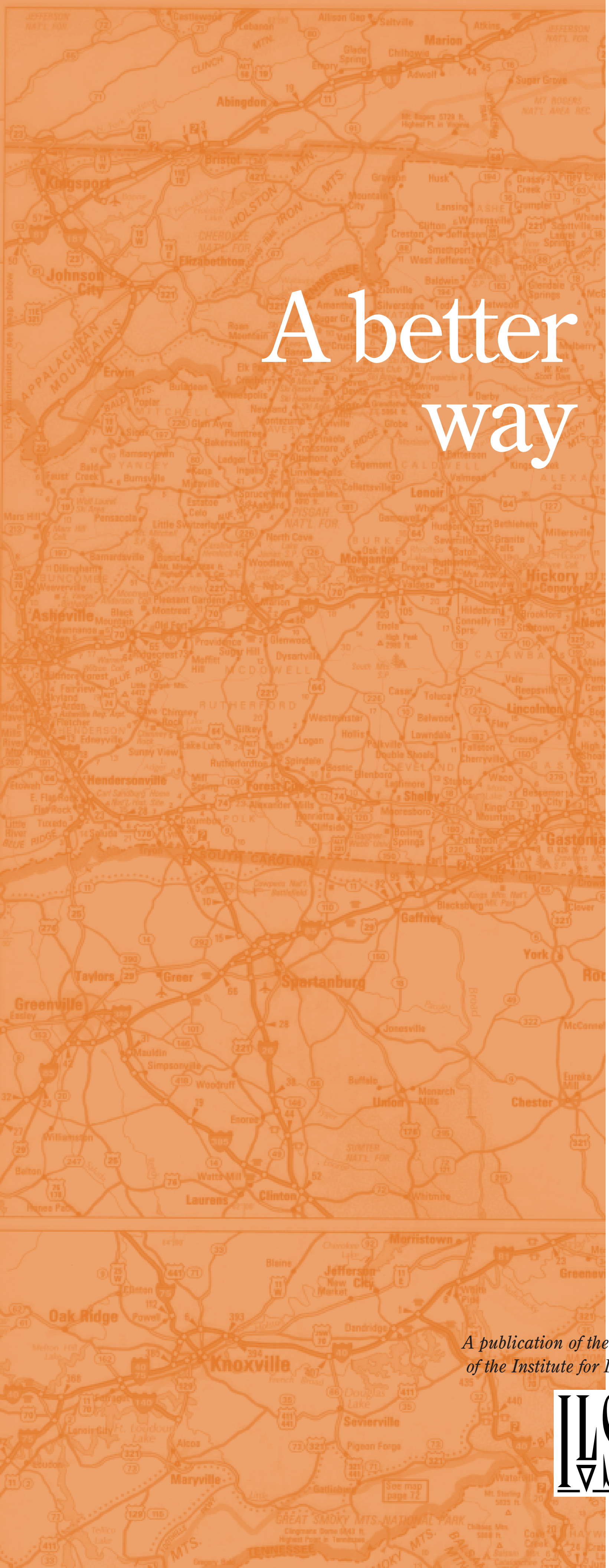

A better way to get from here to there

A commentary on the hydrogen economy and a proposal for an alternative strategy

David Morris

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A Better Way to Get from Here to There

A Commentary on the Hydrogen Economy and a Proposal for an Alternative Strategy

David Morris, Vice President
Institute for Local Self-Reliance
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Executive Summary

The idea of a hydrogen economy has burst like a supernova over the energy policy landscape, mesmerizing us with its possibilities while blinding us to its weaknesses. Such a fierce spotlight on hydrogen is pushing more promising strategies into the shadows.

The hydrogen economy is offered as an all-purpose idea, a universal solution. However, in the short and medium term a crash program to build a hydrogen infrastructure can have unwanted and even damaging consequences. This is especially true for the transportation sector, the transformation of which is the primary focus of hydrogen advocates and the highest priority of federal efforts.

The focus on building a national hydrogen distribution and fueling network to supply fuel cell powered cars ignores shorter term, less expensive and more rewarding strategies encouraged by recent technological developments. The most important of these is the successful commercialization of the hybrid electric vehicle (HEV).

The HEV establishes a new technological platform upon which to fashion transportation-related energy strategies. Its dual reliance on electric and gasoline propulsion systems allows and encourages us to develop a dual energy strategy that expands the electricity storage and propulsion capacity component while rapidly expanding the renewable fuels used both for the electricity and engine side of the vehicle.

The current hydrogen economy strategy focuses almost entirely on the engine side of the hybrid with its inherent ramifications: the creation of a nationwide production and delivery system for hydrogen and the commercialization of a fuel cell car that can use pure hydrogen. A lower cost strategy with a quicker payoff and impact would focus on expanding electricity storage side and substituting biofuels for gasoline. HEV's overcome the key performance liability of all-electric cars: short driving range. But the current generation of HEVs lack the ability to operate solely on batteries. Electricity is used to reduce or eliminate energy losses due to idling and stop-and-go driving in urban areas. Manufacturers should be strongly encouraged to quickly develop the next generation of HEVs that can travel significant distances on battery power alone. Rapid advances have occurred in recent years in electric storage technologies.

One element of this strategy is to encourage plug-in HEVs (PHEVs) that can recharge the batteries from the grid as well as the engine. While HEVs can reduce fuel consumption by 30 percent, PHEVs can reduce consumption by 85 percent or more.

Extending the HEVs electricity-only driving range should be accompanied by a simultaneous strategy that expands the use of renewable energy to fuel both the motor and the engine. On the electricity side, this means dramatically expanding the generation of electricity using wind, sunlight and other renewable fuels. On the engine side it means dramatically expanding the use of sugar-derived biofuels. More than 4 million variable-fueled vehicles are already on the road. They can operate on any combination of ethanol and gasoline. The cost of modifying vehicles to allow them this multiple fuel capacity is small, about $150 per vehicle compared to the tens of thousands of dollars additional cost of a fuel cell vehicle. The cost of developing a network of fueling stations capable of delivering biofuels as a primary fuel (50-100 percent) rather than the current, 6-10 percent additive is a tiny fraction of the cost of establishing a network of hydrogen fueling stations, about $50,000 for a biofuel refueling station versus some $600,000 for a hydrogen refueling station.

Currently in the United States ethanol is made from sugars extracted from corn. In the future the sugars will come from far more abundant cellulose materials like corn stalks and wheat straw and grasses and kelp. A sugar economy would not only reduce the nation's dependence on imported oil but would create the potential for designing a low cost agricultural policy that benefits domestic and foreign farmers alike.

For the foreseeable future, even the hydrogen economy's most ardent supporters concede that theirs will be a high cost strategy ($2.50 to $12 per gallon of gasoline equivalent) based on nonrenewables and likely to increase the emissions of greenhouse gases. These advocates argue that in the long term these various costs can be reduced or eliminated. Technically that may be so. But hydrogen's high cost, poor energetics and scant environmental benefits for the near and medium term future must be taken into account when evaluating it against alternative fuels and strategies.

> **"Hydrogen's** high cost, poor energetics and scant environmental benefits for the near and medium term must be taken into account when evaluating it against alternative fuels and strategies."

For example, hydrogen advocates argue that hydrogen's higher cost will be offset by the higher efficiency of fuel cells. The argument is valid when fuel cells are compared to traditional internal combustion engines (ICEs) but disappears when fuel cells are compared to HEVs.

Some environmentalists have criticized biofuels for their cost and modest net energy yields. Yet hydrogen costs are higher than biofuels even when the latter's subsidies are eliminated. And hydrogen production and distribution has a negative net energy yield. Finally, while electric batteries have a high cost compared to gasoline they are a lower cost storage medium than liquid or compressed hydrogen.

A dual strategy (improvements in electricity storage, electronics controllers and software accompanied by an aggressive fuel substitution policy) has many advantages over a hydrogen focus. It is cheaper, less disruptive and more resilient. It can have a more dramatic short-term impact. It can allow us to tackle multiple societal problems (e.g. the plight of farmers and rural economies) at the same time.

One can argue that this is not an either-or situation. We can promote hydrogen while promoting more efficient vehicles and renewable fuels. But we have scarce financial, intellectual and entrepreneurial resources. Dramatic improvements in the efficiency of our transportation fleet via the introduction of advanced and plug in hybrids and the expansion of renewable fuels to substitute for gasoline can occur incrementally using the current production and distribution systems. For a hydrogen economy to have any impact the nation must change virtually every aspect of its energy system, from production to distribution to the design of our gas stations and our cars.

We may be on the verge of spending hundreds of billions of dollars and diverting enormous amounts of scarce intellectual and entrepreneurial energy to create an infrastructure based on nonrenewable fuels in the hope that after it is in place we might fuel it with renewable energy.

The chicken-and-egg problem of building an infrastructure to allow the hydrogen economy to emerge, even if the initial basis of that economy is nonrenewable fuels has already enticed environmental and renewable energy advocates into a series of unfortunate compromises. For example, to jump-start a hydrogen fueling system the Minnesota legislature in 2003 declared natural gas to be a renewable energy resource so long as it is used to make hydrogen. In 2003 the California Air Resources Board

Worldwide Sources of Commercial Hydrogen 2002 [2]

Origin	Amount in billions Nm3 per year	Percent
Natural Gas	240	48
Oil	150	30
Coal	90	18
Electrolysis	20	4

(CARB) declared a fuel cell car superior to a plug-in hybrid vehicle even though the former would consume more fossil fuels than the latter.

The electricity network is already in place. Why not focus on expanding the portion of this delivery system that relies on renewable energy rather than spend the next generation creating a new delivery infrastructure that, once built, will require renewable energy to once again make inroads? In 2003 renewable resources generate about 1.5 percent of the nation's transportation fuels and about 2.5 percent of the nation's electricity. Why not focus on ratcheting upwards these low percentages rather than face a situation in 2020 where renewable resources generate 1-2 percent of the nation's hydrogen?

A crash program to switch to electricity/biofuel powered vehicles should take into account social and economic issues. The transition should not only expand renewable energy use but do so in a way that maximizes the benefits to hard-pressed rural economies here and abroad. This is best accomplished by having the power plants locally owned.

Farmers who own a wind turbine can earn several times more than those that simply lease their land for large-scale wind developers. Farmers who own a share of ethanol plants can earn several times more per bushel of corn delivered than their neighbors who only sell their corn to ethanol plants.

There is another important reason to treat scale and ownership issues seriously: the concentration of market power. Archer Daniels Midland (ADM) generates about 40 percent of the ethanol produced in the country and dominates nationwide distribution. Although its share has dropped in the last 10 years with the rapid growth of smaller and medium-sized ethanol facilities, many of which are farmer owned, it remains a worrisome situation. This is especially so because of ADM's past involvement in price fixing and its aggressive exercise of market power.

An aggressive biofuels program promises important international benefits as well. The key trade disputes currently involve farmers in industrialized countries pitted against farmers in poorer countries. Rather than have carbohydrates compete with carbohydrates, a biofuel program would allow carabohydrates to compete with hydrocarbons. The agricultural sector and farming communities in poorer countries are far bigger than in the United States and Europe. And the use of plant matter to displace imported fossil fuels is even more compelling in poorer countries that lack the hard currencies needed to pay for these imports.

A decision to focus on an electricity/biofuel path for the transportation sector does not preclude the rapid deployment of fuel cells. Indeed, the fuel cell economy is developing rapidly without a hydrogen distribution network. Fuel cells have the attractive potential of decentralizing and democracizing the electricity system, reducing system costs and lowering the likelihood of repetitions of widespread blackouts like the one that occurred in the northeastern United States in August 2003. A fuel cell economy does not depend on a hydrogen economy as currently envisioned.

The strategy currently envisioned to effect a hydrogen economy may be diverting significant intellectual, financial and political resources from more attractive strategies. Before we take that leap, we should take a long hard look at the premises and promises of the hydrogen economy and at the other alternatives available that could achieve the same goals more quickly and cheaply.

