

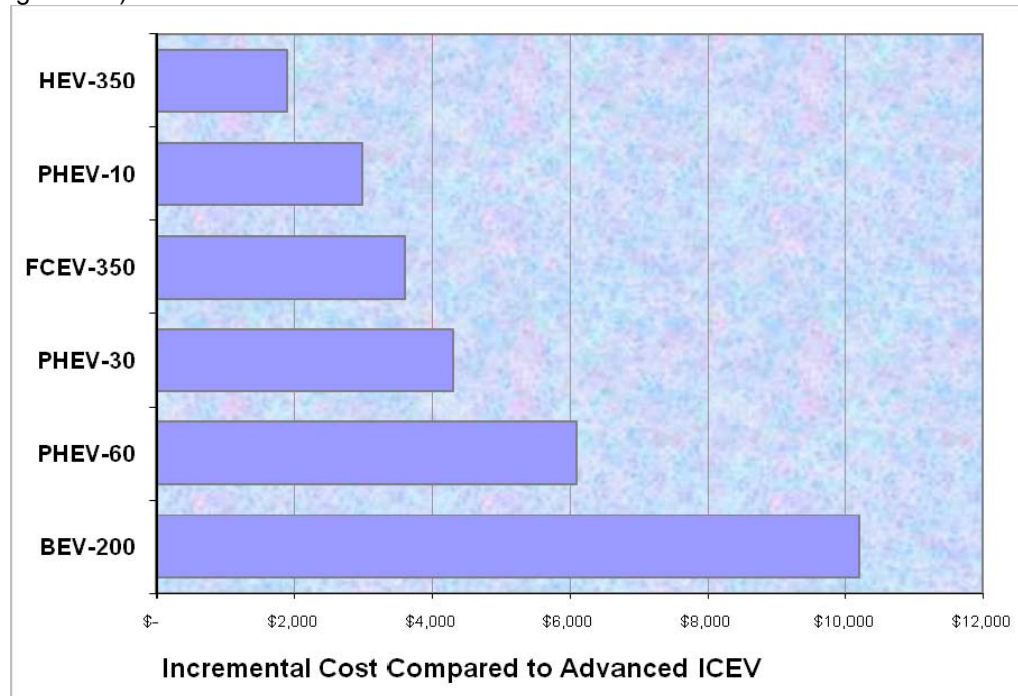
## Facts About Hydrogen Fuel Cell Vehicles: Progress, Potential, and Why We Must Move Ahead

This document lays out the facts about hydrogen fuel cell vehicles as reported in scientific studies and analyses conducted by a variety of government, academic and industry sources. For some topics, comparisons are drawn to battery electric and plug-in hybrid vehicles in order to demonstrate the progress and challenges of all three of these advanced technologies.

1. **Fuel cell durability.** The durability of vehicle fuel cells has improved dramatically. According to DOE's own assessment, projections of on-road durability (this is from cars driven by real people everyday), has improved from 950 hours in 2006 to 1900 hours in 2008. In the lab, durability has exceeded 7,000 hours<sup>1</sup>. The DOE hydrogen program's 2015 target is 5000-hour durability, equivalent to approximately 150,000 miles of driving.

The auto companies have their own proprietary fuel cell development programs that are not reflected in the public record, and state that fuel cell durability is not a show-stopper for beginning commercialization of their FCVs.

2. **Fuel cell cost.** DOE's research efforts have driven the volume production cost of a fuel cell engine down by 75%<sup>2</sup> in just a few years, and developers in 2009 reported even more exciting cost reduction breakthroughs. The first fuel cell vehicles will cost more than the first plug-in hybrids, but according to a detailed analysis by Kromer and Heywood at MIT<sup>3</sup>, a plug-in hybrid with 30 miles all-electric range will cost more in mass production (\$4,300 more than a conventional car) than a fuel cell electric vehicle with 350 miles range (\$3,600 more than a regular car).



