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California's Hydrogen Highway Reconsidered

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CALIFORNIA'S HYDROGEN HIGHWAY RECONSIDERED

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INTRODUCTION AND OVERVIEW

The urgent need to reverse the business-as-usual growth path in global warming pollution in the next two decades to avoid serious if not catastrophic climate change necessitates action to make our vehicles far less polluting. California Governor Arnold Schwarzenegger explicitly recognized that urgency by committing the state in 2005 to reduce greenhouse gas ("GHG") emissions to eighty percent below 1990 levels by 2050,[1] a difficult target that would require a radical change in California's energy system, particularly transportation.

Governor Schwarzenegger's greenhouse target is, however, directly at odds with another of the governor's plans, the hydrogen highway. Hydrogen cars are an exceedingly costly greenhouse gas strategy and an inefficient way to utilize renewable or zero-carbon primary energy resources, which will be critical to achieving California's ambitious greenhouse gas target. In the near-term, the most cost-effective strategy for reducing emissions and fuel use is efficiency. The car of the near

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[1] Gov. Schwarzenegger Signs Executive Order Setting Greenhouse Gas (GHG) Emission Reduction Targets for California, http://www.caprep.com/0605010.htm.

future is the hybrid gasoline-electric vehicle, because it "can reduce gasoline consumption and greenhouse gas emissions zero percent to fifty percent with no change in vehicle class and hence no loss of jobs or compromise on safety or performance."[2] It will likely become the dominant vehicle platform by the year 2020.

Ultimately, we will need to replace gasoline with a zero-carbon fuel. All alternative fuel vehicle ("AFV") pathways require technology advances and strong government action to succeed. Hydrogen is the most challenging of all alternative fuels, particularly because of the enormous effort needed to change our existing gasoline infrastructure. We are many decades away from a time when hydrogen cars could be a cost-effective greenhouse gas mitigation strategy.[3] Devoting significant public resources to developing a hydrogen highway is thus premature.

The most promising AFV pathway is a hybrid that can be connected to the electric grid. These so-called plug-in hybrids or e-hybrids "will likely travel three to four times as far on a kilowatt-hour of renewable electricity as fuel cell vehicles."[4] Ideally these advanced hybrids would also be a flexible fuel vehicle capable of running on a blend of biofuels and gasoline. Such a car could travel 500 miles on one gallon of gasoline (and five gallons of cellulosic ethanol)[5] and have under one-tenth the GHG emissions of current hybrids.

This Article begins with an assessment of anticipated climate change and sea rise impacts on California.[6] Next, the contribution of greenhouse gas emissions from gasoline-powered vehicles to climate change is explained.[7] This is followed by an analysis of the Hydrogen Highway proposal put forth by Governor Schwarzenegger,[8] and a comparison of the potential economic viability and environmental benefits of hydrogen vehicle technology vis-à-vis gasoline-electric hybrid vehicles.[9]

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[2] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, THE CAR AND FUEL OF THE FUTURE: A TECHNOLOGY AND POLICY OVERVIEW, REPORT FOR THE NATIONAL COMMISSION ON ENERGY POLICY 1 (June 2004), http://www.energyandclimate.org/ewebeditpro/items/O79F7833.pdf.

[3] *Id.* at 16.

[4] *Id.* at 1.

[5] *See* Joseph Romm & Andrew Frank, *Hybrid Vehicles Gain Traction*, SCIENTIFIC AMERICAN 72 - 79, April 2006, *available at* http://www.calcars.org/sci-am-romm-frank-apr06.pdf.

[6] *Infra* notes 10 - 27 and accompanying text.

[7] *Infra* notes 28 – 80 and accompanying text.

[8] *Infra* notes 81 – 98 and accompanying text.

[9] *Infra* notes 100 – 114 and accompanying text.

I. CLIMATE CHANGE AND SEA RISE IMPACTS FOR CALIFORNIA

The need for action on climate change is more urgent than is widely understood. That urgent need must quickly become the driving force behind energy and transportation policy in California, the United States, and the world. For California the most catastrophic consequence of global warming is likely to be sea level rise.[10]

According to the Arctic Climate Assessment, a comprehensive 2004 analysis by the top scientists from the nations that border the Arctic Circle, including ours, if we keep up current emissions trends, "warming over Greenland is likely to be. . . of [the] magnitude [that] would eventually lead to a virtually complete melting of the Greenland Ice Sheet, with a resulting sea level rise of about seven meters (twenty-three feet)."[11] A twenty-three foot sea level rise would be devastating to California (and the world). Yet we are close to the point of no return for Greenland melting, and, worse still, twenty-three feet is far from the worst-case scenario.[12]

In April 2005, James Hansen, director of the National Aeronautics and Space Administration's ("NASA") Goddard Institute for Space Studies, added: "There can no longer be genuine doubt that human-made gases are the dominant cause of observed warming."[13] Hansen led a team of scientists that made "precise measurements of increasing ocean heat content over the past 10 years,"[14] which revealed the earth is absorbing far more heat than it is emitting to space, confirming earlier computer models of warming.[15] Hansen called this energy imbalance the "smoking gun" of climate change.[16]

Global concentrations of carbon dioxide, the primary heat-trapping

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[10] *Infra* note 11.

[11] SUSAN JOY HASSOL, ARCTIC CLIMATE IMPACT ASSESSMENT, IMPACTS OF A WARMING ARCTIC 41 (2004), http://www.acia.uaf.edu/.

