Summary of Testimony for the February 21, 2002 Field Hearing on

The Role of Fuel Cells in The Renewable Roadmap to Energy Independence

Subcommittee on Energy of the Committee on Science, United States House of Representatives

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The Emerging Opportunity for Renewable Energy, Energy Efficiency, and Fuel Cells

Chairperson Biggert, members of the Subcommittee, and other invited guests, thank you for this opportunity to appear before you today to provide testimony on how renewable energy and energy efficiency technologies can help to foster energy independence for the United States. I would also like to thank Congresswoman Woolsey and Professor Alexandra von Meier of Sonoma State University for arranging for this hearing to take place in a building that provides such a dramatic example of the comfort, quality, and greater energy efficiency that is possible today. Sadly, without public sector leadership, far too little attention and construction goes into this sort of environmentally and economically appropriate design. I hope this hearing will provide the impetus to move the U. S. significantly toward that goal.

I am a professor in the Energy and Resources Group, the Goldman School of Public Policy, and the Department of Nuclear Engineering at the University of California, Berkeley. At Berkeley I also direct the Renewable and Appropriate Energy Laboratory (RAEL), a research center devoted to the dissemination of clean energy technologies.

The clean energy technology options and policies I will discuss are needed to balance, diversify, and safeguard our energy supplies, and in addition to address the challenge of global environmental sustainability. Despite dramatic technical and economic advances, we have seen far too little R&D[1], and too few incentives and sustained programs to build markets for renewable energy technologies and energy efficiency programs[2]. We stand today at a critical juncture where clean, low-carbon, energy choices make both economic and environmental sense, and where policy action can place us on a path to a clean energy future.

During the last decade the case for renewable energy has become compelling economically, socially, and environmentally. For many years renewables were seen as environmentally and socially attractive options that at best occupied niche markets due to barriers of cost and available infrastructure. That situation has *dramatically* changed. Renewable energy resources and technologies – notably solar, wind, small-scale hydro, and biomass based energy, as well as advanced energy conversion devices such as fuel cells – have undergone a true revolution in technological innovation, cost improvements, and in our understanding and analysis of appropriate applications and policy instruments. There are now a number of energy sources, conversion technologies, and applications, where renewable energy options are either equal, or better, in price and services provided than are prevailing fossil fuel technologies. For example, in a number of settings in industrialized nations, wind energy is now the *least cost* option across *all* energy technologies with the added benefit of being quick to install and bring on-line. In fact, some farmers in the Midwest have found that they can generate more income per hectare from the electricity generated by a wind turbine on their land than from their crop or ranching proceeds. Furthermore, photovoltaic panels and solar hot water heaters placed on buildings across America can dramatically reduce peak-power demands, produce a healthier living environment, and increase our energy supply. Despite these advantages, markets remain largely closed to, or strongly biased against, these new energy systems.

Enter the Fuel Cell

Fuel cells are a key enabling technology for many renewable energy systems and represent a critical bridge between traditional fossil-fuel energy systems and a clean, distributed and diverse energy infrastructure. Fuel cells and the associated hydrogen-based energy storage systems also provide a revolutionary opportunity to transform our energy system from one based on the instantaneous use of power generation to one where energy can be efficiently stored and dispatched.

In a fuel cell, hydrogen and ambient oxygen react electrochemically to produce water and electricity, without emitting air pollutants or greenhouse gases. In an electrochemical reaction there is no combustion, so the efficiency can be far higher than current power plants. The only immediate products of the reaction are electricity, water, and heat. A single fuel cell is shown in Figure 1, and a 'stack' of fuel cells – suitable for applications such as the engine of a vehicle or for powering a home – is shown in Figure 2. This stack illustrates an additional key advantage of fuel cell systems. The power generated by a fuel cell stack can be tailored to meet the size of the demand, simply by adding more cells (membranes). This flexibility means that fuel cell power sources can be sized to meet the electricity demand of a cell phone or that of a large industrial plant. Current power plants are much more standardized in size, so that loads often must be tailored to meet the supply. This makes little technical or economic sense.

Hydrogen is the fuel supply for most types of fuel cells. An energy economy utilizing hydrogen extensively has long been a dream for energy planners. Figure 3 shows the overall energy mix in the past and the transition to a hydrogen-based economy as envisioned for the 21st century. Hydrogen and fuel cells have a diverse range of immediate applications, including:

- Powering electrical devices in remote locations (for construction, family camping and other recreation, ranger stations, etc.);

- Producing reliable power for high-tech industry, hospitals, and other critical services;

- Powering cars, buses, and truck auxiliary power units;

- Powering laptop computers, cell phones, radios, audio devices, and other small electronics;

- Powering military devices and equipment, with improved run times and reliability and a reduced thermal profile;

- Use in "microgrids" that combine various energy technologies, including combined heat and power or CHP systems, in order to maximize efficiency and economic attractiveness;

- Providing energy storage and hence electricity generating capacity that can be dispatched as needed; and

- Use for residences that are not yet served by utility lines, or that wish to shift their fuel use to natural gas.