Ref: Kromer & Heywood, "Electric Powertrains: Opportunities & Challenges in the U.S. Light-Duty Vehicle Fleet Fleet Report # LFEE 2007-03RP, MIT, May, 2007, Table 53

<sup>1</sup> DOE progress report to Congress, Jan. 2009.  
[http://www.hydrogen.energy.gov/pdfs/epact\\_report\\_sec811.pdf](http://www.hydrogen.energy.gov/pdfs/epact_report_sec811.pdf)

<sup>2</sup> *ibid*

<sup>3</sup> Kromer & Heywood, "Electric Powertrains: Opportunities & Challenges in the U.S. Light-Duty Vehicle Fleet Report # LFEE 2007-03RP, MIT, May, 2007, Table 53

The following table shows that the MIT researchers used conservative cost and volume assumptions for fuel cells and hydrogen (i.e. they assumed DOE's targets would not be met.) This demonstrates that commercialization can begin even without meeting all DOE targets.

Assumptions used by MIT compared to DOE targets		DOE	DOE	MIT
		2010	2015	2030
Fuel Cell System Cost	\$/kW	45	30	50
Hydrogen Storage Cost	\$/kWh	4	2	15
Hydrogen Storage Density	kWh/L	0.9	1.3	0.8

The projected high-volume manufacturing cost of automotive fuel cell systems has decreased from \$275/kW in 2002 to \$73/kW in 2008<sup>4</sup>.

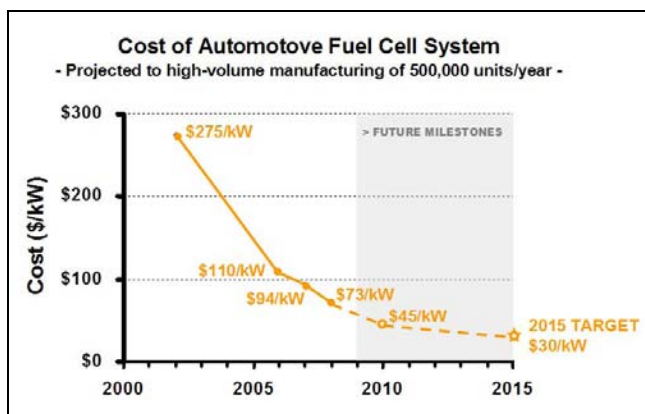


Figure 3.2. The DOE's hydrogen program is reducing the high-volume manufacturing cost of automotive fuel cell systems. (Cost estimates are based on dollars for the year the estimate was made; cost targets are based on 2002 dollars.)

3. Hydrogen cost: Hydrogen when made in large quantities (just like refineries make gasoline) is the same price as gasoline on an energy basis at the plant gate today. When served by pipeline the delivery costs are low, comparable to gasoline delivery tankers. New forms of delivery are being tested and will lower the cost of delivery to the DOE target of <\$1/kg. These new approaches include novel compression systems for liquid trailers and high capacity tube trailers. Systems such as these are similar to the gasoline infrastructure system widely used today<sup>5</sup>.

DOE has projected the cost of hydrogen produced on-site from natural gas to have reached the goal of \$3 per gge<sup>6</sup> for 1500 kg/day stations when the station equipment is manufactured at a volume of 500 per year.

Fuel cell vehicles are 2-3 times as fuel efficient as gasoline vehicles. For example, the 2008 Honda FCX Clarity is EPA rated at 77 mpg city/67 mpg highway<sup>7</sup>. Assuming on average a

<sup>4</sup> DOE progress report to Congress, Jan. 2009.

[http://www.hydrogen.energy.gov/pdfs/epact\\_report\\_sec811.pdf](http://www.hydrogen.energy.gov/pdfs/epact_report_sec811.pdf)

<sup>5</sup> Air Products and Chemicals, private conversation, May 17, 2009

<sup>6</sup> DOE progress report to Congress, Jan. 2009.

