Questions and Answers about Hydrogen and Fuel Cells

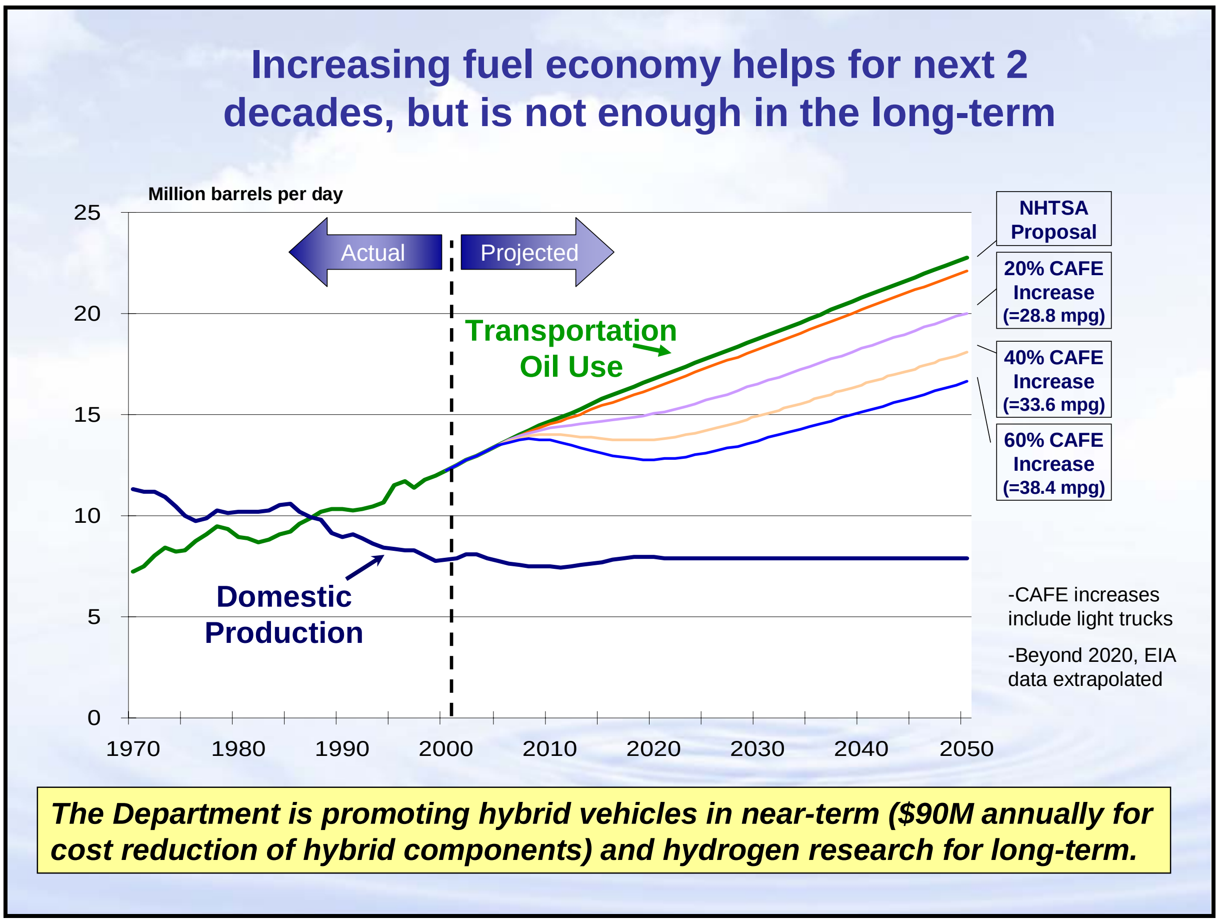
Recent articles have identified the challenges the nation faces in pursuing a hydrogen economy. These articles and comments generally support hydrogen as a long-term energy option, but suggest it will be many decades before a transition to hydrogen is possible. A complete transition to a hydrogen economy will take time, money and the nation's best ideas. But the concerns expressed recently are overstated and unnecessarily pessimistic.

