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**Effects of a Transition to a
Hydrogen Economy on
Employment in the United States
Report to Congress**



EFFECTS OF TRANSITION TO A HYDROGEN ECONOMY ON EMPLOYMENT IN THE UNITED STATES

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EFFECTS OF TRANSITION TO A HYDROGEN ECONOMY ON EMPLOYMENT IN THE UNITED STATES

EXECUTIVE SUMMARY

E.1 Background to the Study

Section 1820 of the Energy Policy Act of 2005, “Overall Employment in a Hydrogen Economy”, requires the Secretary of Energy (Secretary) to carry out a study of the likely effects of a transition to a hydrogen economy on overall employment in the United States. This study, prepared by the Department of Energy (DOE or Department) in response to Section 1820, represents the Department’s “best efforts” to predict the employment impacts of such a transition. Prior to publication, the study was reviewed by an independent panel of experts from industry and academia. While the panel provided valuable additional input,¹ any study of potential future impacts necessarily presents several difficult challenges, including the choice of a sound methodology and the identification of reasonable data inputs and factual assumptions, given the uncertainties. In addition, technological process is extremely difficult to predict and economic forecasts are often unreliable even over the short term. The results must be interpreted in light of these unavoidable limitations.

E.2 Methodology

This study estimated the employment impacts of a transformation of the U.S. economy to the use of hydrogen between 2020 and 2050. This time frame was selected because the ongoing efforts to develop hydrogen based transportation (or “mobile”) and stationary technologies indicate that broad-based commercial and industrial use of and the first significant employment impacts from those technologies are most likely to emerge within the indicated time frame. More specifically, hydrogen production technologies are examined as of three dates-2020, 2035, and 2050-and the share of production contributed by each technology is estimated on the basis of DOE’s Hydrogen Analysis (H2A) models.²

Because it is not possible to predict with precision the rate at which hydrogen technologies will be incorporated into the nation’s economy on the above three dates, the study also considers the differences in employment by industry under two scenarios. The more rapid transformation scenario assumes the success of the President’s Hydrogen Fuel Initiative (HFI)³

¹ The study was reviewed by and benefited from the advice and comments of the members of an industry advisory panel including Dr. John Johnston, former Planning Executive, Corporate Strategic Research Lab, Exxon-Mobil Research and Engineering; Dr. Alan Lloyd, President of the International Council on Clean Transportation; Dr. Walter McManus, Director Automotive Analysis Division, University of Michigan Transportation Research Institute; Mr. Gregory Morris, Senior Vice President, HydroGen, LLC and Executive Director, Cullen Engineering Research Foundation; and Dr. Robert Rose, Executive Director, U.S. Fuel Cell Council.

² DOE initiated its Hydrogen Analysis (H2A) initiative in February 2003 as a means of establishing a standard format and list parameters for estimating and comparing the lifecycle costs of hydrogen production and delivery technologies. See, http://www.hydrogen.energy.gov/h2a_analysis.html.

³ President Bush announced the HFI in his 2003 State of the Union Address. The HFI consists of a \$1.2 billion program to develop commercially viable hydrogen fuel cell and infrastructure technologies by the year 2020.

of saving 11 million barrels of oil per day by 2040 (the “HFI Scenario”), and the less rapid scenario follows DOE’s analysis supporting its 2007 program benefits estimation (the “Less Aggressive Scenario”).⁴ Under the HFI Scenario, for example, the penetration of the light-duty vehicle stock with hydrogen powered vehicles by 2050 is 96%. Under the Less Aggressive Scenario, such penetration by 2050 is 38%.

The study further estimates national employment impacts from the transition to a hydrogen economy using an established economic impact analysis model called IMPLAN (an acronym for “Impact analysis for PLANning”). IMPLAN has been used in other contexts to derive economic impacts of long-term technological developments.⁵ The current study uses the IMPLAN inter-industry model with 509 industrial sectors for the U.S. economy. Revised industry purchase vectors were constructed for three industries for the hydrogen scenarios—vehicle components, vehicle assembly, and hydrogen production. Stationary and portable fuel cells were assumed to be produced in the vehicle components vector together with the automotive fuel cells. The data for these revisions were derived from application of DOE’s H2A production and delivery models and separate cost estimates for fuel cell vehicles and stationary fuel cells. Technological process is extremely difficult to predict and economic forecasts are often unreliable even for short term predictions. Though this study represents our best estimate, it is important to appreciate the tremendous uncertainties involved.

E.3 Scenarios Shaping Future Hydrogen Markets

HFI Scenario. The base case against which the employment impacts of hydrogen market expansion are compared is a predominantly gasoline economy. The HFI Scenario assumes rapid market penetration of hydrogen vehicles. The first sales occur in 2018. By 2020, 27% of new vehicle sales are hydrogen vehicles; by 2035, 89%; and 100% by 2050. This results in stocks of light duty hydrogen vehicles in use, respectively, of 3%, 60%, and 96% of the total of light duty vehicles in use in those years. For hydrogen production, it is assumed that distributed reforming of natural gas provides the greatest share of hydrogen production in 2020. Natural gas feedstocks are then largely superseded by 2035 and replaced by coal gasification with carbon sequestration and, to a lesser extent, by biomass gasification. By 2050, biomass and wind, combined, provide 35% of hydrogen supplies. Hydrogen production from nuclear resources provides small shares in both 2035 and 2050. Hydrogen will also be used to fuel stationary fuel cells. In 2020, stationary fuel cells are assumed to supply 1% of the post-2015 growth in national electricity demand. It is assumed that this will increase to 5% in 2035; and to 10% in 2050.

⁴ Government Performance and Results Act, Public Law No. 103-62. This law requires Federal agencies to develop and report annually on performance measures and goals for each program activity of the agency. The 2007 report was prepared by DOE and the National Renewable Energy Laboratory and is entitled, Projected Benefits of Federal Efficiency and Renewable Energy Programs, FY 2007 Budget Request (March 2006) See, http://www1.eere.energy.gov/ba/pba/2007_benefits.html. (Projected Benefits FY 2007)

⁵ For example, the IMPLAN model has been used for long term technology assessments in the following reports: Robert H. Beach and Martin T. Ross, *General Equilibrium Assessment of Regional Climate Change Policy*, Proceedings of the 2004 National IMPLAN User’s Conference (MIG, Inc., Stillwater, MN (Oct. 2004) at 151-168; and Northwest Economic Associates, *Assessing the Economic Development Impacts of Wind Power* (Feb. 12, 2003).

Less Aggressive Scenario. Market penetration of hydrogen vehicles is slower under the Less Aggressive Scenario, reaching approximately 1% of new sales in 2020, 20% in 2035 and 63% in 2050, resulting in hydrogen vehicle stocks of ½%, 7% and 38%, respectively. The composition of hydrogen production technologies over time is similar to that in the HFI Scenario, but output is lower, in line with the smaller number of hydrogen vehicles. The shares of incremental electricity demand provided by stationary fuel cells are zero in 2020, 2% in 2035, and 5% in 2050.

Table E.1 summarizes the hydrogen vehicle adoption and stationary fuel cell use in 2050 under the two scenarios.

Table E.1: Hydrogen Fuel Cell Vehicles and Stationary Fuel Cell Uses in 2050 in the HFI and Less Aggressive Scenarios			
Scenario		HFI Scenario	Less Aggressive Scenario
Sales	million light-duty vehicles sold/yr	23.9	15.1
	% of all light-duty vehicles sold	100%	63%
Stock	million light-duty vehicles in use	347.5	144
	% of all light-duty vehicles in use	96.0%	38.2%
Hydrogen fuel use	quads/yr ^a	8.02	3.73
	billion gge/yr ^b	64.1	29.95
Stationary fuel cells	percent of incremental electricity demand after 2015 supplied	10%	5%
^a 1 quad = 1 quadrillion Btu. ^b gge = gallons of gasoline equivalent.			

E.4 Employment Creation and Replacement at the National Level

By 2050, under the HFI Scenario, the transformational adjustments are fully completed, with no more anticipatory investment; U.S. employment is increased by a net of 0.37%, or 675,000 jobs out of a total projected base-case employment of 184 million. Under the Less Aggressive Scenario, the transformation is not fully completed by 2050 and U.S. employment is increased by a net of 0.20%, or 361,000.

The more significant changes occur under the HFI Scenario. Thus, under the HFI Scenario, net employment in the automotive industry is unchanged between the gasoline and hydrogen economies, but replacement of gasoline-related skills with hydrogen-related skills is substantial. For example, in automotive parts manufacturing, 10,000 white collar jobs are created by 2035, replacing an equal number of outmoded jobs. The figure is 12,000 by 2050. Blue-collar employment job creation and replacement in automotive parts manufacturing is 104,000 by 2035 and 117,000 by 2050. The greatest job creation and replacement is for automobile dealerships and repair: 436,000 by 2035 and 680,000 by 2050.

Training implications of the job changes vary by industry and skill, as indicated by a survey of industry opinions. The changes will be substantial in some cases, though many will be evolutionary, resulting partly from experience with hybrids. The needs for new skills will be spread over a number of years. Much of the obsolescence of skills will be met by normal retirement rates. Most of the needs for new skills can be supplied by normal rates of entry into the labor force as workers receive training in new, hydrogen-related skills.

With the automobile industry taking a small proportion of all engineers in the U.S., engineering schools easily have the capacity in the long run to respond to changes in the fields of engineering that will be required. This is also true for the most part in the shorter run, in view of university expertise currently being developed in hydrogen technology R&D.

Some but not all of the blue collar training needed to switch from gasoline to hydrogen vehicles can be provided on the job and by in-house classes. Automotive technicians and mechanics are a large group requiring much training and re-training. They are the group for which bottlenecks appear to be most likely. Up to 110,000 technicians and mechanics will need to be equipped with hydrogen-technology skills by 2020 to service new vehicles on the road by that year in the HFI Scenario. By 2035, the number is 335,000. By 2050, the number is 630,000, many of whom will have entered the labor force prior to the beginning of hydrogen market expansion.

E.5 Regional Variations in Economic Impacts

Five regions were selected for examination: 1) the Upper Midwest, consisting of Ohio, Michigan, Indiana, Illinois, and Wisconsin; 2) Lower New England and the Upper Mid-Atlantic, consisting of Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, and New Jersey; 3) California; 4) Tennessee; and 5) the Houston metropolitan area. Unique characteristics of these regions lead to impacts that differ from those at the national level. The Upper Midwest is America's long-established automobile manufacturing belt. The Lower New England and the Upper Mid-Atlantic regions are very diversified economically. California is also a very diversified state, but its industrial mix has been changing in the past decade. Tennessee represents the new automotive manufacturing region of the South. Houston is highly concentrated in petroleum production and is a net exporter of refined products.

Compared to the base case without a hydrogen market transformation, the HFI Scenario leads to a projected gain in the Upper Midwest of 110,000 additional jobs by 2050. The gains will be distributed across 41 industries. The region will lose 4,800 jobs concentrated in 14 industries. The region's net creation of 105,000 jobs is 0.44% of its 2050 base-case employment. Scientific and technical services employment would grow to support both the technical needs of hydrogen production and the technological changes in the automotive industry, while fabricated metals would lose employment.

The Lower New England and Upper Mid-Atlantic region is projected to increase its 2050 employment by 0.56% over what it would be in an all-gasoline economy. The gains are primarily in the production and delivery of hydrogen, while losses are in the corporate offices of upstream energy companies.

California experiences a 0.45% increase over the base case in the hydrogen market expansion under the HFI Scenario. Its high-tech sectors participate in the development of the new hydrogen technologies, as does carbon and graphite manufacturing. The state suffers some loss of employment in petroleum refining relative to the all-gasoline scenario.

Tennessee gains 0.5% in employment relative to the gasoline scenario under the HFI. The state has no significant losses to dampen the gains in hydrogen production and technological and engineering services.

Houston gains 0.37% in employment in the HFI Scenario relative to the base case. Its refining industry suffers in the hydrogen market expansion, compared to the all-gasoline base case scenario, but this impact could be cushioned by the relative ease of retrofitting the area's refineries. Houston's experience in a variety of energy industries helps it gain employment in hydrogen production and in the design and production of energy and chemical pipeline equipment.

E.6 International Competition

The transformation to a Hydrogen Economy will serve at least two major objectives in the international area. First, reduction in oil imports, with the attendant increase in energy independence, is a clear U.S. goal to which hydrogen will contribute. Second, if U.S. companies are able to forge a lead in hydrogen technologies, U.S. global competitiveness will be fostered. The movement to hydrogen in particular could well be an opportunity for U.S. automotive firms to recapture market share lost to foreign multinationals in recent years.

Due to overseas operations of U.S. and multinational corporations, with or without a hydrogen transformation, most vehicle production and employment will continue to be tied to countries with large automobile demands. Some effects on the international location of supplies of particular individual materials could be brought about by a transformation to hydrogen. If the production shares held by U.S. and multinational corporations are affected because some companies get ahead of others in introducing hydrogen vehicles, the location of automobile production within the U.S. could be affected in turn due to the fact that companies differ in their regional concentrations of production capacity. Hydrogen, however, will be produced domestically in either case and will be essentially a non-internationally traded commodity. Inasmuch as natural gas is not projected to be a significant long-term feedstock for hydrogen production, little effect on gas imports is projected.

Oil imports, on the other hand, will fall as gasoline is replaced with hydrogen. By 2050, the difference in oil imports between an all-gasoline economy and a hydrogen economy under the HFI Scenario is projected to be \$370 billion per year, or 1% of the \$38.12 trillion

estimated gross domestic product in 2050. Some of the reduction in expenditures on imported oil will be redirected to a domestically produced, largely nontradable good—hydrogen. The \$370 billion reduction in oil imports equals approximately 7.5% of projected total U.S. imports in 2050 if trade grows at the same rate as gross domestic product.

The oil import reduction introduces a trade imbalance that will lead to a combination of adjustments in non-oil imports and exports. The adjustments will be spread over the many non-oil commodities involved in U.S. trade. Considering that both import and export adjustments will occur over a 30-year hydrogen market expansion period, the average yearly quantity adjustment for a commodity will be less than 0.1 of one percent. Similar considerations apply to all countries adopting hydrogen. On-going globalization effects on trade over the coming years seem bound to overwhelm the small trade adjustments to the reduction in oil imports.

A similar conclusion applies to effects on world capital markets. With falling OPEC incomes, OPEC countries' purchases of U.S. assets would be reduced. Overall financial lending to industrialized countries would be lowered. Any effect on world interest rates is unlikely to be perceptible given that OPEC demand for financial assets is a small part of total world demand for assets.

Recommendations

This study identified possible employment impacts that could result from hydrogen market expansion in the transportation and stationary and portable power sectors. As noted previously, any study of potential future impacts necessarily presents difficult challenges and involves significant uncertainties. Results and recommendations should be considered with those issues in mind. The scenarios, hydrogen generation options, and regions selected for the study yielded a reasonable measure of the potential opportunities that hydrogen presents to U.S. employment. The study considers introduction of the fuel cell vehicle and supporting hydrogen infrastructure development that spans a period of approximately 40-50 years. The study highlights possible skill and education needs to support the associated industries and technologies. In addition to the specific skill requirements of the fuel cell industry, future education of the next generation should be focused on skill sets that have the ability to adapt to changing technologies.

Training implications of the job changes vary by industry and skill, as indicated by a survey of industry opinions. Most of the needs for new skills can be supplied by normal rates of new entry into the labor force as workers receive training in new, hydrogen-related skills. Considering the small proportion of all engineers in the U.S. that the automobile industry employs, engineering schools have the capacity to respond to changes in the fields of engineering.

Following are employment-related recommendations for a transition to a hydrogen economy.

1. Training programs.

a. Training and retraining programs may be needed to help ensure that the U.S. workforce possesses appropriate skills and that sufficient numbers of trained personnel are available to meet the manufacturing requirements at the time that hydrogen fuel cell vehicles begin to come off the assembly lines. Development of these programs should involve close coordination between the fuel providers and auto manufacturers, and schools. At the appropriate time, university and vocational programs will need to be assessed to understand where opportunities lie and what additional curricula may be needed.

b. Training and retraining programs may be useful in related aftermarket areas such as repair and recycling.

c. Educational programs aimed at the general public could help to influence people to pursue jobs in the hydrogen and fuel cells industries.

2. Additional analysis.

a. *Analysis of training needs:* The study found that training for new skills may be needed across a wide spectrum of industries. Most of the needs for new skills can be supplied by normal rates of new entry into the labor force as workers receive training in new, hydrogen-related skills. Some changes in skills appear to be relatively well defined, but many likely changes remain difficult to forecast, since many of the technologies are still maturing. Many job tasks remain unknown at present, making identification of training needs an interactive task with job definition.

b. *Assessment of skill changes, with attention to industry adjustments in different regions:* Unemployment resulting from the elimination of jobs associated with obsolete technologies and industries is estimated to be slight. The supply of labor with technology-specific skill sets may or may not keep pace with the labor demands associated with the rapid growth in hydrogen-related industries. Even though this study indicated every region would gain jobs, surpluses and shortages of skilled workers could vary regionally.

1.0 INTRODUCTION

This Department of Energy (DOE or Department) study is in response to Section 1820 of the Energy Policy Act of 2005 (Public Law 109-58) (EPACT). Section 1820, “Overall Employment in a Hydrogen Economy,” requires the Secretary of Energy (Secretary) to carry out a study of the effects of a transition to a hydrogen economy on overall employment in the United States.⁶ As required by Section 1820, the present report considers:

- Replacement effects of new goods and services
- International competition
- Workforce training requirements
- Multiple possible fuel cycles, including usage of raw materials
- Rates of market penetration of technologies
- Regional variations based on geography
- Specific recommendations of the study

Both the Administration’s National Energy Policy⁷ and the Department’s Strategic Plan⁸ call for reducing U.S. reliance on imported oil and reducing greenhouse gas emissions. The National Energy Policy also acknowledges the need to increase energy supplies and use more energy-efficient technologies and practices. President Bush proposed in his January 2003 State of the Union Address to advance research on hydrogen so that it has the potential to play a major role in America’s future energy system. Consistent with these aims, EPACT authorizes a research, development, and demonstration program for hydrogen and fuel cell technology.

Section 2 of this report considers a base case and two hydrogen adoption scenarios. The base case assumes no broad-based use of hydrogen across the economy. The first hydrogen adoption scenario uses a market penetration rate consistent with the Hydrogen Fuel Initiative (HFI), introduced by President Bush in his 2003 State of the Union Address (the “HFI Scenario”). The HFI consists of programs that focus on the development of commercially viable hydrogen fuel cell and infrastructure technologies by the year 2020. In the HFI Scenario, market penetration begins in 2018, with full market penetration achieved by 2050. The second hydrogen adoption scenario also begins in 2018 but, applying the DOE’s analysis supporting its 2007 program benefits estimation⁹ assumes a less aggressive rate of market penetration by hydrogen technologies (the “Less Aggressive Scenario”). In estimating the effects of the base case and the two hydrogen adoption scenarios on overall employment and the economy, the study uses a modeling tool called IMPLAN. IMPLAN, an acronym for “IMpact Analysis for PLANning,” is a methodology that has been used in other contexts to

⁶ U.S. Congress. *The Energy Policy Act of 2005*. Public Law No. 109-58 (Aug. 8, 2005) (Washington, D.C.: USGPO, 2005), Sec. 1820(a), 119 Stat. 594, 1132.