[12] James E. Hansen, *A Slippery Slope: How Much Global Warming Constitutes "Dangerous Anthropogenic Interference?,"* 68 CLIMATIC CHANGE 269, 270 (2005), *available at* http://www.columbia.edu/~jeh1/hansen_slippery.pdf [hereinafter Hansen, *A Slippery Slope*].

[13] James E. Hansen, The Earth Institute, Answers About the Earth's Energy Imbalance (2005), http://www.earthinstitute.columbia.edu/news/2005/story11-04-05.html [hereinafter Hansen, Answers].

[14] James E. Hansen et al., *Earth's Energy Imbalance: Confirmation and Implications*, SCIENCE, Jun. 3, 2005, at 1431, *available at* http://www.columbia.edu/~jeh1/hansen_imbalance.pdf.

[15] Hansen, Answers, *supra* note 13.

[16] *Id.*

greenhouse gas, are rising at an accelerating rate in recent years - and they are already higher than at any time in the past 3 million years. Bob Corell, the lead scientist of the 2004 Arctic Climate Assessment, reports that "Greenland is melting much more rapidly in the past two or three years than anyone imagined possible."[17] Worse, the ocean's heat content will continue re-radiating heat into the earth's atmosphere even after we eliminate the heat imbalance; the planet will continue warming and the glaciers will continue melting for decades after we cut GHG emissions. It is therefore imperative that we act in an "anticipatory" fashion and reduce emissions long before climate change is painfully obvious to everyone.

The planet has warmed about 0.8°C in the past century,[18] primarily because of human-generated GHG emissions. If we don't sharply reverse the rise of global GHG emissions within the next decade, we will be committing the world to an additional 1°C of warming, probably by mid-century.[19] The last time the earth was more than 1°C warmer than it is today, sea levels were twenty feet higher.[20] That occurred during the Eemian interglacial period about 125,000 years ago, when Greenland appears to have been largely ice-free.[21]

How fast can the sea level rise? Following the last ice age, the world saw sustained melting that *raised sea levels more than a foot per decade.*[22] James Hansen believes we could see such a catastrophic melting rate within the century.[23] Moreover, sea levels ultimately could rise much more than twenty feet. If we do not sharply reverse the rise of global greenhouse gas emissions, we would be headed towards an additional 3°C warming; temperatures not seen for millions of years, when sea levels were fifty to eighty feet higher.[24] It takes little imagination to appreciate the profound effects an eighty-foot sea level rise would have on the California coastline.

Right now, the melting of West Antarctica is counterbalanced by

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[17] Colin Woodard, *The Big Meltdown, Something's Happening at Both Poles,* 16 E/THE ENVIRONMENTAL MAGAZINE, (March/April 2005) *available at* http://www.emagazine.com/view/?2302&src=QSOPN6.

[18] Goddard Institute for Space Studies, http://data.giss.nasa.gov/gistemp/2005/ (last visited at July 4, 2006) (summarizing graph "(a) Global-Mean Surface Temperature Anomaly").

[19] Hansen, *A Slippery Slope, supra* note 12.

[20] *Id.*

[21] *Id.*; James Hansen, *Is There Still Time to Avoid 'Dangerous Anthropogenic Interference' with Global Climate? available at* http://www.columbia.edu/~jeh1/keeling_talk_and_slides.pdf.

[22] Hansen, *A Slippery Slope, supra* note 12.

[23] Hansen, *A Slippery Slope, supra* note 12.

[24] James Hansen, *Can We Still Avoid Dangerous Human-Made Climate Change?, available at* http://www.columbia.edu/~jeh1/newschool_text_and_slides.pdf.

the increased snowfall over East Antarctica, which is also caused by global warming (as higher temperatures cause more atmospheric moisture and hence more precipitation).[25] But the glacial thinning in West Antarctica has accelerated dramatically since the 1990s, and the entire ice shelf has begun to disintegrate.[26] It is only a matter of time and temperature rise before Antarctica begins making its major contribution to sea level rise.[27]

II. CLIMATE, CALIFORNIA AND CARS

California Governor Arnold Schwarzenegger and the California Environmental Protection Agency ("CalEPA") have recognized the threat to California and the urgent need for action. That is why, in 2005, they committed the state to reduce GHG emissions to eighty percent below 1990 levels by 2050.[28] This stringent target represents the level of GHG emissions reduction required by the industrialized nations to have confidence we will avoid the additional 1°C of warming that threatens the melting of Greenland.

This is an ambitious target that will be difficult to reach given the growth in economic activity and population expected in the next several decades. This target would require a radical change in California's energy system, particularly transportation. Indeed, while converting the entire electricity grid to zero-carbon power is no easy task, it can be done straightforwardly, if expensively, using existing technology. In a world of growing economic activity and population, however, dramatic reductions in the transportation sector require a quantum change in both the vehicles, as well as in the fuels.

To put the transportation problem in context, consider the following domestic statistics: roughly ninety-seven percent of all energy consumed by United States cars, sport utility vehicles, vans, trucks, and airplanes is still petroleum-based.[29] Additionally, in the 1990s, the transportation sector saw the fastest growth in carbon dioxide emissions of any major

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[25] Kurt M. Coffey, *There's No Disguising It- Global Warming's No Put-On,* S.F. CHRON., Oct. 9, 2005, at E3, *available at* http://www.sfgate.com/cgi-bin/article.cgi?file=/chronicle/archive/2005/10/09/ING5FF2U031.DTL.

