Executive Summary

The United States pioneered the development of hydrogen and fuel cell technologies, and we continue to lead the way as these technologies emerge from the laboratory and into commercial markets. A tremendous opportunity exists for the United States to capitalize on this leadership role and apply these technologies to reducing greenhouse gas emissions, reducing our dependence on oil, and improving air quality.

Fuel cells can address our critical energy challenges in all sectors—commercial, residential, industrial, and transportation. They can use diverse fuels, including biomass-based fuels, natural gas, and hydrogen produced from renewable resources. And, they can be used in a wide range of applications, including near-term markets such as distributed primary and backup power, lift trucks, and portable power; mid-term markets such as residential combined-heat-and-power (CHP) systems, auxiliary power units, and fleet vehicles; and longer-term markets such as light-duty passenger vehicles.

The central mission of the U.S. Department of Energy's (DOE's) Hydrogen and Fuel Cells Program (the Program) is to enable the widespread commercialization of a portfolio of hydrogen and fuel cell technologies through basic and applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges. The Program integrates activities across four DOE offices–Energy Efficiency and Renewable Energy (EERE), Science, Fossil Energy, and Nuclear Energy–and works with partners in state and federal agencies, foreign governments, industry, academia, non-profit institutions, and the national laboratories. This document describes the status, challenges, and activities of the DOE Fuel Cell Technologies Program [(FCT Program) which is the EERE portion of the DOE-wide Hydrogen and Fuel Cells Program] and how these activities relate to the Program's mission. The current focus of the Program is to address both key technical challenges (for fuel cells and hydrogen production, delivery, and storage) and institutional barriers (such as hydrogen codes and standards). These activities include cost-shared, public-private partnerships to accelerate the development of higher-risk technologies essential to the widespread use of hydrogen and fuel cells.

Key Benefits of Hydrogen and Fuel Cells

- **Reducing greenhouse gas emissions**
- **Reducing oil consumption**
- **Advancing renewable power using hydrogen for energy storage and transmission**
- **Highly efficient energy conversion**
- **Fuel flexibility—use of diverse, domestic fuels, including clean and renewable fuels**
- **Reducing air pollution**
- **High reliability and grid support capabilities**
- **Suitability for diverse applications**
- **Quiet operation**
- **Low maintenance needs**
- **Opportunities for economic growth and leadership in an emerging high-tech sector**

Challenges for Hydrogen and Fuel Cell Technologies

While fuel cells are becoming competitive in a few markets, the range of these markets can be greatly expanded with improvements in durability and performance and reductions in manufacturing cost, as well as advances in technologies for producing, delivering, and storing hydrogen. Successful entry into new markets will also require overcoming certain institutional and economic barriers, such as the need for codes and standards, the lack of public awareness and understanding of the technologies, and the high initial costs and lack of a supply base that many new technologies face in their critical early stages.

Technology Challenges

- For fuel cells to be competitive with incumbent technologies their cost must be reduced and their durability must be improved.
- Some aspects of fuel cell performance must be addressed, including: improvements in operation in wide ranges of temperature and humidity; higher operating temperatures and improvements in efficiency for stationary fuel cells; and higher energy density for portable fuel cells.
- The cost of producing and delivering hydrogen from zero- or near-zero-carbon sources must be reduced.
- Compact, lightweight, and low-cost hydrogen storage systems must be developed. For vehicles, technologies must enable greater than a 300-mile driving range across all vehicle platforms without reducing performance or interior space.
- Improvements in manufacturing technologies and processes will be required to achieve the necessary cost reductions.
- Hydrogen and fuel cell technologies need to be demonstrated in complete, integrated systems operating under real-world conditions.

Economic and Institutional Challenges

- There is a high investment risk for developing and expanding manufacturing capacity for hydrogen and fuel cell technologies.
- There is a high investment risk for developing a hydrogen delivery infrastructure, given the current absence of demand for hydrogen from the transportation sector.
- Additional codes and standards need to be developed and harmonized (nationally and internationally) to ensure safety and insurability of the technologies.
- There is a general lack of understanding and awareness of hydrogen and fuel cells, which is particularly important to address in certain key audiences, including safety and code officials, policy makers, and potential early adopters.
- Deployment costs such as siting, permitting, installation, and financing remain too high and hinder the widespread market penetration of fuel cells in early market applications.