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The Vision

In January 2003, President Bush announced a $1.6 billion five-year effort to make hydrogen the fuel of choice in the transportation sector.[1] The initiative was applauded on both sides of the aisle. In the spring of 2003 the hydrogen title of the Energy Bill (Title VII) was voted on first because of its uncontroversial nature. As Marie Fund, spokeswoman for the Senate Energy Committee correctly noted before the hearings began, "It'll be kind of a love fest."

Spurred by the sudden federal enthusiasm, state legislatures have moved quickly to embrace the hydrogen economy. In late April 2003 California revised its Zero Emission Vehicle program to focus on hydrogen fuel cell vehicles rather than battery-electric vehicles. In June 2003 Minnesota's legislature declared, "It is a goal of this state that Minnesota move to hydrogen..." In July 2003 the Pacific Northwest, led by the Bonneville Power Authority, declared its intention to become the "Saudi Arabia of hydrogen".

The attractiveness of a hydrogen economy is easily explained. Hydrogen is the planet's most abundant element. It can be extracted from water, another abundant material. Hydrogen gas is odorless, tasteless and non-poisonous. Fuel cells using hydrogen emit only water. There are no harmful tailpipe or smokestack emissions.

A future powered by hydrogen extracted from water using electricity generated by renewable fuels like wind or geothermal power is a most appealing vision.

A fundamental reason that the hydrogen economy initiatives have garnered such widespread support is that everyone can play the game. No energy source is excluded. And in this game the fossil fuel and nuclear industries have enormous advantages.

- Currently the industrial hydrogen market is mature and growing. The hydrogen comes primarily from natural gas (95 percent in the United States, 50 percent worldwide) although it is also made from coal and petroleum. Industrial use of hydrogen is about 50 million metric tons and growing at 4-10 percent per year.[3] Some 95 percent of the hydrogen is generated by industries for internal use as a chemical for making fertilizer or in oil refining. Five percent is merchant hydrogen sold to external users.
- The nuclear industry sees itself as a key player in a hydrogen future. "Hydrogen Economy; Boom Time for Hydrogen Production by Nuclear Energy," reads a headline in *Power Economics*.[4] Nuclear power "is the only way to produce hydrogen on a large scale without contributing to greenhouse gas emissions," boasts the trade journal Nucleonics Week. The federal energy bill authorizes as much as $1 billion to build a nuclear reactor and use it to extract hydrogen from water.
- Coal supplies almost 20 percent of the world's hydrogen. At the 2000 World Hydrogen Energy Congress in Beijing, Italy and China announced plans to cooperate to boost that percentage. President Bush has launched a billion dollar initiative to develop a coal gasification-to-hydrogen plant.
- Several automobile and oil companies are betting that petroleum will be the hydrogen source of the future. It was General Motors, after all, that coined the phrase "the hydrogen economy". There is more hydrogen in a gallon of gasoline than in a gallon of liquid hydrogen.
- Wind energy and solar energy advocates support hydrogen production as a way to overcome the limitations resulting from the intermittent nature of producing electricity from these resources.
- There is another reason there is little opposition to a hydrogen economy. After President Bush announced a billion dollar initiative in January 2003 it was apparent that money for hydrogen-related projects would soar even as money for other programs, both fossil fuel and renewable, were projected to decline. Potential recipients for this new money are reticent to criticize the initiative. States have begun to "prime the pump" by investing significant sums up front in the anticipation that it will make them attractive for the increased federal funding.

"There is more hydrogen in a gallon of gasoline than in a gallon of liquid hydrogen."

The Reality

A Hydrogen Economy Is Not A Renewable Energy Economy

For the foreseeable future the vast majority of hydrogen will be made from non-renewable resources. The Department of Energy expects natural gas to be the primary source for transportation-related hydrogen for the next 10-20 years and probably for many years beyond that. After a review of the scientific and engineering literature, MIT researchers announced, “The uniform conclusion is that decentralized gas reforming stations can provide hydrogen at lower cost than any of the other options 20 years from now.”[5] In the longer term, the Department of Energy believes coal could become a significant supplier of hydrogen after 2015. President Bush’s long-term vision, as outlined in his State of the Union address, is to use nuclear fusion to produce hydrogen from water.

Hydrogen can be produced using renewable energy but the cost is far higher than producing hydrogen from non-renewable fuels. “Electrolytic hydrogen from intermittent renewable resources is generally two to three times more costly to produce than hydrogen made thermo-chemically from natural gas or coal, even when the costs of CO2 sequestration are added to the fossil hydrogen production cost,” Joan Ogden, research scientist at the University of California-Davis told the House Science Committee in March 2003.

All advocates of the hydrogen economy discuss the “chicken and egg” problem. We can’t have a hydrogen economy until there is an adequate system for storing, transmitting and fueling cars (and stationary fuel cells) with hydrogen. Doing so will take decades and the cost will run into the hundreds of billions of dollars. While we build the infrastructure hydrogen will come from non-renewable resources like natural gas that has its own distribution system. After the hydrogen infrastructure is in place, renewable hydrogen will be able to enter the market.

To get the hydrogen economy up and running some states are allowing fossil-fueled hydrogen to be considered renewable hydrogen feedstocks. In the spring of 2003, for example, the Minnesota legislature declared that natural gas-derived hydrogen would be considered renewable energy until 2010 and therefore eligible for incentive programs related to hydrogen and fuel cell industry development.

A renewable hydrogen economy is an interesting prospect. But the reality is that the gestation process for the renewable egg is going to be measured in decades. In the meantime the energy for the chicken will come from fossil (or nuclear) fuels.

Which is why some in the renewable energy community question the wisdom of shifting intellectual, financial, political and entrepreneurial resources into a crash program to produce hydrogen. The European Wind Energy Association (EWEA) cautions that a premature push toward a hydrogen economy “could have a serious environmental downside”. Christian Kjaer, EWEA’s policy director notes, “It is a backwards argument that hydrogen opens access to new and renewable energy sources. It is the other way around. Large-scale renewable energy production, such as offshore wind power, is an essential precondition for the deployment of a sustainable hydrogen economy.”[6]

In the last 30 years renewable energy has overcome significant odds. In the United States it has now captured about 2 percent of the total transportation fuels and electricity markets. Wind power is the world’s fastest growing energy resource. The growth curve for photovoltaics is steep. This is the time to make a major effort to move solar energy from the margins of energy production to its center rather than to shift our intellectual and scientific and capital resources toward constructing the infrastructure demanded for a hydrogen economy and end up 25 years from now where we are, in essence today: having 2 percent of the hydrogen market and hoping to increase that fraction.

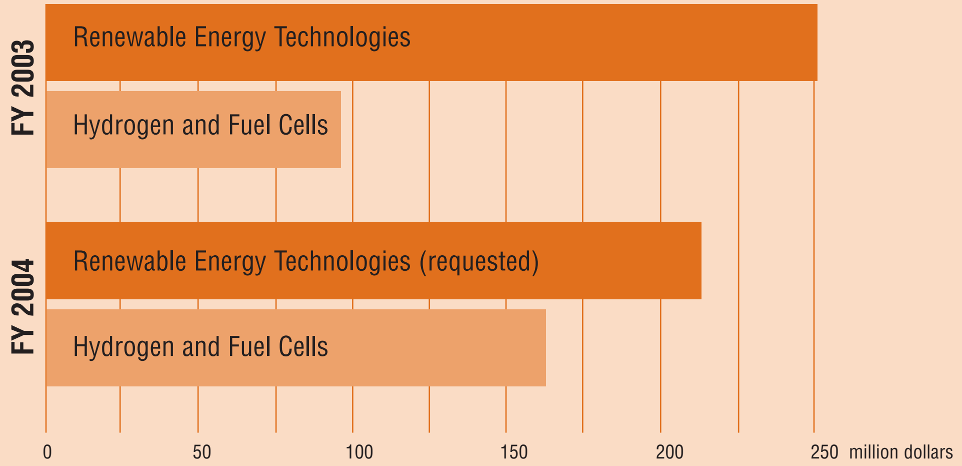
It is instructive to note that while wind-generated hydrogen is far from competitive with fossil fuel-generated hydrogen, wind-generated electricity may already be competitive with fossil fuel-generated electricity. In several states electricity from high-speed winds is the least expensive source of new power. Even when wind-generated electricity is more expensive, it is by 20-40 percent, not 200 percent as is the case with wind-generated hydrogen. One study concludes, “Electrolysis is an uneconomical use of wind and geothermal electricity”.[7]

“While wind-generated hydrogen is far from competitive with fossil fuel-generated hydrogen, wind-generated electricity may already be competitive with fossil fuel-generated electricity.”

A Word About Iceland

Iceland has received well-deserved favorable attention for boldly announcing its intention to convert entirely to hydrogen by 2040. Iceland has enormous amounts of unharnessed renewable energy, mostly geothermal. With a population of only 200,000 it has a tiny internal market. The global hydrogen market for chemical uses is growing rapidly. Iceland is seeking to use its small internal market to nurture technologies and fuels that could eventually become a major export market. It is a commendable strategy. The United States is not in a similar situation.

DOE Appropriation Requests for Renewable Energy and Hydrogen



A Hydrogen Economy is a Diversion of Scarce Resources

Currently federal energy budgets are stable or shrinking but appropriations for hydrogen research are expanding. Inevitably that encourages existing programs to reorient their programs toward hydrogen. Thus new programs are in wind energy to hydrogen, in nuclear power to hydrogen, in coal to hydrogen. R&D on electric batteries and other types of electricity storage systems is shrinking while spending on hydrogen storage is soaring. Spending to create a nationwide system of hydrogen fueling stations will soon surpass spending to create a nationwide system of biofuel filling stations. Growing numbers of states and even cities have convened task forces to discuss how to orient local resources into building a hydrogen economy.

A Hydrogen Economy Is Energy Inefficient

Hydrogen is not a fuel. It is an energy carrier, like electricity. Like electricity, hydrogen must be produced. It may be the world's most abundant element but hydrogen is found only in combination with other elements. Energy must be used to extract the hydrogen. In most cases the energy used to extract the hydrogen could otherwise be used to meet the needs of the final consumer directly.

For example, natural gas can be consumed directly in a highly efficient power plant (e.g. a combined cycle combustion turbine or an on-site fuel cell with heat recovery). This is a more efficient use of natural gas than to use the gas to fuel the process of extracting hydrogen from the gas and then using more energy to compress and transmit the hydrogen to a fuel cell and then converting the hydrogen into electricity. According to one calculation, it takes 64 percent more natural gas to make hydrogen and generate electricity via a fuel cell with it than to generate electricity directly via an efficient power plant (heat rate of 7000 Btus per kWh).[8] Others calculate the loss in system efficiency at a lower but still significant level.

The same disconcerting dynamic holds true for renewable energy technologies. It is more effective to generate electricity using wind power and deliver it directly to the customer than to use wind-generated electricity to produce hydrogen, transport the hydrogen long distances and then convert the hydrogen back into electricity.

The staff of Aerovironment, Inc., an engineering company headed by Paul MacCready, the inventor of the first successful human-powered airplane and the company that helped design GM's sporty all-electric car the EV1, offers an instructive illustration of the inefficiencies involved in making hydrogen rather than electricity.

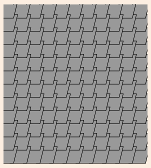
To satisfy the daily driving needs of a battery-powered electric vehicle a home would need a solar electric array of 450 square feet. Many homes have this amount of rooftop space. However, if the solar cell

Comparison of Battery and Hydrogen Fuel Cell Electric Vehicles

75 miles daily

Battery Electric Vehicle

0.33kWh per mile = 25 kWh per day



Solar Array . . . . . .450 square feet: $33,600

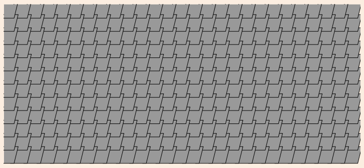
Battery Electric Vehicle . . .$40,000

Charger . . . .$600-$2,000

Hydrogen Fuel Cell Electric Vehicle

50 miles per kg = 1.5 kg per day (hydrogen)

66 kWh per kg = 90 kWh per day



Solar Array . . . . . .1100 square feet: $81,600

Hydrogen Fuel Cell Electric Vehicle . . .$40,000 (future?)

Hydrogen Generator (water electrolysis) $8,000 (?)