[http://www.hydrogen.energy.gov/pdfs/epact\\_report\\_sec811.pdf](http://www.hydrogen.energy.gov/pdfs/epact_report_sec811.pdf)

<sup>7</sup> [http://www.fueleconomy.gov/feg/fcv\\_sbs.shtml](http://www.fueleconomy.gov/feg/fcv_sbs.shtml)

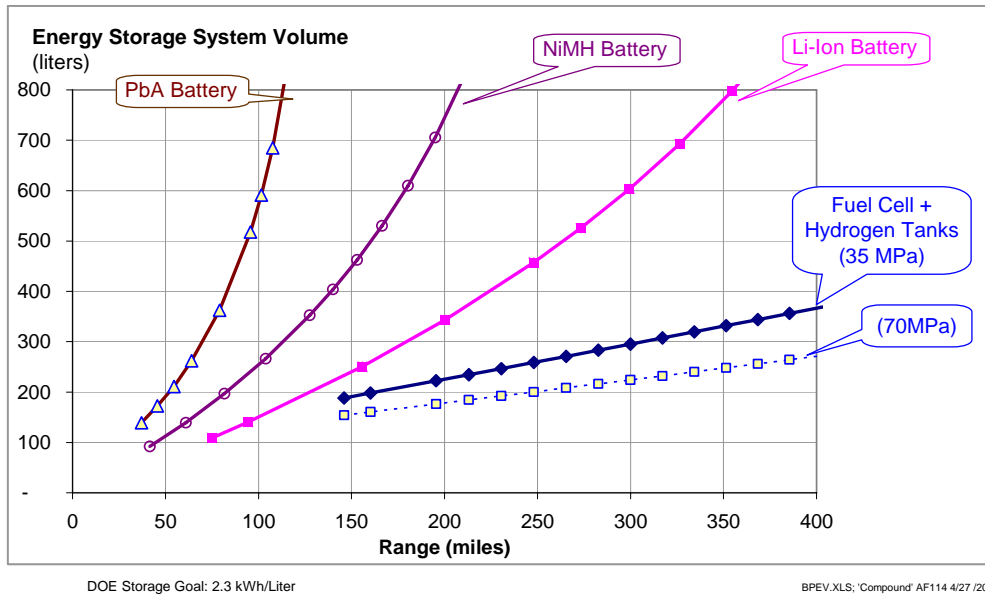
FCV is twice as fuel efficient as a gasoline vehicle, hydrogen at \$3 per gge is equivalent to \$1.50 per gallon gasoline.

4. Hydrogen fueling stations. The National Research Council<sup>8</sup> estimates that it would cost \$2.2 million to build a hydrogen fueling station that could support 2,300 FCVs, or \$955/vehicle, a cost that will be covered by the retail station owner. The Idaho National Laboratory<sup>9</sup> estimates that the average cost of adding a 120V, 20A circuit to charge one PHEV would be \$878, a cost that will be covered by the home owner.

The California Air Resources Board recently awarded \$6.8 million to build four new hydrogen stations<sup>10</sup>. Three of these stations are prototypes of the kind considered by NRC in their analysis. Two will utilize on-site steam methane reforming of natural gas, and another will utilize high pressure gas tankers to distribute pipeline gas.

5. Storing hydrogen fuel on the vehicle. The automobile companies have placed over 300 FCVs on the road, 140 of which are under NREL monitoring under the Technology Validation program. Virtually all of these vehicles use compressed hydrogen tanks to store fuel. Compressed hydrogen storage tanks are safe and can store adequate fuel in an acceptable volume. Automakers are still pursuing new technology for hydrogen storage that is lighter, takes up less space and costs less, but these improvements are not needed to begin vehicle rollout to early markets.

In fact, batteries take up much more space than compressed hydrogen storage tanks to store a given amount of energy. Even advanced lithium ion batteries take up more space than the combination of compressed hydrogen storage tanks plus the fuel cell to power a vehicle the same number of miles, as shown in this figure<sup>11</sup>:



<sup>8</sup> Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, NRC 2008

<sup>9</sup> Morrow, K., D. Karner, J.Fancfort, "Plug-in hybrid electric vehicle charging infrastructure review," Final Report INL/EXT-08-15058, Idaho National Laboratory, November 2008

<sup>10</sup> <http://www.arb.ca.gov/newsrel/nr040609.htm>

<sup>11</sup> "Fuel Cell and Battery Electric Vehicles Compared," C. E. (Sandy) Thomas, Ph.D., President, H2Gen Innovations, Inc. Alexandria, Virginia, Thomas@h2gen.com

To travel 300 miles, a battery pack for an electric vehicle would occupy twice the space of a fuel cell plus high pressure hydrogen storage tank using today's compressed gas tank technology.