Motor vehicles are a particularly attractive application for fuel cell technology, due to the problems of petroleum dependence and vehicle pollution, and the inefficiency of most vehicle use today. The 100 years of internal combustion engine automotive history in the U. S. also makes this a particularly difficult market to enter. The work in our laboratory has shown that in high-volume production hydrogen fuel cell vehicles would likely be cost competitive with conventional vehicles on a lifecycle basis, with much lower air pollutant emissions, even if natural gas is used as the fuel. Table 1 shows a lifecycle cost comparison between conventional vehicles and three zero-emission vehicle options, and Figure 4 shows a similar comparison but also includes approximate amortized infrastructure costs and air pollutant emission damage values (for the California South Coast region). These analyses show that hydrogen fuel cell vehicles, in particular, may offer economic attractiveness and exceptionally low fuel-cycle emissions. Figure 5 shows an example of a stationary fuel cell, and two fuel-cell vehicle prototypes under development and testing for commercial markets.

Recent research in our laboratory (RAEL; http://socrates.berkeley.edu/~rael) has shown that fuel cell vehicles could potentially be used for multiple purposes, including power production when parked at office buildings and shopping malls, in areas where the prevailing fuel and electricity prices make this attractive. This scenario would make use of the tremendous amount of power available in the vehicle fleet to help meet electricity demands, and also provide a potential cost incentive for vehicle owners. Figures 6 and 7 show the estimated costs of producing electricity with stationary and motor vehicle fuel cell systems at homes and office buildings. Once fuel cell systems reach mass production, they will be able to offer electrical power at costs competitive with grid power, particularly the stationary fuel cell systems and motor vehicles used at commercial office buildings that can simultaneously reduce building electricity and demand charges. The results also show that net-metering policies –whereby the utility grid can be used to help meet surge power demands and also to "bank" excess fuel cell power– may be critical to making stationary fuel cell and fuel cell vehicle power attractive at residential settings.

The most economical way to produce hydrogen at the present time is from natural gas, through a process known as reforming that does lead to small air pollutant and greenhouse gas emissions. However, hydrogen can also be produced from water and electricity, as well as from biomass and green algae. If the electricity used to produce the hydrogen is generated from renewable technologies, then the entire energy cycle of producing the hydrogen and using it in a fuel cell to produce electricity is air pollution and greenhouse gas emission free. The electricity produced by such fuel cells could be used to power homes, commercial buildings, and industrial facilities, as well as to power the next generation of super-efficient electric vehicles. And, since fuel cells for stationary applications can be sited near the point of end use, efficiency can be further advanced through the use of CHP, where even the waste heat from the system is used. Fuel cells used in this way can provide pockets of high-reliability power within electrical grids, and can help to alleviate the need for costly and inefficient electricity transmission and distribution.

In order to maximize their benefit and advance energy security and environmental goals, fuel cell systems can be combined with renewable energy sources in the following ways:

- Excess or off-peak wind, PV, or hydro power can be used to produce hydrogen via electrolysis, which provides a critical means to *store* energy, that can then be used for stationary or motor vehicle fuel cell power. Energy storage is a key issue for the widespread production of electricity from intermittent renewable energy;

- Buildings can be designed with rooftop integrated PV systems to help meet building peak demands, along with natural gas-powered fuel cell systems that meet the building's baseload demand;

- Fuel cell generating stations can be sited at landfills, where they use reformed landfill gas as a free "opportunity fuel" to produce power;

- Biomass can be converted into methanol (which can then be reformed in hydrogen) or hydrogen gas for use in fuel cell systems; and

- Green algae can produce hydrogen gas through a biological process for use in fuel cell systems (still at the R&D stage).

While the introduction of fuel cell systems powered by renewably produced hydrogen will initially occur in small niches, renewable hydrogen production will grow as costs fall, particularly if aided by policies and regulations that specifically reward the use of hydrogen produced from renewables. An ideal policy would clearly articulate a transitional strategy to open markets, and reward clean energy generation. I recommend a program where fuel cell systems are initially fuelled with the least cost option, which would likely be natural gas, and then could expand to include ethanol and methanol fuels. Once fuel cell system costs have declined – as do the costs of all new technologies -- the market and policy support can focus on hydrogen production from the cleanest and most sustainable sources, radically improving the efficiency and environmental performance of our national energy system.

In order for this to occur, however, policy changes are needed and R&D funding must be increased. Fuel cell technology has benefited from significant private and public investment, but too much emphasis has been placed on systems that produce hydrogen from fossil fuels and not enough has been placed on hydrogen-based systems using renewables. Significant development challenges remain for fuel cell systems, and government development assistance and program support from agencies and national labs can play a key role in overcoming these remaining hurdles.

I recommend the following policy measures to encourage development and deployment of renewable and fuel cell technologies:

- **Revised and extended tax credits** for consumers who purchase residential PV systems, and tax deductions for businesses and farms that install PV, wind, and/or fuel cell systems (giving the highest incentives to systems that combine fuel cell systems with renewables);

- **Increased R&D on fuel cell systems that run directly on hydrogen**, on hydrogen storage and infrastructure, and on electrolyzer technologies, rather than on gasoline fuel reformers and reformate-based systems, to enable the transition to a hydrogen economy that ultimately can be based heavily on renewable energy sources;

- **Significant government purchase programs for fuel cell vehicles and stationary fuel cell systems**, as they become available, to assist with initial market success and to help move the technologies down their "learning curves";

- **Opening of electricity markets to clean distributed power**, along with clear and fair rules and tariffs for utility interoperability, and with social-welfare based subsidies (e.g. based on avoided human health and other economic damages) for true "zero emission" fuel cell power that is based on renewable sources;

- **Federal assistance for municipalities that install fuel cell systems on landfills** using landfill gas as the fuel; and

- **Utility net metering policies for fuel cell systems**, whereby fuel cells can use electrical grids for assistance with peak power needs (thus eliminating the costs of expensive system components needed to provide momentary surge power, such as batteries, capacitors, and fuel buffers), and can also optimize efficiency by "banking" kWh credits with utilities. This policy directly benefits local utilities by providing reliable power generation to meet peak and backup power needs.