Here are answers to the top questions expressed about hydrogen and fuel cells.

Why do we need a hydrogen economy?

The United States – indeed, the world -- has a fundamental strategic interest in pursuing the hydrogen economy

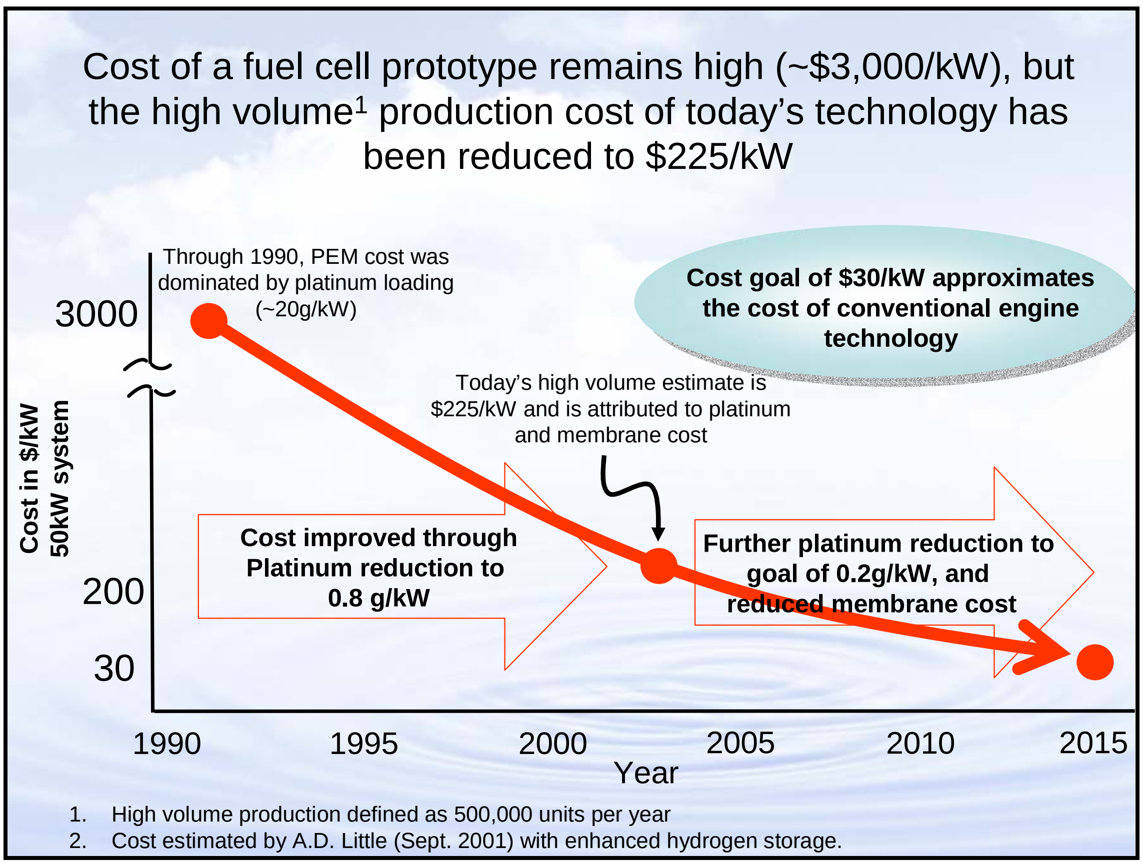
- Commercial fuel cells and hydrogen would yield benefits to society unmatched by alternatives.
- Our nation's reliance on fossil fuels presents fundamental challenges to our economic security, environmental security and homeland security. We must pursue every promising pathway to a more secure energy future.
- Hydrogen can be produced renewably and from local conventional energy sources; the result is fuel flexibility and energy security. Hydrogen is well matched with renewable energy technologies like solar and wind power.
- Hydrogen fuel cells generate electricity with no conventional pollutants.
- Fuel cells produce less carbon dioxide per unit of work, usually much less, than conventional alternatives
- Transitional strategies like hybrid vehicles will help, but because of growth in vehicle use, even if every single vehicle in the U.S. was a hybrid by 2025, we would still need to import as much oil as we import today. We need a permanent solution.



