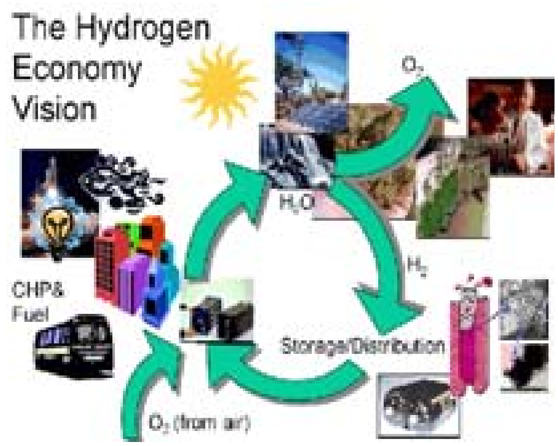
2.2.2 HYDROGEN SYSTEMS TECHNOLOGY VALIDATION

Technology Description



Similar to electricity, hydrogen can be produced from many sources, including fossil fuels, renewable resources, and nuclear energy. Hydrogen and electricity can be converted from one to the other using electrolyzers (electricity to hydrogen) and fuel cells (hydrogen to electricity). Hydrogen is an effective energy-storage medium, particularly for distributed generation.
Implementation of hydrogen energy systems could play a major role in addressing climate challenges and national security issues through 2030 and beyond. Today, hydrogen is produced primarily from natural gas using widely known commercial thermal processes. In the future, we can adapt current technologies to produce hydrogen with significantly reduced CO_2 emissions, through carbon capture and sequestration processes, and by using renewable and nuclear electricity to produce hydrogen with no production-side CO_2 emissions. Using hydrogen in combustion devices or fuel cells results in few, if any, harmful emissions.

In the next 20-30 years, hydrogen systems used for stationary and vehicular applications could solve many of our energy and environmental security concerns. Hydrogen could be affordable, safe, domestically produced, and used in all sectors of the economy and in all regions of the country.

System Concepts and Representative Technologies

- A hydrogen system is comprised of production, storage and distribution, and use. A systems approach is needed to demonstrate integrated hydrogen production, delivery, and storage, as well as refueling of hydrogen vehicles and use in stationary fuel cells. This could involve providing hydrogen in gaseous and liquid form. Technologies are in various stages of development across the system. Hydrogen made via electrolysis from excess nuclear or renewable energy can be used as a sustainable transportation fuel or stored to meet peak-power demand. It also can be used as a feedstock in chemical processes.
- Hydrogen produced by decarbonization of fossil fuels followed by sequestration of the carbon can enable the continued use of fossil fuels in a clean manner during the transition to the ultimate carbon-free hydrogen energy system.
- For hydrogen to become an important energy carrier – as electricity is now – an infrastructure must be developed. Although the ultimate transition to a hydrogen economy requires significant infrastructure investments, it is possible to develop the components of a hydrogen energy system in parallel with infrastructure. As hydrogen applications become more cost effective and ubiquitous, the infrastructure will also evolve. Beginning with fleets of buses and delivery vans, the transportation infrastructure will evolve to include sufficient refueling islands to enable consumers to consider hydrogen vehicles as attractive and convenient. The development of distributed power systems will begin with natural gas-reformer systems and evolve to provide hydrogen from a variety of resources (for all services), including hydrogen-to-fuel vehicles, reliable/affordable power, lighting, heating, cooling, and other services for buildings and homes.
- The technology-validation effort also provides information in support of technical codes and standards development of infrastructure safety procedures.

Technology Status/Applications

- Today, hydrogen is primarily used as a chemical feedstock in the petrochemical, fertilizer, electronics, and metallurgical processing industries. Hydrogen is receiving new capital investments for transportation and power-generation applications.
- Nearly half of the worldwide production of hydrogen is via large-scale steam reforming of natural gas, a relatively low-carbon fuel/feedstock. In the United States, almost all of the hydrogen used as a chemical (i.e., for petroleum refining and upgrading, and ammonia production) is produced from natural gas. Today,

we safely produce about 9 million metric tons of hydrogen annually. Although comparatively little hydrogen is currently used as fuel or as an energy carrier, there are emerging trends that will drive the future consumption of hydrogen.