[26] James E. Hansen, *Can We Still Avoid Dangerous Human-Made Climate Change?* (2006), *available at* http://www.columbia.edu/~jeh1/newschool_text_and_slides.pdf.

[27] Jenny Hogan, Antarctic Ice Sheet is an 'Awakened Giant,' NewScientist.com, Feb. 2, 2005, http://www.newscientist.com/channel/earth/dn6962.

[28] Gov. Schwarzenegger Signs Executive Order Setting Greenhouse Gas (GHG) Emission Reduction Targets for California, http://www.caprep.com/0605010.htm.

[29] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2.

sector of the United States economy. Finally, the transportation sector is projected to generate nearly half of the forty percent rise in United States carbon dioxide emissions forecast for 2025.[30]

Internationally, the situation is equally problematic.[31] As Claude Mandil, Executive Director of the International Energy Agency ("IEA"), said in May 2004, "In the absence of strong government policies, we project that the worldwide use of oil in transport will nearly double between 2000 and 2030, leading to a similar increase in GHG emissions."[32]

Significantly, between 2003 and 2030, over 1400 gigawatts of new coal capacity will be built.[33] As David Hawkins, Director of Natural Resources Defense Council's Climate Center, told the United States House Committee on Energy and Commerce in June 2003, these plants would commit the planet to total carbon dioxide emissions of some 140 billion metric tons over their lifetime unless "they are backfit with carbon capture equipment at some time during their life."[34] Hawkins further explained that this number amounts to half the estimated total cumulative carbon emissions from all fossil fuel used globally over the past 250 years.[35]

It is critical that whatever strategy the world adopts to reduce GHG emissions in the vehicle sector does not undermine our efforts to reduce GHG emissions in the electricity sector. It is also critical to note that improved vehicle efficiency alone cannot achieve an eighty percent reduction in transportation GHG emissions (especially with increased GDP and population growth). A zero-carbon alternative fuel will be required. With this caveat in mind, this Article will explore the AFV issue,[36] hydrogen cars,[37] California's hydrogen highway,[38] as well as the AFV that may be the most plausible alternative to hydrogen: the plug-in

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[30] ENERGY INFORMATION ADMINISTRATION, ANNUAL ENERGY OUTLOOK 2003 Table A19 144 (2003) *available at* http://tonto.eia.doe.gov/FTPROOT/forecasting/0383(2003).pdf.

[31] Press Release, Int'l Energy Agency, Biofuels for Transport: An International Perspective (Nov. 5, 2004) *available at* http://www.iea.org/Textbase/press/pressdetail.asp?PRESS_REL_ID=127.

[32] *Id.*

[33] *Hearing on Future Options for Generation of Electricity from Coal: Hearing Before the Subcomm. on Energy & Air Quality* 108th Cong. 80 (2003) (testimony of David G. Hawkins, Director of Natural Resources Defense Council) *available at* http://www.nrdc.org/globalWarming/tdh0603.asp.

[34] Hawkins, *supra* note 33.

[35] *Id.*

[36] *See infra* notes 40 to 62 and accompanying text.

[37] *See infra* notes 63 to 80 and accompanying text.

[38] *See infra* notes 81 to 98 and accompanying text.

hybrid-gasoline vehicle.[39]

III. ALTERNATIVE FUELS AND ALTERNATIVE FUEL VEHICLES

The federal government and others, such as California, have tried to promote transportation fuels other than gasoline for many years. These fuels include natural gas, methanol, ethanol, propane, electricity, and bio-diesel. AFVs operate on these fuels, although many are dual-fueled, that is, they can also run on gasoline. The 1992 Energy Policy Act established the goal of having "alternative fuels replace at least ten percent of petroleum fuels used in transportation by 2000, and at least thirty percent . . . in 2010."[40] Currently, alternate fuels consumed in AFVs substitute for less than one percent of total consumption of gasoline.[41] A significant literature has emerged explaining this failure.[42] As the June 2004 report by the Center for Energy and Climate Solutions detailed:

> Alternative fuel vehicles and their fuels face two central problems. Primarily, they typically suffer from several marketplace disadvantages compared to conventional vehicles running on conventional fuels. Hence, they inevitably require government incentives or mandates to succeed. Second, they typically do not provide cost-effective solutions to major energy and environmental problems, which undermine the policy case for having the government intervene in the marketplace to support them.[43]

On the second point, in September 2003 the United States Department of Transportation Center for Climate Change and Environmental Forecasting released its analysis, *Fuel Option for Reducing Greenhouse Gas Emissions from Motor Vehicles.*[44] The report assesses the potential for gasoline substitutes to reduce GHG emissions over the next twenty-five years.[45] It concludes that "the reduction in GHG emissions from most gasoline substitutes would be modest" and

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[39] *See infra* notes 99 to 114 and accompanying text.

[40] *Lessons Learned from Previous Research Could Benefit FreedomCAR Initiative: Hearing Before the Subcomm. on Oversight & Investigations* 5 (2002) (testimony of Jim Wells, Director, Natural Resources and the Environment), *available at* http://www.gao.gov/new.items/d02810t.pdf.

[41] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 8.

[42] *Id.*

[43] *Id.*

[44] U.S. DEPARTMENT OF TRANSPORTATION CENTER FOR CLIMATE CHANGE AND ENVIRONMENTAL FORECASTING, FUEL OPTION FOR REDUCING GREENHOUSE GAS EMISSIONS FROM MOTOR VEHICLES, (2003), *available at* http://climate.volpe.dot.gov/docs/fuel.pdf.