Source: Aerovironment Inc.

“Even as world leaders were announcing their support for a hydrogen economy a new technology was entering the marketplace that could and should change the nature of the conversation about transportation futures.”

were instead used to electrolyze water and feed the resulting hydrogen into a fuel cell powered car, the amount of energy needed, and therefore the size of the solar array required, would increase 2.5 times to some 1100 square feet. That is beyond the space available to most residences.

It requires about 60 kWh of electricity to produce 1 kg of hydrogen from water (with current electrolysis systems). An electric vehicle needs only 38 kWh to travel the same distance as a fuel cell vehicle using 1 kg of hydrogen.[9]

An in-depth study by two Swiss engineers found that the energy needed to compact gaseous hydrogen and transmit it long distances dwarfed the energy contained in the hydrogen. They conclude, “We have to accept that (hydrogen’s)...physical properties are incompatible with the requirements of the energy market. Production, packaging, storage, transfer and delivery of the gas....are so energy consuming that alternatives should be considered.”[10]

A Hydrogen Economy Increases Pollution

The combination of higher energy losses and the continuing reliance on fossil fuels could result in increased greenhouse gas emissions at least in the initial stages of shifting to a hydrogen economy. One analysis done for the Department of Energy in 2001 by Directed Technologies found that relying on hydrogen electrolyzed from water would double greenhouse gas emissions compared with conventional gasoline operation (using the average marginal US grid generation mix).

Another study for the British Department of Transportation concluded, “Switching to an accelerated hydrogen fuel pathway…will actually create more CO2 not less. The reason is that the hydrogen used to fuel the vehicle will have to come from steam-reformed natural gas.”[11]

A Green Hydrogen Economy?

The thesis of this report is that a hydrogen economy, for the foreseeable future, will be based on non-renewable fuels and that we can more rapidly progress toward a renewable fueled transportatioin system at far less cost by embracing the strategy elaborated here.

Many argue that we should support a hydrogen economy but only one fueled by “green hydrogen”. Such a position raises several issues.

Do these advocates oppose the elaboration of a hydrogen infrastructure if it is not in its initial stages predominantly powered by renewable energy? Do they reject the “hydrogen highway” proposed by newly elected California Governor Arnold Schwarzenegger unless only green hydrogen were used? Do they oppose the development and installation of distributed steam reformers if these are reforming natural gas rather than biogas or biofuels? Do they reject the financing and installation of electrolyzers unless they were powered by renewable electricity?

There are some R&D areas that would be tailored only to renewable energy (e.g. biofueled fuel cells and reformers). But the vast majority of R&D for a hydrogen economy does not depend on the source of the hydrogen. The electrolyzers that rely on wind generated electricity will not be much different than those that rely on natural gas or coal fired electricity. The creation of the delivery and storage and fueling and on-vehicle consumption technologies is the same whether one relies on renewable or nonrenewable fuels to make the hydrogen.

If 95-99 percent of the R&D and investment is the same whether the hydrogen is "brown" or "green" then those who advocate green hydrogen need to clarify how and where, in the next 10-20 years, their roadmap differs from those who advocate hydrogen from any resource. If not, it is likely that green hydrogen advocates, like green electricity advocates, will ask for a renewable standard. But in the case of electricity the infrastructure for delivery and end-use is already in place and green electricity already has a share, albeit tiny, of the market. Will we see a demand for a 10 percent national renewable hydrogen standard in 2030?

"**Hybrid** vehicles already are approaching the efficiencies the government is projecting for fuel cell-powered vehicles 10 years from now."

Hybrid Electric Vehicles: A New Technological Platform

Most advocates of a hydrogen economy concede that the price of hydrogen is high and the process of making and distributing it may be energy intensive. But they note that when the hydrogen is used in a fuel cell the fuel cell's higher efficiency makes the overall system less costly and more environmentally benign than the present inefficient internal combustion engine system.

That may be accurate. But one should not compare a technology of the future with a technology of yesteryear. For even as world leaders were announcing their support for a hydrogen economy a new technology was entering the marketplace that could and should change the nature of the conversation about transportation futures.

The technology is the hybrid electric vehicle. Hybrid vehicles boast both an engine and an electrical propulsion system. Hybrids enable electric vehicles to overcome their key shortcoming: short driving range. Although EVs have been more popular than auto manufacturers acknowledge, their 60-85 mile driving range has severely inhibited their widespread use.

The hybrid electric vehicle (HEV) overcomes the limitations of the 100 percent battery-powered vehicle. The HEV has excellent acceleration because of the torque generated by electric motors. Tail pipe emissions are extremely low. The first generation Toyota Prius qualified as a Low Emissions Vehicle (LEV) under California regulations. Its second generation, introduced in 2001, qualified as a Super Ultra Low Emissions Vehicle (SULEV) and its third generation is even more environmentally friendly. This type of vehicle reduces hydrocarbon emissions by 97 percent, carbon monoxide emissions by 76 percent, nitrogen oxide emissions by 97 percent and particulate matter emissions by 90 percent compared to the Tier 1 standard emissions set by the Department of Energy.

The commercial success of hybrids caught many in the automobile industry by surprise. The story is instructive and may be one reason why American policy makers have not included hybrids in their future planning. The Hybrid Electric Vehicle (HEV) Program officially began in 1993. The billion dollar five-year cost-shared program, the Partnership for a New Generation of Vehicles (PNGV), partnered the U.S. Department of Energy (DOE) and the three largest American auto manufacturers: General Motors, Ford, and DaimlerChrysler. The "Big Three" committed to produce production-feasible HEV propulsion systems by 1998, first generation prototypes by 2000, and market-ready HEVs by 2003. The automobile companies promised to produce an 80-mile per gallon prototype car by 1997.

The American car companies failed to produce a commercial hybrid. The federal government, relying on the research done by the domestic car companies, designed a future transportation strategy in which hybrid electric vehicles did not play a significant role.

Japanese carmakers, shut out of the PNGV program, succeeded where American carmakers had failed. Toyota introduced the first hybrid electric vehicle, the Prius, in Japan in December 1997 and in the United States in July 2000. In December

1999 Honda introduced the Insight Hybrid in Japan and in May 2002 in the United States. In September 2003 Toyota introduced its third generation Prius, a bigger car with better performance and a higher efficiency than its predecessor.

Hybrid sales doubled in 2002, reaching 35,000 in the United States. As of mid-2003 more than 100,000 were on the road worldwide. Toyota claims to be making a profit on its Prius. JD Powers projects that annual sales and leases of HEVs in the United States will soar to almost 500,000 by 2006 and 900,000 by 2010.[12]

The surprising success of Japanese HEVs has resulted in some equally surprising changes-of-heart by American car manufacturers about the commercial feasibility of HEV. As late as April 2002 General Motors' CEO and President G. Richard Wagoner, Jr told Business Week, "How will the economics of hybrids ever match that of the internal combustion engine? We can't afford to subsidize them." Nine months later Wagoner admitted to CBS News, "I think it's fair to say nobody knows how big this thing can be."

In late 2002 Ford announced it would be introducing a hybrid in the fall of 2003. GM declared it would introduce a hybrid pickup in 2004. Dodge will introduce a hybrid Ram Contractor in 2005. However, American car companies were unable to meet their deadlines. In late 2003 Ford announced it was postponing its introduction of its HEV to 2004. GM announced it was delaying introduction until 2007. Daimler/Chrysler canceled its plans to build a hybrid SUV. Meanwhile Toyota announced that its 40 mile per gallon SUV will be introduced on schedule in 2004.

Toyota introduced its third generation HEV Prius in September 2003. The price is the same as the previous generation Prius but the vehicle is bigger and roomier and with better fuel efficiency.[13] By early November demand had become so high that Toyota was considering adding a night shift to its Japanese factory for the first time in its history. That would increase production from 6,000 to 10,000 units a month. Sales in Japan alone reached 17,500 in September. In the U.S. the hybrid had 10,000 advance orders.

The emergence of the high-efficiency hybrid changes the context for the discussion of the hydrogen economy. For example, all observers agree that the price of hydrogen will be very high for the foreseeable future. Currently merchant industrial hydrogen costs more than $5 per kg (a kg of hydrogen contains the energy of a gallon of gasoline). The Department of Energy's goal is to produce hydrogen for a delivered cost of $2.50 per kg by 2015 excluding federal and state taxes. This is a far higher cost than the projected price of gasoline, excluding environmental costs.[14]

Hydrogen studies assume that the higher price of the fuel will be offset by the 2-3 times higher fuel efficiencies of fuel cell cars over internal combustion engine cars.[15] But it is inappropriate to compare the cost of a fuel cell powered hydrogen car that won't be commercialized for 5-10 years or later with a century-old internal combustion engine whose fuel efficiency has barely improved in the last 50 years. A far more appropriate comparison would be to currently commercialized hybrid vehicles, or even better, to hybrids that could be commercialized in the next five years.

Hybrid vehicles already are approaching the efficiencies the government is projecting for fuel cell-powered vehicles 10 years from now (55-60 miles per gallon). An assessment by MIT concluded, "there is no current basis for preferring either FC (fuel cell) or ICE (internal combustion engine) hybrid power plants for mid-size automobiles over the next 20 years. This conclusion applied even with optimistic assumptions about the pace of future fuel cell development."[16]

Hybrids can rely on fuel cell engines as well as internal combustion engines but they improve the efficiency of ICE's more.. As the MIT researchers note, "hybrids improve urban fuel economy of ICE vehicles, whose engines have lower efficiencies at lower power (and speeds) more than they improve FC vehicles whose fuel cell stack have higher efficiencies at lower power."[17]

Some hydrogen advocates support using hydrogen in internal combustion engines rather than fuel cells. Not only can this be done much more quickly but it can be done much more cheaply. Such a strategy would eliminate the additional cost of fuel cell vehicles although it would still require a costly delivery and storage infrastructure.

"Half of all cars on the road travel a total of 20 miles or less each day."

A Word About Fuel Cells

This report advocates a federal program that accelerates the use of high efficiency hybrid vehicles fueled by biofuels. It is not an argument against fuel cells. The author has argued elsewhere in favor of a vigorous federal and state effort to accelerate the use distributed electricity technologies including fuel cells.

The introduction of fuel cells does not depend on the introduction of a national distribution network for hydrogen. Fuel cells run on hydrogen, but they can make the hydrogen on-site. Currently they do so by using hydrogen carriers like natural gas, propane, methane and methanol.

Since the world's first fuel cell vehicle was introduced in 1959 about 780 fuel cell systems have been used in transport, including bicycles, scooters, cars, busses, submarines and boats. About 200 of these provide auxiliary power for US and Russian spacecraft.[18] In the last year there have been about 150 fuel celled vehicles introduced, virtually all of them pre-commercialization. The conclusion of the most authoritative survey of worldwide operations is, "Exciting it may be, but the advent of fuel cell vehicles is still many years away and the technical, commercial and regulatory issues that must be resolved are far from trivial."[19] The cost of car fuel cells, on the other hand, must drop a hundredfold before they are competitive. Some argue there is "a need for a Nobel Prize-winning breakthrough" to make this happen.[20]

Fuel cells for stationary applications began to be intro-

Comparative Features of Conventional Vehicles and HEVs[22]

Vehicle	Conventional	HEV0	HEV20	HEV60
Engine Peak Power, kW	127	67	61	38
Motor RatedPower, kW	—	44	51	75
Battery Rated Capacity, kWh	—	2.9	5.9	17.9
Vehicle Weight, tons	1.85	1.78	1.83	1.96

A Better Way

Step 1: Maximizing Efficiency: Moving from HEV0 to HEV60

The current generation of hybrid electric vehicles relies on the internal combustion engine to fill the battery. The battery provides electricity to motors for acceleration. In effect, hybrids join together two power plants. As one observer describes the process, "A large electric motor gets the vehicle rolling and even can power it up a hill. A gasoline or diesel engine kicks in for top acceleration and takes over when the vehicle is at cruising speed. When the vehicle stops, the engine shuts off, conserving fuel. A computer turns over cabin heating or cooling to the electric motor which is supplied by powerful batteries recharged by braking."[21]

The HEV has a much more powerful motor and a much smaller engine than its counterparts. Reduced gasoline consumption comes primarily from avoiding energy use during idling and from using the motor for stop-and-go urban driving. One intriguing result is that HEVs are more efficient in the city than on the highway. The second generation Prius for example was rated at 45 miles per gallon on the highway and 52 miles per gallon in the city.