- The long-term goal of the DOE Hydrogen, Fuel Cell & Infrastructure Technologies (HFCIT) Program is to make a transition to a hydrogen-based energy system in which hydrogen will join electricity as a major energy carrier. Furthermore, the hydrogen will be derived from domestically plentiful resources, making the hydrogen economy an important foundation for sustainable development and energy security.
- Requirements in California – especially the Los Angeles basin – are propelling the development of zero-emission vehicles, which in turn, provide incentives for the growth of fuel cell cars, trucks, and buses. Several bus fleets are currently incorporating hydrogen and fuel cell technologies into their fleets. Major car manufacturers are developing fuel cell vehicles in response to concerns about greenhouse gas and other emissions, and in response to policy drivers, especially for higher efficiencies and reduced oil consumption.
- Integrating the components of a hydrogen system in a variety of applications enables the continued development of infrastructure that is needed as we move from concept to reality. The development of the components of an integrated hydrogen system has begun:
- *Production*: Hydrogen production from conventional fossil-fuel feedstocks is commercial, and results in significant CO_2 emissions. Large-scale CO_2 sequestration options have not been proven and require R&D. Current commercial electrolyzers are 60%-70% efficient, but the cost of hydrogen is strongly dependent on the cost of the electricity used to split water into hydrogen and oxygen. Production processes using wastes and biomass are under development, with a number of engineering scale-up projects underway. Longer-term, direct hydrogen production processes (photoconversion) are largely in the research stage, with significant progress being made toward development of cost-effective, efficient, clean systems.
- *Storage and Distribution*: Liquid and compressed gas tanks are available and have been demonstrated in a small number of bus and automobile demonstration projects. Lightweight, fiber-wrapped tanks have been developed and tested for higher-pressure hydrogen storage. Experimental metal hydride tanks have been used in automobile demonstrations. Alternative solid-state storage systems using alanates and carbon nanotubes are under development. Current commercial practices for the distribution and delivery of hydrogen include cryogenic liquid and high-pressure trucks, and limited pipeline transmission. Longer-term, lower-cost delivery infrastructure and technologies will be needed.
- *Use*: Significant demonstrations by domestic and foreign auto and bus companies have been undertaken in Japan, Europe, and the United States. Small-scale power systems using fuel cells are being beta-tested. Small fuel cells for battery replacement applications have been developed.

Current Research, Development, and Demonstration

RD&D Goals

- The overall goal in this area is to validate, by 2015, integrated hydrogen and fuel cell technologies for transportation, infrastructure, and electric generation in a systems context under real-world operating conditions.
- By 2005, demonstrate that an energy station (coproduction of hydrogen as fuel for a stationary fuel cell and for a fuel-cell vehicle) can produce electricity for 8 cents/kWh and $3.60/gallon gasoline equivalent.
- By 2008, demonstrate stationary fuel cells with a durability of 20,000 hours and 32% efficiency.
- By 2009, demonstrate vehicles with greater than 250-mile range and 2,000-hour fuel cell durability.
- By 2009, establish hydrogen production at $3/gallon gasoline equivalent.
- By 2015, provide critical statistical data that demonstrate that fuel cell vehicles can meet targets of 5,000-hour fuel cell durability, storage systems can efficiently meet 300+ mile range requirements, and H_2 fuel can cost less than $2.50/gallon gasoline equivalent.
- The technology validation effort also will provide sufficient information in support of technical codes and standards development of infrastructure safety procedures.

RD&D Challenges

- Low-cost and durable fuel cells need to be developed and demonstrated that can make significant market penetrations in the transportation and electric-generation sectors.

- Low-cost, low-weight, and high energy-density storage systems need to be developed so that there is no compromise to vehicle costs and existing vehicle passenger or trunk compartments.
- Hydrogen can be produced and delivered at a cost that is competitive on a cents/mile basis with current vehicles.
- Codes and standards must be developed and implemented.