6. Sources of hydrogen. Hydrogen can be made from many sources, the same sources that can produce electricity: fossil fuels, renewable energy, nuclear energy, etc. Most hydrogen today is made from natural gas. Using natural gas to make hydrogen and using the hydrogen to drive a fuel cell vehicle reduces greenhouse gas emissions at least 50% compared to a gasoline vehicle<sup>12</sup>. Just a 2% increase in U.S. natural gas supply would support 10 million FCVs<sup>13</sup>. The commercial market can get started with hydrogen from natural gas and still significantly cut GHGs.

Just as with electricity, future methods of making hydrogen will utilize renewable feedstocks and carbon sequestration to further reduce GHGs. The California Air Resources Board recently funded renewable hydrogen stations, one using solar power and another that will produce hydrogen from waste water digester gas utilizing a molten carbonate high temperature fuel cell<sup>14</sup>.

7. Energy needed to make hydrogen. It takes energy to make any fuel. It takes about 20% more energy to make gasoline from crude oil than is contained in the resulting product. It takes more than twice the energy to make electricity from coal and natural gas than you get out of the plug in your home (i.e. only half of the coal or natural gas energy in a power plant is transmitted as electricity to your home outlet). It takes about 30% more energy to make hydrogen from natural gas than is contained in the resulting hydrogen.

Given a certain amount of natural gas, which is more efficient, to make electricity for a battery EV, or to make hydrogen to power a fuel cell vehicle? Here's the answer<sup>15</sup>:

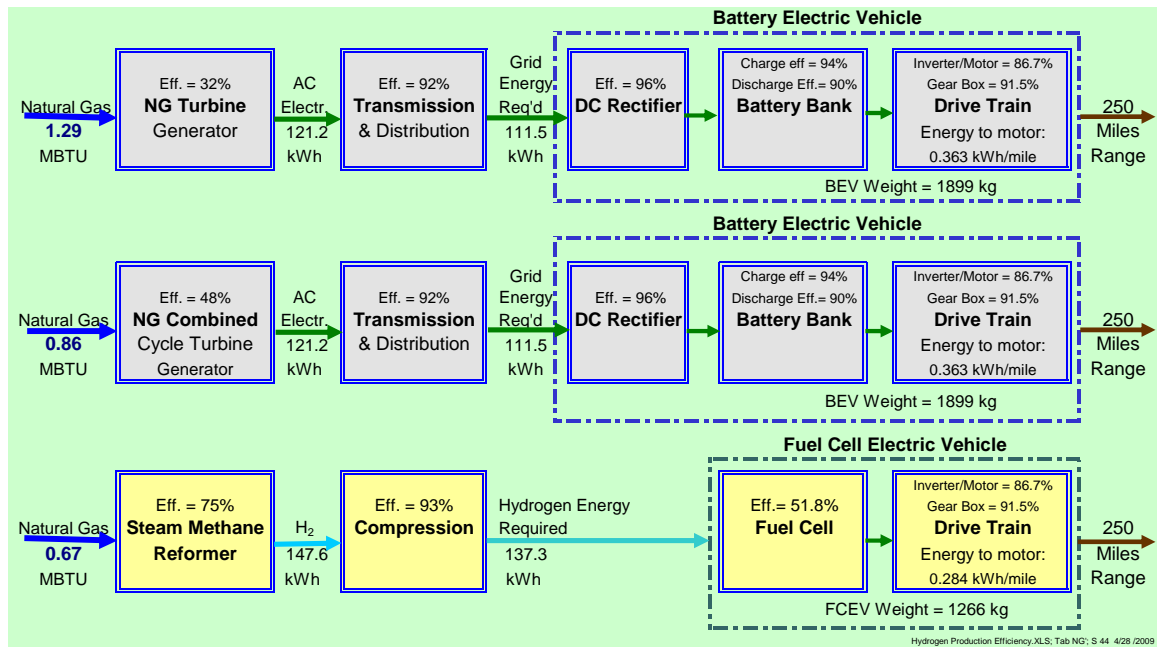
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<sup>12</sup> CARB Low Carbon Fuel Standard, <http://www.arb.ca.gov/regact/2009/lcfs09/lcfsisor1.pdf>

