Executive Summary

The use of hydrogen as an energy carrier has the potential to reduce U.S. dependence on foreign petroleum, diversify domestic energy sources, and decrease pollution and greenhouse gas emissions. Fuels cells operating on hydrogen produced from renewable resources and nuclear energy result in reduced air pollutants and near-zero carbon emissions. In addition, hydrogen production from coal and natural gas with carbon capture and sequestration can provide a means for domestic fossil fuels to remain viable energy resources. Hydrogen's use in fuel cell vehicles can reduce oil demand in the transportation sector, and its use in central and distributed electric power generation can provide a more efficient and diversified energy infrastructure.

Recognizing the potential of hydrogen and fuel cells, President Bush announced the Hydrogen Fuel Initiative (HFI) in his 2003 State of the Union address to accelerate the research, development, and demonstration of technologies for fuel cell vehicles and the hydrogen fuel infrastructure to support them. In 2006, the President announced the Advanced Energy Initiative (AEI), which accelerates R&D of technologies for both transportation and stationary power generation, includes near-term transportation solutions such as plug-in hybrids and ethanol vehicles, and supports the hydrogen R&D efforts that are underway. The central mission of the Department of Energy Hydrogen Program is to research, develop, and validate hydrogen production, delivery, storage, and fuel cell technologies. This document describes the status, challenges, and RD&D activities of the DOE program. The current focus of the Hydrogen Program is to address both key technical challenges (for fuel cells and hydrogen production, delivery, and storage) and institutional barriers (such as

"We're too dependent on foreign sources of energy today, and one way to diversify away from hydrocarbons is to use hydrogen, the byproduct of which will be water and not exhausts which pollute the air ... I'm excited to be part of a technological revolution that's going to change the country."

— President George W. Bush
Visiting the Shell Hydrogen Station
May 25, 2005
Washington, DC
“Investments in fuel cell and hydrogen research today will enable America to lead the world in developing clean, hydrogen-powered automobiles that will reduce our dependence on imported oil.”

Energy Secretary Samuel Bodman Announcing $119 Million in Funding to Advance Hydrogen Fuel Cell Vehicles, January 24, 2006, Washington, DC.

Positive Attributes of Hydrogen as an Energy Carrier

- Can be derived from diverse domestic resources (fossil, nuclear, renewable)
- Can be used with high-efficiency fuel cells, combustion turbines and reciprocating engines to produce power with near-zero emissions of criteria pollutants
- Produces near-zero emissions of greenhouse gases from renewable and nuclear sources and from fossil fuel-based systems with carbon sequestration
- Can serve all sectors of the economy (transportation, power, industrial, and buildings)

hydrogen codes and standards to maximize safety, training, and public awareness). The DOE Hydrogen Program is a partnership between a number of DOE program offices: Energy Efficiency and Renewable Energy (EERE), Fossil Energy (FE), Nuclear Energy (NE), and Science (SC). The Program is currently conducting basic and applied research, technology development and learning demonstrations, as well as underlying safety research, systems analysis, and public outreach and education activities. These activities include cost-shared, public-private partnerships to address the high-risk, critical path technologies preventing widespread use of hydrogen as an energy carrier.

Challenges for Hydrogen as an Energy Carrier

The transition from our current energy infrastructure to a clean and secure energy infrastructure based on hydrogen and other alternative fuels will take decades as the difficult challenges posed by technological, economic and institutional barriers are addressed and overcome. For hydrogen, the “critical path” barriers are list below.

Technology Challenges

- Hydrogen storage systems for vehicles are inadequate to meet customer driving range expectations (>300 miles) without intrusion into vehicle cargo or passenger space.
- Hydrogen is currently more expensive than gasoline.
- Fuel cell system costs are more than internal combustion engines and stacks do not maintain performance over the useful lifetime of a vehicle.
Economic and Institutional Challenges

- Investment risk of developing a hydrogen delivery infrastructure is high, given technology status and current absence of hydrogen vehicle demand.
- Investment risk of developing manufacturing capability for hydrogen and fuel cell technologies is high.
- Uniform model codes and standards to ensure safety and insurability do not exist.
- Local code officials, policy makers and the general public lack education on hydrogen benefits and on safe handling and use.

Hydrogen Program Progress

- As a result of the Hydrogen Program, significant progress in overcoming the “critical path” challenges has been made over the past 3 years. The accomplishments include:
  - Cost of polymer electrolyte membrane fuel cell systems has been reduced to $100/kW, 4x (in high volume) that of internal combustion engines.
  - Cost of distributed hydrogen production from natural gas has been reduced to $3.00/gallon of gas equivalent (gge).
  - New materials with potential for high hydrogen storage capacity have been identified and are under development.
  - Learning demonstrations have provided valuable data on the current performance of fuel cell vehicles and hydrogen stations in real world applications.

“The prospect of massive penetration of renewable sources like wind, solar, geothermal, biomass, biofuels, hydrogen as well as new engine, battery storage, and vehicle efficiency technologies, is not only possible, it is something that is quantifiable; goals that can be planned, and pursued, and managed and funded. If we are willing to do what Americans do best: embrace innovation and entrepreneurship, marry science and commerce, think dynamically, and not be consumed by the seemingly static nature of the status quo.”

DOE/EERE Assistant Secretary Alexander Karsner’s remarks at the Advancing Renewable Energy Conference in St. Louis, Missouri, October 12, 2006.

“Critical-Path” Technologies Necessary for Developing a Hydrogen Infrastructure

- More compact, lighter weight, lower cost, safe, and efficient higher storage systems
- Lower cost, more durable materials for advanced conversion technologies, especially fuel cells
- Lower cost methods for producing and delivering hydrogen
- Technologies for low cost carbon capture and containment for fossil-based production (a separate DOE program coordinated with the Hydrogen Program)
- Designs and materials that maximize the safety of hydrogen use
Developing hydrogen as a major energy carrier will require a combination of technological breakthroughs, market acceptance, and large investments in infrastructure. Success will be incremental over decades; and it will require an evolutionary process that phases hydrogen in, assisted by government policies, as the technologies and their markets mature.

Early market and niche applications (e.g., forklifts, stationary and portable power) can help pave the way for automotive fuel cells by accelerating development of manufacturing capability and facilitating customer acceptance. The successful development of hydrogen energy from diverse domestic resources will ensure that the United States has an abundant, reliable, and affordable supply of clean energy to maintain the nation’s prosperity throughout the 21st Century.