RD&D Activities

- The overall strategy of the HFCIT Program is to conduct a comprehensive and balanced program that includes mid- and long-term research and development of hydrogen production, storage, and utilization technologies; integrated systems and technology validation using close collaboration with industry that develops, demonstrates, and deploys critical technologies emerging from research and development; and an analysis element that helps determine the performance and cost targets that technologies must meet to achieve goals of the HFCIT Program, as well as specific project objectives determined by peer review.
- DOE's HFCIT Program is carried out by national laboratories, universities, and the private sector, including cost-shared industry-led efforts, and CRADA collaborations between industry and the labs.

Recent Progress

- Hydrogen refueling equipment (liquid delivered to the facility) – to provide hydrogen to the small fleet of hydrogen fuel cell vehicles that are currently being tested in California – has been installed by the California Fuel Cell Partnership (Sacramento, California).
- Three Power Park facilities that generate power from fuel cells and engines and hydrogen fuel for vehicles have been built and are being tested. Natural gas, biomass, wind, and solar energy are being used to generate the hydrogen fuel for both stationary power and for vehicles.
- An Energy Station that coproduces hydrogen fuel from natural gas for both stationary and vehicles applications has been demonstrated.
- Four awards have been made to major automobile and energy company teams to demonstrate up to 120 vehicles and 28 stations that will validate program targets under real-world operating conditions.

Commercialization and Deployment Activities

- Major industrial companies are pursuing R&D in fuel cells and hydrogen reformation technologies with a mid-term (5-10 years) time frame to deploy these technologies for both stationary and vehicular applications. These companies include ExxonMobil, Shell, Chevron Corporation, BP, General Motors, Ford, Daimler-Chrysler, Hyundai, Toyota, Honda, Nissan, BMW, United Technology Corporation Fuel Cells, Ballard, Air Products, and Praxair.
- The National Vision of America's Transition to a Hydrogen Economy, completed in November 2002, outlines a vision for America's energy future – a more secure nation powered by clean, abundant hydrogen. This document was used as the foundation for formulating the elements of the National Hydrogen Energy Roadmap.
- The Fuel Cell Report to Congress, completed in February 2003, was a request from Congress that DOE report (within 12 months) to the House and Senate Committees on Appropriations, on the technical and economic barriers to the use of fuel cells in transportation, portable power, stationary, and distributed power generation applications.
- In November 2002, the U.S. Department of Energy issued its National Hydrogen Energy Roadmap. The purpose of the roadmap was to identify the activities required to realize hydrogen's potential to address U.S. energy security, diversity, and environmental needs.
- The DOE Office of Energy Efficiency and Renewable Energy (EERE) – with support from the DOE Offices of Fossil Energy; Science; and Nuclear Energy, Science, and Technology – completed a Hydrogen Posture Plan in response to the President's Hydrogen Fuel Initiative. This document outlines the activities, milestones, and deliverables that the Department plans to pursue to support America's shift to a hydrogen-based energy system.
- The DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program completed a Multiyear Research, Development, and Demonstration (RD&D) Plan in February 2005, detailing the goals, objectives, technical

targets, tasks, and schedule for EERE's contribution to the DOE Hydrogen Program.

- The DOE Office of Fossil Energy (in June 2003) completed the FE Hydrogen Program Plan, focusing on the research, development, and demonstration activities that are required to develop advanced hydrogen production, storage, and delivery technologies from fossil fuels.
- The Basic Research Needs for the Hydrogen Economy, completed by the DOE Office of Basic Energy Sciences in 2003, outlines the findings from the Basic Energy Sciences Workshop on Hydrogen Production, Storage, and Use.
- The DOE Nuclear Energy, Science, and Technology Program completed the Nuclear Hydrogen R&D Plan in March 2004 to identify the candidate advanced hydrogen production technologies most suitable for nuclear energy, assess their viability, and prioritize the needed R&D to enable the demonstration of nuclear hydrogen production. The DOE Nuclear Energy, Science, and Technology Program also completed the Nuclear Hydrogen Initiative Ten-Year Program Plan in March 2005, identifying objectives and priorities to provide programmatic direction within the U.S. Department of Energy (DOE) and among the program participants or collaborators, including national laboratories, industry, universities, and international participants.