<sup>13</sup> <http://www.h2andyou.org/tenThings.asp>

<sup>14</sup> California Hydrogen Highway Network 2008 Report to Legislature, <http://www.hydrogenhighway.ca.gov/update/cah2net2008reporttoleg.pdf>, p.2

<sup>15</sup> "Fuel Cell and Battery Electric Vehicles Compared," C. E. (Sandy) Thomas, Ph.D., President, H2Gen Innovations, Inc. Alexandria, Virginia, [Thomas@h2gen.com](mailto:Thomas@h2gen.com)



On a full-cycle well-to-wheels basis, the hydrogen fuel cell vehicle uses 22% to 48% less energy than a battery EV when converting natural gas to vehicle fuel for 250 miles travel range with existing electric power plants<sup>16</sup>.

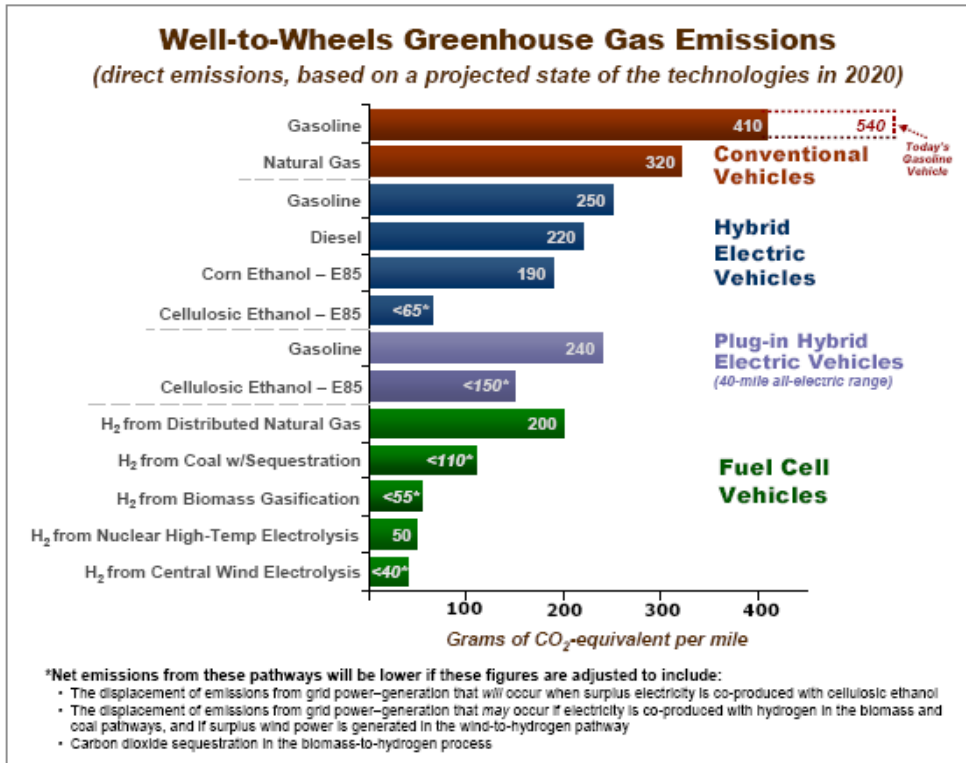
8. Greenhouse gas emissions. Today most hydrogen is made from natural gas. Hydrogen from natural gas and used in a FCV generates over 50% fewer GHGs than a gasoline car. As we move toward renewable hydrogen (and renewable electricity) over the next few decades, and prove out carbon sequestration, we can further reduce greenhouse gas emissions.

The DOE compared “well-to-wheel” emissions of GHGs from various pathways, and the results show that FCVs are one of the cleanest technologies.<sup>17</sup> FCVs using hydrogen from natural gas emit 60% fewer GHGs than today’s gasoline vehicle, and 35% fewer GHGs than natural gas vehicles. FCVs using hydrogen from biomass gasification emit 60% fewer GHGs than a PHEV that uses cellulosic ethanol.