Source: US DOE

Will consumers be able to afford fuel cell vehicles?

- Fuel cell vehicles will be affordable by the time they reach the marketplace.
- Hydrogen opponents look at the price of today's hand-built prototypes and today's stationary power generation systems and leap to the conclusion that fuel cell vehicles will not be cost-competitive. They ignore that prototypes and first-generation systems are almost always very expensive compared with mass produced units. Just like gasoline powered cars, personal computers, digital cameras, and many other innovative products, the price will come down.
- Costs have come down dramatically. The Department of Energy, based on **current** best technology, projects cost of a fuel cell vehicle engine at $225 per kilowatt in mass production. Industry's ultimate goal is $30 to $50.
- General Motors says it can achieve a competitive cost by 2010 and it is investing hundreds of millions of dollars in the technology. They would not be doing this if they did not expect to earn a profit.
- The California Air Resources Board sees mass production volumes by 2014.



Source: US DOE

Can we store enough hydrogen on the vehicle?

- Hydrogen storage is a current challenge that is being addressed by research and technology demonstrations.
- Conventional pressurized tanks yield enough range to meet niche markets that will be the entry point for fuel cell vehicles.
- The best of today's research vehicles report range of well more than 200 miles using conventional compressed hydrogen storage. Ford designed a fuel cell vehicle with range of 380 miles using pressurized tanks (5,000 psi).
- Several vehicles are operating on non-gaseous alternatives that achieve fully commercial range. (greater than 300 miles)
- Increases in stack efficiency will help in the short term.
- The National Academy of Sciences notes that there are options: "there are many possibilities: perhaps hundreds" [that] are still in contention for possible local storage or on-board vehicle storage. (2004: 4-6).

Is hydrogen safe?

- Hydrogen is as safe if not safer than conventional fuels on the market today.
- Hydrogen has been in mass production and transportation for over fifty years in the United States. Experience has shown that hydrogen can be safely produced and transported.
- Ford examined the issue under contract to DOE, and concluded: "Overall, we judge the safety of a hydrogen FCV system to be potentially better than the demonstrated safety record of gasoline or propane, and equal to or better than that of natural gas." (Ford 1997)
- A Norwegian study in 2002 reached a similar conclusion: "There are no technical or safety barriers that prevent the use of hydrogen for fuel in the transportation sector or as a medium for the storage and transportation of energy. It is possible to manufacture and utilize hydrogen just as safely as with today's gasoline systems." (Bellona, p. 15)
- The U.S. used hydrogen as a residential fuel in the last century and it still is used in half a million homes in Japan today.
- The hydrogen industry has compiled an exemplary safety record over the past 50 years as demand for hydrogen for industrial uses has grown. (Sandia 1994 et al.)
- Gasoline-ignited fires took 760 lives in the U.S. in 1986. There are more than 140,000 gasoline related vehicle fires[1] annually (NFPA 2000).
- Hydrogen is different than gasoline and other fuels, so safety procedures will need to be revised.
- To some people ALL codes and standards are "onerous," but hydrogen codes and standards ought to be no more so than those governing other fuels. There's a substantial body of codes and standards governing hydrogen already.

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[1] In 1986 EPA reported 180,000 vehicle fires caused by gasoline ignition, and 500,000 fires overall.