The critical message in each of these policy measures is that technology 'push', namely R&D, is only effective and efficient if combined with 'demand pull'. At present, the electricity markets into which fuel cells and other renewable energy systems are expected to enter are biased strongly toward existing, fossil-fuel power generation and toward traditional utilities. Opening energy markets to smaller-scale, distributed power systems makes the grid and our energy infrastructure more cost-effective, secure, and environmentally friendly. It is therefore disappointing to see the extensive set of barriers placed in the way of these new sources. A more extensive list of important energy policy recommendations is included in the summary box in Appendix A and in recent testimony I provided to the U. S. Senate Commerce, Science, and Transportation (July 10, 2001)[3] and Finance (July 11, 2001) Committees[4].

Industrial and Environmental Leadership

This hearing comes at a critical time, less than a year after the release of the report from Vice President Cheney's National Energy Policy Initiative, and a week after the release of President Bush's Climate policy statement. Both of these recommendations highlight the importance of economic, energy, and environmental leadership to the U. S. At the same time both of these policy initiatives take conventional views of the energy market – namely one where fine-tuning existing energy markets and a bit of R&D will provide for our future. This view makes no sense given the ample evidence from the California energy crisis and the demise of Enron that markets are *not* working either effectively or efficiently. We have an opportunity today to build a clean, efficient and *secure* energy future. Yet so far we have failed to recognize the tremendous domestic and international business opportunities that are open to a leader in the development and marketing of clean and secure energy options. The U.S. was the early innovator in wind, solar photovoltaic, and fuel cell technologies. After two decades of stagnation and decline in funding and policy action the U.S. now trails Japan and several European and nations in the market for each of these promising technologies. A clean energy 'Apollo project' coupled with an opening of market access for renewable energy would by most estimates generate tens of billions of new revenue while going far beyond the meager measures proposed in the Bush climate plan.

We have renewable energy technologies and policies ready *now* to permit us to reduce emissions significantly and at the same time develop profitable new clean energy industries and markets. That is as simple a win-win opportunity as could be. To date, we have not taken advantage of these opportunities and possibilities. The irony is that all of the wrangling over the Kyoto climate treaty would be irrelevant if emerging energy technologies and entrepreneurs were afforded the opportunity to compete in energy markets where efficient, clean production was valued. In the current system, high-cost and high-polluting energy is often rewarded with the highest tariffs and the most institutional support.

Summary: Opportunity Knocks

In summary, there is a wide range of options for achieving energy supply and demand balance, and energy efficiency, renewables, and hydrogen-based systems offer the best hope for allowing our future energy needs to be met in a more environmentally and socially sustainable fashion. By advancing along a path of reduced energy demands through efficiency measures, increased energy supply from renewable sources, and the use of clean energy technologies such as fuel cells, we can meet our energy needs while reducing energy-related military involvement, avoiding increases in greenhouse gas emissions, and reducing sensitivity to energy price shocks. It is clear that an energy policy weighted towards increasing the supply of traditional forms of energy will do little to decrease our energy security risk and greenhouse gas emissions, and will create a host of other environmental, health, and national security problems. Renewable energy technologies and energy efficiency must play a more significant role in protecting our climate as well as our energy future, and these technologies and practices demand far greater examination and commitment to implementation than we have seen to date. And so, I am particularly pleased that this Subcommittee is holding this hearing to discuss how we can effectively and efficiently bring these technologies to market.

Table 1: Lifecycle Cost Comparison of Conventional and High-Production-Volume Zero-Emission Vehicle Options (central case).

Lifecycle cost category	Gasoline ICE Vehicle	Battery EV	Direct Hydrogen FCV	Direct Methanol FCV
Purchased electricity ($0.065 / kWh)	0.00	2.73	0.00	0.00
Vehicle (excluding battery, fuel cell, and hydrogen storage)	17.61	14.65	14.26	14.48
Battery, tray, and aux. (+ recharger for BEV)	0.00	10.93	2.68	2.71
Fuel, excluding excise taxes	5.56	incl. in elect.	3.02	6.66
Fuel storage system	incl. in vehicle	0.00	1.28	0.08
Fuel cell system	0.00	0.00	2.84	3.47
Insurance	6.77	7.88	7.86	7.72
Maintenance and repairs (excluding oil and inspection)	4.88	3.72	4.17	4.32
Oil	0.17	0.00	0.00	0.00
Replacement tires	0.50	0.45	0.32	0.32
Parking, tolls, and fines	1.05	1.05	1.05	1.05
Registration fees	0.50	0.48	0.45	0.46
Vehicle safety and emissions inspection fees	0.60	0.21	0.21	0.21
Federal, state, and local fuel excise taxes	1.75	1.75	1.75	1.75
Accessories	0.30	0.30	0.30	0.30
Total lifecycle cost	**39.68 ¢/mi**	**44.15 ¢/mi**	**40.19 ¢/mi**	**43.52 ¢/mi**

Source: Lipman, T., "Zero Emission Vehicle Scenario Cost Analysis with a Fuzzy-Set Based Framework", Ph.D. Dissertation, UC Davis, 1999. ICE: Internal Combustion Engine; EV: Battery/Electric Vehicle; FCV: Fuel Cell Vehicle.