HEVs currently have no ability to be charged from the electrical grid system and little or no ability to operate solely on battery-power. The industry designates this generation of hybrids HEV0, the zero indicating the number of miles the car can travel on batteries alone. (The 2004 Prius actually can travel a modest distance under light load and low speed conditions.)

Hybrids can be configured to use electricity for the majority of their propulsion needs. These vehicles have larger battery capacity. They are called plug-ins (PHEV) because they can plug into an external electricity system for charging. These PHEVs are identified by numbers that indicate a higher stand-alone electric driving range: HEV20, HEV60.

As long as the battery has sufficient charge, plug-in HEVs operate like a 100 percent battery electric vehicle. When the battery is low they operate like an engine-assisted HEV0. The displacement of gasoline by external electricity depends on the amount of battery capacity the vehicle has and the owner's daily driving habits.

Half of all cars on the road travel a total of 20 miles or less each day. Such modest mileage is especially true of urban vehicles. Thus a vehicle with battery capacity sufficient to travel 20 miles (HEV20) before recharging can substantially reduce the amount of gasoline consumed even in comparison to today's hybrid (HEV0). The electricity, moreover, is used to displace the gasoline used for those parts of a trip that are the most polluting: stop-and-go driving, continuous acceleration or deceleration, cold engine starts, and idling.

HEVs have smaller engines than conventional vehicles and larger motors. They have similar acceleration because the power of the engine and the motor can be combined. The plug-in HEVs have more electrical storage capacity. The greater the battery capacity the higher the percentage of time the vehicle will rely on the battery rather than the engine. A hybrid with the ability to travel 60 miles on its batteries before recharging requires about 18 kWhs of storage capacity.

If a car were driven 20 miles per day and an HEV20's batteries were fully charged daily there would be a drastic reduction in liquid fuel consumption. A hybrid that can travel 60 miles on its battery would allow for more daily driving or fewer recharging cycles and could reduce by 85 percent the amount of fuel the automobile consumes.

Unlike the hydrogen-fueling infrastructure, the electricity-fueling infrastructure is already in place. Andy Franks, professor of engineering at the University of California-Davis, one of the country's leading advocates for PHEVs estimates that 95 percent of homes and 70 percent of multi-family dwellings have relatively easy access to a 120V outlet.

A study for the British Department of Transportation that analyzed various pathways to a hydrogen fuel future concludes, "progressive electrification and hybridisation offers significant CO2 benefits regardless of the fuel or its source, at a risk level more manageable than alternatives such as more radical new vehicle technologies or major infrastructure change."[23]

Plug-in HEVs, says Bob Graham, area manager of the Electric Power Research Institute's (EPRI) transportation program, are "the logical next member of the family of hybrid vehicles...With the possible exception of the batteries, plug-in HEVs require only evolutionary engineering advances over HEV0 technology to meet technical requirements."[24]

Some argue that hybrid developments alone will improve batteries and that since fuel cells are expensive, automobile manufacturers will still have an incentive to increase the amount of work the batteries (and motor) can do. But battery research at automobile companies has virtually ceased. R&D for HEV0 cars focuses on improving the power output of the batteries rather than their energy storage capacity. The technological improvements needed for both purposes do overlap but there are major differences. One is intended to supplement the engine. The other is intended to replace the engine. Increases in power often lead to reductions in energy density, a prime objective for those who want to minimize battery weight while expanding the amount of driving done with batteries.

As Bob Graham, area manager of transportation systems at EPRI observes, "(P)roduced in volume, hybrid EVs such as the Toyota Prius and the Honda Civic will help drive down the cost of motors and controllers that could be used in all types of electric-drive cars.But the commercialization of the plug-in hybrid EV, because of its large market appeal, holds the key to the one remaining barrier to zero emission vehicles-the cost of the 'energy' battery."

Graham warns, "Currently, most incentives do not increase with the all-electric range of HEVs, even though there are larger environmental and energy security benefits associated with electric (battery only) operation…The cost of advanced batteries for non-plug hybrid EVs, plug-in hybrid EVs and battery EVs is highly dependent on the establishment of a growth market situation, a predictable regulatory environment and consistent production volumes that encourage capital investment in production capacity and line automation by battery and automotive manufacturers."

California's recent revisions to its Zero Emission Vehicle program is a good example of regulatory decisions that may dramatically affect the development of PHEVs. The program requires that participants produce a minimum number of "gold standard" vehicles. Only fuel cells and 100 percent battery-powered electric vehicles qualify for that standard.[25] After a long and contentious debate, and after vigorous opposition by leading environmental organizations, the California Air Resources Board decided not to require any hybrid vehicles with electric-only driving ranges. These do qualify as a "silver standard" technology but so do a dozen other technologies, including hydrogen powered internal combustion engines. Thus it is unlikely that this regulation alone will spur manufacturers to introduce plug in HEVs.

Step 2: Expanding Battery Capacity

California recently abandoned its focus on 100 percent battery-powered electric vehicles for promoting zero emission vehicles in part out of frustration by what it believed has been a lack of progress in battery development. By January 2003 all major car companies had eliminated their all-battery electric vehicle sale and leasing programs: Chrysler, Ford, GM, Honda, Nissan and Toyota.) A report done for the California Air Resources Board concluded that, "direct efforts to develop EV batteries have generally declined over the last 3 years."[26]

However, recent evidence suggests that the report's conclusions were premature.[27] It takes a long time between invention and commercialization. Beta R&D, a company that has developed the sodium nickel chloride battery called ZEBRA took 17 years to

duced in field trials in the late 1970s. Today more than 2,500 are in operation. Fuel Cell Today notes, "Progress in the development and deployment of small stationary fuel cells (electrical output less than 10 kW) has continued at a high level, with the cumulative number of systems almost doubling from 1,000 to 1,900 (in the last year)."

The commercialization of stationary power fuel cells is increasing rapidly. Rapid technological advances are occurring in high-temperature fuel cells that can use natural gas and other fuels directly (e.g. solid oxide cells) and in on-site reformers of natural gas and other fuels into hydrogen for use in lower temperature fuel cells.

The price of stationary fuel cells needs to drop in half for them to be price competitive, assuming the waste heat is captured. Nevertheless, increasing numbers of businesses are installing them now because of their high reliability and the high quality of the electricity they produce.

Fuels cells are one of the most promising technologies that can allow for a dramatic decentralization of our electricity system. These technologies along with the necessary regulatory changes should be strongly supported by policymakers. Fuel cell cars and the hydrogen infrastructure needed to power those cars might properly await the development of on-site stationary fuel cells. As Romesh Kymar, head of fuel cell development in the chemical engineering department at Argonne National Laboratory observes, "Maybe fuel cell powered cars will come at the tail end of those stationary developments."

develop a battery technology that in 2002 went into commercial production in a facility owned by MES-DEA. Avestor, a Canadian company, has just introduced a lithium metal polymer battery it claims has been in development for over 20 years.

Recently the Electric Power Research Institute (EPRI) issued a report that found "important and steady improvements in battery technology, even over the past few years. Researchers specifically found that advanced batteries used in electric drive vehicles are far exceeding previous projections for cycle life and durability, a key consideration in cost."[28] EPRI found, for example, that advances in Nickel Metal Hydride batteries (NiMH) meant that only one battery pack rather than the two anticipated in an earlier study would be needed for the life of the vehicle. "It is highly probable that NiMH batteries can be designed, using current technologies, to meet the vehicle lifetime requirements of full function battery EVs, plug-in HEVs with 40 to 60 miles of EV range...."

EPRI and others estimate that an HEV60, in the near term, would cost about $10,000 more than a conventional HEV.

"An urban-based HEV that can travel 60 miles on its batteries could reduce fuel consumption by 85 percent."

Some believe the technological advances in batteries are coming even more quickly, spurred by increasing demands for more power for portable electronic equipment like laptop computers and cell phones. Here consumers are willing to pay several times the price per kilowatt-hour for energy than are electric vehicle owners. That makes the portable electronics market an incubator for storage technologies that can later be scaled up for use in electric vehicles.

Sony Corporation first commercialized lithium batteries for laptop computers in 1991. Current lithium ion batteries have energy capacities four times those of lead acid batteries and almost twice that of nickel metal hydride batteries. Recently scientists reported that it was possible to construct a lithium ion battery that could store 400 Wh per kg, ten times that stored in a typical lead acid battery.[29]

The dynamics of battery advances is such that the cost of those already commercialized and thus mass produced for the premium electronics market are now lower than those that are still produced in small batches for the electric vehicle market. In 2003 San Dimas-based AC Propulsion Inc. replaced the electric batteries in its EV with lithim-ion batteries. The substitution saved 500 pounds and increased by a factor of three the amount of energy that could be stored. Alan Cocconi, AC Propulsion founder and chief engineer noticed the rapid progress that had occurred in the use of these small cells in laptops and power tools. "Manufacturers produce these cells by the tens of millions, so they compete intensely based on performance and costs. The result is commercial, off-the-shelf battery technology with fantastic specs. We decided to use it in electric cars"

Their new battery, called the tzero LiIon is assembled from 6800 standard cells. Tom Gage, President of AC Propulsion notes, "The market for big cells is small so they cost too much. The small cells for the tzero cost less, in total, than the nickel-metal hydride battery in the Toyota RAV4EV and they hold twice the energy. We got a quote from one battery company for a Li Ion pack made from 100 much larger cells. Their price was 10 times higher and neither the energy or the power were as good as we get from the small cells."[30]

It is instructive that California, which was very optimistic about battery development when it launched its Zero Emission Vehicle program in 1991 is now even more optimistic about fuel cell developments. The California Air Resources Board predicts that the additional cost per fuel cell powered vehicle, now about $1 million will drop to $300,000 in the 2006-8 model years, to $120,000 in 2009-2011 and to $10,000 in 2012-14.

Few other researchers are as optimistic as California in the reduction in the cost of fuel cell cars. Indeed, at the Future Car Congress in June 2002 Toyota's fuel cell engineer Norihiko Nakamura announced, "If a certain level of mass production can be achieved the costs 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."[31]

If California's projection does come true, 10 years from now we will be able to buy a $30,000 conventional automobile for $40,000 if powered by a fuel cell. That cost increase is about what the increased cost right now would be for an HEV60.[32] The fuel cell car, however, will achieve fuel efficiencies comparable only to those of the 2003 model HEV0 while the HEV60 will achieve efficiencies 50 percent greater or more.

This cost comparison doesn't include the infrastructure investments required. One recent estimate by two energy experts reported estimates a cost of $5,000 per vehicle to create the infrastructure for hydrogen fueled vehicles.[33]

The infrastructure for battery-driven vehicles is already in place, except for quicker rechargers or a wider availability of electric outlets.

Step 3: Renewable Fuels for the Engine

An effort to expand renewable energy for the electricity part of the hybrid vehicle would take a lesson from the effort to expand renewable electricity overall. Some 15 states have Renewable Portfolio Standards that require an increasing portion of the state's electricity supply to be renewable fueled. The distributed nature of some renewable energy technologies offers diverse scenarios. In parts of California solar cell canopies over parking lots recharge electric vehicles parked during the workday and plugged into outlets at the meters. The Los Angeles Department of Water and power estimated that a 1.87 kWh array could provide roughly 17,000 miles worth of power for an electric vehicle. A recent study found that most cars have sufficient surface area to generate 20 percent of their transportation fuel needs from solar cells embedded into the vehicle's body.[34]

A focus on hybrids and plug in hybrids offers the potential for a remarkable improvement in energy efficiency with no reduction in performance or vehicle room. This is true for all types of vehicles, including and especially SUVs.