<sup>16</sup> “Fuel Cell and Battery Electric Vehicles Compared,” C. E. (Sandy) Thomas, Ph.D., President, H2Gen Innovations, Inc. Alexandria, Virginia, Thomas@h2gen.com

<sup>17</sup> [http://www.hydrogen.energy.gov/pdfs/9002\\_well-to-wheels\\_greenhouse\\_gas\\_emissions\\_petroleum\\_use.pdf](http://www.hydrogen.energy.gov/pdfs/9002_well-to-wheels_greenhouse_gas_emissions_petroleum_use.pdf)

From DOE hydrogen program record #9002:



9. FCVs and hydrogen are one of the best ways to meet our goals: The National Research Council<sup>18</sup> shows that improving vehicle efficiency, using advanced biofuels, and deploying hydrogen fuel cell vehicles can all reduce petroleum use and carbon emissions. However, the greatest reductions come from hydrogen fuel cell vehicles (see figure below).

<sup>18</sup> Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, NRC 2008

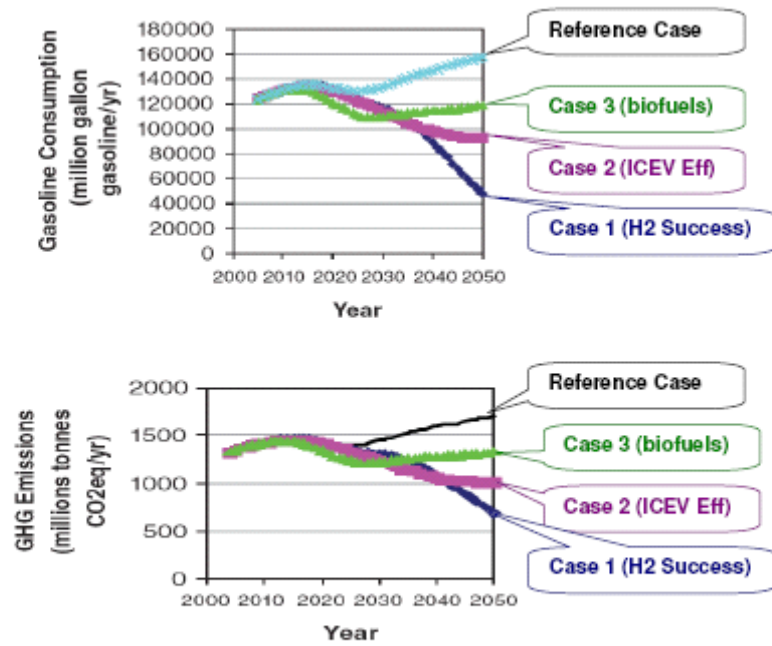
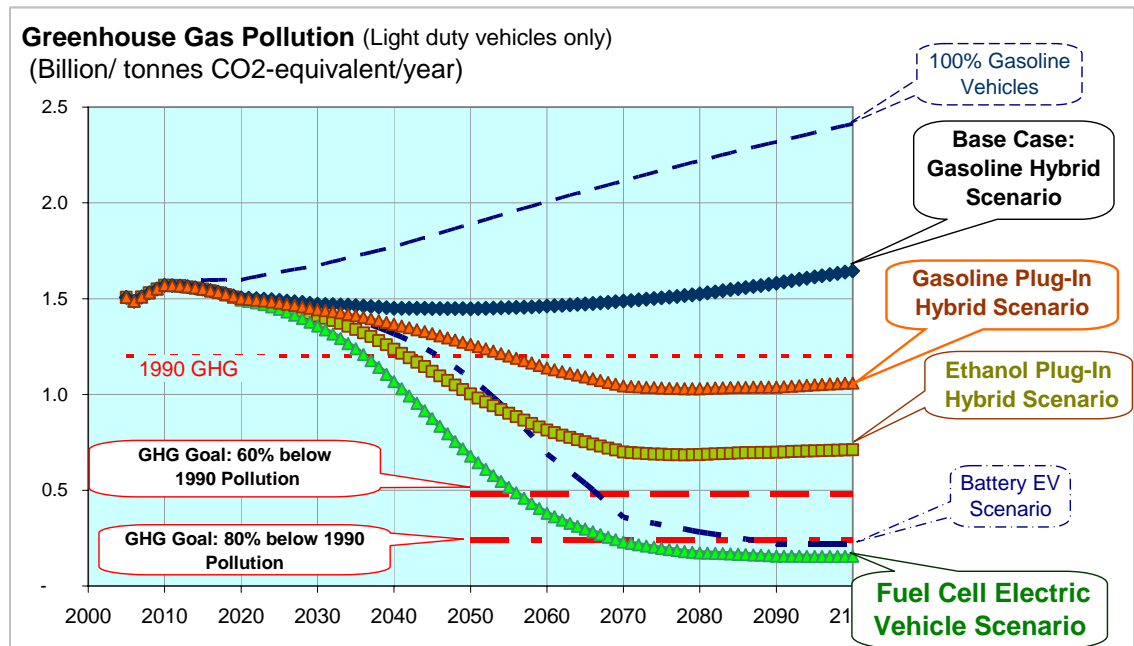