[45] *Id.*

that "promoting alternative fuels would be a costly strategy for reducing emissions."[46]

Besides the question of whether AFVs deliver cost-effective emissions reductions, there have historically been several other barriers to AFV success, including: the high first cost for vehicle;[47] on-board fuel storage issues (i.e. limited range);[48] safety and liability concerns (not addressed in this Article);[49] high fueling cost (compared to gasoline);[50] limited fuel stations;[51] chicken and egg problem regarding fueling infrastructure;[52] improvements in the competition (better, cleaner gasoline vehicles).[53]

All AFVs that have so far been promoted with limited success - electric vehicles, natural gas vehicles, methanol vehicles, and ethanol vehicles have each suffered from some or all of these barriers. According to the 2004 report, any one of these barriers can be fatal for an AFV or an alternative fuel, even where other benefits are delivered:

> . . . Electric vehicles deliver the clear benefit of zero tailpipe emissions, and can even have lower per mile costs than gasoline cars, but range, refueling, and first cost issues have limited their success and caused most major auto companies to withdraw their electric vehicles from the marketplace.
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> The chicken & egg problem—who will build and buy the AFVs if a fueling infrastructure is not in place and who will build the fueling infrastructure before the AFVs are built—remains the most intractable barrier. Consider that there are millions of flexible fuel vehicles already on the road capable of running on E85 (85% ethanol, 15% gasoline), 100% gasoline, or just about any blend, for about the same price as gasoline-powered vehicles, and yet the vast majority of them run on gasoline and there have been very few E85 stations built.[54]

The environmental benefits of natural gas light-duty vehicles were oversold, "as were the early cost estimates for both the vehicles and the

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[46] *Id.* at Abstract.

[47] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 8.

[48] *Id.*

[49] *Id.*

[50] *Id.*

[51] *Id.*

[52] *Id.*

[53] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 8.

[54] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 9.

refueling stations."[55] As Peter Flynn observed, "[e]arly promoters often believe that 'prices just have to drop' and cited what turned out to be unachievable price levels."[56] One study concluded, "[e]xaggerated claims have damaged the credibility of alternate transportation fuels, and have retarded acceptance, especially by large commercial purchasers."[57]

Moreover, all AFVs face the increasing competition from improved gasoline-power vehicles. Indeed, two decades ago when tailpipe emissions standards were being developed requiring 0.02 grams/mile of Nitrogen Oxide ("NOx"), few suspected that this could be achieved by internal combustion engine vehicles running on we [sic] formulated gasoline.[58] The new generation of hybrids, such as the Toyota Prius and Ford Escape hybrid, have substantially raised the bar for future AFVs.[59] These vehicles lack many of the aforementioned problems because: they can be fueled everywhere; possess no different safety concerns than other gasoline cars; generate a substantially *lower* annual fuel bill; provide *greater* range; promise a forty to fifty percent reduction in GHG emissions, and a ninety percent reduction in tailpipe emissions.[60] The vehicles do cost a little more, but that is partly offset by a federal government tax credit for fuel-efficient hybrids and the large reduction in gasoline costs, even ignoring the performance benefits.[61] "Compare that to many AFVs, whose environmental benefits, if any, typically come at the expense not merely of a higher first cost for the vehicle, but a much higher annual fuel bill, a reduced range, and other undesirable attributes from the consumer's perspective."[62]

IV. DECONSTRUCTING THE HYDROGEN ALTERNATIVE

A pollution-free hydrogen car rests on two pillars: a pollution-free source for the hydrogen itself and a fuel cell for efficiently converting it into useful energy without generating pollution.[63] Fuel cells are small, modular electrochemical devices, similar to batteries, but which can be

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[55] *Id.*

[56] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 9 (quoting Peter Flynn, *Commercializing an Alternate Vehicle Fuel: Lessons Learned From Natural Gas For Vehicles*, 30 ENERGY POLICY 613–619 (2002)).

[57] *Id.*

[58] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 9.

[59] *Id.*

[60] *Id.*

[61] *Id.*

[62] *Id.*

[63] JOSEPH J. ROMM, HYPE ABOUT HYDROGEN: FACT AND FICTION IN THE RACE TO SAVE THE CLIMATE (Island Press 2004).

continuously fueled. For most purposes, a fuel cell can be thought of as a "black box" that takes in hydrogen and oxygen and puts out only water plus electricity and heat.[64] The electricity runs an electric motor, and from that perspective, the rest of the vehicle is much like an electric car.[65] Internal combustion engine cars can also be modified to run on hydrogen, although they are considerably less efficient than fuel cell vehicles.[66]

The transition to a transportation system based on a hydrogen economy will be much slower and more difficult than widely realized.[67] In particular, it is unlikely that hydrogen vehicles will achieve significant (>5%) market penetration by 2030.[68]

A variety of major technology breakthroughs and government incentives will be required for hydrogen vehicles to achieve significant commercial success by the middle of this century. "Continued research and development ("R&D") in hydrogen and transportation fuel cell technologies remains important because of their potential to provide a zero-carbon transportation fuel in the second half of the century. But neither government policy nor business investment should be based on the assumption that these technologies will have a significant impact in the near- or medium-term."[69] Bill Reinert, United States manager of Toyota's advanced technologies group, said in January 2005, absent multiple technology breakthroughs, there will not be high-volume sales of fuel cell vehicles until 2030 or later.[70] When Reinert was asked when fuel cells cars would replace gasoline-powered cars, he replied "If I told you '*never*,' would you be upset?"[71]

Hydrogen cars face enormous challenges in overcoming each of the major historical barriers to AFV success. The central challenge for any AFV seeking government support beyond R&D is that the deployment of the AFVs and the infrastructure to support them must cost effectively

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[64] *Id.*

[65] *Id.*

[66] *Id.*

[67] *Id.*

[68] *Id.*

[69] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, HYDROGEN AND FUEL CELLS: A TECHNOLOGY AND POLICY OVERVIEW, REPORT FOR THE NATIONAL COMMISSION ON ENERGY POLICY, 1 (Oct. 2004).