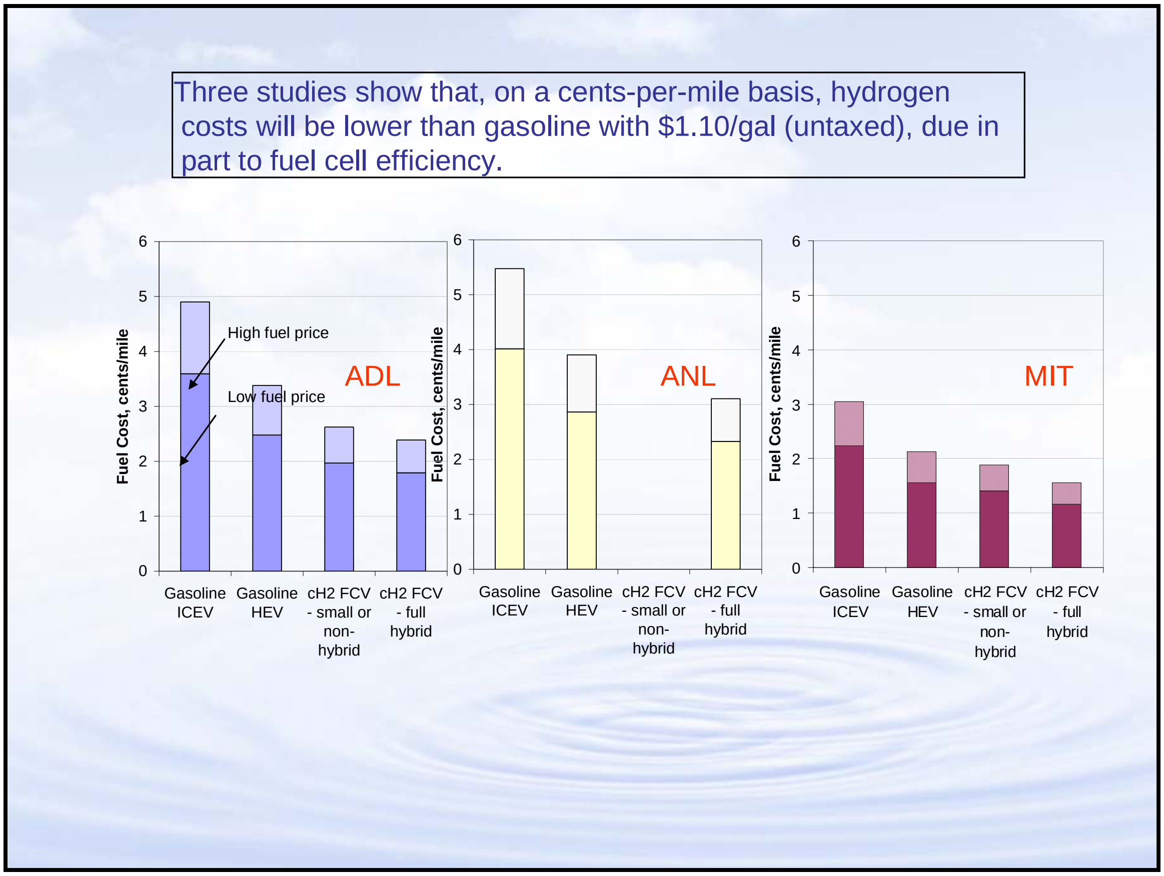
Will hydrogen cost too much?

- The National Academy of Sciences/National research Council studied this question. Data provided in the NRC report show that the cost of hydrogen *per mile driven* ought to be between 27% to 52% lower than the cost of gasoline at $1.80/gallon in a conventional car, and between 3% more to 32% less than the cost of gasoline used in a hybrid electric vehicle[2]
- Even if hydrogen ultimately is more expensive by weight or volume, hydrogen cars are much more efficient than gasoline cars, thus making hydrogen very competitive on a cost per mile basis. Fuel cell vehicles are 50 percent efficient, compared to perhaps 15 percent for gasoline combustion engines. On this basis, the per-mile costs for fuel cell vehicles are comparable to gasoline vehicles even with today's prototypes.
- Gasoline prices are rising rapidly and show no signs of abating. Gasoline is nearing $3 per gallon today in some areas, and is well above $2 in others.
- The NRC report provides the following data for hydrogen produced at the fueling station by reforming natural gas:

	ICEV	HEV	FCV	
Fuel economy in 2015 (p. 6-16)	24 mpg	34 mpg	58 mpkg	
			Current	Optimistic
Fuel Cost /gallon or kg	$1.80/gal	1.80/gal	$3.51/kg (Table E-5)	$2.33/kg (Table E-36)
Fuel Cost (cents/mile)	8.3	5.9	6.1	4

[2] Of course the $1.80/gallon for gasoline includes an average of 43 cents/gallon of highway tax, while the hydrogen is untaxed. We maintain hydrogen would not be taxed initially as a superclean fuel. But even if we include the highway tax, the cost of hydrogen of roughly 2 cents/mile attributed to the gasoline ICEV, the future price hydrogen at 4 cents/mile + 2 cents/mile tax = 6 cents/mile would still be less than an ICEV an approximately equal to the fuel cost (including road taxes) of the HEV. Note that this calculation assumes that the FCV highway tax would be per mile to raise the same revenue, and not per MBTU or per gallon of gasoline equivalent.

- Many other studies reach similar conclusions:



Slide from US DOE

Notes for Graphs above (MIT study):

- Graph 1: Assumes “high” and “low” gasoline prices of $1.50 and $1.10 per gallon and hydrogen fuel prices of $2.00 and $1.50 per equivalent gallon.
- The Arthur D Little (ADL) and MIT “cH2 FCV - full hybrid” cases are for large battery/hybrid fuel cell vehicles.
- The “cH2 FCV - small or non-hybrid” cases use the ADL small 9 kW battery hybrid and the MIT study assumes no battery.
- Both MIT “cH2 FCV” cases use their “integrated” FCV results.
- The MIT “2020 Advanced” vehicle was used as the baseline gasoline ICEV.

Where Will I buy the hydrogen?

- Consumers will be able to buy hydrogen at energy stations. Some may even choose to generate hydrogen at home using small systems called electrolyzers that make hydrogen from water using electricity.
- A national hydrogen infrastructure exists today to serve an expanding industrial market. Getting hydrogen in consumers' hands will require new production and delivery systems, but they need not be built all at once, and they may begin as widespread small scale ("distributed") facilities.
- The gasoline infrastructure is not free. The EIA (2003) estimates the US we will need to invest $3 *trillion* in the oil sector through 2030. At least one study suggests it would be cheaper to install a hydrogen infrastructure
- The important issue is not what the infrastructure will cost, but whether suppliers can make money on the investment. Fuel infrastructure is expensive. But the energy business is profitable even given the costs.
- Claims that more than half of all gasoline stations would need a hydrogen fueling station before the first car was sold are simply unfounded. There are only 5,000 truck stops in the U.S., yet there is a thriving market for diesel trucks (ORNL 2002). In all, only about one in six gas stations carries diesel today, a dramatic increase from the total only a few years ago, yet auto and truck manufacturers happily sell diesel vehicles, and oil companies happily profit from supplying the fuel (ORNL).
- We might choose to build a massive centralized national hydrogen distribution system, but we won't need it all at once or right away. We can get started for much less.
    - GM estimates that an initial nationwide hydrogen infrastructure to support 1 million FCVs and to place a hydrogen fueling pump within 2 miles of the homes of 70% of the US population as well as every 25 miles on the interstates connecting the 100 largest cities, would cost between $10 billion and $15 billion. (McCormick 2003)
    - Independent studies also have developed nationwide models costing about $15 billion (e.g. RMI 1999). We spend $5 billion annually on natural gas pipeline expansion (Argonne 2002). The oil industry spends at least $11 billion a year just to maintain its service station fleet (Mark 1997).
- Argonne estimated (2002) that it might cost $600 billion to supply *100 million* fuel cell vehicles via construction of a national hydrogen pipeline system, not something we will need right away.
    - The same Argonne study also reported these estimates may be overstated because pipeline costs "may be overestimated in the literature."
    - Argonne's lowest estimate, using different assumptions, was little more than $100 billion.