Figure 1: Schematic of a Single Fuel Cell

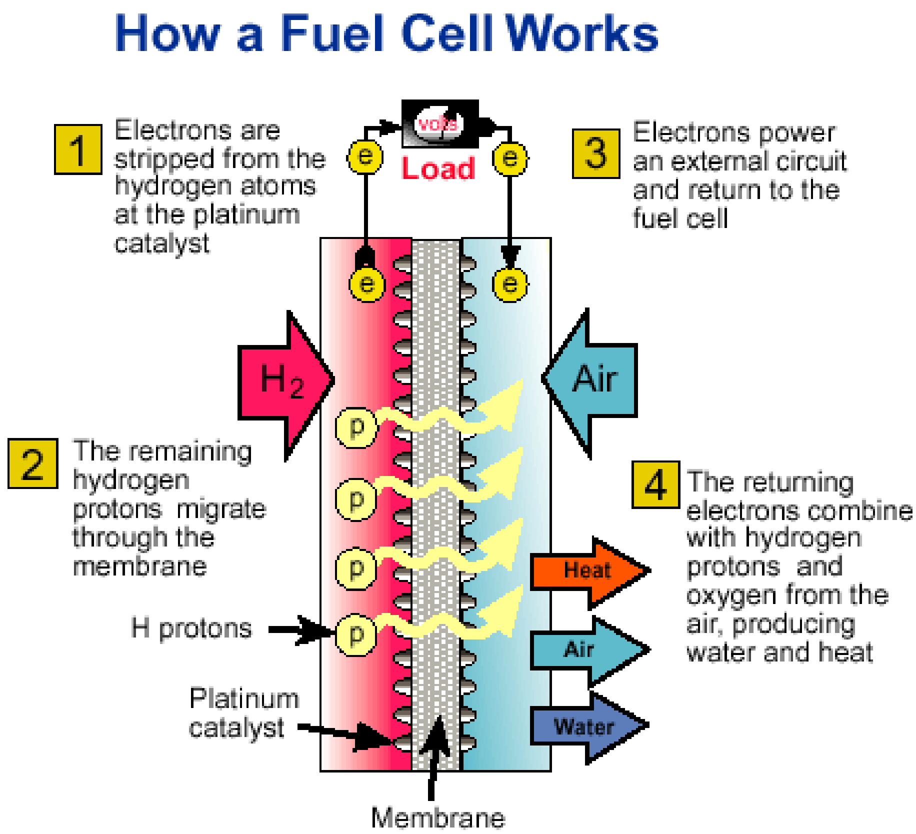


Figure 2: Fuel Cell ‘Stack’ to produce current and voltage output to match an application