[70] Richard Truett, *Volume Fuel Cell Cars at Least 25 Years Away, Toyota says*, AUTOMOTIVE NEWS, Jan. 10, 2005, http://www.autonews.com/apps/pbcs.dll/article?AID=/20050110/FREE/501100785&SearchID=73237167298935.

[71] Jamie Butters, Alejandro Bodipo-Memba, & Jeffrey McCracken, *Fuel-Economy Technologies: GM Changes Course, Embraces Hybrids*, DETROIT FREE PRESS, Jan. 10, 2005, *available at* LEXIS.www.freep.com/money/autonews/clean10e_20050110.htm.

address some energy or environmental problems facing the nation.[72] Yet two hydrogen advocates, Dan Sperling and Joan Ogden of University of California at Davis, concede, "[h]ydrogen is neither the easiest nor the cheapest way to gain large near- and medium-term air pollution, greenhouse gas, or oil reduction benefits."[73] A 2004 analysis by Pacific Northwest National Laboratory concluded that even "in the advanced technology case with a carbon constraint . . . hydrogen doesn't penetrate the transportation sector in a major way until *after 2035*."[74](emphasis in original) "A push to constrain carbon dioxide emissions actually delays the introduction of hydrogen cars because sources of zero-carbon hydrogen, such as renewable power, can achieve emissions reductions far more cost-effectively by simply replacing planned or existing coal plants . . . [O]ur efforts to reduce GHG emissions in the vehicle sector must not come at the expense of our efforts to reduce GHG emissions in the electric utility sector."[75] The 2004 report noted:

> In fact, *Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context*, a January 2004 study by the European Commission Center for Joint Research, the European Council for Automotive R&D, and an association of European oil companies, concluded that using hydrogen as a transport fuel might well *increase* Europe's greenhouse gas emissions rather than reduce them. That is because many pathways for making hydrogen, such as grid electrolysis, can be quite carbon-intensive and because hydrogen fuel cells are so expensive that hydrogen internal combustion engine vehicles may be deployed instead (which is already happening in California). Using fuel cell vehicles and hydrogen from zero-carbon sources such as renewable power or nuclear energy has a cost of avoided carbon dioxide of more than $700 a metric ton, which is more than a factor of ten higher than most other strategies being considered today.
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> A number of major studies and articles have recently come out on the technological challenges facing hydrogen . . . transportation fuel cells currently cost about $5,000/kw, some 100 times greater than the cost

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[72] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 9.

[73] Dan Sperling & Joan Ogden, *The Hope for Hydrogen*, ISSUES IN SCIENCE AND TECHNOLOGY, Spring 2004, *available at* http://www.issues.org/20.3/sperling.html.

[74] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 9 –10 (quoting J. EDMONDS et al, TRANSPORTATION AND CLIMATE CHANGE: THE POTENTIAL FOR HYDROGEN SYSTEMS (Society of Automotive Engineers)).

[75] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 10.

of internal combustion engines. [76]

A 2004 article for the Society of Automotive Engineers noted, "[e]ven with the most optimistic assumptions, the fuel cell powered vehicle offers only a marginal efficiency improvement over the advanced [diesel]-hybrid and with no anticipation yet of future developments of I[nternal] C[ombustion] engines ("ICE"). At $100/kW, the fuel cell does not offer a short term advantage even in a European market."[77]

Furthermore, another study concluded that "a new material must be discovered" to solve the storage problem.[78] Another analysis found, "[f]uel-cell cars, in contrast [to hybrids], are expected on about the same schedule as NASA's manned trip to Mars and have about the same level of likelihood."[79]

There is a tendency in analyses of a future hydrogen economy to assume the end state - mass production of low-cost fuel cells, pipeline delivery, and so on. Yet while transportation fuel cells would undoubtedly be far cheaper if they could be produced at quantities of one million units per year, the unanswered question is who will provide the billions of dollars in subsidies during the many years when vehicle sales would be far lower and vehicle costs far higher. Additionally, while hydrogen pipelines are the desired end result, and "the costs of a mature hydrogen pipeline system would be spread over many users," as the National Academy panel noted, "the transition is difficult to imagine in detail."[80] The AFV problem is very much a systems problem where the transition issues are as much of the crux as the technological ones. It therefore follows that AFV analysis should be conservative in nature, stating clearly what is technologically and commercially possible today, and, when discussing the future, be equally clear that projections are speculative and will require both technology breakthroughs and major government intervention in the marketplace. Analysis should treat the likely competition fairly: If major advances in cost reduction and

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[76] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 10.

[77] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, *supra* note 2, at 10 (quoting ANTONI OPPENHEIM & HAROLD SCHOCK, RAISON D'ETRE OF FUEL CELLS AND HYDROGEN FUEL FOR AUTOMOTIVE POWER PLANTS (Society of Automotive Engineers 2004)).

[78] AM. PHYSICAL SOC'Y PANEL ON PUB. AFFAIRS, THE HYDROGEN INITIATIVE 6 (2004), *available at* http://www.aps.org/public_affairs/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=49633.

