ARB staff has met with battery developers to review advances in technology. During this latest regulatory process, no battery developers approached ARB with new information that would fundamentally alter the cost and performance situation.

> Not true. MES-DEA, the Swiss Company that makes the Zebra battery wrote to CARB with information that there had been an investment of $66M in their battery manufacturing facility, and that they were ready to deliver assembled battery packs of 120 Wh/kg Zebra batteries at a volume price of $220/kWh. This does fundamentally alter CARBs cost assumptions. CARB had this information and chose to ignore it. A 20 kWh pack that lasts 150,000 miles would cost $4,400. An EV with this pack could be cheaper to operate than the average gasoline powered car. A paper from MES-DEA at an industry conference in late 2003 showed that in very high volumes, the battery pack price could be as low as $100/kWh.

Regarding the three technologies identified in the comment, Dr. Anderman did assess developments in advanced lead acid as part of his review. He concluded that although battery life has been slightly improved, there have been no significant changes in specific energy, cost, or life. Dr. Anderman also reviewed the latest development in lithium ion and concluded that current batteries do not have adequate durability, and their safety under severe abuse is not yet proven. Moreover, he concluded that, even in true mass production, the cost of the technology is unlikely to drop below cost of nickel metal hydride without advances in material and manufacturing technology. As for sodium nickel chloride, Dr. Anderman did not specifically address this technology. However, the use of sodium nickel chloride in battery EVs has not been seriously considered by automakers due to additional costs and concerns associated with the high temperature operation of the battery.

> Regarding lead acid batteries: In their summarization of my comments CARB left out that I had showed an example of a full function powerful freeway capable EV that used only $1400-worth of lead acid batteries. Part of the problem of the original battery technology advisory panel report from 2000 was that it overstepped the panel's charter by weighing in on vehicle energy consumption issues. At the September 2000 CARB meeting, the panel indicated that EVs would use 300 to 330 Watt-hours/mile of DC energy from the battery. The panel members may have been experts on battery technology but they were not experts on electric vehicle energy efficiency. The original Impact EV had energy consumption of only 120 Wh/mile. Efficient four-door lead acid conversion vehicles have DC energy consumption of under 200 Watt-hours/mile. Rather than just report on batteries, the panel reported uninformed and incorrect numbers for the energy consumption of electric vehicles. The significance of the error is that the report rejected lead acid batteries as not having enough energy to be viable, and overestimated the energy capacity needed for a vehicle (and hence battery cost) by more than 50

percent. It is in fact quite feasible to make a useful electric vehicle with low cost lead acid batteries.

Anderman's recent supplemental report did not adequately report on the current price of high volume small lithium cells as used in laptop computers. I had presented first hand data in December 2002 that these lithium cells had been procured in quantity sufficient for a single electric vehicle at a price per kilowatt-hour <u>less</u> than that of Panasonic lead acid EV batteries. At the time, I suggested that there were no apparent barriers to using these same small cells for EVs. AC Propulsion subsequently proved that these batteries are suitable for electric vehicles by developing a packaging system and installing a pack in the tzero. The lithium ion tzero has a driving range of 300 miles, and can drive from Los Angeles to Las Vegas without stopping to charge.

CARB's dismissal of sodium nickel chloride (Zebra) batteries demonstrates their ignorance of recent history. Their statement "the use of sodium nickel chloride in battery EVs has not been seriously considered by automakers due to additional costs and concerns associated with the high temperature operation of the battery" is just plain false. In 1997, before the Daimler and Chrysler merger, Daimler had developed a very nice A-class EV powered by the Zebra battery. It was rated at more than 125 miles range in real world driving. (DaimlerChrysler's recent fuel cell vehicle the F-cell is also based on the A-Class. Guess what? Its range is rated at only 90 miles!) In 1997, Daimler published an eight-page color brochure that explains in great detail the rationale for this car and its sodium nickel chloride battery system. After explaining how robust and durable the Zebra battery is, Daimler concluded with:

> *"Thanks to the ZEBRA battery system, the electric drive train has been able to shake off many of its drawbacks vis a vis conventional internal combustion engines. Consequently, there is no longer any need for compromises in utility. Drivers can simply sit back and enjoy the pleasure of driving a quiet, comfortable car that is not only easy to operate, but produces no harmful exhaust emissions when running."*