Are there environmental benefits from switching to hydrogen?

- Claims that hybrid vehicles are just as clean environmentally as fuel cell vehicles are inaccurate.
- Only hydrogen offers the promise of completely removing motor vehicles from the pollution equation.
- Although fossil fuels will be used to produce hydrogen in the medium term, in the long term hydrogen can be derived largely from renewable sources. Gasoline, on the other hand, can only be derived from fossil fuels.
- Although a Prius hybrid is significantly cleaner than a conventional gasoline vehicle, it is not cleaner than a hydrogen vehicle where the hydrogen is derived from clean sources.
- Argonne National Laboratory evaluated a natural gas-based hydrogen FCV and calculated it emits 60% less greenhouse gases than a conventional gasoline vehicle[3] and 25% less than a Prius hybrid. (2004)
- The NRC reached the same conclusion in 2004 (See below.)
- So did a respected German research institution (LBST, 2003)

	ICEV	HEV	FCV	
Fuel economy in 2015 (p. 6-16)	24 mpg	34 mpg	58 mpkg	
			Current	Optimistic
Carbon emissions (kg/gal or kg/kg of H2)	3.0 kg/gal (pg. 5-13)	3.0 kg/gal	3.31 kg/kg (pg. 5-39	2.82 kg/kg (pg. 5-30)
Carbon emission (grams of carbon/mile)	130	88	57	49
Carbon Reductions relative to ICEV	0	-32%	-56%	-63%

[3] Achieving 28 mpg.

What's important about where the hydrogen comes from?

Some people say hydrogen should *only* come from renewable energy sources like wind or solar power. These people want to assure that hydrogen delivers its maximum environmental potential since renewably derived hydrogen is a truly zero emission fuel. Others say that renewable energy should *never* be used to generate hydrogen, at least not until 15% to 20% of our energy is generated renewably. Until then, they want to use renewable energy to displace coal-fired electric generation.

- Clearly, renewable hydrogen is the most beneficial end point but the scarcity of renewable generation and its cost suggest most hydrogen will come from natural gas in the short term. This will provide *significant benefits* to society and facilitate the commercialization of hydrogen.
- Meantime, renewables will find the market to which they are best suited given their cost, distance from market and other factors.
- As the amount of available renewable energy grows, hydrogen can actually provide a benefit, by allowing storage of intermittent energy such as wind power at times of slack demand from the grid.

Is there enough natural gas to fuel our fuel cell cars?