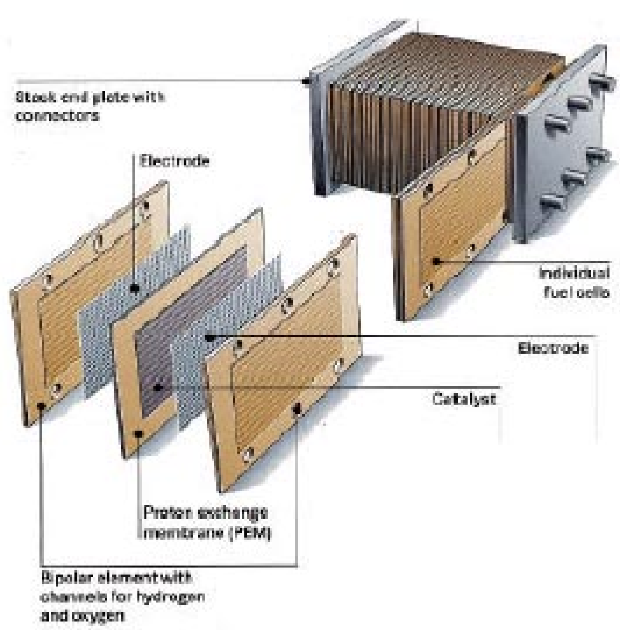


Figure 3: History of Fuels in Global Use, and Envisioned Hydrogen Energy Future

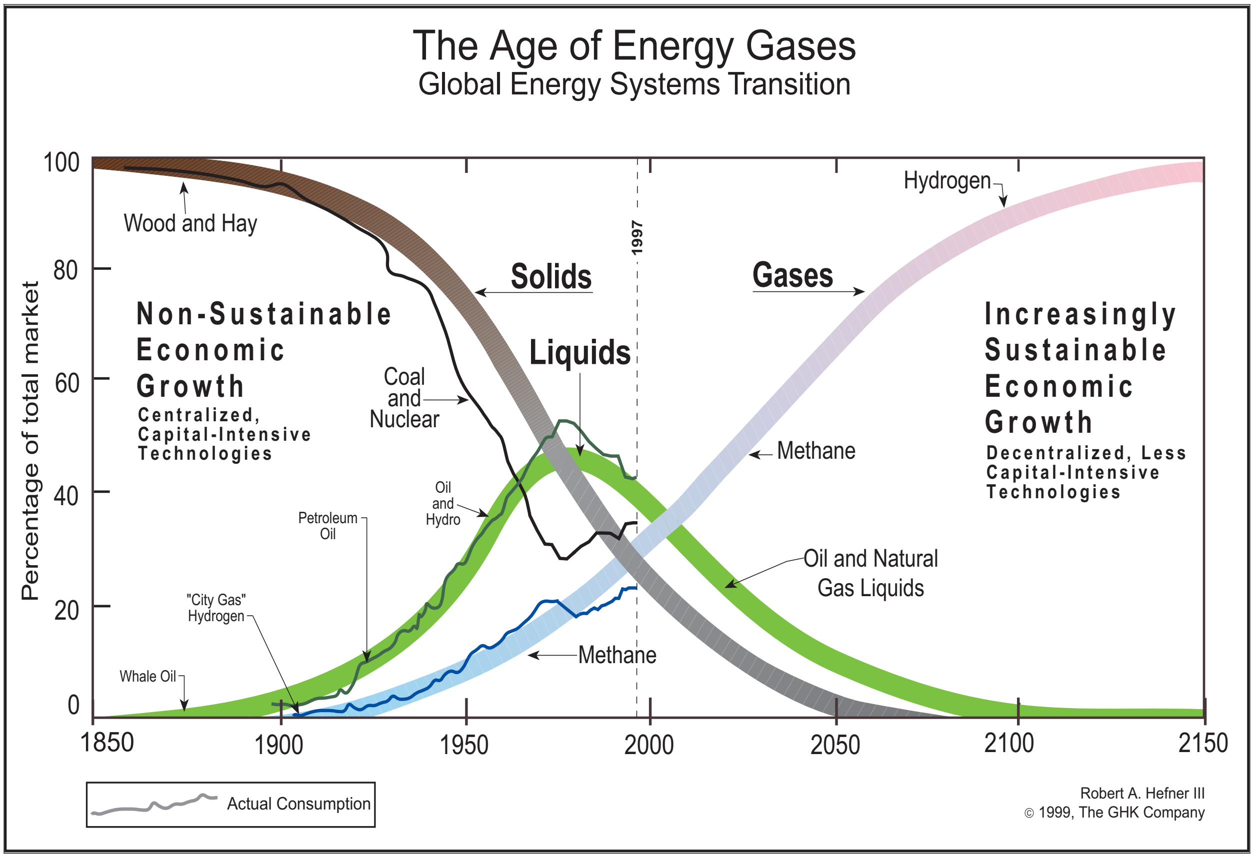
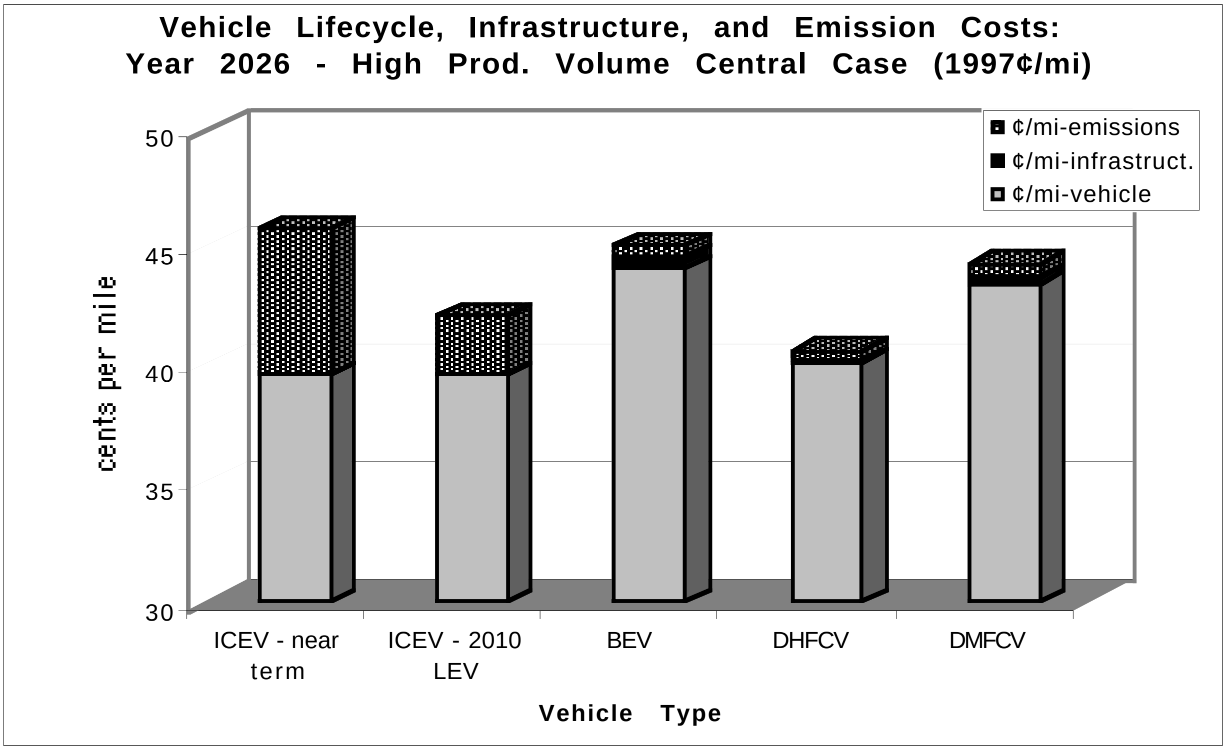
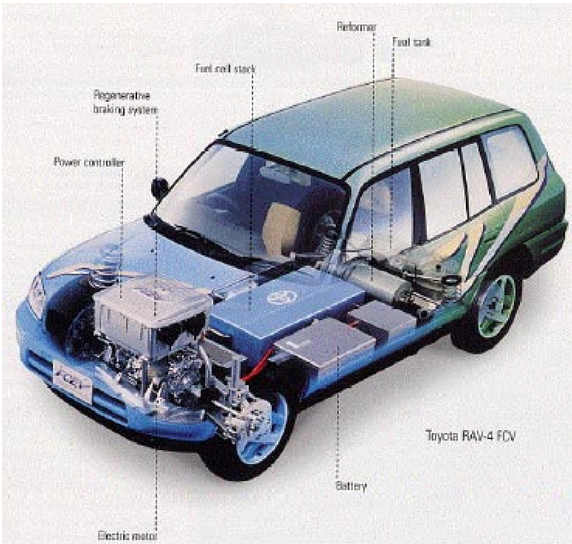