⁷ *National Energy Policy; Report of the National Energy Policy Development Group* (Washington, D.C.: USGPO, May 2001), pp. 2-9, 3-11.

⁸ U.S. Department of Energy, Office of Program Analysis and Evaluation, *Department of Energy Strategic Plan*. 2006, p. 9.

⁹ Projected Benefits FY 2007, *supra* note 4.

predict the economic impacts of long-term technological developments.¹⁰ Specifically, the study utilizes a 509-sector input-output IMPLAN model of the U.S. economy based on the most recent available U.S. input-output table (2002). Furthermore the mix of hydrogen production technologies considered in the study spans a range of the most likely production scales and feedstock options. Most of the technologies used in the study are relatively mature, have been intensively studied, or both. Thus, the cost studies that have been completed are based on conservative assumptions regarding the technologies that will be available under the various scenarios. The studies accordingly provide equally conservative estimates of future costs and the detail needed for input to the IMPLAN model. The IMPLAN methodology is described in greater detail in Section 3 and Appendix 4 of the study.

In order to identify the impacts of a hydrogen economy, one must look far enough into the future for that economy to be well underway. For this study, the year 2050 was selected as a target because DOE's own analysis using its Hydrogen Analysis (H2A) model¹¹ for comparing the lifecycle costs of different hydrogen technologies indicated that development of the hydrogen economy could be well underway and the impacts readily apparent by that year. Key parameters were extrapolated from 2030 (the latest year of the Annual Energy Outlook forecasts) to 2050. Two other years were selected for detailed analysis – 2020, when new hydrogen industry sectors begin to appear in the two hydrogen scenarios, and 2035, when those sectors are likely to reach the critical mass needed to identify them as belonging to a nascent hydrogen economy.

Section 3 gives estimates of employment effects of the transition to hydrogen technologies at the national level in the years 2020, 2035 and 2050. Using a model of the U.S. economy, estimates are presented of: (1) the net effect on total employment during and after market penetration, (2) employment creation and replacement of jobs and (3) education, training and re-training needs.

Section 4 considers impacts in five geographic regions of the country: the Upper Midwest, the combined area of Lower New England and the Upper Mid-Atlantic, California, Tennessee and metropolitan Houston.

Section 5 considers the international position of the U.S. as it relates to hydrogen. Estimates are given of impacts on the U.S. share of world production of vehicles, vehicle parts and other products using hydrogen, and on oil and natural gas imports. The role of multinational corporations in hydrogen markets is assessed. The nature and importance of repercussions through the balance of payments and the dollar exchange rate are also analyzed.

Section 6 reprises the conclusions and recommendations resulting from the study.

¹⁰ Minnesota IMPLAN Group, Inc., *IMPLAN Professional, Version 2.0, Social Accounting & Impact Analysis Software, User Guide, Analysis Guide, and Data Guide*, 3rd Edition Stillwater, Minn., February 2004.

¹¹ DOE initiated its H2A initiative in February 2003 as a means of establishing a standard format and list of parameters for estimating and comparing the lifecycle costs of hydrogen production and delivery technologies. See, http://www.hydrogen.energy.gov/h2a_analysis.html.

This report is being disseminated by the Department of Energy. As such, the document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by the Department of Energy. The study was reviewed both internally and externally prior to publication. For purposes of external review, the study benefited from the advice and comments of the members of an independent advisory panel. That panel included Dr. John Johnston, former Planning Executive, Corporate Strategic Research Lab, Exxon-Mobil Research and Engineering; Dr. Alan Lloyd, President of the International Council on Clean Transportation; Dr. Walter McManus, Director, Automotive Analysis Division, University of Michigan Transportation Research Institute; Mr. Gregory Morris, Senior Vice President, HydroGen, LLC and Executive Director, U.S. Fuel Cell Council.

2.0 SCENARIOS SHAPING A HYDROGEN ECONOMY

As indicated above, three scenarios were defined to provide a context for the analysis and an internally consistent set of assumptions for analyzing the employment impacts of a hydrogen economy. These include:

- a base or reference case,
- the HFI Scenario, an aggressive hydrogen market development case modeled on President Bush's Hydrogen Fuel Initiative (HFI) as outlined in his 2003 State-of-the-Union address, referred to in this report as the HFI, and
- the Less Aggressive Scenario, an intermediate market development case modeled on supporting analyses from the DOE 2006 report satisfying requirements of the program benefits estimation,¹²

Each of the scenarios is summarized below.

2.1 Base Case

The base case represents a world in which hydrogen has only a minimal role as a primary energy carrier, thereby providing a point of reference against which to measure the impact of the hydrogen economy. While small fleets of hydrogen vehicles are operated as part of technology validation and other R&D projects and small quantities of hydrogen fuel are supplied, primarily from existing industrial gas production facilities, the base case assumes that there is no widespread demand for hydrogen fuel or vehicles. For purposes of analysis, the high oil price case in the Energy Information Administration's 2006 Annual Energy Outlook (AEO-06) was selected to represent such the future under the base case.¹³ This base, or high oil price, case reflects a continuation of recent demographic, economic and oil price trends.

¹² *Projected Benefits FY 2007*, *supra* note 4.

¹³ *Annual Energy Outlook 2006, with Projections to 2030*, U.S. Department of Energy, Energy Information Administration report DOE/EIA-0383(2006), Feb. 2006, accessed Aug.-Sept. 2006 at <http://www.eia.doe.gov/oiaf/aeo/aeohighprice.html>.

Table 2.1 shows the values and associated growth rates of selected economic and demographic parameters under the base case. Beyond 2030, energy prices and economic and demographic variables are based on trends from the Annual Energy Outlook, while fuel use is estimated using the VISION model (described in Appendix 1).¹⁴ Economic output rises at approximately 2.5% per year from 2005 to 2050. The population grows much less rapidly (at approximately 0.8% per year), while the number of light-duty vehicles and vehicular travel rise at 1.2% and 1.4% per year, respectively. Because of steady increases in the world oil price (which reaches over \$117 per barrel in 2050), conventional light-duty vehicles become more fuel-efficient and fuel use grows somewhat more slowly, at 1% per year.

Table 2.1: Key Economic and Demographic Features of the Base Case						
Parameter	2005	2020	2035	2050	Average % change/yr (2005-2050)	
Population (millions)	296.8	337.0	378.1	420.1	0.78%	
Employment (millions)	131.6	147.3	164.8	184.4	0.75%	
Driving age population (millions)	231.7	265.3	298.5	331.4	0.80%	
GDP (billions of 2005 \$)	12,566	19,693	29,249	38,342	2.48%	
Gasoline (2005 \$/gal)	2.38	3.01	3.38	3.56	0.90%	
Crude oil (2005 \$/bbl) ^a	55.93	85.06	104.50	117.27	1.65%	
Light-duty vehicles (millions)	223.4	286.6	339.1	386.6	1.22%	
Light-duty-vehicle fuel use	quads/yr ^b	16.0	19.9	23.6	25.6	1.04%
	billions of gallons of gasoline equivalent/yr	135.6	168.6	199.9	216.2	1.04%
^a Imported low-sulfur light crude oil; ^b 1 quad = 1 quadrillion Btu. Sources: Population, GDP, crude oil price, light-duty vehicles, travel and fuel use 2005-2030: <i>Annual Energy Outlook 2006, with Projections to 2030</i> , U.S. Department of Energy, Energy Information Administration report DOE/EIA-0383(2006), February 2006, accessed August-September 2006 at http://www.eia.doe.gov/oiaf/aeo/aeohighprice.html . Population, GDP, crude oil price 2030-2050: extrapolated from AEO-06 high price forecast. Employment: <i>Quarterly Census of Employment and Wages</i> , U.S. Department of Commerce, Bureau of Labor Statistics, accessed August-September 2006 at http://www.bls.doc.gov/cew/home.htm . Gasoline price: Adjusted from the AEO-06 high price forecast to reflect long-term relationships between crude oil and delivered gasoline prices and extrapolated to 2050.						

¹⁴ VISION 2006 AEO High Price Base Case, personal communications from A. Vyas, Argonne National Laboratory, recalibrated to AEO 2006 high price case from posted AEO 2006 base case, accessed August-September 2006 at <http://www.transportation.anl.gov/software/VISION/index.html>.

2.2 Hydrogen Use in the HFI Scenario

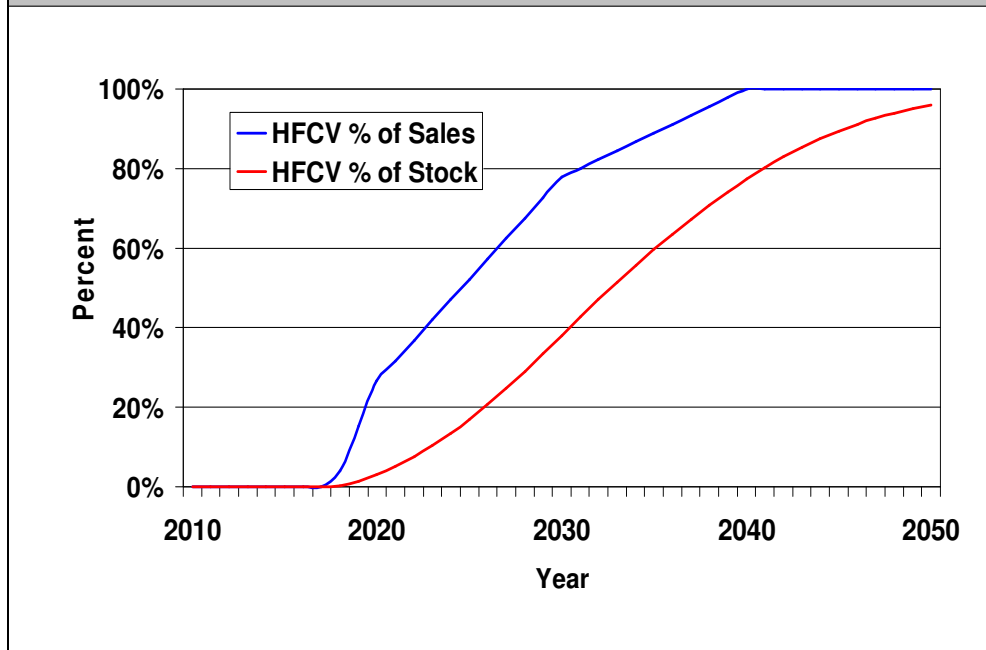
Compared with the base case in which hydrogen vehicles achieve no more than token market penetration, the HFI presents a vision of rapid market development.¹⁵ Following achievement of the program's technical targets for hydrogen, fuel cells and infrastructure technologies, hydrogen fuel cell vehicles are introduced to the general public around 2018. Hydrogen vehicle production increases rapidly, capturing all segments of the light-duty-vehicle market. As older, conventional vehicles are retired from use, nearly all light-duty vehicles are hydrogen-fueled by 2050, as shown in Figure 2.1.

Under the HFI Scenario, fuel infrastructure is installed in lock-step with the growing population of hydrogen-fueled vehicles, thereby providing both the supply chain for a growing hydrogen fuel industry and a push to propel ever-higher hydrogen vehicle sales. Initially, most hydrogen is produced on-site, in relatively small, "distributed" facilities or delivered to fueling stations from existing, large industrial plants. Though similar to gasoline stations in outward appearance, distributed facilities are more costly to build and maintain. Thus, as demand for hydrogen rises, fuel production shifts to centralized facilities that can better capture economies of scale. A mix of centralized hydrogen production technologies arises as different regions capitalize on local resources. Regions with nearby coal supplies and CO₂ sequestration sites opt for more coal gasification while those with ample wind or biomass favor hydrogen production technologies that rely more on those resources. From centralized production facilities, hydrogen is delivered to local fuel stations where it is dispensed along with conventional motor fuels. As demand increases, delivery technologies shift from primarily tanker trucks carrying cryogenic liquid hydrogen to a mix of trucks carrying cold compressed hydrogen in insulated high-pressure tanks, and, beginning between 2020 and 2035, gas pipelines. By 2050, when hydrogen has replaced nearly all motor gasoline, most local fuel stations no longer dispense gasoline.

The development of an on-board hydrogen storage technology for hydrogen-powered vehicles has implications for the hydrogen delivery infrastructure. Currently, compressed hydrogen storage is the dominant approach for on-board hydrogen storage, with most systems using 5,000 psi composite tanks. Next generation systems, which have started to appear in demonstrations use higher pressure 10,000 psi tanks.

¹⁵ *Hydrogen Posture Plan*, U.S. Department of Energy report, February 2004, accessed August-September 2006 at http://www1.eere.energy.gov/hydrogenandfuelcells/posture_plan04.html.

Figure 2.1: Hydrogen Fuel Cell Vehicles (HFCVs) as a Percent of Light-Duty Vehicles Sold and Total Light-Duty Vehicle Stock in the President's Initiative



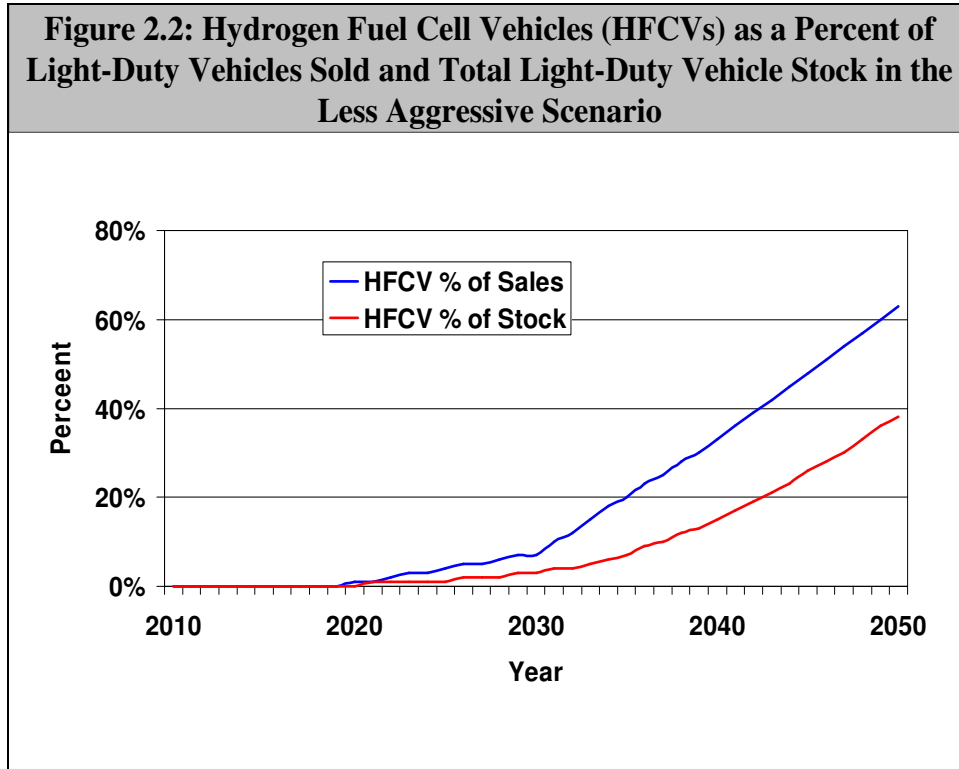
Sources *Hydrogen Posture Plan*, U.S. Department of Energy report, February 2004, August-September 2006 at <http://www1.eere.energy.gov> (for sales data); Stock data were simulated by the VISION model, calibrated to reflect parameters of AEO 2006 high price case.

Consequently, under the HFI Scenario, stations will need high-pressure compressors and delivery systems. The HFI Scenario also reflects the fact that, even today, two other general storage approaches are being investigated: solid-state and chemical hydrogen storage systems. Solid-state on-board storage encompasses complex metal hydrides and carbon-based materials. The infrastructure for solid-state storage will likely have somewhat lower pressurization requirements, but will probably require additional thermal management systems to cool the solid-state material and on-board storage system (and potentially the hydrogen fuel itself) during the fill process. A third approach to on-board storage includes chemical hydrogen (e.g., chemical hydrides, hydrocarbon compounds) that will have to be regenerated off-board. Off-board regeneration has significant infrastructure implications involving return of the spent material to central facilities and the energy needed for regeneration. The current study assumes compressed hydrogen storage on the vehicle only.

For the HFI Scenario, it is assumed that by 2050, 55% of all hydrogen is produced from coal with carbon sequestration, 20% from biomass, 15% from wind, and 10% from nuclear processes. These are estimated national averages. The mix for individual regions (and indeed for individual states and localities within regions) is likely to vary considerably.

2.3 Hydrogen Use in the Less Aggressive Scenario

The Less Aggressive Scenario represents a future midway between the optimism of the HFI Scenario and the status quo of the base case.¹⁶ Like the HFI, the Less Aggressive Scenario superimposes a set of hydrogen fuel cell market penetration assumptions on the economic and demographic features of the base case. However, unlike the HFI Scenario, hydrogen vehicles come on the market somewhat later in the Less Aggressive Scenario and, amid stiff competition from hybrids, plug-ins, flex-fuel vehicles, and advanced conventional vehicles, gain market share at a slower pace, as shown in Figure 2.2.



Sources: sales: *FY 2007 Benefits Estimates*, U.S. Department of Energy accessed August-September 2006 at http://www1.eere.energy.gov/ba/pba/2007_benefits.html; Stock: calculated by VISION model, calibrated to reflect parameters of AEO 2006 high price case.

Though hydrogen technologies are slower to gain acceptance under the Less Aggressive Scenario than the HFI Scenario, demand nevertheless grows quickly under the Less Aggressive Scenario relative to historic standards. Thus, the same shift from distributed to centralized hydrogen production and the same mix of delivery technologies in 2020, 2035 and 2050 as in the HFI Scenario are assumed.

¹⁶ Projected Benefits FY2007, supra note 4.

2.4 Hydrogen Vehicles

Table 2.2 summarizes the fuel cell and hydrogen storage cost targets of the DOE Hydrogen Program.¹⁷ Both the HFI and Less Aggressive Scenarios assume achievement of all targets. The resulting fuel cell vehicle costs roughly the same as the gasoline-fueled vehicle. Achievement of the targets also results in a fuel cost comparable to a gasoline vehicle on a \$/mile-traveled basis.

Table 2.2: Selected Fuel Cell Vehicle Cost Targets (2005 Prices)			
Component	Unit	2004 Status	2015 Target
Fuel cell stack ^a	\$/kW _e	75	20
Fuel cell system ^a	\$/kW _e	120	30
On-board storage system	\$/kWh net	>6	2
^a Based on high volume (500,000 stacks per year). Source: U.S. Department of Energy, <i>Hydrogen, Fuel Cells & Infrastructure Technologies Program, Multi-Year Research, Development and Demonstration Plan</i> , February 2005, accessed September 2006 at http://www1.eere.energy.gov/hydrogenandfuelcells/mypp .			