[79] Matthew L. Wald, *Questions About a Hydrogen Economy*, SCIENTIFIC AMERICAN MAGAZINE, May 2004, at 5 (66-73) *available at* http://www.heartland.org/pdf/15486.pdf.

[80] NAT'L ACAD. OF ENGINEERING ET AL, THE HYDROGEN ECONOMY: OPPORTUNITIES, COSTS, BARRIERS, AND R&D NEEDS 117 (The Nat'l Academies Press 2004).

performance are projected for hydrogen technologies, similar advances should be projected for hybrids, batteries, biofuels, and the like. After all, AFVs must compete against the most efficient gasoline-powered vehicles for market share.

V. THE CALIFORNIA HYDROGEN HIGHWAY

In his 2004 State of the State address, Governor Schwarzenegger announced, "I am going to encourage the building of a hydrogen highway."[81] In May 2005, the blueprint plan for that highway was announced.[82]

The blueprint establishes a multi-phase approach, and the first phase includes a network of 50 to 100 fueling stations and 2000 hydrogen cars (1200 fuel cell vehicles and 800 hydrogen ICE cars) by 2010.[83] The network is supposed to achieve "30% reduction in greenhouse gas emissions relative to a comparable number of today's fuels and vehicles."[84] Over a longer period of time, Phase Two calls for a "network of 250 hydrogen stations and 10,000 hydrogen vehicles."[85] Finally, in Phase Three, the number of stations remains the same but the number of hydrogen cars doubles to 20,000.[86]

This Article has established that from a practical and technological standpoint, it is highly premature to be deploying cars and fueling stations.[87] The blueprint appears to recognize this to some extent by the fact that of the 2000 hydrogen cars planned for 2010, a full 800 will not be fuel cells, but rather ICEs that burn hydrogen.[88]

From a GHG standpoint, hydrogen ICE vehicles are among the least attractive and least efficient vehicles imaginable. Hydrogen ICEs are likely to be far less efficient than fuel-cell vehicles and perhaps only twenty-five percent more efficient than gasoline ICEs.[89] They are likely to have a reduced range because of the difficulty of storing large volumes of hydrogen onboard.[90] Furthermore, vehicle owners would directly

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[81] California Governor Arnold Schwarzenegger, State of the State Address (January 6, 2004).

[82] CAL. ENVTL PROTECTION AGENCY, 2 CALIFORNIA HYDROGEN BLUEPRINT PLAN 2 (May 2005), *available at* http://www.hydrogenhighway.ca.gov/plan/reports/volume2_050505.pdf.

[83] *Id.* at 2.

[84] *Id.* at 3.

[85] *Id.* at 19.

[86] *Id.* at 20.

[87] *See supra* note 70 and accompanying text.

[88] CAL. ENVTL PROTECTION AGENCY, 1 CALIFORNIA HYDROGEN BLUEPRINT PLAN 25, *available at* http://www.hydrogenhighway.ca.gov/plan/reports/volume1_050505.pdf.

[89] *Id.* at 2.

[90] Joseph J. Romm, *The Hype about Hydrogen*, ISSUES IN SCIENCE AND TECHNOLOGY

experience the high price of hydrogen. As a result, annual vehicle ownership costs for mid-sized hydrogen ICE vehicles would be thirty percent higher than current gasoline vehicles (and only slightly lower than fuel-cell vehicles), according to an analysis by Arthur D. Little.[91]

Moreover, because of the energy consumed in generating hydrogen (from natural gas or electricity, for instance) and because of the energy consumed compressing hydrogen for storage, the "well-to-wheel" energy use of a hydrogen ICE vehicle may actually be higher than that of a gasoline ICE.[92] A 2002 analysis of ten different AFVs found that ICEs running on hydrogen from natural gas had the *lowest overall efficiency* on a life-cycle (well-to-wheel) basis.[93] Running an ICE car on hydrogen from natural gas would probably not save any GHG emissions compared with running a gasoline ICE car and would *increase* emissions compared to a hybrid gasoline-electric car.[94] Running an ICE car on hydrogen made from renewable electricity is one of the most wasteful uses of that renewable electricity conceivable, especially compared to using that renewable electricity to run a plug-in hybrid.[95] If mitigating global warming is the goal, hydrogen ICE cars are not a viable strategy for the foreseeable future.

The dilemma for California seems apparent from the blueprint. While hydrogen ICE vehicles make very little sense from an environmental perspective, they do have the advantage of relatively lower cost. In Phase One, the state is only planning to offer a $10,000 per vehicle incentive for hydrogen cars.[96] Since hydrogen fuel cell cars currently cost on the order of $1 million apiece, and are unlikely to be even a factor of 10 less expensive in 2010, this incentive has essentially no impact on the cost of a hydrogen fuel cell car.[97] But $10,000 represents a substantial fraction of the added cost of a hydrogen ICE car. The end result is thus the perverse situation that the state is providing the

(Spring 2004), *available at* http://www.issues.org/20.3/romm.html (last visited July 5, 2006).

[91] ARTHUR D. LITTLE, INC. (ADL), GUIDANCE FOR TRANSPORTATION TECHNOLOGIES: FUEL CHOICE FOR FUEL-CELL VEHICLES, FINAL REPORT 32 (2002), *available at* http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel_choice_fcvs.pdf.

[92] *See* Romm, *supra* note 63.