Program Progress

The DOE FCT Program has been integral to the important progress in hydrogen and fuel cell technologies in recent years. Specific examples of accomplishments and progress resulting from Program-funded projects include the following:

- Reduced the cost of automotive fuel cells by more than 30% since 2008 and 80% since 2002 (from $275/kW in 2002 to $49/kW in

2011, based on projections of high-volume manufacturing costs).

- More than doubled the durability of automotive fuel cell systems operating under real-world conditions, with more than 2,500-hour durability (about 75,000 miles) that can be demonstrated on the road (membrane durability has exceeded 5,000 hours at the single-cell level, with load cycling and less than 0.2 g/kW of platinum group metal.)
- Reduced the projected high-volume cost of producing hydrogen (untaxed and not including delivery or dispensing costs) through several pathways, including distributed electrolysis ($4.20/kg), central electrolysis ($4.10/kg), and central biomass gasification ($2.20/kg).
- Reduced the capital cost of electrolyzer stacks by more than 80%—from over $2,500/kW in 2001 to less than $500/kW in 2011.
- Independently produced and verified two new sorbent materials with specific surface areas in excess of 6,000 square meters per grams with excess hydrogen capacities exceeding 8 wt.% and 28 g/L at 60 bar and 77K, a greater than 13% increase in gravimetric capacity over the prior best known hydrogen sorbent.
- Developed an integrated model consisting of vehicle, fuel cell, and hydrogen storage system units, allowing for rapid and consistent evaluation of hydrogen storage system concepts and designs against the full set of 20 onboard storage performance targets.
- Demonstrated 25 fueling stations and more than 180 fuel cell electric vehicles operating under real-world conditions (these vehicles have traveled 3.6 million miles, demonstrating efficiencies of up to 59%—more than twice the efficiency of today's gasoline vehicles—and refueling times of approximately 5 minutes for 4 kg of hydrogen).
- Validated vehicles with more than 250-mile driving range, and one vehicle capable of 430 miles on a single fill of hydrogen.
- Collected and analyzed data from second generation fuel cell buses, demonstrating fuel economies more than 100% higher than diesel internal combustion engine (ICE) buses and more than 80% higher than natural gas ICE buses.
- Demonstrated combined efficiency of 54% for co-producing hydrogen and power from a stationary fuel cell.
- Demonstrated the potential for a 25% cost reduction of membrane electrode assemblies through a novel three-layer manufacturing process.
- Conducted safety research and development to provide a sound technical basis for development of critical codes and standards—including the comprehensive hydrogen code, NFPA 2.
- Developed online resources to disseminate best practices and safety information and to facilitate and streamline the permitting process for hydrogen installations.
- Educated more than 9,600 teachers about hydrogen and fuel cells.
- Completed "well-to-wheels" analysis, which shows the potential for significant reductions in emissions and petroleum use through the use of fuel cells in multiple applications.
- Supported deployments of fuel cell lift trucks, which have led to more than 3,500 additional fuel cell lift truck deployments by industry, purchased or on order—with no DOE funding.

Many of the advances that the Program has made can be seen in the marketplace today—commercial customers are choosing fuel cells for the benefits they offer. Success in early markets such as material handling equipment and stationary and portable power can help pave the way for transportation fuel cells by accelerating the development of manufacturing capacity, spurring the growth of localized infrastructure, developing and implementing codes and standards, and facilitating customer acceptance.

Hydrogen and fuel cells are also being demonstrated in growing fleets of automobiles, transit buses, and supporting refueling infrastructure. These demonstrations show strong and steady improvements in performance and durability, confirming progress toward commercial viability in these important markets. By pursuing innovative concepts and promising pathways for research, development, and demonstration, DOE has made significant technological advances; and by working to ease the transition of technologies into the marketplace, DOE has moved hydrogen and fuel cells substantially closer to the crucial role they can play in our energy economy. The successful development of hydrogen and fuel cell technologies will help to ensure that the United States has an abundant, reliable, and affordable supply of clean energy.