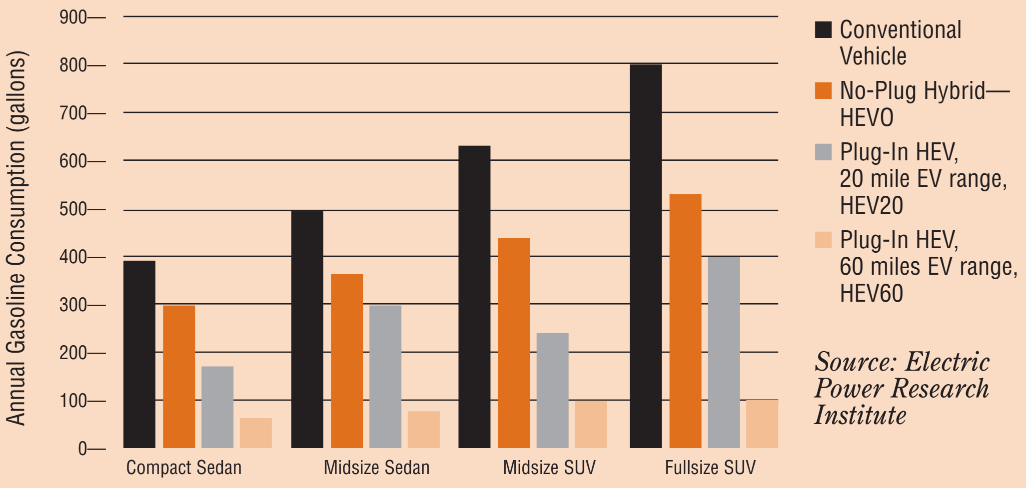
An urban-based HEV that can travel 60 miles on its batteries could reduce fuel consumption by 85 percent. This would reduce the fuel consumption of a typical mid-sized car from 600 gallons of gasoline per year to 100 gallons. If all vehicles were equipped with this technology, annual national gasoline consumption could decrease from about 140 billion gallons to about 40 billion.[35]

Such an improvement in efficiency in and of itself would virtually eliminate our reliance on imported oil. High efficiency hybrids would also allow us to take a closer look at using biofuels as a primary fuel rather than an additive.

Currently the gas tanks of vehicles using ethanol blends contain 5.7-10 percent ethanol. With minor costs vehicles can be modified to run on ethanol or gasoline or any combination thereof. According to Eron Shostek of the Alliance of Automobile Manufacturers, the cost of these adjustments, which include toughening some hoses and installing a computer device to

> **"For ethanol** or other biofuels to become a primary fuel will require a shift to a reliance on a more abundant feedstock."

Gasoline Consumption by Vehicle Size and Type



Source: Electric Power Research Institute sense the amount of alcohol in the fuel so it can mix with the correct amount of air for combustion, is less than $160 per vehicle. Thus for less than $1.5 billion all of the 9 million new cars sold each year in the United States could be capable of using biofuels to supply a majority or even all of their engines' needs.[36]

Because of government incentives automakers plan to sell nearly 1.8 million flexible-fueled vehicles in 2004, doubling the 2 million cars already on the road.[37] Currently more than 10 models of flexible-fueled vehicles are available including the best selling Taurus and Explorer.[38]

Ethanol and other biofuels currently account for about 2 percent of our transportation fuel supply. Production is increasing rapidly. In the last three years annual production capacity has expanded by one billion gallons. By the end of 2007 it could reach a capacity of 5 billion gallons per year.

In several midwestern states, like Minnesota, ethanol accounts for almost 10 percent of the transportation fuel consumed by cars each year. A 10 percent ethanol blend on a national level would require about 15 billion gallons a year. An aggressive national effort could achieve this production level by about 2015 at a far lower cost and with a far greater environmental and national security benefit than a national effort to achieve significant inroads of fuel cell vehicles powered by hydrogen. Instructively, the federal hydrogen roadmap doesn't envision a 10 percent penetration of hydrogen into the market until well after 2030.

Ethanol has burst out of its identity as a regional fuel because of the phase out by 18 states of their use of MTBE in gasoline. MTBE is a petroleum and natural gas derived oxygenate that has been used, in proportions of about 13 percent, in a significant portion of our gasoline since 1996. The discovery that it is polluting groundwater led states, beginning with California, to phase out its use. The result? In California ethanol consumption, virtually non-existent in 2000 will exceed 600 million gallons in 2003. Similar jumps in consumption can be expected as New York's phase out becomes operational in early 2004.

Ethanol is a much-misunderstood fuel. Ethanol is alcohol. Liquor. Given its 100 percent alcohol content, it might more aptly be called moonshine. Ethanol is fermented from sugars just as wine and beer is. The low-content alcohol that is produced is then distilled to higher and higher concentrations, making it useable as a power fuel.

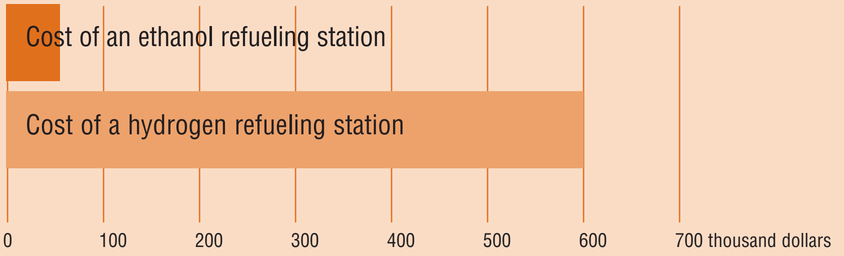
Currently the sugars come from starch crops because starch is easily and inexpensively broken down into sugars and because the harvesting and processing of starch crops (e.g. corn, wheat) is a mature industry with mature byproduct markets.

Today more than 98 percent of ethanol made in the United States is derived from corn. Starch crops could produce 7-15 billion gallons of ethanol, although there would be an impact on both corn prices (higher) and animal feed prices (lower) as a result. The higher volume is sufficient to allow for the universal use of a 10 percent ethanol blend, something that requires no infrastructure or vehicle modifications. This could be done at a fraction of a cost and achieved ten to thirty years earlier than achieving similar gasoline displacement through the use of hydrogen and fuel cell cars. Karen Miller, vice president of technical operations for the National Hydrogen Association estimates that to have 10 percent of Americans driving fuel cell powered cars will require 80 percent of the existing "gas" stations to be retrofitted to offer hydrogen.[39] This would be enormously costly. Almost as great a petroleum displacement could occur without any modifications in the vehicles or the filling stations by achieving a 10 percent blend of ethanol nationwide.

Making ethanol a primary fuel will require the installation of new fueling tanks in gas stations. To date there are almost 200 E85 (85% ethanol) refueling tanks in place, far more than the 15 hydrogen-fueling tanks currently operational in the United States. The cost of installing a 12,000-gallon E85 tank and three E85 gas pumps (dispensers) is less than $50,000. This would serve scores of cars a day. Some gas stations are converting the nozzles for poor selling grades (e.g. premium) to allow for dispensing E85. The dispenser conversion costs of doing this is about $1,000. The cost of installing a hydrogen fueling station at the University of California Davis was roughly $600,000 and this doesn't include

> **"We should** compare the cost of ethanol not to current gasoline prices but to current and future hydrogen prices."

Comparing the Cost of an Ethanol Highway vs. a Hydrogen Highway



the cost of a hydrogen reformer at each fueling station. The fueling station can service only 8 vehicles per day.[40]

For ethanol or other biofuels to become a primary fuel will require a shift to a reliance on a more abundant feedstock. The key is to access the sugars in cellulose, the most abundant biological material on the planet, found in all plants from grasses to trees to crops, and convert these sugars into ethanol. This means converting the corn stalks and wheat straw into ethanol rather than the corn and wheat kernels.

Hundreds of millions, perhaps billions of tons of biological materials are available for conversion into fuels and chemicals. Each year the United States produces about 300 million tons of cellulosic waste (urban wastes and agricultural residues that can be removed from the soil without environmental harm). Another 1 billion tons of cellulosic materials could be grown on available lands without interfering with our food supply or causing environmental damage. Assuming current yields of 80 gallons per ton, and half of the cellulosic material actually being converted into ethanol, production could exceed 50 billion gallons per year.

Cellulose is not as easily broken down into sugars as is starch but significant progress has been made in the last ten years. One commercial cellulose-to-ethanol plant is operating in Canada at a small scale. The cost of the ethanol is higher than the cost of ethanol from starch because of the high value of the byproducts of conventional ethanol production (e.g. high protein animal feed or high fructose corn syrup and lower protein animal feed). In part this is because the cost of gathering and baling and transporting the agricultural residues is currently very high. The cost will come down as new technologies and techniques are developed to serve a growing new agricultural sector.

The cost of ethanol is high today compared to the cost of gasoline. Handsome subsidies equivalent to 54 cents per gallon of ethanol make up the difference.[41] If ethanol production (or biodiesel production[42]) were to increase substantially, the cost to the taxpayer would increase dramatically.

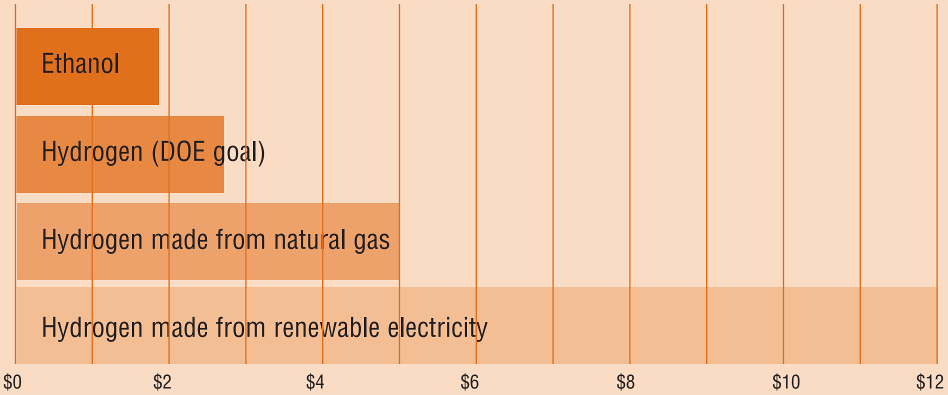
However, in the context of a hydrogen economy we should compare the cost of ethanol not to current gasoline prices but to current and future hydrogen prices.

The wholesale price of ethanol ranges from $1.10-1.50 per gallon. On an energy equivalent basis, this translates into a price of about $1.65-2.15 per kg of hydrogen or gallon of gasoline (excluding taxes). This is substantially lower than the federal goal of $2.50 per kg of hydrogen by 2015. Thus to compete with hydrogen, ethanol would need no incentives.

“**Making** hydrogen from natural gas has a negative net energy ratio.”

Comparing the Cost of Ethanol and Hydrogen

gallon of gasoline equivalent



> "**When corn** is converted into ethanol it is the starch, which is otherwise often converted into sweeteners, that is lost. The process actually concentrates the protein."

A Few Words about Ethanol

Biofuels and the Environment

The use of plants as a primary transportation fuel is controversial. There are several key issues. Will the dramatic substitution of carbohydrates for hydrocarbons deprive the world of needed food? Will the increased use of plants lead to increase soil erosion or ground water pollution? Does it take more fossil fuel energy to grow a plant and convert it into biofuels than the energy contained in the biofuels and its byproducts?

Food versus Fuel

When corn is converted into ethanol it is the starch, which is otherwise often converted into sweeteners, that is lost. The process actually concentrates the protein. As we switch to cellulosic materials the food versus fuel problem becomes more one of the availability of land. Although estimates vary, it appears that sufficient land area exists to allow us to produce significant quantities of fuels (and biochemicals) without disrupting or diminishing the food or feed supply. The Union for Concerned Scientists, citing an in-depth analysis by the Audubon Society concludes, "Overall, around 200 million acres of cropland might be suitable and available for energy or "power" crops, without irrigation and without competing with food crops.[43] At current yields of cellulosic crops like fast growing trees, 200 million acres could provide 1 billion tons a year of feedstock. Yields could be increased significantly. Ten tons per acre is a likely figure for the medium term future. Tests of sugar cane bred to maximize fiber rather than sugars resulted in yields as high as 60 tons per acre in Puerto Rico.