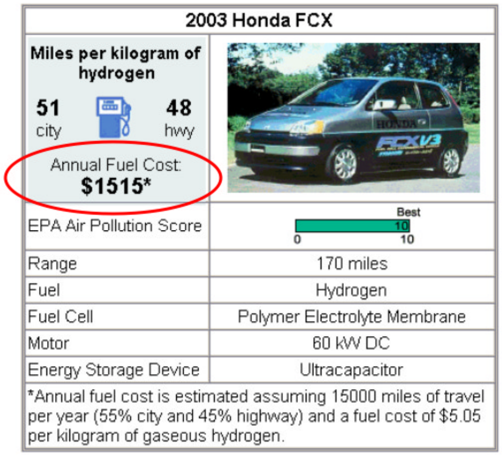
By the way, the ZEBRA battery has been improved since that vehicle was made. Back then the specific energy was rated at 81 Wh/kg. Now ZEBRA batteries are achieving 120 Watt-hours/kg. That same vehicle with a current technology ZEBRA battery would have 180 miles driving range, double that of the fuel cell version! (The A-class EV program was unfortunately cancelled after the Daimler and Chrysler merger; EVs would be developed on the US side of the merged company.)

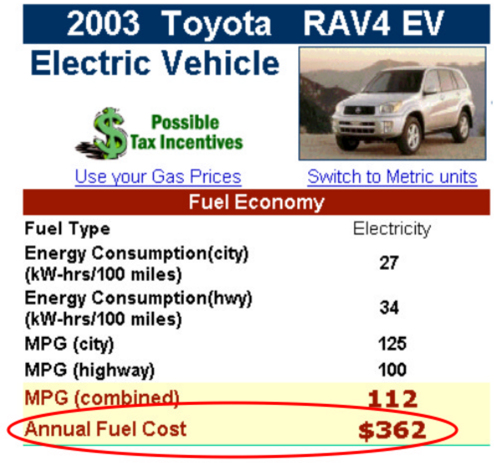
S-9. Comment: Battery electric vehicles based on the same platform as fuel cell vehicles can have greater range than the fuel cell version if latest battery technology is employed. We've looked at putting a pack of lithium ion cells into the Prius EV described above. The energy on board would be about 34 kilowatt-hours and the vehicle weight would be about the same as the stock Prius. Range would be between 160 and 200 miles. If the Prius EV were loaded down with more lithium batteries to equal the weight of the Focus fuel cell vehicle, it would have 400 miles range. How about a battery electric Toyota Highlander? Even with many special lightweight body components, the fuel cell vehicle weighs in at 4100 pounds, 616 pounds more than a 4 cylinder Highlander. An all-electric 4100 pound Highlander employing lithium ion batteries would have a range of more than 300 miles. (Alec Brooks)

Agency Response: We agree that current battery EVs can have greater range than the prototype fuel cell vehicles being demonstrated. We expect that fuel cell range will improve substantially as progress is made in system efficiency and hydrogen storage. These improvements, coupled with the relatively quick refueling capability of the technology, are expected to make fuel cell vehicles attractive to consumers.

> CARB admits that, with current technology for both battery and fuel cell vehicles, battery vehicles can have greater range than fuel cell vehicles. But then they go on to say that that improved fuel cell vehicles will be attractive to consumers. But they leave un-addressed whether improved EVs will be even more attractive to consumers. As noted earlier, the personal inconvenience time associated with fuelling a fuel cell vehicle is far larger than for battery EVs or gasoline vehicles. And the per-mile fuelling cost will be four times more for the fuel cell vehicle. Just look at the EPA's annual fuel cost

estimates to drive 15000 miles for the Honda FCX fuel cell vehicle and the Toyota RAV4 EV:





S-10. <u>Comment</u>: To demonstrate the type of EV that could be made with the ZEBRA battery, we have developed a concept based on the Prius. The manufactured cost would be very close to that of the standard hybrid Prius, possibly lower. The vehicle weight would be about the same as the standard Prius too. Toyota could produce a battery EV Prius at the same cost as the hybrid Prius. (Alec Brooks)

<u>Agency Response</u>: According to Toyota, the latest generation of the Toyota Prius is being sold at a retail price premium of $1,500 – if one compares it to what a similar-sized, similarly equipped Toyota would sell for. If it were redesigned as a City EV and carried a 15-kilowatt hour of batteries at an eventual large volume price of $300/kilowatt hour, that would amount to $4,500 additional manufacturing cost (not retail). This difference is more than what would be saved by deleting the Prius engine and fuel system.