In all scenarios, sales and stock of light-duty vehicles grow, and the stock of all light-duty vehicles grows faster than population grows. As a result, the number of vehicles per person and the number per driving-age person continue to rise (from 0.75 to 0.92 vehicles per capita and from 0.96 to 1.17 vehicles per driving-age population). Saturation (i.e., ratios approaching some natural limit) does not occur in these ratios, as indeed it has not occurred with respect to vehicles per household or vehicles per licensed driver. With expanding sales of total light-duty vehicles, the market penetration rates of the two hydrogen scenarios result in significant numbers of hydrogen vehicles on the road by 2030.

2.4.1 Hydrogen Vehicles in the HFI Scenario

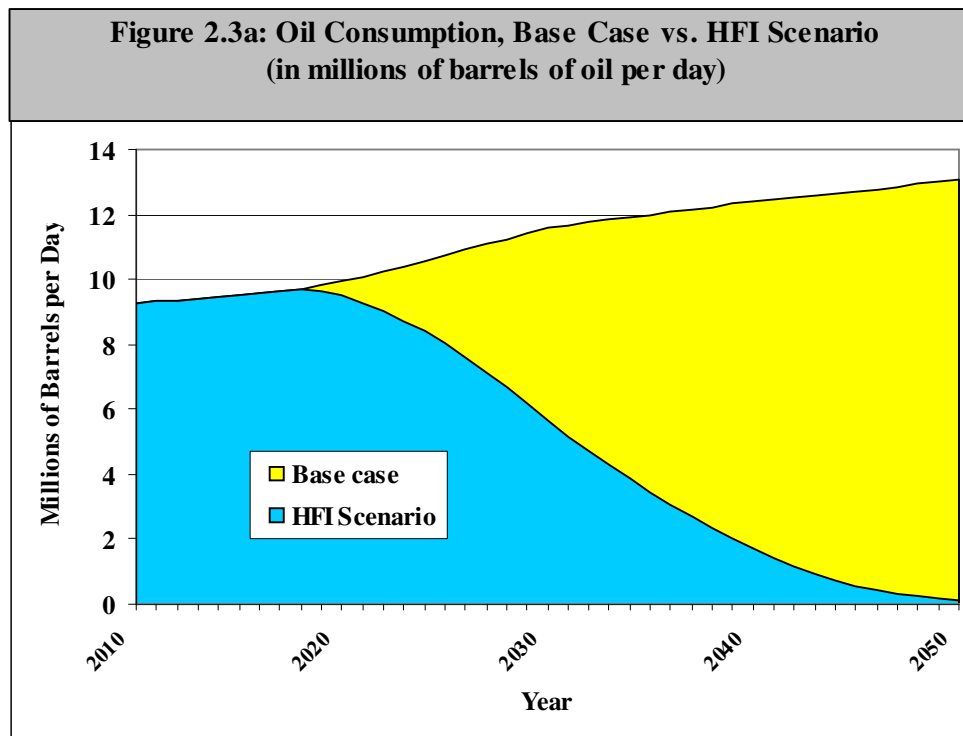
In this report, the market penetration assumptions of the HFI Scenario (Figure 2.1) were selected as the upper bound or most aggressive market penetration scenario. As shown in Table 2.3, hydrogen fuel cell vehicles account for 27% of new sales and 3% of light-duty vehicles on the road in 2020, 89% of sales and 60% of vehicles on the road in 2035, and all light-duty-vehicle sales and 96% of the light-duty vehicle stock by 2050. This translates into nearly 24 million vehicles sold and nearly 350 million hydrogen vehicles on the road in 2050.

¹⁷ U.S. Department of Energy, *Hydrogen, Fuel Cells & Infrastructure Technologies Program, Multi-Year Research, Development and Demonstration Plan*, February 2005, accessed September 2006 at <http://www1.eere.energy.gov/hydrogenandfuelcells/mypp>.

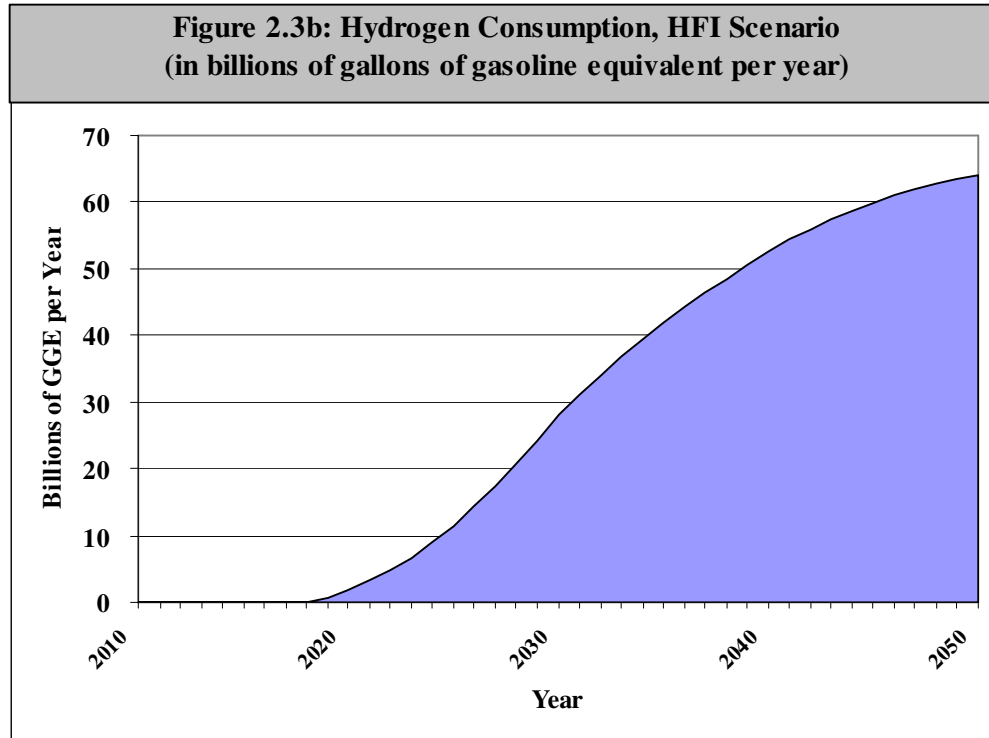
Table 2.3: Hydrogen Fuel Cell Vehicles in the HFI Scenario				
Year		2020	2035	2050
Sales	millions of light-duty vehicles sold/yr	4.9	19.5	23.9
Stock	millions of light-duty vehicles in use	8.8	197.5	347.5
	% of all light-duty vehicles sold	26.6%	88.9%	100%
Hydrogen fuel use	% of all light-duty vehicles in use	3.1%	59.6%	96.0%
	quads/yr ^a	0.22	5.24	8.02
	billion gge/yr ^b	1.8	41.9	64.1

^a1 quad = 1 quadrillion Btu; ^bgge = gallons of gasoline equivalent.
Source: Calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the HFI.

Figure 2.3a and 2.3b display the distribution of fuel use by light-duty vehicles under the HFI Scenario. As the stock of conventional vehicles is displaced by fuel cell vehicles, gasoline consumption declines. Total fuel use also declines as a result of the increased fuel efficiency of hydrogen fuel cell vehicles relative to conventional vehicles. Estimates of the production cost of light-duty hydrogen fuel cell vehicles are reported in Appendix 3.



Source: calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the HFI.



Source: calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the HFI.

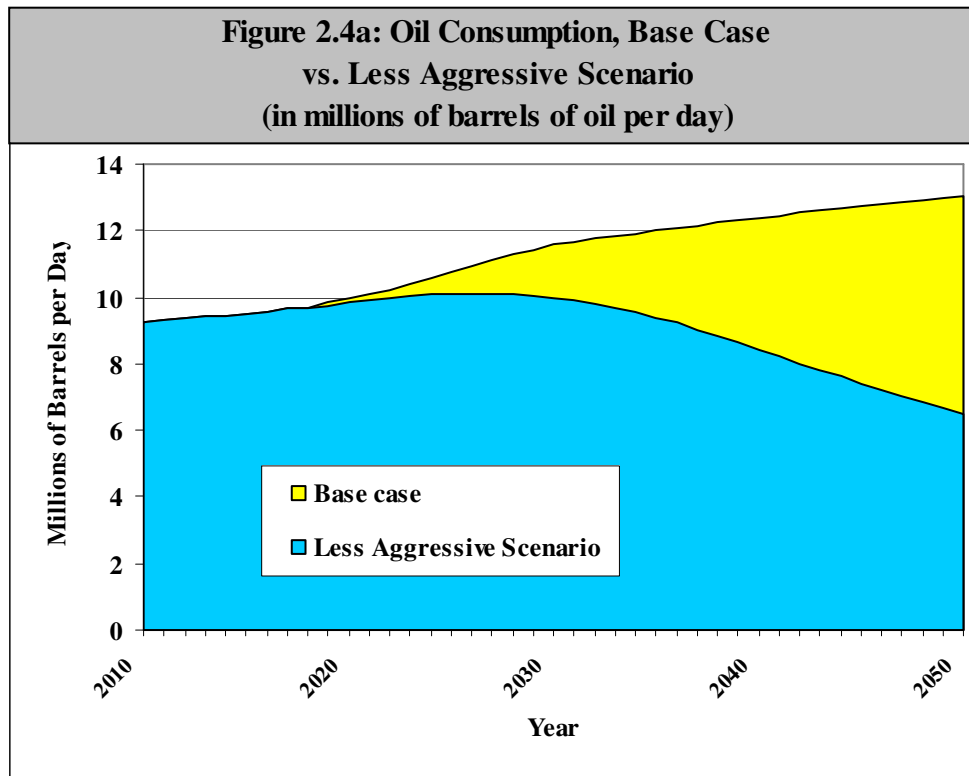
2.4.2 Hydrogen Vehicles in the Less Aggressive Scenario

Figure 2.2 illustrates the hydrogen fuel-cell-vehicle market penetration assumptions and the resulting shares of total light-duty vehicles in the Less Aggressive Scenario. Compared with the HFI Scenario (in which hydrogen vehicles gain complete market dominance by 2050), hydrogen vehicles capture 63% of sales and represent 38% of light-duty vehicles in use in the Less Aggressive Scenario. As shown in Table 2.4, these shares represent the sale of 15 million hydrogen vehicles and 144 million hydrogen vehicles on the road in 2050. The 144 million hydrogen vehicles on the road are expected to consume approximately 3.7 quads (3.7 quadrillion Btu) of hydrogen fuel per year. Given the vehicle and fuel economy assumptions of the Less Aggressive Scenario, hydrogen vehicles displace 11.9 quads of oil (nearly 6.6 million bbls/day) in 2050 under the Less Aggressive Scenario.

Year		2020	2035	2050
Sales	millions of light-duty vehicles sold/yr	0.2	4.4	15.1
	% of all light-duty vehicles sold	0.8%	20.1%	63%
Stock	millions of light-duty vehicles in use	1.4	25.3	144
	% of all light-duty vehicles in use	0.5%	7.5%	38.2%
Hydrogen fuel use	quads/yr	0.04	0.70	3.73

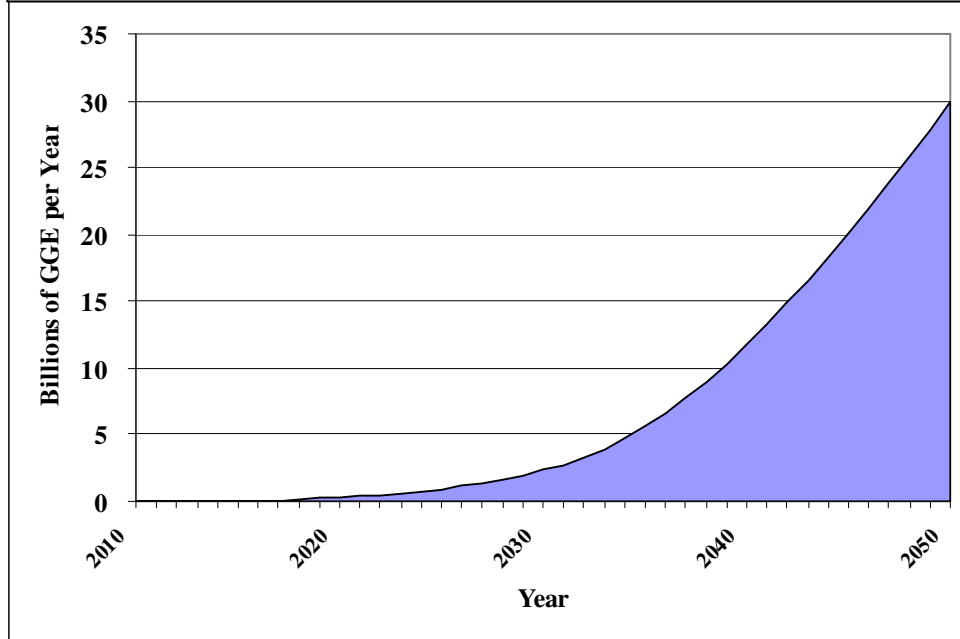
Table 2.4: Hydrogen Fuel Cell Vehicles in the Less Aggressive Scenario				
Year		2020	2035	2050
	billion gge/yr ^a	0.32	5.59	29.95
^a gge = gallons of gasoline equivalent. Source: Calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the Less Aggressive scenario.				

As shown in Figure 2.4a and 2.4b, hydrogen’s share of light-duty vehicle energy use is substantially lower in the Less Aggressive Scenario than in the HFI Scenario. Not only is there less hydrogen fuel use (due to fewer fuel cell vehicles in operation by 2050), but total energy use is substantially higher under the Less Aggressive Scenario. The latter is due to a combination of more conventional vehicles on the road and the relatively lower fuel economy of those vehicles, compared with hydrogen vehicles.



Source: calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the Less Aggressive scenario.

**Figure 2.4b: Hydrogen Consumption, Less Aggressive Scenario
(in billions of gallons of gasoline equivalent per year)**



Source: calculated by VISION model using AEO 2006 high price calibration and market penetration assumptions of the Less Aggressive scenario.

2.5 Other Transportation Markets

This report focuses on light-duty vehicles since fuel substitution in this market will have the greatest impact on reducing oil consumption in the transportation sector. However, hydrogen fuel cell technologies will likely have applications beyond the light-duty fleet. For example, transit and school buses are important potential markets. Transit buses are a relatively small market with high utilization and turnover. School buses are a larger market, but with relatively low utilization and slow turnover. Together, these markets could add 1% to the total value of light-duty vehicle sales in 2050.

2.6 Stationary Fuel Cells

In both hydrogen adoption scenarios, stationary fuel cells initially provide power, including back-up power, for remote locations not easily served by the electric power transmission and distribution grid. Following success in these markets, fuel cells begin to penetrate markets for portable power, then markets for all types of distributed power. For back-up and remote power markets, users are willing to pay a premium for secure, reliable electricity. Such markets include hospitals, hotels, data centers, and computer facilities, where uninterrupted power is critical. While these initial markets provide the sales volumes to launch the industry, the fuel cells themselves operate relatively few hours per year and displace little grid electricity.

Portable power is a likely follow-on market for fuel cells. Fuel cells are being eyed for a wide array of portable applications ranging from consumer electronics to small-scale power production. Portable electronics (e.g., cell phones and notebook computers) utilizing premium lithium-ion and nickel metal-hydride batteries are particularly promising candidates for substitution by fuel cells. Premium batteries are popular because of their high energy density. As portable devices become more complex and their power requirements increase, fuel cells become an increasingly promising alternative.

Since 2002, the number of devices containing premium batteries that the average American carries has grown 10% annually, to 0.5 devices per person.¹⁸ As the variety and functionality of portable consumer electronics grow, each person will carry increasingly multi-functional devices. While this will increase the demand for portable power, it may not increase the total number of devices beyond some natural limit of perhaps 1 device per person on average. Assuming the base-case population forecast of 420 million, some 400 million portable fuel cells could be in use in 2050.

As fuel cells penetrate the portable power market and enter the broad residential and commercial power market, electricity displacement becomes substantial. Like fuel cells for mobile applications, stationary fuel cells are assumed to meet program cost and performance targets. In this study, stationary fuel cells are assumed to be natural gas fueled, where the fuel cell system includes an integrated reformer to produce the hydrogen.

2.6.1 Stationary Fuel Cells in the HFI Scenario

In the HFI Scenario, stationary fuel cells are assumed to achieve 1% penetration of “new” electric demand in 2020, 5% in 2035, and 10% in 2050.¹⁹ “New” demand is defined as the difference between electricity demand in 2015 and the analysis year (2020, 2035 or 2050), and is meant to include a variety of markets – back-up power, portable power and the broader market for residential and commercial power – which increasingly shift to fuel cells. Penetration by fuel cells results in displacement of 0.01 quad of grid electricity in 2020, 0.3 quads in 2035, and slightly over 1 quad in 2050.

2.6.2 Stationary Fuel Cells in the Less Aggressive Scenario

As in the HFI Scenario, stationary fuel cells are assumed to first penetrate remote and back-up power markets, followed by portable power and the broad market for residential and commercial electricity. Large-scale deployment is assumed to begin in 2020 and to proceed at roughly half the rate that applied in the HFI Scenario. Thus, stationary fuel cells achieve 2% penetration of new electric demand in 2035 and 5% in 2050, thereby displacing approximately 0.1 quad of electricity in 2035 and 0.5 quads in 2050. As in the HFI Scenario, program cost and performance targets are assumed to be met.

¹⁸ Darnell Group, *Fuel Cells for Portable Power: Markets, Manufacturer and Cost*, January 13, 2003.

¹⁹ U.S. DOE, Energy Information Administration, *Annual Energy Outlook 2005*, Table 8.8.

2.7 Hydrogen Production and Delivery in the Two Hydrogen Adoption Scenarios

In addition to employment generated (or displaced) by hydrogen vehicles replacing conventional vehicles and by fuel cells replacing stationary power, the infrastructure to produce and distribute hydrogen will be an important source of employment impacts. To model these impacts *vis-à-vis* the base case, candidate production and delivery technologies were identified and characterized in sufficient detail to provide estimates of (1) the size and number of facilities required to supply a given quantity of hydrogen fuel, (2) when those facilities might become widely available, (3) required feedstock and other inputs (including necessary expansion of feedstock transportation and other supply chain infrastructure), and (4) capital and operating costs. These costs were then used to characterize new industries in the IMPLAN model.

The following production technologies were included in the analysis:

- Distributed reforming of natural gas
- Centralized reforming of natural gas, with carbon capture and sequestration²⁰
- Distributed electrolysis
- Coal gasification, with carbon capture and sequestration
- Centralized biomass gasification
- Nuclear electrolysis
- Nuclear thermo-chemical water splitting
- Centralized wind electrolysis

Although most of these technologies could be of several designs, a single representative design was characterized for each. The H2A model, a tool developed by DOE with industry assistance, was used for this purpose.²¹ Further detail on that tool and key parameters assumed in the analysis are contained in Appendix 1.

As stated above, the same shift from distributed to centralized production and the same mix of hydrogen production and delivery technologies are assumed for the HFI and the Less Aggressive Scenarios. Tables 2.5-2.7 list the production technologies included in these scenarios, along with the number of plants required for each scenario for the three analysis years. Estimates of the capital, construction, and operating costs of these facilities are reported in Appendix 2.