The amount of cellulosic wastes available, through the harvesting of agricultural residues like corn stalks and wheat straw and forest industry wastes like sawdust and bark and a part of the organic waste stream of municipal solid waste could add another 300 million tons or more to the annual volume.[44] The resulting overall harvest (assuming that only 40 percent of the agricultural residue is removed) is about 1.3 billion tons. At current yields this is sufficient to provide over 100 billion gallons of ethanol as well as significant quantities of biochemicals and "waste" biomass that can be used to provide the energy for the conversion process.

Net Energy

A remarkable number of studies have been done on the energetics of ethanol. The vast majority of studies done since 1990 conclude that there is a positive net energy generation of more than 1.3:1 for corn derived ethanol.[45] The table below extracts from a 1995 study by the Institute for Local Self-Reliance. Based on case study data from farms and ethanol facilities, it estimated a positive net energy ratio of 1.36:1. The study examined three scenarios. The base line relied on national average energy inputs by corn farmers and ethanol plants. The second scenario used the energy inputs of corn farmers in the state the used the lowest energy inputs and the most efficient existing ethanol plant.

Energy Used to Make Ethanol from Corn (BTUs per Gallon of Ethanol)

	Corn Ethanol (Industry Average)	Corn Ethanol (Industry Best)	Corn Ethanol (State-of-the-Art)
Feedstock Production	27,134	19,622	14,765
Processing	53,956	37,883	33,183
Total Energy Input	81,090	57,504	47,948
Energy Output (inc. co-products)	111,679	120,361	120,361
Net Energy Gain	30,589	62,857	72,413
Percent Gain	38%	109%	151%

Source: How Much Energy Does It Take to Make A Gallon of Ethanol?, ILSR, 1995

> **"Before** we invest hundreds of billions of dollars to remake our transportation system we should be clear that the means we embrace enable the ends we pursue."

The third scenario used the energy inputs from the most efficient corn farmer using organic methods and the next generation ethanol plant. The last scenario showed an energy output to input ratio over 2.0.

The fundamental conclusion from these energetics studies is that the net energy ratio of ethanol is positive and growing more positive as farm productivity improves and ethanol fuel efficiency improves. For example, one ethanol facility is in the process of substituting corn stover and wood chips for natural gas in providing all of its heat energy and a portion of its electrical energy. Once the substitution takes place the positive net energy ratio of that facility should soar.

Cellulose to ethanol plants may have an even more positive energetics ratio because the feedstock uses less energy-intensive inputs to grow and the parts of the plant not converted into ethanol can be used to fuel the plant.

Just as we need to compare hydrogen and ethanol on cost we need to compare ethanol and hydrogen on net energy generation. Margaret Mann, one of the leading researchers, has concluded that whereas making hydrogen from biomass has a positive net energy yield of 17 to 1 and wind energy to hydrogen a positive net energy yield of 12 to 1, making hydrogen from natural gas has a negative net energy ratio. Taking into account upstream operations such as extraction and delivery of natural gas, steam methane reforming, the most popular hydrogen generation technology, is only 67 percent efficient. That means for every 1 unit of fossil fuel energy in, one gets .67 units of energy out.[46] If hydrogen were made from electrolysis the electrolyzing process itself uses 50-60 kWh to make 1 kg of hydrogen. Assuming 3414 Btus per kWh the process itself uses more energy than the kg of hydrogen contains. This is compounded if the electrical process uses steam, since the input per kWh out could be over 8000 Btus.

Air Quality

There have been a number of evaluations of ethanol's impact on air quality. What we know is that a 10 percent blend of ethanol reduces carbon monoxide, a precursor for ozone formation, significantly (by more than 25 percent). We also know that ethanol when used as an additive displaces highly toxic and volatile components of gasoline (e.g. benzene, toluene, xylene).

We also know that ethanol at a 10 percent or lower blend also increases the total volatile organic compound emissions from the gasoline by about 15 percent. However, since the VOCs emitted by pure gasoline are more reactive than those produced with ethanol blends and because of the significant carbon monoxide reductions resulting from the use of ethanol, any increase in ozone formation is negligible.[47]

At higher concentrations of ethanol the volatility of the gasoline-ethanol blend drops. At concentrations above 25-40 percent evaporative emissions drop below the level they were before a drop of ethanol was added to the gasoline. This eliminates volatility as a problem. The reduction in carbon monoxide emissions, a contributor to ozone formation at ground level, increases as the percentage of ethanol in the fuel increases. There is some concern that an increase in oxygen will increase nitrous oxides (NOx), also a contributor to ozone formation. But NOx is generated from high combustion temperatures and ethanol burns cooler than gasoline. That is one of the reasons it makes such a good racing fuel. And the new low emitting vehicles that are entering the marketplace in ever-higher numbers (including hybrids) appear not to lead to a NOx increase from an increase in fuel oxygen.[48]

Some studies have compared greenhouse gas emissions of ethanol used as a primary fuel in an internal combustion engine versus hydrogen made from natural gas used in a fuel cell powered car. One analysis found that an E85 car using corn-derived ethanol produces, over the entire fuel cycle (fuel used to grow the feedstock and convert it to ethanol and convert the ethanol into useful work in the engine) generates about a third less carbon dioxide equivalent greenhouse gases than a conventional car getting 27.7 miles per gallon (275 vs. 400 grams per mile).[49]

The same study found that a hybrid EV that gets 45 miles per gallon with no stand-alone electric driving range using gasoline formulated to California's rigorous air quality standards would emit the same amount of greenhouse gases as the E85 car. A hydrogen car relying on hydrogen produced from natural gas at the gas station generates about a third less greenhouse gases than an E85 car (175 vs. 275 grams per mile). Producing hydrogen from electrolysis generates about the same as an E85 car (240 vs. 275 grams of CO2 per mile).[50]

The report concludes, "If all passenger vehicles in California used E85 instead of RFG3 (gasoline formulated to meet California standards) in 33 mpg vehicles ... (there would be a) 7 percent reduction in annual California GHG emissions."

This report assumes ethanol is made from corn. If it were derived from the sugars in cellulosic material and if the lignin in the cellulosic material were used to generate the energy needed by the manufacturing process, a net reduction in greenhouse gases could occur. That is, more carbon dioxide would be absorbed by the plant while growing than is generated by all the inputs into growing the plant, converting it into transportation fuel and consuming that fuel.[51]

One other environmental point should be made about biofuels. A biorefinery, like a petroleum refinery, will make many end products. Production will be optimized to maximize the enterprise's profit. Petroleum refineries make fuel, chemicals and other end products. Biorefineries would do the same. Indeed, ethanol may become a byproduct of many facilities. A cellulose-to-ethanol facility may convert only about 25 percent of the overall weight of the material into ethanol. The rest can be used to fuel the manufacturing process and as feedstock for making higher value chemicals than ethanol. The environmental benefits, both upstream and downstream, from displacing petrochemicals with biochemicals is significant.[52]

Assuming that 600 million tons of cellulosic materials are converted into 50 billion gallons of ethanol, some 400 million tons of biological materials could become available for conversion into chemicals. Although one cannot substitute on a pound for pound basis, the quantity of materials available is about equal to the consumption of all organic and inorganic chemicals in the United States today.

"Public policy initiatives that resulted in a large number of small and medium-sized biorefineries could change the face and structure of American (and perhaps world) agriculture."

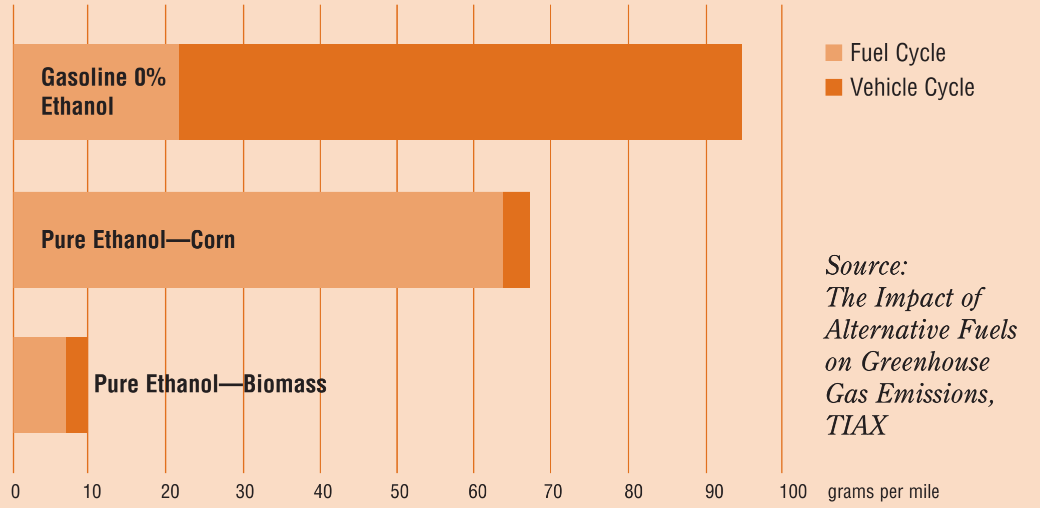
Biofuels and Fuel Cells

As discussed above, a fuel cell economy is possible without building a national distribution, storage and fueling system for pure hydrogen. Some fuel cells can extract the hydrogen directly from hydrogen-carrying liquids or gases. Others can extract the hydrogen with built-in reformers. Alcohols represent one of the hydrogen-carrying fuels that could be used in fuel cells. Thus expanding the use of alcohols in our engines could, if hydrogen and fuel cells do prove to be a cost-effective alternative, become a stepping-stone to using hydrogen derived from those alcohols.

Most of the work in direct conversion of alcohols in fuel cells has used methanol. A fueling station in California dispenses methanol into a fuel cell powered car that doesn't need onboard reforming. The phase out of MTBE promises to make significant quantities of methanol available. Methanol can be made from biological materials but it is currently cheaper to make it from natural gas.

Ethanol too reportedly is being used in fuel cells. Several Chicago buses powered by fuel cells are using hydrogen reformed from ethanol. Significantly, the fuel cell can use low-grade ethanol that contains 15-20 percent water (needed in the reforming

Greenhouse Gas Emissions from Ethanol Blends



Source: The Impact of Alternative Fuels on Greenhouse Gas Emissions, TIAX

process) rather than fuel-grade ethanol that contains no water. Low-grade ethanol can be produced using less energy and at a lower cost.

Just as small battery technologies are developing rapidly because of the introduction of more powerful mobile electronic equipment so are small fuel cells. Micro fuel cells using liquid fuels that can be purchased in cartridge form (like refills for cigarette lighters) are beginning to enter the market. Toshiba announced in March 2003 a 12 watt direct methanol fuel cell for portable computers that can run for 5 hours on a single cartridge filled with 50 cc of methanol. It expects to introduce it into the market in 2004.

A start-up company, Medis Technologies, has announced that it will introduce a micro-fuel cell that converts ethanol directly into electricity. Medis believes that ethanol is a better fuel than methanol because of restrictions regarding methanol's use in certain situations. The Federal Aviation Authority, for example, currently prohibit poisonous methanol from being carried on airplanes.

Meanwhile, researchers at Saint Louis University in Missouri are developing an even more fascinating biological storage and conversion device. Professor Shelley Minteer recently announced a breakthrough in enzymatic batteries that break down ethanol fuel. These are potentially much cheaper than existing fuel cells that rely on expensive metals like platinum or ruthenium catalysts. According to one report, these biobatteries could have power densities more than 30 times greater than other batteries.[53]

Ownership Matters

"Perfection of means and confusion of ends seems to characterize our age," Albert Einstein wisely observed half a century ago. Before we invest hundreds of billions of dollars to remake our transportation system we should be clear that the means we embrace enable the ends we pursue.

The three ends most people agree upon are: enhanced national security; improved environmental stewardship; healthier rural economies.

The currently envisioned hydrogen economy addresses the first end. The second, arguably, is undermined unless the hydrogen comes from renewable resources or the fossil fuel generated electricity is coupled with the long term storage of the carbon emitted. The strategy does not address economic development goals. A dual fuel approach that maximizes the use of renewable resources for the electricity used by the hybrid electric vehicle's motors and maximizes the use of renewable resources for the fuel used by its engine addresses all three objectives.