CARB's response missed my point. First of all, the retail price premium of a Prius over some other Toyota vehicle has nothing to do with what I said. What I said was that Toyota could manufacture a Zebra-battery-powered EV based on the Prius and that the manufacturing cost would be about the same as that of the standard Prius. In my December 02 testimony I noted that the manufacturer of the ZEBRA battery had quoted a volume price for packs (not cells) of $220/kWh. This same information was also communicated directly to CARB in a January 2003 letter from Cord Dustmann, head of the ZEBRA battery product line at MES-DEA. So, with the data CARB had for this battery, in their example above they should have shown a battery price of 15*220 = $3,300, not $4,500. CARB also forgot that in addition to the engine and fuel system, the Prius hybrid battery pack would also be deleted for the EV version. So the incremental manufacturing cost of the EV Prius would be $3300 for the EV battery pack, less the cost of the hybrid battery pack, engine, fuel system, cooling system, and emissions and exhaust systems. It is very likely that the cost savings from all of these deleted components could easily be as much as the $3,300 battery pack cost.

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Summary of CARB's Responses

CARB's response to the issues I raised has the overall appearance of grasping at straws. They continue to ignore every bit of good news about batteries, and cling to the conclusions of the 2000 battery report, which in itself was flawed as it related to vehicle energy consumption. They brush aside the issue of energy consumption of fuel cell vehicles being too high; high enough that consumers would reject fuel cell vehicles solely on the cost of the fuel. They brush aside the range problems of fuel cell vehicles, saying that there are promising hydrogen storage solutions just around the corner. They say that automakers "appear" to think there is a business case for fuel cell vehicles, but they don't wonder how this squares with automakers' unwillingness to put battery electric ZEV's on the market now and with statements by GM that hybrids don't make business sense for them or their customers.

CARB has decided that neither battery electric nor fuel cell vehicles are ready for mass production and that "time is needed" to see if they will suddenly be ready at some point in the future. They say this despite a generally positive track record for battery electric vehicles that were, and in some cases still are, in use in California. Southern California Edison operates a large fleet of EVs, some of which have passed 100,000 miles on the original battery pack. CARB now says that ZEVs should only be in very small demo programs unless they are ready for mass production. What happened to a phased rollout of vehicles with the recognition that in the beginning the technology won't be ready for mass production?   CARB's strategy now is to allow automakers to stop making real ZEVs for real customers, in exchange for working up a handful of fuel cell vehicles for demo programs. In another five or ten years, CARB's expert review panel will 'discover' that fuel cell vehicles aren't ready for mass production either. A battery supplier summed up the situation as follows: "The sole interpretation I have on the decisions made by the automotive companies is that they found a way to 'fool' CARB for another few years in order to do something reasonable as late as possible."

The Decline of the ZEV Program

Throughout the 1990's CARB spearheaded a bold program to compel automakers to produce zero emission vehicles. A great deal of effort was expended by CARB staff, stakeholders, auto companies, and local agencies. A lot of money was spent to begin installing a public recharging infrastructure. Stakeholder meetings were held. Vehicles started to appear. But automakers didn't have their hearts in it. EVs from Nissan, Toyota, and DaimlerChrysler were not made available to retail customers. Honda offered their EVplus at so few dealers that it was a practical choice only for people that lived nearby, limiting the market. GM, on the other hand, made a giant splash with the EV1, launching it at all Saturn Dealers in several major market areas. EV1 ads were everywhere – billboards, newspapers, magazines, even one television ad. But somehow the ads always seemed a little off – as if they weren't actually trying to sell the car.

The ads didn't mention where to go to get one; they didn't show people driving the cars. There is ample testimony on the record at CARB from people who were interested in the EV1, but were either turned away at Saturn dealers, or were discouraged by salespeople. GM also cultivated an image that the EV1 was for rich or famous people. One lessee explained how, in the interview process, he had to prove to GM that he was enough of a "high profile individual' to be allowed to lease an EV1. Collectively the marketing actions of GM, Honda, and Ford didn't appear to be building a real market for EVs. Instead, it appeared that the effort was aimed at spending a lot of marketing money while not moving many cars.