Similarly, delivery technologies were characterized at a level of detail sufficient to produce estimates of total fixed and variable costs under the two hydrogen scenarios. As with production technologies, delivery technologies were characterized using a DOE-developed H2A tool.²²

²⁰ Although this technology is available for hydrogen production, it is not being pursued in DOE's R&D program.

²¹ *H2A Production Analysis*, U.S. Department of Energy, Central and distributed production analysis tools accessed August-September 2006 at http://www.hydrogen.energy.gov/h2a_production.html.

²² *H2A Delivery Analysis*, U.S. Department of Energy, accessed August – September 2006 at http://www.hydrogen.energy.gov/h2a_delivery.html.

Table 2.8 lists the delivery technologies included in this analysis and the shares of total production served by each. Totals add to the share of hydrogen produced in central plants, not 100%; production at local refueling stations (“distributed production”) accounts for the remainder.

Table 2.5: Unit Size, Number of Units and Percent Hydrogen Production by Technology and Scenario – 2020				
Hydrogen Production Technology	Unit size (T/d)^a	% of Hydrogen Produced^b	Units in HFI^b	Units in Less Aggressive Scenario^b
Distributed reforming of natural gas	1.5	30%	1,319	235
Distributed electrolysis	1.5	10%	440	79
Wind electrolysis	86	5%	3	1
Nuclear electrolysis	719	0%	0	0
Central reforming of natural gas	380	20%	3	1
Biomass gasification	164	10%	4	1
Coal gasification	246	25%	5	1
Nuclear thermochemical	768	0	0	0
^a Metric tons/day.				
^b Production shares and number of units are estimated from hydrogen demand under each scenario and facility construction schedules.				

Table 2.6: Unit Size, Number of Units and Percent Hydrogen Production by Technology and Scenario – 2035				
Hydrogen Production Technology	Unit size (T/d)^a	% of Hydrogen Produced^b	Units in HFI^b	Units in Less Aggressive Scenario^b
Distributed reforming of natural gas	1.5	2%	2,073	277
Distributed electrolysis	1.5	1%	1,036	139
Wind electrolysis	86	15%	156	22
Nuclear electrolysis	719	7%	14	2
Central reforming of natural gas	380	1%	4	1
Biomass gasification	164	19%	156	21
Coal gasification	246	50%	224	30
Nuclear thermochemical	768	5%	9	2
^a Metric tons/day.				
^b Production shares and number of units are estimated from hydrogen demand under each scenario and facility construction schedules.				

Hydrogen Production Technology	Unit size (T/d)^a	% of Hydrogen Produced^b	Units in HFI^b	Units in Less Aggressive Scenario^b
Distributed reforming of natural gas	1.5	1%	1,586	741
Distributed electrolysis	1.5	0.5%	794	370
Wind electrolysis	86	15%	243	114
Nuclear electrolysis	719	4.5%	13	7
Central reforming of natural gas	380	0.5%	4	2
Biomass gasification	164	20%	251	118
Coal gasification	246	53%	363	170
Nuclear thermochemical	768	5.5%	14	7

^a Metric tons/day.
^b Production shares and number of units are estimated from hydrogen demand under each scenario and facility construction schedules.

Share by Delivery Mode (%)	2020	2035	2050
Pipeline	0	55	70
Compressed gas truck	25	24	17
Cryogenic liquid truck	35	18	11.5
Total delivered	55	97	98.5
Distributed production	43	3	1.5

^a Estimated as a function of hydrogen demand and infrastructure construction schedules.

As with hydrogen production, hydrogen distribution can be accomplished by various technologies. For this analysis, distribution (i.e., delivery) is assumed to occur via liquid or compressed gas truck or gas pipeline. These alternatives represent relatively mature technologies for which cost models have been developed and a considerable body of analysis has been completed. The delivery cost models were developed as part of the H2A project to be consistent in form and approach to the production cost models mentioned above. Both sets of H2A models (delivery and production) are discussed in Appendix 2. Research and development are continuing on other delivery technologies that ultimately may be less costly to implement and more efficient to operate and maintain than those assumed in this report. These technologies include hydrogen carriers, adsorbing materials and other novel processes, any or all of which could play an important role in hydrogen delivery. As with the choice of production technologies, determining the most realistic mix of future delivery options is a

study in and of itself and will depend heavily on research and development accomplishments in the coming years.

3.0 EMPLOYMENT CREATION AND REPLACEMENT AT THE NATIONAL LEVEL

3.1 Modeling the U.S. Economy

3.1.1 The IMPLAN Inter-Industry Model

Transactions between many industries are required in the production of the equipment used in transportation, as well as in providing the fuels that are the source of the energy. These transactions spread throughout the economy as the directly affected industries alter their transactions with other industries with which they deal, which in turn affect still other industries. These effects can be estimated using input-output modeling, which is described in detail in Appendix 4. As discussed previously, the present report estimates, the employment impacts of the transformation to a hydrogen economy with the use of a 509 industrial sector IMPLAN, input-output model of the U.S. economy, a 509-sector input-output model of the U.S. economy in 2002.²³ The IMPLAN model is run for an essentially all-gasoline economy and for the two market penetration scenarios of a hydrogen economy described in section 2. The employment impacts of the transformation of the economy to hydrogen are the differences in employment in various industries between the with- and without-hydrogen cases.

3.1.2 Future of the U.S. Economy in the Absence of a Hydrogen Transformation

The industries likely to be affected directly by the market expansion of hydrogen between 2020 and 2050 employed 3.3%, or 4.4 million, of the total U.S. employment of 132 million in 2005. Employment in the light vehicle manufacturing industries has decreased in the past decade, with the losses concentrated in assembly and components, while employment in vehicle sales, maintenance, and repair increased. Employment in petroleum refining has been falling in the past decade, as that industry has become more capital intensive.²⁴ In the base case, employment in these industries continues to evolve without the changes brought about by hydrogen market expansion.

Using the IMPLAN model, a base case for the U.S. economy was estimated. The base case depicts changes in the U.S. economy that are expected to occur in coming decades in the absence of a hydrogen transformation. The base case relies on reputable projections that

²³ Minnesota IMPLAN Group, Inc., *IMPLAN Professional, Version 2.0, Social Accounting & Impact Analysis Software, User Guide, and Data Guide*, 3rd Edition Stillwater, Minn., February 2004. IMPLAN is a static economic model, in so far as it does not contain models of investment and labor supply responses. However, in light of the relative magnitude of hydrogen investments and the lack of detailed knowledge regarding the timing of hydrogen-related actions 25 to 45 years in the future, a static model is satisfactory for the purposes of this analysis. Since IMPLAN is a national rather than an international model, the investigation of international competition relies on other models.

²⁴ Bureau of Labor Statistics, Quarterly Census of Employment and Wages (QCEW), accessed August – September 2006 at <http://www.bls.gov/cew/home.htm>.

have been done by others. It corresponds closely to projections by Regional Economic Models, Inc. (REMI).²⁵ The REMI model and its projections have been widely used for policy impact analysis by more than 50 federal and state agencies, as well as by many private firms and universities.²⁶ However, REMI has only 70 sectors and IMPLAN allows a user to develop a model using 509 sectors and also permits the user to modify the model's internal tables which characterize the structure of production, which was of central importance to this study. Both of these features rendered IMPLAN more suitable for the employment analysis of this report.

3.1.3 Modification of IMPLAN for Hydrogen Economy Scenarios

The unmodified version of IMPLAN used for the base case is satisfactory for modeling the future in the absence of a hydrogen transformation. However, no existing input-output model allows for widespread hydrogen adoption. Businesses that provide hydrogen-powered vehicles, stationary and mobile equipment, hydrogen infrastructure and hydrogen fuel are embedded in non-hydrogen sectors.

To remedy this limitation, the IMPLAN model was reconfigured for the present analysis for use in the hydrogen economy simulations. In particular, to characterize the changes in production caused by the market transformation to hydrogen, the purchase patterns of motor vehicle assembly, motor vehicle parts manufacturing, and industrial gases were modified with information derived from the cost data reported in Appendices 2 and 3. The procedures are reported in Appendix 4. In addition to characterize the changes in infrastructure required to produce and deliver the new products—vehicles and fuel—the industry composition of investment was altered to represent additional purchases from industries manufacturing equipment installed in these facilities as well as purchases from the construction sectors that assemble them. These changes are also reported in detail in Appendix 4.

3.2 Net Effects on Total U.S. Employment

Table 3.1 shows cumulative effects on U.S. employment in 2020, 2035 and 2050 resulting from the HFI and the Less Aggressive Scenarios, as calculated using the modeling procedures described in the preceding section. Base-case employment for each of the 509 industry sectors was subtracted from employment under each of the hydrogen adoption scenarios to obtain changes in sector employment resulting from the scenario. The results were summed to obtain Table 3.1. The net effect is the effect on total number of people at work in the U.S. economy resulting from gains in some industries and losses in others due to the hydrogen transformation. The top of the table gives numbers of workers affected. The bottom of the table gives the numbers as a percent of total U.S. employment.

²⁵ Regional Economic Models, Inc., *Policy Insight Model Version 8.0* (Amherst, Mass., Spring 2006); documentation of all elements utilized in the REMI forecasts are contained in Regional Economic Models, Inc., *Model Documentation: REMI Policy Insights Version 8.0* (Amherst, Mass., 2006), pp. 51-71. REMI forecasts of component demands are tied to Bureau of Labor Statistics 10-year forecasts of the national input-output matrix, published in Berman, J.M., "Industry Output and Employment Projections to 2012," *Monthly Labor Review* 127, No. 2 (February 2006), 58-79.

²⁶ Accessed August – September 2006 at <http://www.remi.com/support/clients.shtml>.

Table 3.1: U.S. Cumulative Gains and Losses from Shifts of Employment between Sectors^a				
Scenario		2020	2035	2050
Numbers of Workers				
HFI	Net Effect	182,840	677,070	674,500
	Gains	252,040	754,030	751,060
	Losses	69,200	76,960	76,560
Less Aggressive	Net Effect	58,010	184,560	360,740
	Gains	126,680	242,820	417,390
	Losses	68,670	58,260	56,650
Percentage Effects on Total Employment				
HFI	Net Effect	0.13%	0.42%	0.37%
	Gains	0.17%	0.46%	0.41%
	Losses	0.05%	0.05%	0.04%
Less Aggressive	Net Effect	0.04%	0.11%	0.20%
	Gains	0.09%	0.15%	0.23%
	Losses	0.05%	0.04%	0.03%
^a All numbers represent differences between the hydrogen scenario and the baseline. For example, there are 182,840 more workers in all sectors in 2020 according to the HFI Scenario than there would have been in 2020 according to the baseline scenario.				

Under both the HFI and the Less Aggressive Scenarios, the net effect on U.S. employment is a slight increase to 2020, by 0.13% under the HFI Scenario and by 0.04% under the Less Aggressive Scenario. Growth of jobs in the production of hydrogen vehicles and other hydrogen-using equipment will be offset by job declines in traditional activities. Investments to create the capital goods needed in producing the equipment may have some jobs effects but that impact is likely to be negligible. Depreciation of equipment used in traditional production accompanied by its gradual replacement with hydrogen economy equipment is likely to take care of much, but not all, new investments needed by 2020, without net job creation in connection with the new investments. For some types of equipment, anticipatory investment in new infrastructure and production facilities, in preparation for expected near-term demand increases beyond 2020, can be expected to increase jobs in both construction and durable goods manufacture. The new job effects become greater in the years following 2020, due to the later more rapid pace of market expansion. By 2035, the net effect on U.S. employment is increased by 0.42% under the HFI Scenario and by 0.11% under the Less Aggressive Scenario. By 2050, under the HFI Scenario, the transformational adjustments are fully completed, with no more anticipatory investment; U.S. employment is increased by a net of 0.37%, or 675,000 jobs out of a total projected base-case employment of 184 million. Under the Less Aggressive scenario, the transformation is not fully completed by 2050 and

U.S. employment is increased by a net of 0.20%, or 361,000. The difference in employment between the HFI Scenario and the base case, in 2050, is equivalent to roughly half of a year's growth of the total U.S. employment of 1.38 million, occurring at that time.

The maximum net effect in Table 3.1 is less than ½ of 1% of U.S. employment. Table 3.1 reports cumulative impacts occurring over a period of years. The annual changes leading to the cumulative impacts would be even smaller. The smallness of the impacts indicates that significant macroeconomic effects, such as large-scale unemployment or inflation, will not occur.

3.3 Job Creation and Replacement

3.3.1 Employment Shifts between Gaining and Losing Industries

Underlying the percentage changes in total numbers of people employed in the U.S. will be changes in how the work force is deployed among industries. New jobs will be created in hydrogen-related manufacturing and services industries, and these new jobs will replace jobs in non-hydrogen-related manufacturing and services industries. The IMPLAN model simulations shed partial light on job creation and replacement effects by indicating how employment will expand in some industries and contract in others.

The shifts of employment between sectors are very small as a percent of total U.S. employment. Employment shifts many-fold greater than those in Table 3.1 occur continually in the U.S. economy for reasons apart from hydrogen. Among the reasons are shifts in consumer demands for various products, industrial technological changes connected with diverse developments that occur in a growing economy, effects of environmental and other regulations, and global economic changes affecting the U.S. As with the net U.S. employment effects, the aggregate effects of job gains and losses from employment shifts between industries due to hydrogen transformation are too small to raise macroeconomic concerns.

3.3.2 Job Creation and Replacement within Key Industries

The IMPLAN sector employment changes in Table 3.1 do not take account of changes in the composition of employment within sectors. Within sectors that are key to hydrogen systems, demands for skills in hydrogen-related production will increase, and demands for skills in traditional production will decrease.

For example, within automotive sectors, in switching from producing gasoline-powered to hydrogen-powered vehicles, skills used in hydrogen-oriented production will experience increased demand, while skills used in non-hydrogen-oriented production will become outmoded. While automobile assembly primarily entails a switch from producing one kind of vehicle to another with no expected effect on labor productivity in the sector and hence no effect on employment in the sector, a part of the sector's employment is subject to skill change. Even though much assembly may continue as is, some specialized assembly tasks are likely to be required for fuel cells and new types of powertrains requiring new blue collar

skills. At the engineering level, not as many mechanical and other engineers will be needed, but electrical, electronics and chemical engineers will be in greater demand. As another example, in the auto repair sector the total number of service technicians is not estimated to be greatly affected by the switch to hydrogen. However, service technicians in the future will need to have expertise to service hydrogen fuel cell vehicles. As the transformation progresses, service technicians who only service internal combustion vehicles will find their skills in reduced demand if they are unable also to service hydrogen vehicles. Ultimately, substantial turnover in skills will be required. Experience with hybrid vehicle technologies will form the basis for many of these skill changes.

The foregoing examples are for sectors where employment is not much affected, but skill composition changes are large. As a contrasting case, industrial gas manufacturing, with its large increase in hydrogen production, will undergo large employment changes due to industry demand growth even though the skill composition within the industry does not change much. The fuel cells and batteries sector experiences a similar change driven by demand growth. The employment changes for these sectors are fully included in the employment shifts between industries in Table 3.1. While small as part of the national effect, the employment changes for key hydrogen sectors may be important for considering education, training and re-training needs in these sectors.

Table 3.2 (white collar workers) and Table 3.3 (blue collar workers) present estimates of cumulative job creation and job replacement within several industrial sectors that will be key to the expansion of hydrogen markets. “Job creation” connected with changes in skill composition within an industry is defined as the addition of a job whose skill requirements cannot be met by workers with the skills of presently employed workers without outside re-tooling of skills. “Job replacement” is the loss of a job of a worker who is not qualified to fill a newly created job vacancy without such training. Tables 3.2 and 3.3 pertain to a part of the employment in a sector, either white collar or blue collar, and are congruent with the total sector employment changes from the IMPLAN model. The job creation and job replacement figures within sectors shown in Tables 3.2 and 3.3 are medium term estimates based on opinions of people with first-hand knowledge of the industries and on analysis of data on occupational breakdowns of employment in each industry from the Bureau of Labor Statistics (BLS).²⁷ The occupational breakdown is very detailed, with figures for over 200 occupations in some industries. Appendix 5 contains a complete description of how the occupational and IMPLAN modeling results were used to produce the estimates of creation and replacement by occupation shown in Tables 3.2 and 3.3.

²⁷ Bureau of Labor Statistics (BLS), Occupational Employment Statistics, data as of May 2005, accessed August-September 2006 at http://data.bls.gov/oes/search.jsp?data_tools=OES.

Table 3.2: Cumulative White Collar Job Creation and Replacement within Sectors^a

Industry	HFI			Less Aggressive		
	2020	2035	2050	2020	2035	2050
Auto Assembly						
Net Change	-	-	-	-	-	-
Creation	580	1,770	1,840	20	300	1,100
Replacement	580	1,770	1,840	20	300	1,100
Auto Body Mfg						
Net Change	-	-	-	-	-	-
Creation	100	330	360	5	60	210
Replacement	100	330	360	5	60	210
Auto Parts Mfg, incl. Fuel Cells						
Net Change	-	-	-	-	-	-
Creation	3,220	10,640	12,060	100	1,780	7,240
Replacement	3,220	10,640	12,060	100	1,780	7,240
Hydrogen Production						
Net Change	600	8,510	10,050	120	1,100	4,070
Creation	600	8,510	10,050	120	1,100	4,070
Replacement	0	0	0	0	0	0
Refining						
Net Change	-30	-370	-400	-10	-100	-210
Creation	0	0	0	0	0	0
Replacement	30	370	400	10	100	210
Construction						
Net Change	1,550	1,470	1,340	1,040	980	900
Creation	1,790	15,250	25,940	1,040	2,280	15,540
Replacement	240	13,780	24,600	0	1,300	14,640

^aAll numbers are cumulative full-time equivalent jobs (FTEs) from 2018. Job replacement is the elimination of jobs, and net change is creation minus replacement. For example, there are 8,510 more white collar jobs in the hydrogen production sector in 2035 under the HFI than there would have been under the baseline scenario. Those jobs are created starting in 2018, meaning the 600 jobs created in that sector from 2018 to 2020 are included in the 8,510.