America's hard-pressed rural areas and farmers have two abundant renewable resources: wind and biomass. The former can be harnessed to provide the electricity for the HEV's batteries. The latter can be

> **"The social** and economic impact of an increased demand for biofuels is similar to that for wind energy. It depends on the structure of ownership."

harnessed to provide the fuels for the HEV's engine.

However, the shift to a renewable fueled transportation system will not in and of itself make a significant contribution to the welfare of rural America. Currently a wind developer may pay a farmer land-lease payments of $3,000-4,000 a year per turbine. This is welcome income for the landowner because the turbine requires very little land to be taken out of production and the land owner has no responsibilities. However, if the landowner owns the turbine his or her revenue can double or triple during the 10 year financing period. After the turbine is paid off the annual income could soar to $100,000.

With regard to wind there are economies of scale in the size of the turbine but few if any economies of scale in the size of the ownership structure. Thus a 1 MW wind turbine will be able to generate electricity at a cost substantially cheaper than a 50 kW turbine. But the farmer who owns a single 1 MW turbine will be able to generate electricity at a price comparable to that offered by the wind developer who owns 50 1 MW turbines. This assumes the farmer is part of a management structure that diffuses the risks and spreads the management costs over more machines. This has been the case in Minnesota.

A typical large wind farm today generates some 100-150 MW. The same amount of power could be generated by 100 farmers. Given the hundreds of thousands of turbines that will be needed to power our transportation system the number of farmer-owners could run into the hundreds of thousands and the amount of additional income earned by rural residents into the billions of dollars.

The social and economic impact of an increased demand for biofuels is similar to that for wind energy. It depends on the structure of ownership. The corn farmer benefits from an increase in ethanol demand because the increase in the overall demand for corn increases its price. But the price increase is small, perhaps on the order of 5-10 cents per bushel. If an ethanol plant locates nearby the farmer may receive a modestly higher net price for his or her corn because of lower transportation costs. This amounts, on average, to 5-10 cents per bushel. But the farmer who owns a share in an ethanol refinery can expect to receive annual dividends ranging from 25-50 cents per bushel or more.[54] Of course, there will be periods when the farmer receives no dividends. One unpublished analysis of a large Minnesota ethanol plant concluded that farmer-owners earned 18 percent annually on their investment.

With regard to ethanol, there are economies of scale in the size of the facility. A 100 million gallon per year facility might have production costs 10-15 cents per gallon lower than a 15 million gallon per year facility. To aggressively increase the amount of biofuels available one might argue for a focus on larger plants. But there is a technological and socio-economic dynamic that comes from a proliferation of smaller plants.

The Minnesota experience, often called the Minnesota Model, is instructive. In the early 1980s Minnesota's state ethanol incentive mirrored that of the federal incentive—a partial exemption from the gasoline tax. That incentive succeeded in making the price of ethanol competitive with other gasoline additives. The demand for ethanol-blended gasoline soared. But the demand was met entirely by ethanol imported into the state from out of state large manufacturing facilities owned by one multinational corporation. Minnesota farmers and Minnesota's farming communities were not benefiting from the expanded consumption of ethanol inside the state.

To remedy this problem, Minnesota converted its state ethanol incentive from a consumer-oriented excise tax exemption to a producer-oriented direct payment. Instead of reducing state gasoline taxes by a couple of pennies for a 10 percent ethanol blend, the state paid 20 cents a gallon for ethanol produced within the state. To encourage the construction of many plants in different parts of the state the incentive, which ran for 10 years, applied only to the first 15 million gallons produced.

The result? Minnesota became home to 14 small and medium-sized ethanol plants. The scale of the plants encouraged farmer ownership. As of 2002, 12 of the 14 plants were owned by more than 9,000 farmers.

Because of the large number of plants

built, several engineering firms competed with each other to design and build the least expensive and most efficient facility. Yields of ethanol in dry mills quickly rose from 2.5 to over 2.8 gallons per bushel. The large number of plants, coupled with equal numbers of plants being built in surrounding states accelerated the engineering and operational learning curves.

One result was to rapidly reduce the cost of ethanol produced from small dry mills. Indeed, a 1998 study by USDA that examined the comparative economics of small and medium sized corn dry mills and large wet mills showed how this dynamic had occurred between 1987 and 1998. In 1987 small and mid sized dry mills had cash operating costs that were higher than those of large wet mills. By 1998 dry mills had dropped their operating costs far below those of wet mills. The 1998 report concluded, "Wet mill variable costs appear to have remained very stable at about 46 cents per gallon. Improved energy cost management was offset by several factors, including waste management and overhead…In contrast, dry mills have experienced a l5-percent reduction in operating costs, due to the effects of reduced energy, labor and maintenance expenditures and possibly economy of scale."[56]

Public policy initiatives that resulted in a large number of small and medium-sized biorefineries could change the face and structure of American (and perhaps world) agriculture. A 50-billion gallon national market for ethanol would support about 1,500 30-million gallon per year biorefineries. This translates into one manufacturing facility in every other county in the country. Each biorefinery would serve local and regional markets. Each would produce biochemicals as well as biofuels. Assuming an average of 400 local investors per facility, some 600,000 households would have an equity interest in these ventures.

Clearly the location and ownership structure of the biorefineries will be more concentrated than in this ideal scenario, but it indicates the potential for widespread economic development. Today only about 120 petroleum refineries are operating in the United States, a significant drop in the last 20 years. On the other hand, there are over 85 biorefineries operating as of October 2003 and the number could exceed 100 by the end of 2004.

A biorefinery has a very attractive local economic impact because it buys its materials locally and sells its product locally. A majority of a biorefinery's expenditures are local while a majority of a petroleum refinery's expenditures leave the region. For example, about 45 cents of the cost of a gallon of gasoline produced in a refinery consists of the cost of the crude oil, often imported over long distances. On the other hand, about 45 cents of the cost of ethanol consists of the cost of the raw material, the vast majority of which is gathered from an area within 50 miles of the manufacturing facility.

Local ownership of wind turbines and ethanol plants will not occur inevitably. In both cases the conventional dynamic would be to build ever-larger wind farms of 100-500 MW and ever-larger and absentee owned ethanol plants with capacities of 100 million gallons and over. Currently ethanol production is dominated by a single firm. That firm, Archer Daniels Midland (ADM), has repeatedly engaged in price fixing. Enforcement of anti-trust rules is essential to enable the biofuels market to become competitive and dynamic. And federal policies should offer incentives for medium sized and locally owned wind farms and biorefineries and disincentives for large-absentee owned conversion facilities.

The Path to Be Taken

The interest at all levels in dramatically restructuring the energy foundation of our transportation sector is unprecedented and welcome. The introduction of high efficiency hybrid electric vehicles offers a new technological platform upon which to fashion public policy. Such a strategy should have a dual approach. One is to increase the electric-only driving range of the vehicle by increasing its electrical storage capacity while encouraging the rapid expansion of renewable transportation-using electricity. The second focuses on increasing the renewable energy portion of the fuels used in the engine. Here biofuels using existing internal combustion engines may have a significant advantage over hydrogen fuel cells.

A dual renewable fuel approach (electricity and biofuels) should also be

"**Economic** development can and should be as important a goal as improving environmental stewardship and enhancing national security."

designed to maximize the economic and social benefits to those who cultivate and harness the fuels. Economic development can and should be as important a goal as improving environmental stewardship and enhancing national security.

New Rules For a Sustainable Transportation System

- To maximize the use of grid electricity for transportation public policy should offer incentives based on the electric-driving range of a car.
- To maximize the use of renewable electricity policy makers should raise state Renewable Portfolio Standards that mandate specific numerical goals for renewable energy and adopt a national meaningful RPS that does not preempt or undermine state efforts.
- To maximize the use of biofuels policy makers at the state and federal level should adopt Renewable Fuel Standards (RFS) to complement their RPS standards. These would begin with a 10 percent standard. The standard should encompass all renewable fuels not just biofuels. Thus renewable electricity for electric cars, renewable hydrogen for fuel cell cars as well as biofuels for internal combustion engine cars would qualify.
- To enable biofuels to move beyond a 10 percent blend, policy makers should require that all new vehicles have a flexible-fuel capacity. This requirement should be tied to the rapid construction of a nationwide infrastructure of E85 fueling facilities.
- To enable biofuels to move beyond a 10 percent blend, policy makers should accelerate the commercialization of cellulose-to-ethanol plants. This involves financing at least three commercial-sized facilities testing different technological approaches by 2008. It also involves research and development into low cost and environmentally benign ways to collect and store cellulose.
- To maximize rural economic development federal and state incentives need to be changed to encourage smaller, locally owned biorefineries and wind turbines.

Adopting these policies will allow the country to reduce its reliance on imported oil while strengthening its rural economies and reducing its energy-related pollutants. It will also create a technological dynamic that can be adopted by other countries that might be poor in oil and coal and gas but rich in wind and sunlight and plant matter. It can also provide a new market for plant matter that overcomes the present competition between farmers around the world for slow-growing food and feed markets that has fueled international trade conflicts.

Hydrogen is a worthy energy storage technology and the hydrogen economy is an attractive vision. But there are other strategies that can achieve a high efficiency, renewable energy fueled transportation system more quickly and at a far lower cost.

Notes

1. The United States effort is not unique. The European Commission has a handsomely funded European Integrated Hydrogen Project. Japan's hydrogen program is better funded and more advanced than that of the United States.

2. National Hydrogen Association, www.hydrogenUS.org

3. Much of the demand for hydrogen is to convert heavy crude oils to gasoline and jet fuel. As we exhaust the supplies of light crude oil and shift toward Venezuelan crude or Canadian tar sands oil the demand for hydrogen for this purpose is expected to expand substantially.

4. *Power Economics*, April 30, 2002.

5. Malcolm A. Weiss, *et. al.*, *On the Road in 2020: A life Cycle Analysis of New Automobile Technologies*, MIT. Cambridge, MA. 2002. MIT El 00-003.

6. SolarAccess.com. News. May 1, 2003.

7. Duane B. Myers, et. al., *Hydrogen from Renewable Energy Sources*, Directed Technologies, Arlington, VA. October 2003. Notes that the cost of producing electricity from wind and geothermal is about the same as generating electricity using natural gas, the cost of producing hydrogen from wind and geothermal is about 85 percent more than producing hydrogen from natural gas.

8. Alex Brooks, *EV World*. December 5, 2002.

9. Alex Brooks, *EV World*. April 23, 2003.

10. Ulf Bossel, Baldur Eliasson, Gordon Taylor, *The Future of the Hydrogen Economy: Bright or Bleak?*, April 15, 2003. Final report

11. Ricardo Consulting Engineers, *Carbon to Hydrogen Roadmaps for Passenger Cars*. British Department of Transportation. 2003.

12. *California Journal*. February 1, 2003. A more recent report by JD Powers projects a slower growth as a result of announcements by American car companies that they were delaying their previously announced introduction of hybrids.

13. The 2004 Prius has EPA estimated 60 mpg city/51 highway, 55 combined. It has 15% more cargo space than its predecessor.

14. At a price of 3 cents per kWh, electrolysis produces hydrogen at a cost of $2.35 per gallon of gasoline equivalent, excluding transportation and storage. Several studies have estimated a price per kg of hydrogen of over $4 per kg. Directed Technologies estimates that with electricity produced in a Class 6 wind regime the cost of hydrogen delivered 500 miles to the station would be a little over $4 per kg of hydrogen, excluding sales taxes and dispensing markup. The analysis concludes that hydrogen produced from landfill gas would cost about $2.75 per kg. William Leighty has developed a detailed analysis in *Transmitting 4000 MW of New Windpower from North Dakota to Chicago: New HVDC Electric Lines or Hydrogen Pipeline*. 2002. With an effective wind electric price of 2.8 cents per kWh Leighty estimates a cost in Chicago of the equivalent of $2.89 a gallon. Including the local distribution and fuel station costs, the retail price in Chicago would be $3.68-4.34 per gallon of gasoline equivalent. See also Duane B. Myers, et. al., *Hydrogen from Renewable Energy Sources*, Directed Technologies, Arlington, VA. October 2003

15. For example Leon Walters and Dave Wade, *Hydrogen Production from Nuclear Energy*, Department of Energy and Argonne National Laboratory, November 12, 2002 compares the cost of hydrogen and gasoline this way. The authors assume the vehicle using hydrogen would be getting over 85 miles per gallon of gasoline equivalent. The gasoline driven car, on the other hand, would be getting 20 miles per gallon.