But one thing didn't go according to plan for the automakers. People that drove EVs actually liked them – a lot. A growing chorus was heard from people who wanted EVs but couldn't get them. The automakers have tried their best to explain the demand away – 'sure there are enthusiastic drivers, but these people are on the fringe'. In a 'lessons learned' page on GM's web site they (cynically) lament that they were not able to find enough customers:

> *"EV1 owners are a proud, loyal group. Unfortunately, there were not enough of them. GM was able to lease only about 800 EV1s in four years -- not enough to establish commercial viability."*

I learned of GM's real EV1 strategy at the EV1's birthday party at Universal City on December 5, 1999. GM threw this lavish bash to celebrate the EV1's third birthday and to make the first deliveries of the new Gen II EV1 which had been delayed about a year due to unspecified development problems. As GM officials were ceremoniously handing over the keys to the beaming EV1 drivers, I chatted about the EV1 program with one of the GM executives present. What he said startled me, but it shouldn't have because it confirmed what I had expected: Those full page newspaper ads were not intended to sell cars and there was no way that GM was ever going to make any more EV1's after the current batch of Gen II's, no way, no how. He said they would fight CARB all the way to the Supreme Court if they had to. There was of course quite a contrast between the uplifting party atmosphere celebrating the EV1 and the GM's real plan for the demise of the EV1.

Why Did CARB Cave on Battery Electric Vehicles?

Alan Lloyd ran the March 2003 CARB meeting as a man with a mission. He knew what he wanted – which was to adopt the alternate compliance path that would allow automakers to meet all of their ZEV requirements with a handful of fuel cell vehicles. He was clearly almost hostile to any new testimony that would undermine this proposal. He pushed back suggestions by other board members that perhaps the number of vehicles in the alternate compliance path should be larger and that maybe some of them should be battery electric vehicles (or BEVs as they called them). There was a suggestion that some number of BEVs could be substituted, with a ceiling on the number, but not a floor. The number of BEVs would be determined by a contorted 'fuel cell equivalent' scaling. The 'equivalence' was to be an equivalent cost of compliance; since fuel cell vehicles were assumed to cost $1 million each, something like 10 or 20 BEVs would have to be produced to be the 'equivalent' of a fuel cell vehicle. CARB's twisted logic goes like this: fuel cell vehicles are incredibly expensive, so one fuel cell vehicle in a demo program will be counted in the ZEV program as equally good as 10 or 20 battery electric vehicles in real customer usage.

The result of that March meeting was that Alan Lloyd didn't get what he wanted. There were many questions and concerns raised by some of the other board members, so a vote on the proposed new regulations was deferred until the next meeting, scheduled for April 24. This gave the staff time to come back with answers to the questions raised.

After the March meeting, I decided to talk to a couple of board members that had showed some resistance to Lloyd's plan. I set up appointments to talk by phone with Dorene D'Adamo and Matt McKinnon. My goal in speaking with them was to go over the written testimony I had submitted for the March board meeting. I had, perhaps naively, assumed that the board members had read my written testimony. The CARB web site instructions for written testimony says:

> *If you have provided written comments on any agenda item, your submission is in the public record. Board members receive copies immediately and read them as they arrive.*

In my calls with D'Adamo and McKinnon, they apologized for not having read my testimony and assured me that they would before the April meeting. (It wasn't all that surprising that they hadn't read it – they noted that a very large quantity of written comments had been submitted). I discussed with them the main points of my submission, and found them to be quite open and interested. I got the sense that each of them was uncomfortable with the direction the rulemaking was heading. In talking with them, I got a better understanding of how the board usually operates. It was described to me as a 'collegial' board, whereby individual board members usually look to the Chairman for the direction of the board's policies. It was quite unusual for board members to vote in opposition to the chairman. After speaking with them, it was clear that it was not going to be possible to get a majority of the board members to vote in opposition to what Lloyd wanted.

At the April board meeting, D'Adamo, McKinnon, and Mark DeSaulnier demonstrated their thoughtful consideration of the proposed rules by voting in opposition to Lloyd's plan.

From the September 2001 board meeting when the entire board strongly backed keeping a real ZEV program up through the March 2003 board meeting, Lloyd had made a slow, but complete reversal of his earlier strong support of a ZEV program that would put real vehicles into the marketplace in the near term. Although Lloyd was known as a fuel cell partisan since his days as chief scientist at the South Coast Air Quality Management District, he had shown strong support for battery EVs. But by March 2003 he had changed his tune, and to many he appeared to be caving in to the wishes of the auto industry. It was inexplicable. But a series of events around that time frame sheds some light on what may have influenced his thinking.