[93] Frank Kreith et al, Legislative and Technical Perspectives for Advanced Ground Transportation Systems, 56 Transportation Quarterly 51 –73 (2002).

[94] *See* Romm, *supra* note 63.

[95] *Id.*

[96] CAL. ENVTL PROTECTION AGENCY, 1 CALIFORNIA HYDROGEN BLUEPRINT PLAN 25 (May 2005), *available at* http://www.hydrogenhighway.ca.gov/plan/reports/volume1_050505.pdf.

[97] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, THE CAR AND FUEL OF THE FUTURE: A TECHNOLOGY AND POLICY OVERVIEW, REPORT FOR THE NATIONAL COMMISSION ON ENERGY POLICY 11 (June 2004), http://www.energyandclimate.org/ewebeditpro/items/O79F7833.pdf.

maximum proportional subsidy to the least environmentally desirable new product. This merely serves to underscore the premature nature of the entire Hydrogen Highway effort.

When I was at the United States Department of Energy, the only reason we were interested in hydrogen - a fuel that is expensive, difficult to store in small volumes, and very inefficient to make - was the possibility that it could be converted with very high efficiency in fuel cells. That very high efficiency was needed to compensate for the added cost, the storage problems, and the inefficiency in hydrogen generation. Hydrogen ICE vehicles are a very bad public policy idea and deserve no state or federal subsidy at all.

As for hydrogen fuel cell vehicles, they still face major challenges to overcome each and every one of the barriers discussed in the previous section. It is possible we may never see a durable, affordable fuel cell vehicle with an efficiency, range, and annual fuel bill that matches even the best *current* hybrid vehicle.[98] Of all AFVs and alternative fuels, fuel cell vehicles running on hydrogen are probably the least likely to be a cost-effective solution to global warming, which is why the other pathways deserve at least equal policy attention and funding.

VI. COMPARING E-HYBRID AND HYDROGEN VEHICLES

A. E-HYBRID ADVANTAGES

In contrast to the hydrogen vehicles, there is another AFV technology that appears to have clear environmental benefits, including substantially lower GHG emissions, a much lower annual fuel bill, a much longer range than current cars (with the added ability to fuel at home), and far fewer infrastructure issues than traditional AFVs. This AFV is the plug-in hybrid, also called the e-hybrid.

A straightforward improvement to the current generation of hybrids allows them to be plugged into the electric grid and run in an all-electric mode for a limited range between recharging. Since most vehicle use is for relatively short trips, such as commuting, followed by an extended period of time during which the vehicle is not being driven and could be charged, even a relatively modest all-electric range of 20 or 40 miles could allow these vehicles to replace a substantial portion of gasoline consumption and tailpipe emissions.[99] If the electricity were from CO_2-

[98] *See* Alec Brooks, CARB's Fuel Cell Detour on the Road to Zero Emission Vehicles 2 (May 2, 2004), http://www.evworld.com/library/carbdetour.pdf.

[99] *See* Joseph Romm & Andrew Frank, *Hybrid Vehicles Gain Traction*, SCIENTIFIC

free sources, then these vehicles would also have dramatically reduced net GHG emissions.

Because they have a gasoline engine, and are thus a dual-fuel vehicle, e-hybrids avoid two of the problems facing pure electric vehicles.[100] First, they are not limited in range by the total amount of battery charge.[101] If the initial battery charge runs low, the car can run on gasoline and on the charging possible from the regenerative braking.[102] Second, electric vehicles take many hours to charge, so that if for some reason owners were unable to charge the car - either due to a lack of time between trips to charge or a lack of local charging capability - then the pure-electric car could not be driven.[103] Thus, e-hybrids combine the best of both hybrids and pure electric vehicles.

Battery improvement will lead to increased functionality for e-hybrids. Reductions in cost and increases in cycle life (durability) will make plug-in hybrid electric vehicles ("PHEV") more affordable.[104] Adequate safety is a requirement. Operating temperature is important, but batteries with unusual operating temperatures may be considered if other benefits are demonstrated. Convenience of recharging is crucial, but the definition of "convenience" varies by user. A full recharge overnight from an ordinary home outlet is generally considered to be sufficient for a personal e-hybrid.

B. E-HYBRID BARRIERS

E-hybrids avoid many of the barriers to AFVs discussed earlier. They do not have a limited range. They do not have major safety and liability issues - although great care would have to be taken in the design of any home-based system that charged e-hybrids or allowed them to feed back into the grid. They do not have a high fueling cost compared to gasoline. In fact, the per-mile fueling cost of running on electricity is about one third the per-mile cost of running on gasoline.[105] The chicken and egg problem is minimized because electricity is widely available and charging is relatively straightforward.

AMERICAN 72 - 79, April 2006, *available at* http://www.calcars.org/sci-am-romm-frank-apr06.pdf.

[100] THE CENTER FOR ENERGY AND CLIMATE SOLUTIONS, THE CAR AND FUEL OF THE FUTURE: A TECHNOLOGY AND POLICY OVERVIEW, REPORT FOR THE NATIONAL COMMISSION ON ENERGY POLICY 11 (June 2004), http://www.energyandclimate.org/ewebeditpro/items/O79F7833.pdf.

[101] *Id.*

[102] *Id.*

[103] *Id.*

[104] Romm & Frank, *supra* note 99, at 78.

[105] Romm & Frank, *supra* note 99, at 78.

The vehicle will almost certainly have a higher first cost, but this is likely to be more than compensated by the economic benefit of a lower fuel bill concluded a study by the California Energy Commission and California Air Resources Board.[106] Also, that study did not consider a large potential revenue stream the vehicle owner may be able to extract from the utility by having what is essentially a portable electric generator.