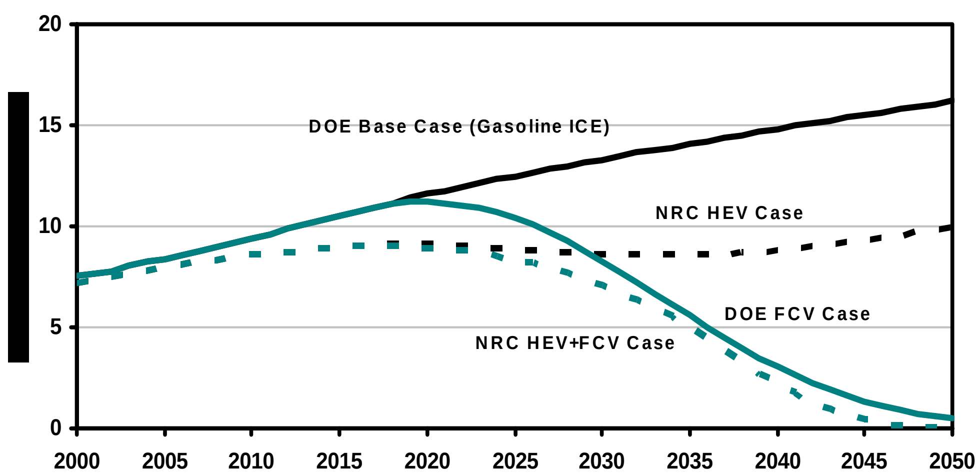
- Using natural gas to produce hydrogen will not put an undue strain on our natural gas supplies.
- The National Academy of Sciences (2004) estimated that hydrogen production for vehicles would have "only an insignificant impact" on natural gas demand "during the next 25 years."[4]
- Alternatives to natural gas will become more attractive as demand for hydrogen increases.
- We don't need a massive hydrogen fuel infrastructure all at once.
- Even if we relied long term on natural gas to produce enough fuel for 150 million FCV's -- virtually the entire U.S. fleet – DOE estimates it would yield only a 20 percent increase in today's natural gas demand. We will have plenty of time to manage that increase in demand. (Posture Plan 2004)

[4] Page 6-13.

Can fuel cell vehicles compete in the marketplace with hybrid vehicles?

- Hybrid vehicles are emerging as a real-world option for consumers, and they deliver significant benefits (though smaller benefits than their boosters claim). But hybrids only allow us to manage our national addiction to gasoline. Only fuel cell vehicles and hydrogen offer a cure.
- Fuel cell vehicles currently exist in research form, whereas hybrid vehicles are in commercial production. It is too early to tell whether a commercial fuel cell vehicle will compete with a commercial hybrid or other commercial alternative fuel vehicle. But the evidence, including a large investment in fuel cells by the auto industry, suggests fuel cells and hybrids will be cost competitive when they are commercialized.
- Hybrids are a transition to fuel cells. Most fuel cell vehicles today are hybrids themselves; the success of hybrids paves the way for fuel cell vehicles.
- Because of growth in vehicle use, even if every single vehicle in the U.S. was a hybrid *by 2025, we would still need to import as much oil as we import today. We need a permanent solution.*
- Toyota, the world leader in hybrid vehicle technology, is also a world leader in fuel cell development; they see fuel cells as essential to the long-term solution to the environmental and energy consumption challenges of the automobile.
- The auto industry itself is putting its money where its mouth is, investing more than $1 billion annually on fuel cell research even as it commercializes hybrids. Given the payoff to society, this effort deserves support.
- The chart below shows independent evaluations by the Department of Energy (solid lines) and the National Academy of Sciences (dotted lines) of the impact of fuel cell vehicles (FCV) on oil use over the next half century. NRC also evaluated the impact of achieving a 45% improvement in fleet average fuel economy via widespread purchase of hybrid internal combustion engine vehicles. Fuel cell vehicles achieve the ultimate goal. Hybrids buy time, but their benefits decline over time.
- **Federal research and demonstration support can help accelerate these time lines!**

Oil Use by Light-Duty Vehicles



Will the investment in fuel cells and hydrogen overlook alternatives, like fuel efficiency?

- Our energy security needs are too great to limit our options to any technology. The U.S. Department of Energy supports research into renewable energy, efficiency, hybrid vehicles and advanced combustion systems. It is in the nation's interest to pursue all the promising options, and that is just what the DOE has proposed.
- Federal research support for hydrogen and fuel cells is on the increase, but from a small base. Hydrogen is simply becoming a mainstream energy option, not the only option.
- Requested DOE research funding for FY 2005 seeks more for hybrid vehicles than for fuel cell vehicles ($92 million/$77.5 million).
- Requested DOE research funding for FY 2005 seeks about as much for hybrid vehicles as for hydrogen. ($92 million/$95 million).
- Requested DOE research funding for FY 2005 seeks about as much for biofuels as for hydrogen ($81 million/$95 million).