In early 2003, Lloyd became the Chairman of the California Fuel Cell Partnership. He had been the driving force behind the formation of the Partnership and he clearly relished the stature of California being perceived worldwide as the focal point for fuel cell vehicles. On March 5, 2003, he testified about the Partnership in Washington D.C. at a hearing of the House Committee on Science.

The new ZEV rules were originally supposed to be considered by CARB at the February 2003 board meeting. But in January, it was announced that the February meeting would be delayed until March 23 in order to provide more time to make changes and for additional public comment.

Then at the February 2003 meeting of the California Fuel Cell Partnership steering team, several automakers dragged their feet about committing to a renewal of their participation in the Partnership. Meanwhile, back in Michigan, an initiative called NextEnergy was aiming to make Michigan the center for fuel cell vehicle development and component manufacturing, setting up a competition with California for the attention of the automakers and their fuel cell vehicles. An Automotive News headline from March 10, 2003 summed it up: “California, Michigan and Ohio are jockeying for the title of "fuel cell state."

The word on the street was that several automakers were going to jump ship from the California Fuel Cell Partnership and take their fuel cell vehicles back to Michigan if they didn’t get the ZEV rules that they wanted. (What they wanted was to be allowed to meet all of their ZEV requirements with a small number of fuel cell vehicles over a number of years, with no requirement to make any more battery electric vehicles.)

In early April, there was some scrambling at CARB when a planned April 22, 2003 earth day event with the governor to tout the Fuel Cell partnership had to be cancelled. Some of the automakers in the Partnership were balking at participating. The automakers hadn’t gotten the ZEV rules that they wanted at the March meeting because the vote had been deferred until the April meeting, which wouldn’t be held until after earth day. In the end, an event did take place with the governor, likely on Lloyd’s assurance that he would be able to deliver at the April meeting (which he did, but with three dissenting votes).

In the end, Lloyd was faced with a choice – either give up on battery electric vehicles or lose the Fuel Cell Partnership. He chose the former. A state employee later said to me “we sold out on EVs to save the Partnership.”

What Needs to be Done to Fix the Mess

As this is written in April 2004, there have recently been a growing number of voices making themselves heard questioning whether hydrogen fuel cell cars are in fact something we want or need. (A number of references are included in the further reading section at the end.) The frenzy that has developed over hydrogen cars over the last few years has fed on itself, and has grown to an alarming mass dash without enough analysis and discussion on whether this is where we want to go. Below are a number of recommended steps that can help moderate the frenzy and support due consideration of alternatives.

1. Stop using efficiency ratios in comparing fuel cell vehicles to gasoline powered vehicles. Everywhere you turn, it is stated as fact that fuel cell vehicles are far more efficient than conventional cars. Usually, this is expressed as a ratio; typical values given are from two

to three. There are many flaws to this kind of approach. The efficiency of converting energy from one form to another (such as with a converting hydrogen to electricity or gasoline to shaft power) is not at all the same as how much fuel does it take to drive a vehicle a specific distance. They are related, but high efficiency in itself is not sufficient for high fuel economy. The engine in a 10 mpg Lamborghini might have great efficiency at some operating points, but the vehicle still has lousy fuel economy. Another flaw in using ratios is that conventional vehicles are a moving target. It is not very likely that the relative difference in fuel economy between fuel cell vehicles and conventional gasoline vehicles will remain a fixed ratio over time. Finally, and most importantly, fuel cell vehicles have been unable to show better fuel economy than the current state of the art gasoline powered cars – hybrids. The fuel cell studies do list smaller fuel economy ratios for hybrids; but the case can be made that non-plug in hybrids like the Prius should not be categorized as anything other than a gasoline-powered vehicle. With the growing consumer demand for hybrid vehicles, the "conventional" gasoline powered vehicle in the time frame that fuel cell vehicles are said to be coming to market most likely <u>will</u> be an ultra efficient hybrid. Even today, hybrids beat fuel cell vehicles on fuel economy. The 2004 Prius, a midsized car, has EPA ratings of 60 mpg city, 51 highway. The 2004 Honda FCX, a subcompact, has EPA ratings (in miles/kg hydrogen) of only 51 city, 46 highway. (A kilogram of hydrogen has for practical purposes, the same energy content as a gallon of gasoline). The Prius, two size classes <u>larger</u> than the FCX, has convincingly <u>higher</u> fuel economy; the oft-claimed two to three times fuel economy ratio is in reality less than one.