16. Malcolm A. Weiss, John B. Heywood, Andreas Schafer, Vinod K. Natarajan, *Comparative Assessment of Fuel Cell Cars*. MIT. January 2003

17. *Ibid.*

18. Fuel Cell Today. *Fuel Cell Systems: A survey of worldwide activity*. Mark Cropper, Stefan Geiger, David Jollie, November 5, 2003

19. *Ibid.*

20. *Electronic Engineering*. May 26, 2003.

21. “A Pivotal Juncture for Hybrids”, *Indianapolis Star*, November 4, 2003

22. *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options*. 1000349. Electric Power Research Institute. Palo Alto, CA. 2001. July 2001.

23. Carbon to Hydrogen Roadmaps for Passenger Cars. *Op. Cit.*

24. Bob Graham, *Plug-in Hybrid Electric Vehicles. Significant Market Potential*. December 5, 2002. See also Bob Graham, *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options*. EPRI. Menlo Park, California. July 2001.

25. If all manufacturers opt for building fuel cell powered cars, about 2500 will be on the road by 2011, about the same number of all-battery electric vehicles on the road by 2000 as a result of the Zero Emissions Vehicle program in California initiated in the early 1990s.

26. Dr. Menahem Andersman, *Brief Assessment of Progress in EV Battery Technology since the BTAP* June 2000 Report. California Air Resources Board. February 2003.

27. There are many stories that indicate that the car companies' involvement in introducing electric vehicles was half-hearted and even hostile. After GM increased the range of its EV1 to 100 miles there were two-year waiting lists but GM built only 500 models. GM ended the program in 2003 and required all those leasing EV1s to return them. One GM employee who was involved in the electric vehicle initiative by GM remembers, “We launched the car in December of 1996 and by about April I figured we'd been duped. They weren't marketing the vehicle.” *New York Times*, October 22, 2003. Jerry Martin, spokesman for the California Air Resources Board recalls, the car companies and oil industry “fought California's electric car mandate…every way you can think of”. *Washington Post* October 22, 2003.

28. Lous Browning, Mark Duvall, et. al, *Advanced Batteries for Electric-Drive Vehicles*, March 25, 2003. Electric Power Research Institute. Palo Alto, CA.

29. Donald R. Sadoway and Anne M. Mayes, *Portable Power: Advanced Rechargeable Lithium Batteries*. MRS Bulletin August 2002. Lithium ion polymer batteries have another advantage. They can be molded into virtually any form to fit the shape of any device even as small as a credit car. The Electrofuel corporation's PowerPad 160, introduced in early 2000 for use by owners of portable computers, weighs less than 2.2 pounds and gives up to 16 hours of power. It is 3/8 inches thick.

30. Press Release. November 5, 2003. www.acpropulsion.com. The Beijing People Daily reports on the development of Chinese lithium ion batteries that will have a 200-mile charge range and be rechargeable in under 10 minutes.

31. Reported by Alec Brooks, *Perspectives on Fuel Cell and Battery Electric Vehicles*, Presentation to CARB ZEV Workshop, December 5, 2002.

32. "the cost of grid connected HEV60 in a mature market was estimated to range between $7,000 and $10,200 per vehicle" more than a conventional gasoline vehicle. *Reducing California's Petroleum Dependence. Joint Agency Draft Report*. California Energy Commission and California Air Resources Board. July 2003. Sacramento, CA.

33. Alex Farrell and David Keith, Rethinking Hydrogen Cars. *Science Magazine*, July 18, 2003

34. Steven Letendre, Christy Herig, Richard Perez, *Real Solar Cars*. October 2003. A Chevrolet Cavalier, for example, has 3.22 square meters of surface area available for solar cells. At present efficiencies these could generate 407 watts. Assuming a PV capacity factor of 15% and .206 kWh per mile, the 526 kWh generated could drive the car about 2550 miles.

35. Vehicle miles driven will undoubtedly increase as will car ownership. But the key variable is the increase in vehicle miles driven outside urban areas, since an HEV60 will account for virtually all local driving.

36. There is a significant loss of mileage in E85 cars because of the lower energy content of ethanol versus gasoline. However, there is some indication that if the flexible fueled cars were optimized for E85 or if there were cars dedicated to E85 that the mileage difference would be small. See Mark Stuhldreher, *Research in High-Efficiency Alcohol-Fueled Engines at EPA*, U. S. Environmental Protection Agency National Vehicle and Fuel Emissions Laboratory. Ann Arbor, MI. February 25, 2003

37. Currently automobile companies can count each flexible fueled car as the equivalent of a car with high high fuel efficiency to comply with the CAFÉ standards. This is what has driven car manufacturers to include multi-fuel capacity. The incentive is provided regardless of whether these cars actually run on biofuels. The environmental community notes that as a result this incentive perversely allows an increase in pollution because car companies can build a gas guzzling SUV for every flexible fueled car even when the latter doesn't use a drop of ethanol. There have been proposals to modify the incentive for flexible fueled vehicles to require that ethanol be available in those markets.

38. In Brazil, where almost all cars run on ethanol blends and at one time most ran on 100 percent ethanol one company, working with GM, has introduced an inexpensive and reliable multi-fuel technology. Following the launch of the 1.8 liter flex-fuel engine, GM Brazil announced that it is ending production of its l.8 liter gasoline Corsa and only selling the flex fueled engine Corsa. GM do Brasil plans to sell flex fuel versions of all its cars. Fiat and Ford are preparing to launch flex fuel cars in Brazil. Volkswagen already has.

39. *Environment and Energy Daily*. April 7, 2003

40. *Wired Online*. October 22, 2003. Another estimate by a private company puts the cost of a fueling station facility, without the electrolyzer, at $150,000. *Hydrogen Energy Projects*, HyGen Industries LLC. Topanga, CA. 2003.

41. The incentives are equivalent of 54 cents per gallon for the ethanol since the tax exemption is on the whole gallon of gasoline (a 5.4 cent exemption from the federal excise tax) whereas ethanol is only 10 percent of the gallon.

42. This section focuses on ethanol because it is a relatively mature industry and an abundant feedstock is available for its expansion. Fuels made out of vegetable oils are coming into the market. Sales were about 30 million gallons in 2003. The energy bill offers a handsome incentive for the production of biodiesel. Biodiesel usually consist of a 2-20% vegetable oil blend although trucks are currently running on 100 percent vegetable oil. Sufficient oil crops and recycleable fats and oils are available to displace about 20 percent of diesel fuel. Further supplies might come from converting cellulosic materials or animal wastes to oils.

43. *Powerful Solutions: Seven Ways to Switch America to Renewable Energy*, Union for Concerned Scientists, 2001 citing James Cook, Jan Beyea, and Kathleen Keeler, "Potential Impacts of Biomass Production in the United States on Biological Diversity," *Annual Review of Energy and the Environment*, 16:401–431, 1991

44. The amount of removal possible depends significantly on the topography and soil quality of the farm. For detailed analysis see Paul Gallagher, et. al., *Biomass from Crop Residues: Cost and Supply Estimates*. Agricultural Economic Report Number 819. United States Department of Agriculture. Washington, D.C. March 2003. For breakdown of components of the cellulosic waste stream and assumptions see David Morris and Irshad Ahmed, *The Carbohydrate Economy: Making Chemicals and Industrial Materials from Plant Matter*. Institute for Local Self-Reliance. Minneapolis, MN. August 2002.

45. Michael Wang, Hosein Shapouri, James Duffield, *The Energy Balance of Ethanol: An Update*. National Agricultural Statistics Service. USDA. August 2002. Seungdo Kim and Bruce E. Dale, Allocation Procedure in Ethanol Production System from Corn Grain, *Journal of Life Cycle Assessment*. 2002. David Lorenz and David Morris, *How Much Energy Does It Take To Make A Gallon Of Ethanol?*. 1995 Institute for Local Self-Reliance. For an analysis that concludes that the net energy ratio is negative, see David Pimentel, “Ethanol Fuels: Energy Balance, Economics and Environmental Impacts are Negative.” *Natural Resources Research*, Vol. 12, No. 2, June 2003. For a detailed response see, Michael Graboski, Bruce McClelland, “A Rebuttal to ‘Ethanol Fuels: Energy, Economics and Environmental Impacts’, by D. Pimentel”. Colorado School of Mines, Golden, CO. May 2002

46. “Talking Hydrogen with Margaret Mann”. *The Carbohydrate Economy*. Institute for Local Self-Reliance. Minneapolis, MN. Winter 2003. Another study put the net energy ratio of wind to hydrogen at 22 to 1 and the ratio for natural gas to hydrogen at .7 to 1. Carolyn C. Elam, Catherine E. Gregoire Padro, Pamela L. Spath, *International Energy Activities*, Proceedings of the 2002 U.S. DOE Hydrogen Program Review. NREL/CP-610-32405.

47. For an extended discussion of ethanol and air quality see David Morris and Jack Brondum, *Ethanol and Ozone*. Institute for Local Self-Reliance. Minneapolis, MN. Sept. 25, 2000

48. Michael D. Jackson, Stefan Unnasch, Jennifer Pont. *The Impact of Alternative Fuels on Greenhouse Gas Emissions—A ‘Well-to-Wheel’ Analysis*. Reference M7100. TIAX, Cupertino, CA. 2002. See also, *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems. North American Analysis*. General Motors, Argonne National Laboratory, BP Amoco, ExxonMobil, Shell. April 2001. Draft Final. Volume 1.

49. In Brazil 20 percent ethanol blends have been used for decades. A 1977 paper by Furey and Jackson of General Motors (No. 779008 delivered at the 12th ICECEC meeting) showed that the volatility of ethanol blends peaked near 5 percent levels. Ethanol itself has a very low volatility, which is one of the reasons that small quantities of higher volatility additives are used in cars using a high ethanol percentage to enable cold starts. Thus it is reasonable to expect reduced volatile organic emissions at levels of ethanol above 25-30 percent. A study by The Alliance, AIAM, Honda, “Industry Low Sulfur Test Program” presented at the California Air Resources Board workshop, 7/2001 shows that the NOx emissions were not affected by higher levels of fuel oxygen for the most recent low emitting vehicles and fuels that had low sulfur (30 ppm). The potential impact on air quality and human health from increases in acetylaldehydes from using large quantities of ethanol is also discussed. Modern engines will be made ever-cleaner. Therefore all toxic emissions will be very low. Also, the catalyst efficiency impact of ethanol would be expected to help lower acetylaldehyde emissions. Also of all the toxics addressed in vehicle emissions regulations, acetylaldehyde appears to be the least toxic, as indicated by California’s regulations that estimate its potency at 0.016 relative to butadene, which is given a value of 1.0. See Staff Report on California RFG, California Air Resources Board, April 22, 1994).

50. Michael D. Jackson, Stefan Unnasch, Jennifer Pont. *The Impact of Alternative Fuels on Greenhouse Gas Emissions—A ‘Well-to-Wheel’ Analysis*. Reference M7100. TIAX, Cupertino, CA. 2002. See also, *Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems. North American Analysis*. General Motors, Argonne National Laboratory, BP Amoco, ExxonMobil, Shell. April 2001. Draft Final. Volume 1.

51. See Louis Browning, Climate Change. International Vehicle Technology Symposium. ICF Consulting. Inc. March 12, 2003.

52. Irshad Ahmed and David Morris, *Replacing Petrochemicals with Biochemicals: A Pollution Prevention Strategy for the Great Lakes Region*. Institute for Local Self-Reliance. Minneapolis, MN. 1994

53. *Associated Press*. March 24, 2003.

54. Several ethanol facilities in Minneapolis report dividends as high as $1 a bushel for the past several years. This compares to a price of corn of about $2 per bushel.

55. Hosein Shapouri, Paul Gallagher and Michael S. Graboski, *USDA’s 1998 Ethanol Cost-of-Production Survey*. USDA. Washington, D.C. 1998.