Table 3.3: Cumulative Blue Collar Job Creation and Replacement within Sectors^a

Industry	HFI			Less Aggressive		
	2020	2035	2050	2020	2035	2050
Auto Assembly						
Net Change	-	-	-	-	-	-
Creation	3,150	9,580	9,950	100	1,610	5,970
Replacement	3,150	9,580	9,950	100	1,610	5,970
Auto Body Mfg						
Net Change	-	-	-	-	-	-
Creation	1,560	4,970	5,440	50	830	3,270
Replacement	1,560	4,970	5,440	50	830	3,270
Auto Parts Mfg, incl. Fuel Cells						
Net Change	-	-	-	-	-	-
Creation	31,280	103,560	117,360	940	17,360	70,410
Replacement	31,280	103,560	117,360	940	17,360	70,410
Auto Dealerships & Repair						
Net Change	-	-	-	-	-	-
Creation	25,130	435,770	681,730	760	50,510	409,040
Replacement	25,130	435,770	681,730	760	50,510	409,040
Hydrogen Production						
Net Change	2,450	34,550	40,780	480	4,480	16,540
Creation	2,450	34,550	40,780	480	4,480	16,540
Replacement	0	0	0	0	0	0
Refining						
Net Change	-180	-2,300	-2,480	-40	-650	-1,290
Creation	0	0	0	0	0	0
Replacement	180	2,300	2,480	40	650	1,290
Construction						
Net Change	3,880	3,700	3,360	2,600	2,470	2,250
Creation	5,460	50,180	85,670	2,600	7,430	51,460
Replacement	1,580	46,480	82,310	0	4,960	49,210

^aAll numbers are cumulative, full-time equivalent jobs (FTEs) from 2018. Job replacement is the elimination of jobs, and net change is creation minus replacement. For example there are 34,550 more blue collar jobs in the hydrogen production sector in 2035 under the HFI than there would have been under the baseline scenario. Those jobs are created starting in 2018, meaning the 2,450 jobs created in that sector from 2018 to 2020 are included in the 34,550.

As expected, the cumulative effects in these industries become greater over time, and they are greater for the HFI than the Less Aggressive Scenario. Common influences for the two hydrogen scenarios are as follows.

Automotive Sectors. For the automotive sectors (vehicle assembly, body manufacturing, parts manufacturing, and repairs), employment creation and replacement within each sector is the dominant influence. Total employment in these sectors is not forecast to change appreciably, in view of the expectation that total labor productivity in automobile production will not be significantly affected by the switch from gasoline to hydrogen vehicles. Some tasks within the automotive sectors will remain the same, such as task involved in producing and assembling certain automobile parts e.g., automobile wheels. But new skills will be required in other tasks, such as producing and installing fuel cells new powertrains and other associated equipment. These new jobs will utilize workers with experience and training different from that possessed by workers in the production of gasoline-powered vehicles.

Hydrogen Production. Important changes in types of jobs within the hydrogen production sector are not anticipated because the majority of the hydrogen production process is expected to be similar to the industrial gas processes that exist today. One notable difference is introduced with coal gasification, with its use of solid inputs. The use of solid inputs would change the occupational structure by adding staff for coal handling at the hydrogen production sites, similar to the coal-handling performed by employees at today's coal-fired power plants. However, these inventories are handled by small numbers of workers whose addition should be noted but would not affect the occupational structure of the sector significantly.²⁸ In this sector, the dominant influence is job creation for all skill levels to meet the increasing demand for hydrogen.

Petroleum Refining. Skill sets in the petroleum refining sector are not changed by the market transformation. However, jobs will be lost due to the emergence and substitution of hydrogen-based fuels. Consequently, the change in employment in this sector reflects employment losses in Table 3.1. The petroleum refining employment losses, resulting from the reduction in the demand for gasoline, are further detailed in Tables 3.2 and 3.3.

Construction. Increased pipeline construction for carrying hydrogen fuel from centralized production sites to dispensing and other use sites will lead to increased employment in the construction sector and will create jobs for all workers in pipeline construction. The increasing importance of pipeline construction relative to industrial buildings will change the skill mix in this sector. Job creation and replacement in this sector thus represent a combination of increases in sector employment and changes in skill mix.

²⁸ Bureau of Labor Statistics, Occupational Employment Statistics: Electric Power Generation, Transmission and Distribution (NAICS code 221100), accessed August – September 2006 at <http://data.bls.gov/oes/search.jsp>.

3.4 Education, Training, and Re-Training

3.4.1 Human Capital in the Hydrogen Market Expansion

A Variety of Needs. Education, training and re-training needs will depend on the skills involved in particular jobs. Some jobs requiring university education will call for re-direction in the capacity and nature of engineering programs offered in universities. Assembly line workers accustomed to routine tasks in the manufacture and installation of gasoline engines may be able to turn to hydrogen powertrain tasks with only a minimum of on-the-job instruction or in-house re-training. For high-skill blue collar workers, technical differences in basic technology used in gasoline- and hydrogen-powered vehicles, accentuated by the increasingly skill-intensive use of computers in automobiles, will change the content of vocational education. Entering workers will receive instruction with new content. Those who began their careers before the advent of hydrogen vehicles will need vocational re-training. In addition to workers involved in producing vehicles, this group includes vehicle service technicians and workers involved in delivering and dispensing fuel to automobiles.

Short-Term vs. Long-Term Adjustment. Rapid rates of job creation in the early years of hydrogen market expansion may lead to bottlenecks in the availability of workers for jobs being created, with the growth in number of workers preparing for newly created jobs lagging behind job openings. The more rapid the job creation, the more likely it is that growth in job availability will be under-estimated at the time career decisions are being made, and the more likely that there will be difficulties in finding qualified teachers and in gearing up for expanded education and training programs in new fields. For cases where small numbers of workers are involved, the changes that need to be made in university and vocational education may be limited. For occupations where a large number of workers relative to present numbers are needed and the skill levels require highly technical instruction, lags in meeting instructional needs could occur that might interfere with, or at least make difficult, the transformation to a hydrogen economy. In some cases, even though numbers are small, the new skill sets required for the hydrogen economy may be so different, so specialized and so highly education-intensive that bottlenecks may develop in supplying enough specialists to meet demands.

Over time, much of the response to job creation and replacement will come about through retirement of older workers and the education and training of younger, entering workers. If the number of jobs being replaced is smaller than the number of workers in those jobs who are retiring, and if entering workers are preparing themselves for the new jobs being created, few noticeable education, training, or re-training concerns may arise. Given that a worker's career spans approximately 40 years, on the order of 2½% of workers in an occupation will retire in any one year.²⁹ An annual rate of job replacement of 2½% provides an approximate dividing line between whether replacement will exceed or fall short of retirement. As an example of the variation in this rate that could be caused by demographic differences, the baby boomers, who are expected to retire between 2011 and 2029, would retire at a rate of

²⁹ Social Security Administration, Office of Policy Data, Annual Statistical Supplement, 2005, Tables 4.B1, 6.A1, accessed September 2006 at <http://www.ssa.gov/policy/docs/statcomps/supplement/2005/4b.pdf>.

about 2.7% per year, as opposed to the 2.5% assumed above. More rapid changes could mean that jobs are replaced faster than older workers retire—resulting in an excess of workers wishing to remain in these jobs, who then turn to other jobs with or without re-training, become unemployed, or retire early. For re-training to enable displaced workers to complete a normal career path, a series of events must transpire: a re-training course must be offered, the displaced workers must be willing to enroll in the course, they must complete the course, and they must find jobs afterwards. Because of slippages in this process, some unemployment and premature exit from the labor force could occur.

3.4.2 White Collar Workers

Occupational Composition. White collar workers include engineers, engineering managers, drafters, and engineering technicians. Engineers and engineering managers comprise the majority of this group and have university-level education. Drafters and engineering technicians receive training mostly from vocational and technical schools.

Industry Opinions on Skill Changes. In the interviews of persons with first-hand knowledge of developments in the automobile industry, referred to in the preceding section, most interviewees believed that the current set of engineering skills used for conventional internal combustion engine vehicles will likely change significantly. They agreed mechanical engineering skills will focus less on purely mechanical functions and more on developing electro-mechanical systems. Some suggested that this will be particularly true in the event that alternative platforms such as by-wire technology (in which steering, braking, and acceleration will be controlled electronically rather than mechanically) are adopted. Others suggested that the traditional vehicle platform will evolve but not change radically. On balance, it appears that new designs will be required for hydrogen-powered vehicles but non-propulsion-related systems such as heating and cooling systems will likely employ the same mechanical engineering skills that as are in use today.

Regardless of design, interviewees believed that changes in required engineering skills will be evolutionary rather than revolutionary. Examples of evolutionary training changes in the auto industry include the introductions of the front-wheel drive system and various fuel injection systems, and the use of different on-board computer systems. In all of these cases, the automotive industry will rely upon internal re-training and on-the-job experience, as well as changes in curricula at universities and community colleges to support the turnover in new skills.

Most interviewees agreed that as a result of work on hybrid electric vehicles, there are already a significant number of engineers with either educational backgrounds or on-the-job experience in electronics, controls, sensors, control system integration, power controllers, electric motors, on-board computing, and system integration. New elements required in a fuel cell vehicle system include the fuel stack and some attendant sensing and control systems. But a great many system requirements are already present in conventional and hybrid vehicle systems.

Estimation of Education, Training, and Re-Training Needs. The cumulative effects that were discussed in connection with Tables 3.1, 3.2 and 3.3 are estimates of how the future industrial structure of the economy will be affected by the hydrogen transformation. However, in addition to studying the cumulative impacts of the hydrogen transformation, it is important to consider how the impacts in any given year will determine the number of additional people that will need to complete education and training to equip them for jobs created that year and the number of additional jobs that will be replaced in that year, thereby requiring layoffs in that year for workers who are not re-trained. Tables 3.4 and 3.6 provide an analysis of the job impacts on white collar and blue collar workers for key industries on an annual basis for three representative years- 2020, 2035, and 2050. The results show how many new jobs are expected to be created in those years and how many old jobs disappear in those years. In the tables, the average annual job changes are expressed as a percentage of the number of workers in seven affected occupations. These percentages facilitate discussion of the burdens that will be placed on education and training relative to existing numbers receiving instruction in the case of job creation, and comparison with expected industry retirement rates in the case of job replacement. The first step in deriving Table 3.4 is to calculate the cumulative percentage impacts on white collar employment in each industry from the beginning of market expansion in 2018 up to 2020, 2035, or 2050, as appropriate. These percentage impacts are obtained by dividing the cumulative effect on number of white collar workers given in Table 3.2 by the total number of white collar workers in affected occupations in the industry. Because the impacts will be spread over 2 years for 2020, 17 years for 2035, and 32 years for 2050, the annual figures in Table 3.4 are obtained by dividing the cumulative percentage impacts by the appropriate number of years.

Under the HFI Scenario, the highest positive average annual percentage impacts on job creation in Table 3.4 are 10.41% for hydrogen production job creation in 2035 and 4.66% for auto parts (including fuel cells) in 2020.

Most of the data presented in Table 3.4 involves situations where job replacement is as large or nearly as large as job creation. The average annual percentage impacts are generally less than 2 ½% and most often are far less. As a point of comparison, churning rates, a measure of job creation and replacement under normal conditions, defined in footnote 32, are available for many industries in the economy. Typical churning rates are 13% to 28% of an industry's employment; those of vehicle components and vehicle body manufacturing have been 7% and 9% recently, with considerable variation among states.³⁰ The much smaller percentages in Table 3.4 indicate that employment impacts from job creation and replacement brought on by hydrogen transformation are small compared to the normal employment churning that occurs in the economy. Furthermore, because many of the annual percentage rates of replacement will be substantially less than 2½% it is likely that retirement

³⁰ Brown, C., Haltiwanger, J., Lane, J., *Economic Turbulence: Is a Volatile Economy Good for America?* (Chicago: University of Chicago Press, 2006), Table 4.1, p. 48. Churning is defined as the average of job accessions (job creation) and separations (job replacement) as a percent of total employment in the industry. Thus, churning is measured as ½ x (accessions plus separations)/total employment: Abowd, J. M., Stephens, B. E., Vilhuber, L., Anderson, F., McKinney, K.L., Roemer, M., Woodcock, S., "The LEH Infrastructure Files and the Creation of the Quarterly Workforce Indicators," Technical Paper No. TP-2006-01, U.S. Census Bureau, Silver Hill, Md., December 5, 2005, p. 108. Data on churning rates by industry and state are available at <http://lehd.dsd.census.gov/led/datatools/qwiapp.html>.

rates should be sufficient to adjust to declining demands for outmoded jobs, generally without downward employment pressures on workers not choosing to retire

Because the number of engineers in each discipline working in the hydrogen area is small compared to the total number of engineers working in the U.S., the current education system easily will have the capacity to train engineers needed in the hydrogen economy over the longer run.

Industry	HFI			Less Aggressive		
	2020	2035	2050	2020	2035	2050
Auto Assembly						
Net Change	-	-	-	-	-	-
Creation	3.96%	1.56%	0.93%	0.12%	0.26%	0.56%
Replacement	3.96%	1.56%	0.93%	0.12%	0.26%	0.56%
Auto Body Mfg						
Net Change	-	-	-	-	-	-
Creation	2.66%	1.05%	0.63%	0.08%	0.18%	0.38%
Replacement	2.66%	1.05%	0.63%	0.08%	0.18%	0.38%
Auto Parts Mfg, incl. Fuel Cells						
Net Change	-	-	-	-	-	-
Creation	4.66%	1.83%	1.10%	0.14%	0.31%	0.66%
Replacement	4.66%	1.83%	1.10%	0.14%	0.31%	0.66%
Hydrogen Production						
Net Change	6.11%	10.41%	6.23%	1.19%	1.35%	2.53%
Creation	6.11%	10.41%	6.23%	1.19%	1.35%	2.53%
Replacement	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Refining						
Net Change	-0.36%	-0.66%	-0.49%	-0.08%	-0.19%	-0.25%
Creation	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Replacement	0.36%	0.66%	0.49%	0.08%	0.19%	0.25%
Construction						
Net Change	1.32%	0.13%	0.06%	0.88%	0.09%	0.04%
Creation	1.52%	0.95%	1.11%	0.88%	0.20%	0.67%
Replacement	0.21%	0.82%	1.06%	0.00%	0.11%	0.63%

^a All averages are from 2018 to the year listed. For example, in auto assembly, on average, 3.96% of skill-affected white collar jobs are created and replaced each year from 2018 to 2020, 1.56% are created and replaced each year from 2018 to 2035, and 0.93% are created and replaced each year from 2018 to 2050.

The possibility of shorter run problems remains to be considered. Table 3.5 compares the total number of engineers in the U.S. to the number of engineers in key industrial sectors. Numbers are presented for the major engineering disciplines that are most likely to be involved in the transformation to a hydrogen economy.

Table 3.5 indicates that in the hydrogen economy, engineers will still need to complete basic undergraduate programs at a minimum, but will need to include hydrogen-related subjects in their undergraduate curriculum. As undergraduate education curricula develop and as demand for engineers in the fuel cell and hydrogen technologies areas increases, there should be sufficient numbers of students to fill the need for qualified engineers. However, it takes approximately 4 to 8 years for engineers to complete professional education, including undergraduate and graduate schools. The high annual growth rates in the hydrogen production and fuel cell sectors to 2020 suggest that shortages of engineers trained for these sectors could arise in the early years of vigorous hydrogen market expansion, although it should be kept in mind that the absolute number of engineers in these industries is small.

Table 3.5: Comparison of Total Engineers Nationwide to Engineers in Sectors Directly Affected by Hydrogen (“Key” Sectors), by Engineering Discipline			
Engineering Occupations	Total U.S., 2005	Total Key Sectors, 2005	% in Key Sectors
Chemical Engineers	27,280	1,415	5%
Civil Engineers	226,900	2,608	1%
Electrical/Electronics Engineers	313,040	1,757	1%
Health and Safety Engineers	24,110	1,058	4%
Industrial Engineers	185,620	18,702	10%
Mechanical Engineers	210,790	12,180	6%
Materials Engineers	20,850	442	2%
Total	1,008,590	35,912	4%
Source: Bureau of Labor Statistics (BLS), Occupational Employment Statistics, data as of May 2005, accessed August-September 2006 at http://data.bls.gov/oes/search.jsp?data_tool=OES .			

The engineering disciplines needed to develop technology solutions for hydrogen systems include chemical engineering, electrical/electronics engineering, industrial engineering, mechanical engineering, and materials engineering. R&D activity at universities increases the number of personnel and the knowledge base for speeding up the educational response. Development of educational programs and courses at universities has begun, and much progress is apparent. However, very few degree programs specific to fuel cells and hydrogen technology are in place. Currently, approximately 60 colleges and universities offer research and coursework in fuel cells and hydrogen technology. Four schools in the U.S. have been identified that have degree programs specifically targeted to fuel cells or alternative energy

technologies.³¹ Most of the activity is at research centers. At least 20 schools have established multidisciplinary groups and research centers, many of which include industry partners.

Re-training needs for white collar workers, both engineers and non-engineers, will depend on the pace of new technological developments as the hydrogen transformation proceeds. Continuing education courses, workshops, and on-the-job training are likely means of carrying out the white collar re-training.

3.4.3 Blue Collar Workers

Occupational Composition. Blue collar workers include, but are not limited to, manufacturing employees, construction employees, automotive service and repair technicians, service station attendants, and hydrogen fuel deliverers. Blue collar workers obtain training from vocational and technical schools where necessary.

Industry Opinions on Skill Changes. Interviewees generally agreed that blue collar jobs in manufacturing will be significantly affected by a transformation to hydrogen fuel cell vehicles. Most interviewees focused on the level of training of workers on the line. Computer literacy skills, knowledge of electrical systems, and the ability to use computerized diagnostic equipment will be particularly important for assembly skills in the future. Machining skills related to internal combustion engine construction are not likely to be needed, as fuel cell stacks require little to no machining and are unlikely to be manufactured by the automobile companies themselves. Skills related to assembly of electro-mechanical systems and computer hardware would be in greater need. The balance of components required to complete the fuel cell system requires skills for assembly similar to those for a traditional gasoline engine.

As with engineering skill development, interviewees believed that training will be evolutionary rather than revolutionary. In addition to training courses on skills needed for increasingly computerized vehicles and manufacturing techniques, on-the-job training will assist in the transformation. The development of hybrid vehicles has provided an environment for the development of new manufacturing skills. For example, dedicated lines for hybrid vehicle systems have provided much-needed learning about procedures, failure rates, stoppage points, line coordination, and other matters. The dedicated lines thus were in some respects the classroom that was used to train the production in the supporting industries, and interviewers indicated that the same sort of experience likely would emerge in the production of hydrogen fuel cell vehicles.

³¹ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, accessed August – September 2006 at http://www.eere.energy.gov/hydrogenandfuelcells/education/related_prog.html.

Industry	HFI			Less Aggressive		
	2020	2035	2050	2020	2035	2050
Auto Assembly						
Net Change	-	-	-	-	-	-
Creation	2.00%	0.78%	0.47%	0.06%	0.13%	0.28%
Replacement	2.00%	0.78%	0.47%	0.06%	0.13%	0.28%
Auto Body Mfg						
Net Change	-	-	-	-	-	-
Creation	2.00%	0.78%	0.47%	0.06%	0.13%	0.28%
Replacement	2.00%	0.78%	0.47%	0.06%	0.13%	0.28%
Auto Parts Mfg, incl. Fuel Cells						
Net Change	-	-	-	-	-	-
Creation	3.99%	1.57%	0.94%	0.12%	0.26%	0.56%
Replacement	3.99%	1.57%	0.94%	0.12%	0.26%	0.56%
Auto Dealerships & Repair						
Net Change	-	-	-	-	-	-
Creation	1.00%	1.46%	1.81%	0.03%	0.24%	1.09%
Replacement	1.00%	1.46%	1.81%	0.03%	0.24%	1.09%
Hydrogen Production						
Net Change	6.11%	10.41%	6.23%	1.19%	1.35%	2.53%
Creation	6.11%	10.41%	6.23%	1.19%	1.35%	2.53%
Replacement	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Refining						
Net Change	-0.36%	-0.66%	-0.49%	-0.08%	-0.19%	-0.25%
Creation	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Replacement	0.36%	0.66%	0.49%	0.08%	0.19%	0.25%
Construction						
Net Change	0.57%	0.06%	0.02%	0.38%	0.04%	0.02%
Creation	0.79%	0.53%	0.63%	0.38%	0.11%	0.38%
Replacement	0.23%	0.48%	0.60%	0.00%	0.07%	0.36%

^a All averages are from 2018 to the year listed. For example, in auto assembly, on average, 2.00% of skill-affected blue collar jobs are created and replaced each year from 2018 to 2020, 0.78% are created and replaced each year from 2018 to 2035, and 0.47% are created and replaced each year from 2018 to 2050.