2. When regulators and government agencies talk about hydrogen, they need to stop saying that <u>everyone agrees</u> that a hydrogen powered vehicles and the hydrogen economy are inevitable and are the end-game. There are a broad range of well considered points of view in this area that are different and need to be heard and considered.

3. CARB needs to undo the damage it has caused to the ZEV program. If CARB wants zero emission vehicles they should not pick in advance which kind of vehicle they think will win in the long run. Let the market decide that. CARB should decide on a reasonable percentage of vehicles that can be zero emission, and ramp that number up slowly over time, and go back to one vehicle, one credit. The only requirement for the vehicle would be that it is a ZEV and is certified to federal motor vehicle safety standards for a passenger car or truck. CARB should also recognize that as these vehicles are built initially in small numbers, they won't be ready yet for mass production, and costs to manufacturers will be higher than they will be in the future when volumes are higher.

4. The environmental leaders of the California state government should put the brakes on the Hydrogen Highways Initiative. They need to have a careful look at the cost, energy, greenhouse gas, and pollution impacts before jumping to the conclusion. (And a hydrogen powered Hummer is just a bad idea; it would barely have enough range to drive between one hydrogen highway fuelling station and the next).

5. It is time for some new faces in the CARB board. The board needs to be reinvigorated with a few new members that are engaged, ask probing questions, and have a real understanding of the new frontiers of automotive technology.

6. Re-launch the California Fuel Cell Partnership as the California Zero Emission Vehicle (ZEV) Partnership. The new California ZEV Partnership should bring together all kinds of zero emission vehicles, and would require participants to disclose the key performance parameters of their vehicles; range, energy consumption, acceleration etc. These parameters would be measured at driving events such as the recent "Rally through the Valley" and reported on the Partnership web site. The friendly competition and cross pollination (a good feature of the existing partnership) will help speed the spread of knowledge of what is working and what isn't.

7. Create ZEV-friendly market conditions in California. Economic incentives, user privileges, infrastructure support, outreach and marketing, and assistance for qualified low-volume manufacturers and sellers are all required to boost the demand and supply of ZEVs. The original ZEV mandate became an unproductive CARB-vs-the-OEMs showdown. The OEMs won this round. CARB needs to work with the OEMs and also work around them via the market and alternative businesses.

8. Bring energy issues front and center. Energy impacts must be considered along with emissions in the regulation of automobiles and fuels. Transportation energy use requires state-, national-, and international-level policy analysis and coordination. CARB, an air quality agency, is neither authorized nor qualified to address energy issues. The CEC, PUC, and other agencies need to be involved.

Additional Reading:

Tom Gage, "The EV Business: A Post-Mandate Perspective"
http://www.acpropulsion.com/EAASV_101803.pdf

Joe Romm, "The Hype about Hydrogen"
http://www.cool-companies.org/

Joe Romm, testimony to Congress
http://www.house.gov/science/hearings/full04/mar03/romm.pdf

Stephen and James Eaves: "A Cost Comparison of Fuel-Cell and Battery Electric Vehicles"
http://www.modenergy.com/BEVs%20vs%20FCVs%20EavesEaves%20120603.pdf

Baldur Eliasson and Ulf Bossel, "Future of the Hydrogen Economy, Bright or Bleak?"
http://www.efcf.com/reports/hydrogen_economy.pdf

Ulf Bossel, "The World Needs a Sustainable Energy Economy, not a Hydrogen Economy http://www.efcf.com/reports/E09.pdf

Ulf Bossel, "Efficiency of Hydrogen Fuel Cell, Diesel-SOFC-Hybrid and Battery Electric Vehicles"
http://www.efcf.com/reports/E04.pdf

Ulf Bossel, "Well-to-Wheel Studies, Heating Values, and the Energy Conservation Principle"
http://www.efcf.com/reports/E10.pdf

Robert Uhrig "Engineering Challenges of the Hydrogen Economy"
http://www.tbp.org/pages/publications/BENTFeatures/UhrigSp04.pdf

Wilson, "(The Truth about Hydrogen, A Response to Amory Lovins' "Twenty Hydrogen Myths")
http://www.tmgtech.com/images/Truth_about_Hydrogen_Myths_Response_-_v4.1.doc

EPRI battery report, March 2003
http://www.epri.com/corporate/discover_epri/news/downloads/EPRI_AdvBatEV.pdf