Figure 4: Vehicle Lifecycle Cost Comparisons, including emissions charges. DHFCV, direct hydrogen fuel cell vehicle, DMFCV, direct methanol fuel cell vehicle.

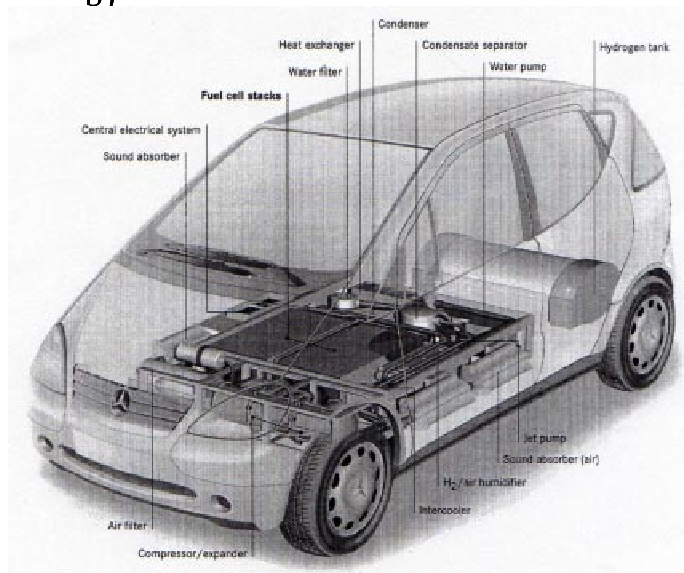


Figures 5: Fuel Cell Vehicle Prototypes (a, b) and Stationary Fuel Cell (c)

a)



b)



c)

Figure 6: Commercial Office Building Self-Generation Electricity Cost Estimates Under Load Following (LF) and Net Metering (NM) Conditions for 75 and 250 kW fuel cell systems.