In the area of vehicle service and repair, all interviewees agreed that the most significant skill set change will be in troubleshooting, repair, and service of propulsion systems. They believe that these skills will be very new, and very technical in nature. Technicians will have

to become more competent in computer and electrical system maintenance. However modularization of key components such as batteries, fuel cell stacks, and power converters, may reduce the amount of re-training needed. Similar to production, hybrid vehicle maintenance will provide a means of developing new repair and maintenance skills. However, hydrogen fuel cell vehicles will require new safety training at all levels because of their use of hydrogen and high-voltage electrical systems.

Estimation of Training and Re-training Needs. Table 3.6 shows average annual percentage impacts on the blue collar workers for industry sectors of interest. The percentage impacts on blue collar workers are very similar to the white collar impacts in Table 3.4. The Automobile Dealer and Repair sector, excluded in Table 3.4, is added in Table 3.6. While appreciable changes in white collar workers are not expected in this sector, considerable impact is expected for the major blue collar category, auto service technicians. The same general comments apply to Table 3.6 as were made for Table 3.4. These are the rapid increase required in auto parts (including fuel cells) manufacture and hydrogen production in the early years of a rapid transformation, the otherwise small impacts compared to normal employment churning in the economy, and the excess of worker retirements over job replacement rates.

The training and re-training implications for blue collar workers are different from the white collar implications. Many more blue collar workers are affected, because the numbers of blue collar workers are many-fold greater than those of white collar workers. Examples of blue collar workers in the key sectors include employees involved in manufacturing, construction, and repair and maintenance of both vehicles and production facilities. Training for the blue collar group will depend on the employee functions and may range from as little as basic safety training to very specialized automotive technician training.

The employment impacts are modeled on annual average levels, as full-time equivalents. Because not all workers are year-round workers, particularly among the blue collar labor force, more people have some work experience during a typical year than is indicated by the full-time equivalent calculation. Consideration of all persons with work experience during the year by industry sector could increase the retraining needs identified below to a modest extent, more so in some sectors than others. For example, nearly 96% of durable manufacturing workers, which includes the auto sectors were full-time in 2005, and 94% of nondurable manufacturing workers, which include refining and industrial gases, were full time. Full-time employment was lower in construction, around 90% in construction that includes residential and commercial buildings as well as pipelines; 70% of full-time construction workers in all construction sectors worked 50 to 52 weeks that year.³²

Manufacturing and Construction. Much of the training and re-training for automobile manufacturing and construction workers as a result of hydrogen technologies may be accomplished through on-the-job training sponsored by employers. In the manufacturing area, for example, there are large numbers of assemblers and machine operators who may be affected as production lines are changed to accommodate potential changes in vehicle

³² Bureau of Labor Statistics, "Wage and salary workers with work experience in 2005 by industry of the job held the longest, March 2006," Current Population Survey, Washington, D.C., 2006.

designs. In the construction area laborers may need safety training for working with hydrogen pipelines, while plumbers, pipe fitters and welders may need training on new piping specifications and safety requirements. These few examples are not inclusive of all affected manufacturing and construction occupations, but are meant to illustrate the wide range of blue collar workers who may be affected by the introduction of hydrogen technologies.

Automotive Service Technicians and Mechanics. Automotive service technicians and mechanics are a large group which will be significantly affected by a change to hydrogen fuel cell vehicles. Automotive service technicians and mechanics receive training at vocational and technical schools, and most take standard certification tests in order to be qualified to work on vehicles. According to the Bureau of Labor Statistics, as of May 2005, there were 654,000 automotive service technicians and mechanics in the U.S. working in dealerships and independent maintenance shops; additional workers are employed at large firms with extensive light-duty vehicle fleets in other industries.³³ This figure does not include automotive body-related repairers, automotive glass installers, or tire changers and repairers. The study uses data from the BLS Quarterly Census of Employment and Wages (QCEW) Program, which does not cover self-employed individuals and agricultural workers who are not subject to unemployment insurance payroll taxes. Accordingly, the prevalence of self-employed individuals in the automotive service and repair industry could tend to increase re-training needs among those skill sets somewhat beyond the extent estimated here.

Two organizations are responsible for developing and certifying training programs for automotive service technicians and will have to be involved in program changes: the National Automotive Technicians Education Foundation (NATEF), and the National Institute for Automotive Service Excellence (ASE). The NATEF is an independent, non-profit organization which evaluates technician training programs against standards developed by the automotive industry and recommends qualifying programs for certification by ASE. NATEF also evaluates the providers of in-service technician training programs under its Continuing Automotive Service Education (CASE) program. The ASE is an independent, non-profit organization that provides testing and certification of repair and service professionals.

Currently, automotive vocational and technical training based on gasoline internal combustion engines in the U.S. is offered at approximately 2,100 schools. Most programs take 1 to 2 years to complete. As an example of programs offered, the Universal Technical Institute (UTI), with operations nationwide, provides accredited gasoline automobile programs in auto service and repair. These programs include a basic program that lasts a minimum of 51 weeks. Enrollees can gain more specific skills by taking manufacturer - specific certification programs that are approximately 16 weeks long (the manufacturer - specific certification programs offered at UTI include Toyota/Lexus, and Ford/Lincoln/Mercury). At the most advanced level, students can take additional manufacturer-specific programs (Audi, BMW, Mercedes, Volkswagen, Volvo) that last

³³ Bureau of Labor Statistics, Occupational Employment Statistics, accessed August – September 2006 at http://data.bls.gov/oes/search.jsp?data_tool=OES, search of Automotive Service Technicians and Mechanics (493023) for all sectors and all industries, as of May 2005.

approximately 20 weeks. These manufacturer-specific programs indicate that there is a high level of coordination between the servicing industry and these vocational schools.

In the future, to meet demands for servicing of the hydrogen vehicle fleet drawing on training and re-training at these schools, the growth in numbers of qualified service personnel must exceed that of vehicle sales. Vehicle buyers will not be willing to purchase hydrogen vehicles unless they are assured of the availability of competent and conveniently located service allowing flexibility in where they choose to drive. As many as 20% of mechanics and technicians, or approximately 110,000, could need hydrogen-oriented training to be prepared to service the hydrogen vehicles that are estimated to be on the road by 2020 under the HFI Scenario. By 2035, 60% of the stock of total vehicles will be hydrogen vehicles under the HFI Scenario, requiring approximately 340,000 trained mechanics and technicians to service them. By 2050, when the vehicle stock is 95% hydrogen under the HFI Scenario, approximately 630,000 would need to know how to service hydrogen vehicles. These figures are summarized in Table 3.7.

Table 3.7: Potential Demand for Automotive Service Technicians and Mechanics Trained in Hydrogen Vehicles under the HFI Scenario^a			
Year	Total Projected Service Technicians	Demand for Hydrogen Trained Service Technicians	%
2020	539,000	110,000	20%
2035	561,000	340,000	60%
2050	663,000	630,000	95%
^a Values estimated using IMPLAN model results and hydrogen vehicle stock penetration assumptions.			

Two major types of training will be needed—initial training for workers starting their careers with no previous training and re-training for workers already trained in gasoline engine technology. Because the vehicle stock will include a significant number of gasoline vehicles for many years, overall training programs will need to address both technologies. A major emphasis on getting the new programs in place will be required to meet demands for servicing the hydrogen vehicle fleet. The effort includes coordination, and mustering resources necessary to develop, certify, and deploy training for the automotive service technicians and mechanics.

Work has started in this area but is still in the beginning stages. For example, in California, the College of the Desert and the Sun Line Transit Agency have developed the first training program for hydrogen fuel cell buses called “Hydrogen Fuel Cell Engines and Related Technologies Course Manual.”³⁴ The National Alternative Fuel Training Consortium, headquartered at the University of West Virginia, provides a one-day course on the basics of hydrogen production and potential uses in vehicles, as well as an introductory workshop for hydrogen-powered vehicles.³⁵

Fueling Stations and Hydrogen Delivery. Vocational training and re-training needs not considered above pertain to service attendants at retail fuel stations who will require some training. The importance of fuel station instructional needs is suggested by the fact that there were an estimated 167,000 gasoline stations in the U.S. as of May 2006.³⁶ Similarly, truck drivers who deliver hydrogen to fueling stations will require special instruction in handling hydrogen fuel.

³⁴ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, accessed August – September 2006 at http://www.eere.energy.gov/hydrogenandfuelcells/tech_validation/h2_manual.html.

³⁵ The National Alternative Fuel Training Consortium, accessed August 2006 at <http://www.naftc.wvu.edu/>.

³⁶ *National Petroleum News* 2006 Survey, www.npnweb.com, annual survey of all retail outlets of any kind at which the public can buy gasoline.

4.0 REGIONAL VARIATION IN ECONOMIC IMPACTS

4.1 Characteristics of Selected Regions

Five contrasting geographic regions illustrate the potential for differences in the impacts of a transformation to hydrogen across the nation. These regions include:

- Upper Midwest
- Lower New England and Upper Mid-Atlantic
- California
- Tennessee
- Houston/Galveston

The Upper Midwest is a cluster of states consisting of Ohio, Michigan, Indiana, Illinois, and Wisconsin. This region has the greatest concentration of auto and auto parts manufacturing in the country.

The Lower New England and Upper Mid-Atlantic regions consist of Massachusetts, Rhode Island, Connecticut, New York, Pennsylvania, and New Jersey. This region has a more diversified economy. It is broadly representative of the national economy, but is distinguished by the fact that it is a large importer of oil-based products, including gasoline.

California has several unique economic characteristics. It has a substantial but declining refining and petrochemical sector; it has been under significant industrial transformation in recent years; and it has been at the forefront of energy conservation and the use of alternative energy sources.

Tennessee is representative of states that have been participating in the new part of the auto industry. Vehicle assembly and automotive parts manufacturing have represented a growing share of the state economy, stimulated by the location initially of foreign, and then domestic, automotive firms.

The Houston/Galveston metropolitan area is a port destination for imported oil, has sizeable exports of refined products and petrochemicals, and is dominant in upstream energy exploration and development industries.

Table 4.1 identifies the current industry composition within each region and shows the extent to which the industrial composition of each region differs from the industrial composition of the nation as a whole. Sectors that will be significantly affected either positively or negatively by the expansion of hydrogen markets are noted.

The Upper Midwest has a much larger proportion in automobile and automotive parts related employment than the nation as a whole. Although it has a larger concentration of chemical sector related employment than the nation as a whole, the Lower New England and Upper Mid-Atlantic region is otherwise fairly representative of the nation as a whole. Tennessee is somewhat similar to the Upper Midwest. California, with an economy larger than that of

many countries, is more diversified than the other regions, although its share of employment in refining is higher than the nation as a whole. Houston is the least representative of the regional areas. The oil and gas extraction sector is nearly 10 times more important to Houston than it is to the national economy, and the regional share of automobile and automobile parts manufacturing is only a small fraction off the national average.

Table 4.1: Industry Shares of Employment in the Regions, 2005					
	Upper Midwest	Lower New England and Upper Mid-Atlantic	California	Tennessee	Houston
Over Represented	<u>Auto/Auto Parts</u> 8.0%	<u>Chemicals</u> 3.3%	<u>Refining</u> 2.0%	<u>Auto/Auto Parts</u> 5.5%	<u>Petrochemicals</u> 11.0%
	<u>Chemicals/Plastics</u> 4.4%		<u>Natural Gas Dist</u> 1.0%	<u>Chemicals</u> 3.0%	<u>Refining</u> 9.5%
Under Represented	<u>Oil & Gas Extract</u> 0.3%	<u>Oil & Gas Extract</u> 0.2%	<u>Auto/Auto Parts</u> 0.6%	<u>Oil & Gas Extract</u> 0.1%	<u>Auto/Auto Parts</u> 0.2%
	<u>Refining</u> 0.9%	<u>Refining</u> 0.4%	<u>Power Generation</u> 0.6%	<u>Power Generation</u> 0.2%	
		<u>Auto/Auto Parts</u> 0.5%		<u>Refining</u> 0.5%	

Source: Bureau of Labor Statistics, accessed August-September 2006 at <http://www.bls.gov/cew/home.htm>.

Table 4.2 gives the percent difference in a sector's share of regional output from the sectoral share of national employment. For example, the chemical sector's share of total employment in the Lower New England and Upper Mid-Atlantic region is 47% greater than the national share, but its oil and gas extraction sector's share of output is 89% smaller than the national share. These statistics provide the context of these regions' economic differences.

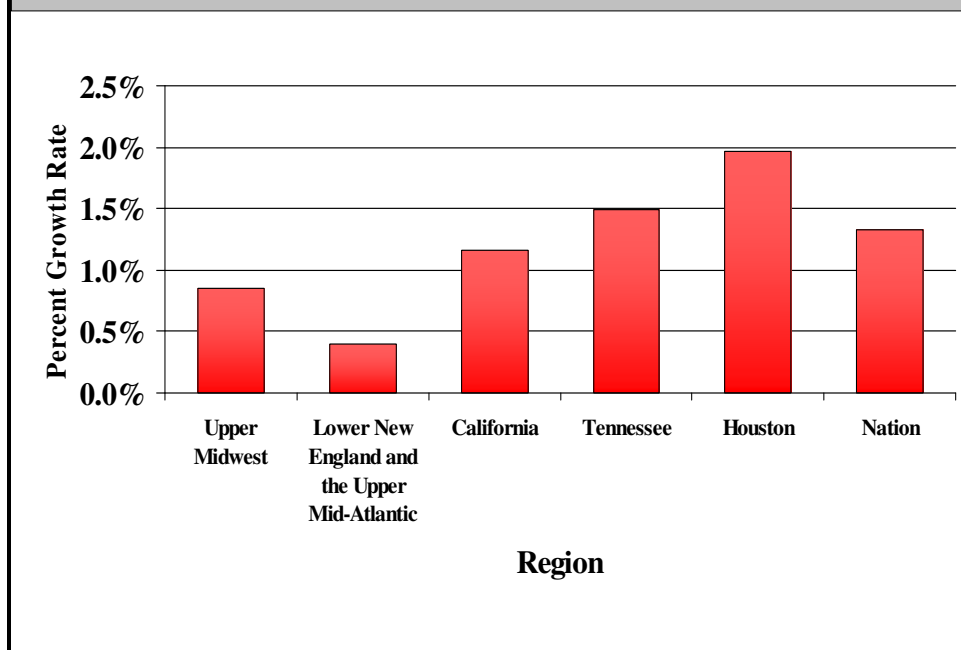
Table 4.2: Percentage Differences between Regions' Shares of Industry Employment and National Shares, 2005					
	Upper Midwest	Lower New England and Upper Mid-Atlantic	California	Tennessee	Houston
Over-Represented	<u>Auto/Auto Parts</u> 253%	<u>Chemicals</u> 47%	<u>Refining</u> 40%	<u>Auto/Auto Parts</u> 146%	<u>Petrochemicals</u> 281%
	<u>Chemicals/Plastics</u> 36%		<u>Natural Gas Dist</u> 150%	<u>Chemicals</u> 36%	<u>Refining</u> 576%
					<u>Oil & Gas Extract</u> 1089.00%
Under-Represented	<u>Oil & Gas Extract</u> -91%	<u>Oil & Gas Extract</u> -89%	<u>Auto/Auto Parts</u> -75%	<u>Oil & Gas Extract</u> -89%	<u>Auto/Auto Parts</u> -91%
	<u>Refining</u> -34%	<u>Refining</u> -68%	<u>Power Generation</u> -53%	<u>Power Generation</u> -81%	
		<u>Auto/Auto Parts</u> -77%		<u>Refining</u> -63%	

For example, in the “over-represented” portion of the table, the auto/auto parts sector’s share of employment in the Upper Midwest is 253% greater than the nation’s share of employment in auto/auto parts; in the “under-represented” portion, the Upper Midwest’s share of employment in oil and gas extraction is 91% smaller than the nation’s share in oil and gas extraction.

Source: Bureau of Labor Statistics, accessed August-September 2006 at <http://www.bls.gov/cew/home.htm>.

Not only do the five regions analyzed here have different proportions of key sectors, but their growth rates have also differed over the past 15 years, as shown in Figure 4.1. These growth rates give a context for the hydrogen scenario impacts. If a region experiences an additional 2% employment by 2050 because of a stimulus from the hydrogen economy, that impact should be placed within the context of the overall gains the region was expected to experience without hydrogen. For a region that has been experiencing ½ % growth per year, a 2-percentage-point addition represents about 4 years of growth, which is a significant impact. For a region that has been growing at 4% per year without hydrogen, the impact of a 2-percentage-point addition because of hydrogen would constitute only 6 months of normal growth. The same need for context is true for growth within sectors.

**Figure 4.1: Average Annual Employment Growth:
1990 - 2006**



Source: Bureau of Labor Statistics, accessed August-September 2006 at <http://www.bls.gov/cew/home.htm>.

The Upper Midwest grew an average 0.85% per year between 1990 and 2006. Despite sluggishness of the region's auto sectors, manufacturing in this region fell less than the national average, and the region shared to some extent in the national growth in non-manufacturing industries. The slowest growing of the five regions was the Lower New England and Upper Mid-Atlantic region. The average growth in employment over the 16 years was 0.4% per year. The region's employment growth was impeded by a nearly 3% per year decline in manufacturing, though strong growth occurred in professional services, particularly scientific and technical services, in which all regions experienced solid growth. California grew at 1.2% per year, a rate also affected by the real estate crash in the early 1990s and the high tech crash during the first part of the present decade. Tennessee experienced solid growth during the 16-year period. Like most regions, Tennessee lost manufacturing jobs, but its losses were smaller than in other regions because of growth in auto assembly and auto parts manufacturing. Among the 5 regions studied, Houston experienced the highest average growth rate, nearly 2.0% per year. This growth occurred despite the recession of 1991-92 and the energy mini-bust in 1998-99. Houston shared in the national growth in scientific and technical services, and while non-durable manufacturing declined, durable goods manufacturing held up quite well. Upstream energy employment (exploration) has been a source of growth. Since 1999, downstream energy (refining and petrochemicals) has experienced moderate job losses.