FIGURE S.5 Comparison of (top) annual gasoline use and (bottom) annual greenhouse gas (GHG) emissions (as equivalent CO<sub>2</sub> for Cases 1-3 compared with the reference case.

The National Hydrogen Association's Energy Evolution<sup>19</sup> report shows that BEVs, PHEVs and fuel cell vehicles can all reduce GHGs, but the greatest reductions come from fuel cell vehicles.



Story Simultaneous.XLS; Tab 'Graphs'; AN 344 5/10/2009

<sup>19</sup> <http://www.hydrogenassociation.org/general/taskForce/evolutionReport.pdf>

The National Research Council<sup>20</sup> determined that a portfolio approach yields the deepest cuts in petroleum and greenhouse gases.

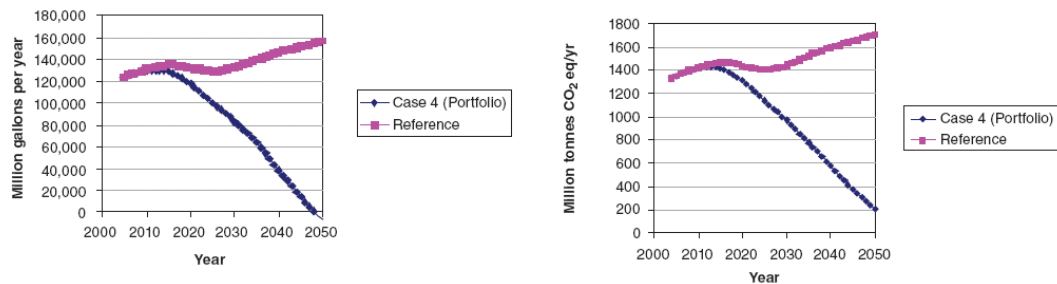


FIGURE S.6 Impact of combining the potential of HFCVs with advanced conventional vehicles, hybrid vehicles, and biofuels in a portfolio approach—Case 4: (Left) annual gasoline use and (right) annual greenhouse gas emissions.

## 10. Conclusions:

- a. To reduce greenhouse gases, reduce petroleum use and improve the air we breathe, we must move to electric-drive vehicles.
- b. There are two ways to power electric-drive vehicles: batteries or fuel cells (in fact, fuel cell vehicles use both – they are hybrids!).
- c. Both fuel cells and batteries can help achieve our environmental and energy goals.
- d. The fuel cell enables full-function vehicles, long driving range and quick refueling.
- e. Neither battery vehicles nor fuel cell electric vehicles are proven in the marketplace, and both require continued government support to succeed.
- f. Given excellent real-world performance and high-potential cost reduction pathways for vehicles and hydrogen fuel production and delivery systems, fuel cell vehicles are ready to take the next step to early market deployment.
- g. Until fuel cells, batteries and advanced biofuels have an opportunity to compete with gasoline vehicles in the marketplace, the government should make the smart choice and support all three.

<sup>20</sup> Transitions to Alternative Transportation Technologies: A Focus on Hydrogen, NRC 2008