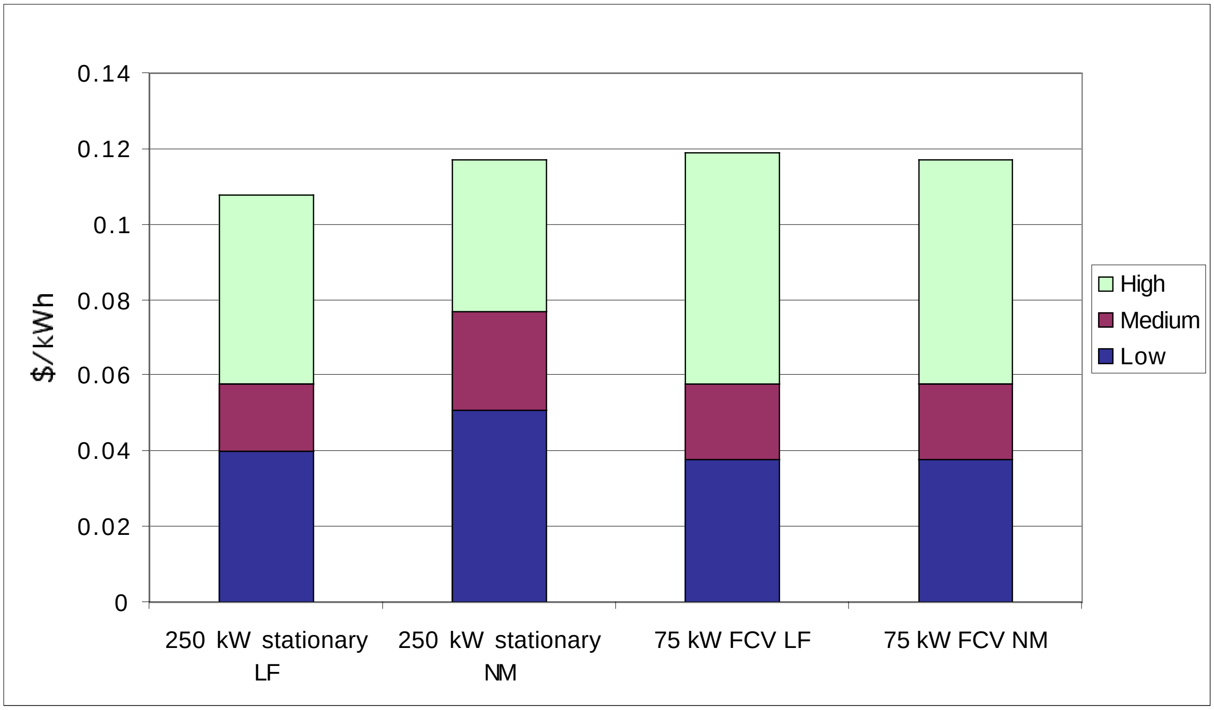
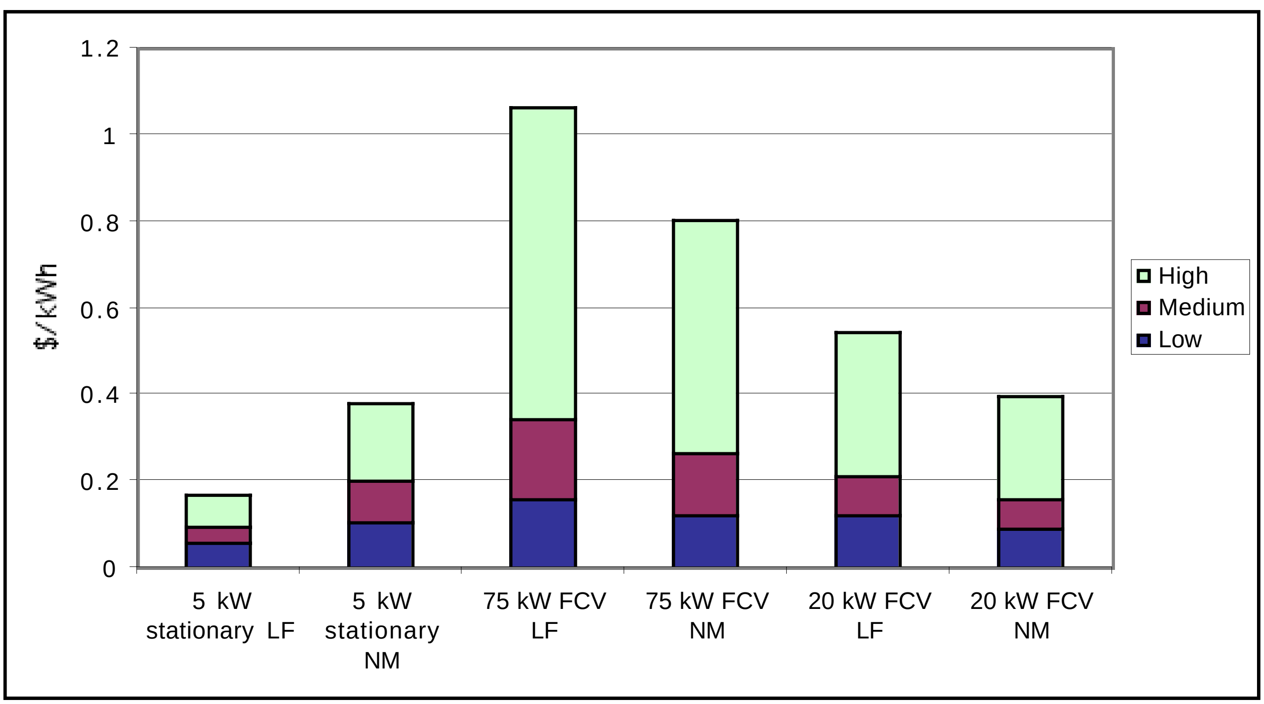


Figure 7: Residential Self-Generation Electricity Cost Estimates Under Load Following (LF) and Net Metering (NM) Conditions for various fuel cell system sizes (5, 20, and 75 kW)



Appendix A: Policy Recommendations to Build A Clean Energy Future

- **Increase Federal R&D Funding for Renewable Energy, Fuel Cell, and Energy Efficiency Technologies**

Federal investment in renewable energy and energy efficient technologies has been sparse and erratic, with each year producing an appropriations battle that is often lost. A combination of increased, steady, funding and active political leadership would transform the clean energy sector from a good idea to a pillar of the new economy.

- **Provide Tax Incentives for Companies the Develop and Use Renewable Energy and Energy Efficiency Technologies**

Support for the production and further development of renewable fuels, all found domestically, would have a greater long-term effect on the energy system than any expansion of fossil-fuel capacity, with major health and environmental benefits as an added bonus. We should extend the existing production tax credits (PTC) for electricity generated from windpower and biomass for five years. I also support a minimum of a 15 percent investment tax credit for residential solar electric and water heating systems. In addition, I support a 30 percent investment tax credit being proposed for small (75 kW and below) windpower systems.