4.2 Impacts of Hydrogen Transformation in the Five Regions Under the HFI Scenario

4.2.1 Overview

All five regions studied are estimated to experience some additional job growth as a result of the expansion of hydrogen markets. Figure 4.2 gives the difference in jobs in 2050 between the HFI scenario and the base case, as a percent of 2050 base-case jobs. Since these regions have been experiencing significant differences in annual growth rates,

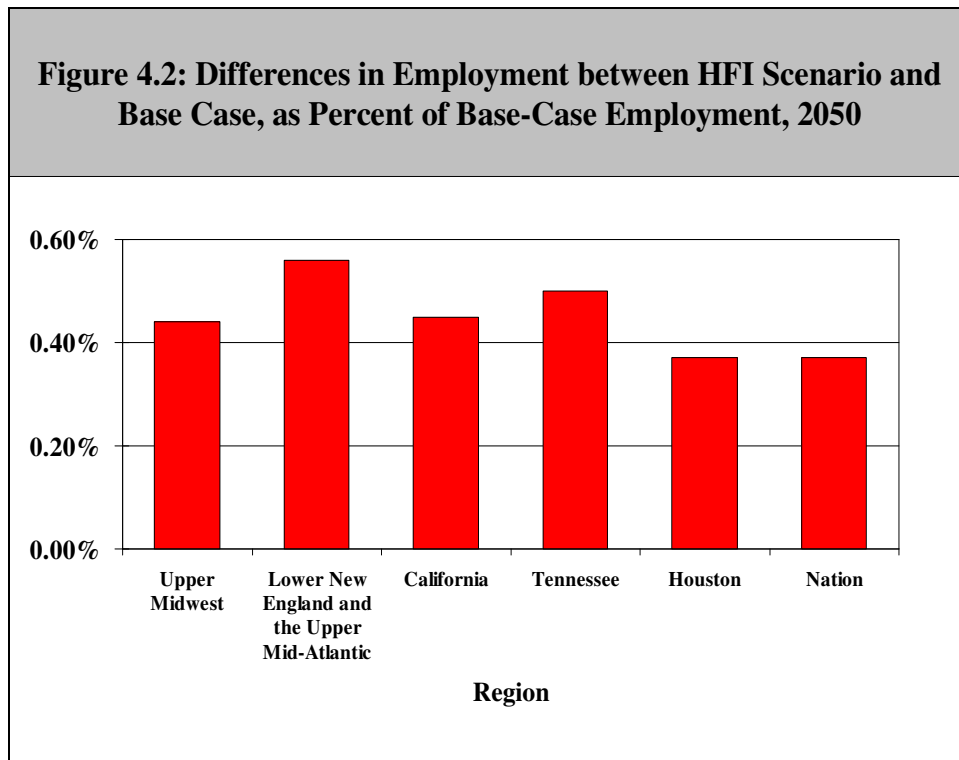
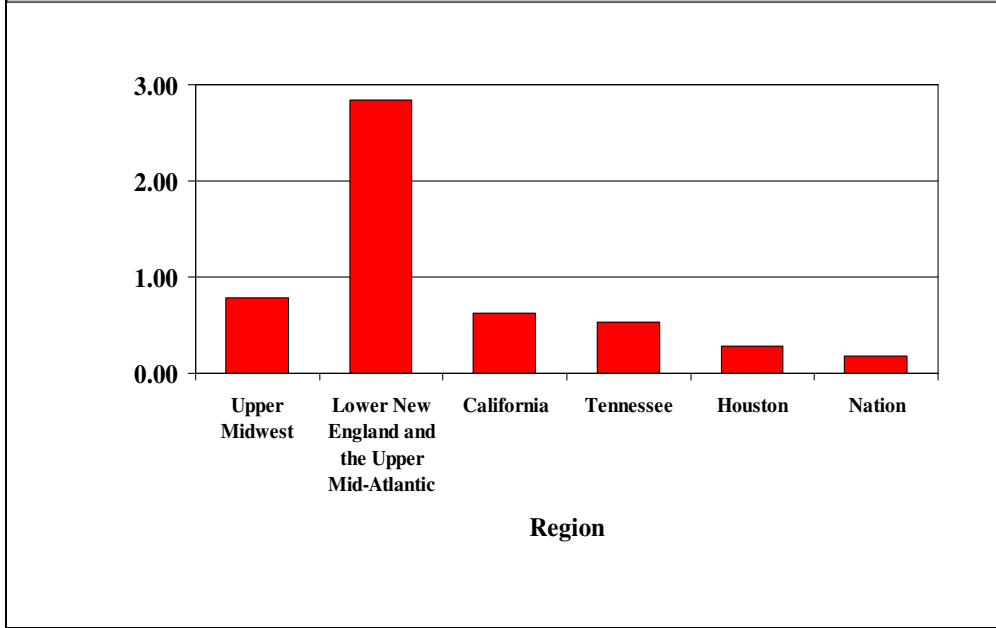


Figure 4.3 puts these impacts in context by showing the ratio of difference in jobs in 2050 under the HFI Scenario compared to the yearly increase in jobs that would be experienced in the region in the absence of the additional jobs due to hydrogen. This number is equivalent to the years of additional growth gained from hydrogen market expansion if the region's growth otherwise continued at its accustomed rate.

Even under the HFI Scenario, the regional employment effects of hydrogen market expansion are modest but positive and will be spread out over more than a 30-year period. All regions will gain some additional jobs, though industries reaping the greatest employment benefits will vary across regions. Houston and California will gain the most from additional jobs in professional and technology services; the Lower New England and Upper Mid-Atlantic states will gain the most from the production and delivery of hydrogen; and Tennessee and the Upper Midwest region will see modest gains more evenly spread across a wide array of sectors.

Figure 4.3: Differences in 2050 Employment between HFI Scenario and Base Case as Years of Average Annual Base-Case Employment Growth



All regions likewise enjoy a modest boost in employment from the production and distribution of hydrogen under the HFI Scenario. All regions also experience noticeable impacts of the hydrogen transformation on professional and technical services, which expand to meet the technical and engineering needs of transforming the auto and refining industries and of creating a mass production hydrogen industry. Losses in energy and fabricated metals occur in some regions. Some of the major results are summarized in qualitative terms in Table 4.3.

Table 4.3: Greatest Employment Impacts by Sector and Region	
<u>Sectors</u>	<u>Regions</u>
Greatest Gainers	
Hydrogen Production	All Regions
Professional & Technical Services	All Regions
Greatest Losers	
Fabricated Metals	Upper Midwest
Downstream Energy	California
Upstream Energy	Houston
Downstream Energy	Houston

4.2.2 The Upper Midwest Region

The fact that the Upper Midwest region is a center of automobile and automobile parts manufacturing does not mean that its employment will necessarily be significantly affected. Because the switch to hydrogen vehicles is not projected to affect overall labor productivity in the industry, the auto sectors are not expected to be significant net gainers or losers of jobs as a result of the transformation to hydrogen. In the present report, the shares of U.S. automobile production provided by U.S. companies and multinationals are assumed to be the same in the base case and in the two hydrogen scenarios. As discussed in Section 5 on international effects, differences in the relative performance of companies in introducing and marketing hydrogen vehicles, toward which the present report takes a neutral view, is an uncertainty that could affect the regional distribution since companies differ in their regional concentration of production.

The Upper Midwest, like the Lower New England and Upper Mid-Atlantic region, is an importer of gasoline, so the shift to hydrogen will promote employment gains from the transformation as the region shifts from gasoline importation from other states to hydrogen production within the state. Still, the stimulus of hydrogen production and delivery does not have a very large impact under either scenario. Although the Upper Midwest is not a major refining region, the sector experiencing the greatest hydrogen-related losses in the region is refining. A small number of other types of upstream-energy-related jobs are lost in the Upper Midwest.

In total, under the HFI Scenario, roughly 4,800 job losses occur in the region, scattered across 14 sectors, compared to 110,000 jobs created across 41 sectors, for a net creation of 105,000 jobs, or 0.44% of the region's base-case employment in 2050. Thus, compared to the nationwide employment creation of 0.37% under the HFI Scenario, the Upper Midwest region experiences modestly more expansion than the nation on average. Expressed alternatively, the net jobs created in the Upper Midwest account for 0.06 points of the nationwide 0.37%.

4.2.3 The Lower New England and Upper Mid-Atlantic Region

The Lower New England and Upper Mid-Atlantic Region experiences the largest percentage gains in employment as a result of the switch to hydrogen, with 0.56% greater employment in 2050 under the HFI Scenario than in the base case, accounting for 0.08 points of the national total of 0.37%. Given the modest growth of this region over the past decade and a half, this amounts to almost 3 years' growth.

The primary stimulus to the Lower New England and Upper Mid-Atlantic Region stems from the production and delivery of hydrogen to a large and relatively dense population. The region is not projected to experience any serious employment losses as a result of the hydrogen transformation, though some minor losses are projected in upstream energy, tied to corporate energy office workers. The minimal amount of losses helps keep the net gain high. Essentially, the gains to this region stem from the fact that it is currently a major importer of

gasoline. Thus, the move to hydrogen transforms this economy from an energy importer to an energy producer, at least for its automotive needs.

4.2.4 California

California's economy also is stimulated by the new hydrogen industry. As a result, the state is projected to experience employment decreases in downstream energy, which includes the refining sector. California's high-tech sectors will participate in the development of the new technology needs of hydrogen systems. Because of the state's strength in science and engineering, California should experience some employment growth induced by a shift to hydrogen vehicles, although most production of these autos will occur elsewhere.

Overall, California is projected to see an additional 0.45% employment over the all-gasoline scenario by 2050 in the HFI Scenario, approximately equivalent to 8 months' growth under the base case. California's job creation contributes 0.04 points to the national total of 0.37%.

4.2.5 Tennessee

Tennessee's economy will be stimulated by hydrogen production, though somewhat less than other regions studied, because of a smaller population and lower population density. Tennessee's net job gain under the HFI Scenario of roughly 14,500, or 0.5% of its base-case employment in 2050, is second highest among the five regions, primarily because Tennessee has no significant losses to dampen the gains in hydrogen production and delivery, and technological and engineering services. The state's employment growth accounts for 0.01 points of the 0.37% nationwide employment creation.

4.2.6 Houston

Houston gains employment at the same rate of the nation as a whole. However, given its large percentage of employment in the petrochemicals, refining, and oil and gas extraction sectors (see Table 4.2). Houston is the region that has the largest share of employment at risk. Because of this fact and because Houston is only a single metropolitan area with a smaller population than the other areas studied, Houston gains the least of any of the five regions by 2050 in absolute numbers of new employees. Thus, Houston's gains contribute only 0.005 point to the total national employment gain of 0.37% under the HFI Scenario. This is representative of oil dependent economies, even though Houston's energy base is quite diverse. Exploration activity will, on net, be hurt by the shift to hydrogen systems, though much of Houston-based exploration is tied to the search for natural gas, which will be modestly stimulated. Houston's refining will be deleteriously affected, but this sector has not been a source of growth since the late 1990s and is not expected to be so in the future under an all-gasoline scenario. The key for this sector will be the extent to which it transforms its product mix away from gasoline and toward other products.

On the positive side, Houston has been producing hydrogen for decades for use in refining and petrochemical processes. Though roughly half of the production of hydrogen is assumed

to come from coal in the hydrogen adoption scenarios, the technical expertise in Houston in energy, chemicals, and gases has the potential for applications in the hydrogen economy. Houston firms are already involved in a wide array of non-oil-related energy projects and activities. Thirty percent of Houston's increase in employment under the HFI Scenario, for example, will be in the high-tech-oriented professional and technical services sector.

During the 1990s, the non-energy portion of Houston's economic base grew more than three times as fast as its combined upstream and downstream energy, thereby reducing energy's share of the region's economic base below 50%. Hydrogen market expansion will likely help this trend continue.

5.0 INTERNATIONAL COMPETITION

Two major objectives will be served in the international arena. First, reduction in oil imports, with the attendant increase in energy independence, is a clear national goal to which the hydrogen economy will contribute. Second, if U.S. companies are able to forge a lead in hydrogen technologies, U.S. global competitiveness will be fostered. In light of these objectives, this section considers effects on U.S. production of hydrogen-related products and hydrogen infrastructure, energy imports, multinational corporations, the balance of payments, and capital markets.

5.1 U.S. Share of Hydrogen-Related Products

5.1.1 Vehicles and Vehicle Parts

The high cost of shipping automobiles and automobile bodies dictates that body manufacture and assembly of the vast majority of vehicles will continue to be located in the countries of final demand. The location of vehicle parts manufacturing is much less tied to final demand location.

System	Imports			Exports		
	Value, \$ billion	% of Total Imports	% of Domestic Production	Value, \$ billion	% of Total Exports	% of Domestic Production
Engine	21.338	31%	32%	9.015	21%	14%
<i>Gasoline Engine and Engine Parts</i>	12.651	19%	31%	5.871	13%	14%
<i>Electronic Equipment</i>	8.687	13%	34%	3.145	7%	12%
Transmission and Powertrain Parts	11.090	16%	24%	5.388	12%	12%
Storage Battery	1.948	3%	46%	0.766	2%	18%
Body	1.135	2%	3%	1.817	4%	5%
<i>Motor Vehicle Metal Stampings</i>	0.518	1%	2%	1.643	4%	6%
<i>Motor Vehicle Bodies</i>	0.617	1%	5%	0.174	<1%	1%
Steering and Suspension	3.845	6%	26%	1.322	3%	9%

Table 5.1. Value of U.S. Trade in Vehicle Components, by Component System, 2004 (in 2005 Prices)

System	Imports			Exports		
	Value, \$ billion	% of Total Imports	% of Domestic Production	Value, \$ billion	% of Total Exports	% of Domestic Production
Brake System	3.771	6%	21%	2.198	5%	12%
Interior	5.474	8%	19%	2.343	5%	8%
Seating and Interior Trim	3.873	6%	18%	1.780	4%	8%
Air Conditioning	1.601	2%	21%	0.563	1%	7%
All Other Parts Manufacturing	19.760	29%	43%	21.036	48%	46%
Total	68.361	100%	26%	43.886	100%	17%

Source: U.S. International Trade Commission: accessed August-September 2006 at <http://dataweb.usitc.gov/>.

Present patterns of imports and exports in vehicle parts provide a basis for estimating how U.S. competitiveness in parts manufacture would be affected by a transformation to hydrogen vehicles. Table 5.1 reports the value of trade in vehicle components, by component group, in 2004. Engine-related components (including complete engines, air and fluid handling, and electrical parts), the largest traded component group, accounted for \$21.3 billion of the \$68 billion in imports in 2004. Trade in transmission and powertrain components and storage batteries was also dominated by imports, accounting for 50% of U.S. vehicle component imports and 35% of exports.

Canada, Japan and Mexico were the countries of origin for 72% of all auto parts imported into the U.S. in 2004, with particular concentrations in engine components. Japan has been the leading exporter of powertrain parts, and Japanese domestic producers remain closely tied to Japanese multinational vehicle producers located in the U.S. Most U.S. exports of engine and powertrain parts are destined for Canadian assembly plants of DaimlerChrysler, Ford, and General Motors. The recent decline in these U.S. parts exports to the Canadian plants largely reflects the loss in U.S. motor vehicle market share.³⁷

The components in the fuel cell system can be categorized into the fuel cell stack, the fuel cell balance-of-plant (consisting of heat exchangers, controller, and air compressor or blower), and the hydrogen storage tank. Manufacture of the fuel cell stack involves new materials combined with traditional manufacturing processes tailored to fuel cells. Development of these processes is being pursued in the U.S., Japan, Korea, and the U.K. primarily, although China also has development programs. Once developed, the manufacturing processes could be moved readily to low-cost countries. Pressure to do so could be lessened because the largest cost contributor, the electrodes, will be made in automated processes, which would reduce their labor cost. Developers may want to keep manufacturing in-house to protect the intellectual property and proprietary knowledge. The high contribution of materials to the cost would tend to reduce the drive to move off-shore. The balance-of-plant components can easily be made in low-labor-cost countries, although

³⁷ Klier, T.H., Rubenstein, J.M., "Competition and Trade in the U.S. Auto Parts Sector," *Chicago Fed Letter*, No. 222 (January 2006).

the size of heat exchangers might favor their being made locally. Controllers and compressors can be made anywhere. At this time, hydrogen storage technology is an active area of research with compressed hydrogen available for purchase. Composites are made worldwide, and this should not be different for hydrogen storage tanks. Safety requirements and manufacturing controls may be considerations that keep manufacturing domestic for some period of time. The United States, Canada, and Japan each currently have a domestic leader in tank development. While any technology can be made in low-labor-cost manufacturing regions, maintaining control of intellectual property and continued development of the processes would tend to keep manufacturing of an array of components in the U.S.

Companies of many nations are competing in the emerging technologies that will be used to produce materials and components for hydrogen vehicles. Many of these companies, American as well as foreign, have manufacturing facilities in their home countries as well as abroad, and they will supply foreign markets through combinations of exports from the home country and production in the host countries. There may be some tendencies to supply more exports in early years of hydrogen market expansion (around 2020) to keep closer control of intellectual property, but even this tendency may be diluted by multinationals' location of R&D facilities in the U.S. The scope for sending maturing, labor-intensive production processes and products to lower-income countries is not expected to be substantially different for hydrogen vehicle components than for conventional components, and that could characterize issues of concern around 2035. Under either the HFI or Less Aggressive Scenario, by 2050, the vehicle elements of the hydrogen market will have matured. The effects of hydrogen market expansion on the location of automobile parts production depends on considerations such as the likely prospect of continuing change in the technologies, the experience of the companies in the automotive industry with evolving platforms and component systems, and specific developments in the many components and technologies over which competition will take place. While individual parts could be affected favorably or unfavorably, there are no indications that U.S. exports or imports of parts as a whole will be significantly affected by hydrogen market expansion.

However, a hydrogen transformation may significantly affect U.S. competitiveness in specific auto parts. The hydrogen fuel cell system will completely replace the engine, transmission, and powertrain parts and will modify storage batteries. Foreign producers have dominated these conventional, gasoline-vehicle components in recent years. Substitution of hydrogen fuel cell technology for gasoline systems could give U.S. manufacturers of the hydrogen systems an opportunity to re-capture recently lost market shares in vehicle components. With the exception of platinum, most of the materials used to manufacture fuel cell systems can be sourced domestically. Current and likely future sources of materials and components are as follows:

Carbon fiber (gas diffusion layer and hydrogen storage tank). Two grades of fiber are used in the overall system. Within the stack, the carbon fiber used in gas diffusion layers must be of high purity and be graphitized for stability. There would be many options to source this type of fiber domestically and internationally. The carbon fiber used in compressed hydrogen storage tanks must be aerospace grade with a high strength and quality to ensure reliability.

While several sources of aerospace grade material exist, Toray of Japan is currently one of the dominant suppliers. In this industry, when large quantities of material are needed for a dedicated customer (e.g., by AirBus), suppliers (e.g., Toray) have built local plants to meet these needs. With the high volumes anticipated for transportation fuel cell vehicles in the U.S., suppliers would probably do the same in a hydrogen economy.

Fuel cell membrane materials (the electrolyte). Several options are available for manufacturers of electrolyte membranes in the U.S. DuPont is currently the largest supplier. 3M and Gore are also major companies producing membranes. While there are several companies in Japan and Europe supplying membranes, U.S. manufacturers are very competitive in this area.