An e-hybrid owner may be able to extract revenue for grid regulation services - generators that can provide fast response when grid voltage needs to be increased or decreased.[107] Utilities would pay for this service if there was a guarantee that the car could deliver juice when needed, which suggests that this is more practical for vehicle fleets or for a corporate sponsor. The potential value of such services is significant: over $2000 per year.[108] This value is so large that it might allow the monthly cost of purchasing or leasing an e-hybrid to be *lower* than a conventional car, and perhaps even cover the replacement cost for batteries. It is critical that we fund some real-world demonstrations of e-hybrids providing these services, to see if this value can be extracted. If it can, we might see major utilities helping to subsidize the cost and/or financing of e-hybrids.

Environmentally, e-hybrids offer significant potential benefits over hydrogen vehicles. First, since they are designed to run all-electric for short trips such as commuting, they offer the possibility of being zero-emission vehicles ("ZEV") in cities. The best early uses of e-hybrids may well be to replace dirty diesel engine vehicles used regularly in cities, such as buses, maintenance vehicles, and delivery trucks. If we are unable to overcome the multiple technical and practical hurdles to hydrogen fuel cell cars, then e-hybrids may be the only viable option for urban ZEVs.

The potential GHG benefits of e-hybrids are even more significant, if a source of zero-carbon electricity can be utilized for recharging. E-hybrids have an enormous advantage over hydrogen fuel cell vehicles in utilizing zero-carbon electricity. That is because of the inherent inefficiency of generating hydrogen from electricity, transporting

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[106] CAL. ENERGY COMM'N & CAL. AIR RES. BD., REDUCING CALIFORNIA'S PETROLEUM DEPENDENCE (August 2003), *available at* http://www.energy.ca.gov/reports/2003-08-14_600-03-005.PDF.

[107] *See* Alec Brooks & Tom Gage, Integration of Electric Drive Vehicles with the Electric Power Grid- - A New Value Stream (2001) *available at* http://www.acpropulsion.com/EVS18/ACP_V2G_EVS18.pdf. (last visited July 5, 2006).

[108] Steven E. Letendre & Willett Kempton, *The V2G Concept: A New Model for Power?*, 140 PUBLIC UTILITIES FORTNIGHTLY 16-26, Feb. 15, 2002, *available at* http://www.pur.com/pubs/3901.cfm.

hydrogen, storing it onboard the vehicle, and then running it through the fuel cell. The total well-to-wheels efficiency with which a hydrogen fuel cell vehicle might utilize renewable electricity is roughly twenty percent (although that number could rise to twenty-five percent or a little higher with the kind of multiple technology breakthroughs required to enable a hydrogen economy).[109] The well-to-wheels efficiency of charging an onboard battery and then discharging it to run an electric motor in an e-hybrid, however, is eighty percent (and could be higher in the future) - four times more efficient than current hydrogen fuel cell vehicle pathways.[110]

As Dr. Alec Brooks, a leading electric vehicle designer has shown, "Fuel cell vehicles that operate on hydrogen made with electrolysis consume four times as much electricity per mile as similarly-sized battery electric vehicles."[111] Ulf Bossel, founder of the European Fuel Cell Forum, arrived at a similar conclusion in a recent article: "The daily drive to work in a hydrogen fuel cell car will cost four times more than in an electric or hybrid vehicle."[112]

This relative inefficiency has enormous implications for achieving a sustainable energy future. To replace half of United States ground transport fuels (gasoline and diesel) in the year 2050 with hydrogen from wind power, for example, might require 1400 gigawatts of advanced wind turbines or more.[113] To replace those fuels with electricity in e-hybrids might require fewer than 400 gigawatts of wind.[114] That 1000 GW difference may represent an insurmountable obstacle for hydrogen as a GHG mitigation strategy - especially since the U.S. will need several hundreds of gigawatts of wind and other zero-carbon power sources in 2050 just to sharply reduce GHG emissions in the electricity sector.

VII. CONCLUSION

Credit is due Governor Schwarzenegger and his Hydrogen Highway proposal for helping elevate the political profile of the need for alternatives to fossil fuel energy sources. In this regard, it can be said

[109] *See generally*, Brooks, *supra* note 98; Romm & Frank, *supra* note 99, at 79.

[110] Romm & Frank, *supra* note 99, at 79.

[111] Brooks, *supra* note 98, at 2.

[112] Ulf Bossel, *The Hydrogen "Illusion"*, Cogeneration and On-Site Power Production 55, 58, March-April 2004, *available at* http://www.efcf.com/reports/E11.pdf; *see also* David Morris, A Better Way to Get from Here to There?, Institute for Local Self-reliance, Minneapolis, MN, December 2003.

[113] Romm, *supra* note 63.

[114] *Id.*

that this effort places California ahead of the renewables curve vis-à-vis the federal United States government and vis-à-vis most other states. This is the good news.

The bad news is that, although perhaps well-intentioned, a decision by California to pin its renewable energy enhancement policy on hydrogen-powered cars would be terribly misplaced. There are significant hurdles that face the hydrogen sector, which make it far less viable – from a technological, economic and environmental benefit perspective – than other alternative fuel vehicles. California's Hydrogen Highway may have public relations appeal, but it may have the unfortunate result of diverting needed resources and attention away from those renewable transportation energy technologies that actually have a real chance to meaningfully reduce the GHG releases that are contributing to global warming.