- **Improved Federal Standards for Vehicle Fuel Economy and Increased Incentives for High Fuel Economy Vehicles**

We need to first remove the separate fuel economy standards for cars and light trucks (i.e., close the light truck 'loophole' as proposed in S. 804 by Senators Feinstein and Snowe and H.R. 1815 by Representative Olver). I then believe that a 40 mpg combined car and light truck fuel economy standard could be accomplished in the 2008 to 2012 timeframe with negligible net cost. I support tax credits for hybrid electric vehicles, battery electric vehicles, and fuel cell vehicles, and an incentive scheme for energy-use performance that rewards both fuel savings and lower emissions, as is proposed in the CLEAR Act, S. 760, introduced by Senators Hatch, Rockefeller, and Jeffords, and its companion bill (H.R. 1864) introduced by Representative Camp.

- **A Federal Renewable Portfolio Standard (RPS) to Help Build Renewable Energy Markets**

I support a 20 percent RPS by 2020. A number of studies indicate that this would result in renewable energy development in every region of the country with most coming from wind, biomass, and geothermal sources. A clear and properly constructed federal standard is needed to set a clear target for industry research, development, and market growth. I recommend a renewable energy component of 2 percent in 2002, growing to 10 percent in 2010 and 20 percent by 2020 that would include wind, biomass, geothermal, solar, and landfill gas. This standard is similar to the one proposed by Senators Jeffords and Lieberman in the 106th Congress (S. 1369). An alternative is for the federal government to provide incentives to states that enact local RPS policies.

- **Federal Standards and Credits to Support Distributed Small-Scale Energy Generation and Cogeneration (CHP)**

Small scale distributed electricity generation has several advantages over traditional central-station utility service, including reducing line losses, deferring the need for new transmission capacity and substation upgrades, providing voltage support, and reducing the demand for spinning reserve capacity. In addition, locating generating equipment close to the end use allows waste heat to be utilized to meet heating and hot water demands, significantly boosting overall system efficiency. I support at least a 10 percent investment tax credit and seven-year depreciation period for renewable energy systems or combined heat and power systems with an overall efficiency of at least 60-70 percent depending on system size.

- **Enact New and Strengthen Current Efficiency Standards for Buildings, Equipment, and Appliances**

Significant advances in heating and cooling systems, motor and appliance efficiency have been made in recent years, but more improvements are technologically possible and economically feasible. A clear federal statement of desired improvements in system efficiency is needed to remove uncertainty and reduce the economic costs of implementing these changes. Under such a federal mandate, efficiency standards for equipment and appliances could be steadily increased, helping to expand the market share of existing high efficiency systems.

- **Institute a National Public Benefits Fund**

I recommend a public benefits fund financed, for example, through a $0.002/kWh charge on all electricity sales. Such a fund could match state funds to assist in continuing or expanding energy efficiency programs, low-income services, the deployment of renewables, research and development, as well as public purpose programs the costs of which have traditionally been incorporated into electricity rates by regulated utilities.

Biographical Sketch: Daniel M. Kammen

Daniel M. Kammen received his undergraduate degree physics from Cornell University 1984, and his Masters (1986) and Doctorate (1988) degrees in physics, from Harvard University. He was a Bantrell & Weizmann Postdoctoral Fellow at the California Institute of Technology, and then a lecturer in the Department of Physics at Harvard University. From 1992 – 1998 Kammen was on the faculty of the Woodrow Wilson School of Public and International Affairs at Princeton University, where he was Chair of the Science, Technology and Environmental Policy Program. Kammen is now Professor of Energy and Society in the Energy and Resources Group (ERG), and in the Department of Nuclear Engineering at the University of California, Berkeley. At Berkeley Kammen is the founding director of the Renewable and Appropriate Energy Laboratory (http://socrates.berkeley.edu/~rael), and is campus representative to the University of California Energy Institute. He has been a Lecturer in Physics and Natural Science at the University of Nairobi.

Professor Kammen's research centers on the science, engineering, economics and policy aspects of energy management, and dissemination of renewable energy systems. He also works on the health and environmental impacts of energy generation and use; rural resource management, including issues of gender and ethnicity; international R&D policy, climate change; and energy forecasting and risk analysis. He is the author of over 120 journal publications, a book on environmental, technological, and health risks (*Should We Risk It?*, Princeton University Press, 1999) and numerous reports on renewable energy and development. Kammen received the *1993 21st Century Earth Award* and is a Fellow of the American Physical Society. He is a Permanent Fellow of the African Academy of Sciences. He appears frequently as a commentator on energy and environmental issues in the media.

For information of any of these activities and for copies of Professor Kammen's writings, see http://socrates.berkeley.edu/~dkammen.

References:

[1] Margolis, R. and Kammen, D. M. (1999) "Underinvestment: The energy technology and R&D policy challenge", *Science*, **285**, 690 - 692.

[2] Duke, R. D., and Kammen, D. M. (1999), "The economics of energy market transformation initiatives", *The Energy Journal*, **20**: 15 – 64.

[3] Kammen, D. M. (2001) Testimony for the Hearing on 'Technology and Policy Options for Climate Change' for the U. S. Senate Committee on Commerce, Science, and Transportation, July 10 (United States Senate: Senate Committee on Commerce, Science, and Transportation).
URL http://www.senate.gov/~commerce/

[4] Kammen, D. M. (2001) Testimony for the 'Hearing on the Role of Tax Incentives in Energy Policy' for the U. S. Senate Committee on Finance, July 11 (United States Senate: Committee on Finance).
URL http://www.senate.gov/~finance/071101dktest.pdf