Graphite powder (for bipolar plates). Within the stack, the bipolar plates that electrically connect the individual cells within the stack are the largest mass of material. Graphite powder can be sourced both domestically and overseas. The resins that bind the graphite powder together can also be sourced in the U.S. Additionally, developers are considering using metal bipolar plates as an alternative to graphite bipolar plates. These metals and the required surface treatments can be obtained domestically.

Electrode materials (primarily platinum). Platinum is the dominant material in the electrode and would have to be imported. Catalyst supports used in the fuel cell may be manufactured in the U.S. or by foreign sources. South Africa is the dominant supplier (approximately 80%). As the number of fuel cell vehicles increase, recycled platinum will become an important source of material, and the volume of imports will decrease significantly. The recycling plants probably would be sited in the U.S. for proximity to the recycled materials.

Other materials for stack hardware. All other materials, such as metal or composite endplates, bolts, and wires, and balance-of-plant components (e.g., blowers, heat exchangers) could also be obtained domestically. The raw materials for these components could be produced domestically or imported.

Compressed (on-board) hydrogen storage. Several companies in North America have developed carbon fiber composite high pressure tanks for hydrogen storage. Toyota has also made announcements concerning their own technology developments. Due to the large number and size of compressed hydrogen storage systems, it is anticipated that tanks and systems would be manufactured in proximity to the automotive plants.

High-tech batteries. Japan, China, and Taiwan now dominate the manufacturing of high-tech batteries for digital electronics. A partnership of Panasonic and Toyota make the Prius nickel metal hydride battery today. Adoption of hybrid electric vehicles or plug-in hybrid electric vehicles would significantly stimulate the production of advanced batteries in these countries.

5.2 Hydrogen Infrastructure

Different opportunities will arise in the manufacture of infrastructure components and construction and operation of hydrogen production and delivery facilities. Construction and

operation will be conducted domestically, but manufacture of components will involve a combination of imports and export opportunities.

5.2.1 Infrastructure Construction

Because of the difficulties in transporting it, hydrogen will not be an internationally traded commodity, with the possible exception of some relatively short-distance, cross-border trade with Canada and Mexico. Consequently, the production facilities serving the U.S. market will be built and operated domestically. Foreign participation in the construction of the large, centralized hydrogen generation facilities is likely to resemble current involvement in U.S. refinery or chemical plant construction. The bulk of the engineering contractual work would likely be undertaken by domestic companies. While some foreign firms could design some of the generating facilities, they would have to contract out the actual construction work to U.S. companies. Most of the cement would be provided by local firms, while most of the steel probably would be imported. The U.S. currently has a strong position in supplying reforming equipment for domestic operations, and the U.S. shares the provision of domestically operated electrolyzers with Canadian and European suppliers.

5.2.2 Infrastructure Components

Because of the increase in the volume of hydrogen, the quantities of these infrastructure components will increase. The present distribution among countries of sources for hydrogen infrastructure materials and components gives a basis for assessing the extent to which hydrogen transformation will lead to relative changes in the sources.

Large container vessels. These vessels, used in centralized production facilities, use high pressures and temperatures and would require specialized alloy materials and manufacturing techniques that no longer exist in the U.S. They would have to be imported.

Pipelines. The U.S. has several large manufacturers of pipeline (Air Products, Praxair) but there is no reason to discount European and Japanese involvement in hydrogen pipeline manufacturing when pipeline demand reaches large scale. Given the large capital outlays, any hydrogen pipeline manufacturer would probably be looking for partners, and those are likely to be domestic or foreign oil or gas companies.

The smaller pipelines are likely to be produced in the U.S., while many of the larger pipelines could be manufactured in Canada, which possesses a current advantage given its large natural gas industry.

Carbon fiber and aluminum liner. Unlike natural gas, hydrogen causes embrittlement and metal fatigue. Light-weight materials like aluminum liner will be used to contain the hydrogen inside any storage facility, pipeline or cylinder. Carbon fiber will be used to add strength to the liner. The carbon fiber, even if produced by a foreign company, probably would be located near its mature markets, and aluminum liner could be supplied domestically.

Dispensers (at fueling stations). At least one-half of dispensers are currently manufactured in the U.S. Most of the metering equipment, however, is imported.

Compressors. Large compressor stations for hydrogen are currently manufactured both domestically and abroad. Europe, Japan and Canada are expected to remain competitive.

Turbines and generators. These large capital goods contain numerous components, many of which are sourced from both the U.S. and abroad. Germany, Japan, the U.S. and eventually China are expected to be competitive in this product field.

Valves, bolts, threads, and well fittings. These products are made abroad, in both Europe and Asia. The exception is large valves, which are manufactured in the U.S. This pattern of comparative advantage is not foreseen to change.

5.3 Energy Imports

5.3.1 Oil

In 2005, oil imports accounted for 1.5% of gross domestic product, nearly 11% of all imports, and 24% of the trade deficit.³⁸ Light-duty vehicle oil consumption in 2020 is estimated at \$300 billion, with two-thirds or \$200 billion being imported. Assuming further increases in oil consumption will have to come primarily from increased imports, growth in demand due to growth in population, vehicles per household and miles driven per vehicle would add \$79 billion to the import bill by 2050.³⁹ Adding the \$79 billion to the \$200 billion gives a total 2050 import savings of \$279 billion at 2020 prices if gasoline-powered light-duty vehicles were eliminated. The world oil price is projected to rise 38% between 2020 and 2050, so at 2050 prices, the import savings would be \$385 billion. Under the HFI Scenario, ninety-six percent of the light-duty vehicle stock is expected to be hydrogen in 2050. Ninety-six percent of the \$385 billion is \$370 billion in import savings from going to hydrogen. This estimate assumes no increase in fuel efficiency in gasoline vehicles, which to the extent it occurs will reduce import savings. Import savings would be lower in the years before 2050 and also lower under the Less Aggressive Scenario—\$229 billion in 2050.

5.3.2 Natural Gas

The volume of natural gas imports nearly tripled between 1990 and 2005, and their value increased by a factor of 7 because of the price increases over that period. Imports of natural

³⁸ Trade data: Office of Trade and Industry Information (OTII), Manufacturing and Services, International Trade Administration, U.S. Department of Commerce, accessed August – September 2006 at <http://ese.export.gov/>; oil imports data: Energy Information Administration, accessed August – September 2006 at http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mdbl_m.htm; balance of payments data: Bureau of Economic Analysis, accessed August – September 2006 at <http://www.bea.gov/bea/di/table1.xls>; GDP data: <http://www.bea.gov/bea/dn/home/gdp.htm>.

³⁹ \$79 billion is derived from 0.78% growth award factor to the total annual.

gas accounted for 1.7% of all U.S. imports in 2005.⁴⁰ With the assumption that coal gasification with carbon sequestration and biomass will be used in preference to reforming of natural gas, the demand for natural gas will not see an appreciable increase due to large expansion of hydrogen markets. Some natural gas will be used during early market growth and may continue to be used in some cases, for stationary fuel cells, for example; however that would be offset to some extent by diversion of natural gas demand from electric utilities as fuel cells supply a portion of incremental electricity demand.

5.4 Multinational Corporations

Continued U.S. federal investment in hydrogen R&D will foster global competitiveness of U.S. firms as the economy is transformed to hydrogen. The movement to hydrogen could well be an opportunity for U.S. automotive firms to recapture market share lost to foreign multinationals in recent years.

The backdrop is the on-going growth in production of U.S. corporations in other countries and of foreign multinationals in the U.S., which is a part of economic globalization. These changes affect where assets are owned, but they do not necessarily have a great effect on the location of production and employment, which is determined largely by underlying cost and demand considerations. U.S. firms have successfully established vehicle assembly plants in India and China, which will be the world's major purchasers of light-duty vehicles by 2030, while Japanese, Korean, and German firms have located plants in the U.S. Competition among U.S. companies and multinational producers in other countries can be expected to continue with hydrogen vehicles. R&D in hydrogen vehicle technologies is occurring worldwide, and it can be expected that most major vehicle and components manufacturers will find the new technologies available to them. As research becomes more applied, companies may follow different development paths, though any predictions about the relative success of companies of different national origins would have a weak basis.

Two areas where effects could be noticeable, however, stem from the choices of multinationals as to where to carry out R&D—which could in turn affect the location of parts production—and differences between the choices made by U.S. corporations and multinationals regarding the location of their automobile production facilities.

Foreign vehicle multinationals have begun conducting significant automotive research and development in the U.S., for two principal reasons: to take advantage of America's relative abundance of engineering talent and its engineering education facilities, and to ensure their vehicles meet U.S. environmental and safety standards. Japanese firms have led the way, with 34 U.S.-based R&D centers employing more than 3,000 in 2004, up from 200 in 1987.⁴¹ These U.S.-based facilities are being given more responsibility over time. For example, the 2005 Avalon sedan is the first Toyota vehicle engineered from start to finish at its Toyota's

⁴⁰ Energy Information Administration sources: accessed August – September 2006 at http://tonto.eia.doe.gov/dnav/ng/ng_move_imp_c_sl_a.htm and http://tonto.eia.doe.gov/dnav/ng/ng_move_exp_c_sl_a.htm.

⁴¹ Japan Automotive Manufacturers Association (JAMA), "Growing in America," accessed August – September 2006 at http://www.jama.org/library/factsheets/Contributions_2005.pdf, pp.1, 4.

Ann Arbor facility. Foreign firms can be expected to locate R&D facilities for hydrogen vehicle technology in the U.S. for the same reasons their R&D centers are growing rapidly today. This development could offset the tendency among foreign firms to keep new technology developments close to home, with concomitantly greater production of both automobiles and parts in the U.S.

5.4.1 Future Hydrogen Production by Multinationals

Both foreign and American multinationals are well represented in the energy and industrial gas manufacturing industries. The multinational oil companies are likely prospects to produce hydrogen, particularly from centralized facilities. Their hydrogen production activities overseas probably would parallel those in the U.S.

The industrial gas manufacturing firms also include both U.S. and foreign multinationals: the American Air Products and Praxair in the United States, Linde in Germany, and Air Liquide in France. Linde recently purchased British BOC Gases to become the world's largest industrial gas company. Each of these firms will acquire shares of the expanding U.S. hydrogen market, but there is little basis for predicting changes among their shares of the market.

The construction of the reactors to provide nuclear-generated hydrogen likewise could involve both American and foreign multinational reactor vendors. The operation of the facilities would be strictly domestic, however.

5.4.2 Regional Implications

The location of foreign multinationals' plants in the U.S. has changed the distribution of the vehicle industry from the Upper Midwest and along the east coast toward the South, in a north-south strip largely between Interstates 65 and 75, with allowance for new plants in South Carolina.⁴²

The past twenty years' experience of foreign multinationals' locational choices in the U.S. is a reasonable guide to their participation in hydrogen vehicle components and assembly. The future division of production in the U.S. between domestic and foreign multinational corporations may continue to affect the regional distribution of production. If so, the extent to which U.S. corporations or foreign multinationals take the lead in introduction of hydrogen vehicles could affect the location of automobile production within the U.S., with implications discussed above in Section 4 on regional impacts.

⁴² Klier, T.H., Rubenstein, J.M., "The Supplier Industry in Transition—The New Geography of Auto Production," *Chicago Fed Letter*, No. 229b (August 2006).

5.5 Indirect International Effects on the U.S. Economy

5.5.1 Effects on the Trade Balance and Exports

The \$370 billion oil import savings estimated above under the HFI Scenario in 2050 amounts to 1% of the \$38.12 trillion projected 2050 gross domestic product. Some of the reduction in expenditures on imported oil will be redirected to a domestically produced, largely nontradable good—hydrogen. The \$370 billion reduction in oil imports equals approximately 7.5% of projected total U.S. imports in 2050 if trade grows at the same rate as gross domestic product. The oil import reduction introduces a trade imbalance that will lead to a combination of adjustments in non-oil imports and exports. The adjustments will be spread over the many non-oil commodities involved in U.S. trade. Considering that both import and export adjustments will occur and that they will occur over a 30-year hydrogen market expansion period, the average yearly quantity adjustment for a typical commodity will be less than 0.1 of one percent. Similar considerations apply to all countries adopting hydrogen. On-going globalization effects on trade over the coming years seem bound to overwhelm the small trade adjustments to the reduction in oil imports.

5.5.2 Effects on the World Capital Market and Interest Rates

A similar conclusion applies to effects on world capital markets. Some of the oil producing, and particularly OPEC, countries have had high propensities to save their oil profits and have invested extensively in industrialized nations' assets. In 2005, OPEC dollars recycled into net direct and portfolio investments, worldwide, amounted to around \$100 billion.⁴³ With falling OPEC incomes, OPEC countries' purchases of U.S. assets would be reduced.

Overall financial lending to industrialized countries would be lowered. Because OPEC demand for financial assets is a small part of total world demand for assets, any effect on interest rates might not be perceptible. The fact that the effect is spread over many years would make it even less noticeable, particularly since non-hydrogen events can be expected to have many and varied influences of much greater magnitude on world interest rates.

⁴³ International Monetary Fund, *World Economic Outlook – Globalization and Inflation*, Washington D.C., April 2006, Figure 2.3, p. 74.

6.0 CONCLUSION

This report estimated the employment impacts of a transformation of the U.S. economy to hydrogen economy between 2020 and 2050. The report examined the differences in employment by industry between a non-hydrogen base case scenario and two scenarios of expanded market penetration of mobile and stationary hydrogen fuel use. The more rapid transformation scenario followed the HFI of saving 11 million barrels of oil per day by 2040, and the less rapid scenario followed DOE's analysis supporting its 2006 program benefits estimation. Under the HFI Scenario, the penetration of the light-duty vehicle stock with hydrogen powered vehicles by 2050 is 96%. Under the Less Aggressive scenario, penetration by 2050 is 38%. The choices of hydrogen production technologies supplying the demands for hydrogen at the three dates examined—2020, 2035, and 2050—and the shares of production contributed by each, were based on DOE's H2A models.

National employment impacts were estimated from the 509-sector IMPLAN inter-industry model for the U.S. economy. Revised industry purchase vectors were constructed for three industries for the hydrogen scenarios—vehicle components, vehicle assembly, and hydrogen production. By 2050, under the HFI Scenario, the transformational adjustments are fully completed, with no more anticipatory investment; U.S. employment is increased by a net of 0.37%, or 675,000 jobs out of a total projected base-case employment of 184 million. Under the Less Aggressive scenario, the transformation is not fully completed by 2050; U.S. employment is increased by that year by a net of 0.20%, or 361,000.

Projections of the job creation and job replacement underlying the total employment changes were based on expected changes in the occupational and skill structure of directly affected industries, estimated with the assistance of industry opinions. While net employment in the automotive industry is unchanged between the gasoline and hydrogen economies, replacement of gasoline-related skills with hydrogen-related skills is substantial under the HFI Scenario. In automotive parts manufacturing, 12,000 white collar jobs are created by 2050; and blue-collar job creation and replacement is 117,000 by 2050. The greatest job creation and replacement is for automobile dealerships and repair: 680,000 by 2050.

Training implications of the job changes vary by industry and skill, as indicated by a survey of industry opinions. Most of the needs for new skills can be supplied by normal rates of entry into the labor force as workers receive training in new, hydrogen-related skills. Considering the small proportion of all engineers in the U.S. that the automobile industry employs, engineering schools have the capacity to respond to changes in the fields of engineering. Up to 110,000 technicians and mechanics will need to be equipped with hydrogen-technology skills by 2020 to service new vehicles in the HFI Scenario. By 2050, the number is 630,000, many of whom will have entered the labor force prior to the beginning the hydrogen transformation.

Regional employment impacts were estimated using regional differences in industry structures and resource bases for hydrogen production. Compared to the base case without a hydrogen transformation, the HFI Scenario leads to a projected gain in the Upper Midwest of 105,000 net additional jobs by 2050, or 0.44% of its base-case employment, distributed

across 41 industries. Projected increases in employment over the base case are 0.56% for the Lower New England and Upper Mid-Atlantic region, 0.45% for California, and 0.5% for Tennessee. Houston's energy experience leads to employment gains in hydrogen production and pipeline equipment, with an overall 0.37% gain over the base case.

The employment impacts of a hydrogen transformation on international competitiveness are limited by the fact that most vehicle production will continue to be tied to countries with large automobile demands. If the shares of U.S. production provided by U.S. multinational corporations are affected because some companies get ahead of others in introducing hydrogen vehicles, the location of automobile production within the U.S. could be affected due to the fact that companies differ in their regional concentrations of production facilities.

Recommendations

This study identified possible employment impacts that could result from hydrogen market expansion in the transportation, and stationary and portable power sectors. As noted previously, any study of potential future impacts necessarily presents difficult challenges and involves significant uncertainties. Results and recommendations should be considered with those issues in mind.

The scenarios, hydrogen generation options, and regions selected for the study yielded a reasonable measure of the potential opportunities that hydrogen presents to U.S. employment. The study considers introduction of the fuel cell vehicle and supporting hydrogen infrastructure development that spans a period of approximately 40-50 years. The study highlights possible skill and education needs to support the associated industries and technologies. In addition to the specific skill requirements of the fuel cell industry, future education of the next generation should be focused on skill sets to have the ability to adapt to changing technologies.

Training implications of the job changes vary by industry and skill, as indicated by a survey of industry opinions. Most of the needs for new skills can be supplied by normal rates of new entry into the labor force as workers receive training in new, hydrogen-related skills. Considering the small proportion of all engineers in the U.S. that the automobile industry employs, engineering schools have the capacity to respond to changes in the fields of engineering. Following are employment-related recommendations of a transition to a hydrogen economy.

1. Training programs.

- a. Training and retraining programs may be needed to help ensure that the U.S. workforce possesses the appropriate skills and that sufficient numbers of trained personnel are available to meet the manufacturing requirements at the time that hydrogen fuel cell vehicles begin to come off the assembly lines. Development of these programs should involve close coordination between the fuel providers and auto manufacturers, and schools. At the appropriate time university and vocational programs need to be assessed to understand where the opportunities lie and what additional curricula may be needed.
- b. Training and retraining programs may be useful in related aftermarket areas such as repair and recycling.
- c. Educational programs aimed at the general public could help to influence people to pursue jobs in hydrogen and fuel cells.

2. Additional analysis.

- a. *Analysis of training needs:* The study found that training for new skills may be needed across a wide spectrum of industries. Most of the needs for new skills can be

supplied by normal rates of new entry into the labor force as workers receive training in new, hydrogen-related skills. Some changes in skills appear to be relatively well defined, but many likely changes remain difficult to forecast, since many of the technologies are still maturing. Many job tasks remain unknown at present, making identification of training needs an interactive task with job definition.

b. *Assessment of skill changes, with attention to industry adjustments in different regions:* Unemployment resulting from the elimination of jobs associated with obsolete technologies and industries is estimated to be slight. The supply of labor with technology-specific skill sets may or may not keep pace with the labor demands associated with the rapid growth in the hydrogen-related industries. Even though this study indicated every region would gain jobs, surpluses and shortages of skilled workers could vary regionally.