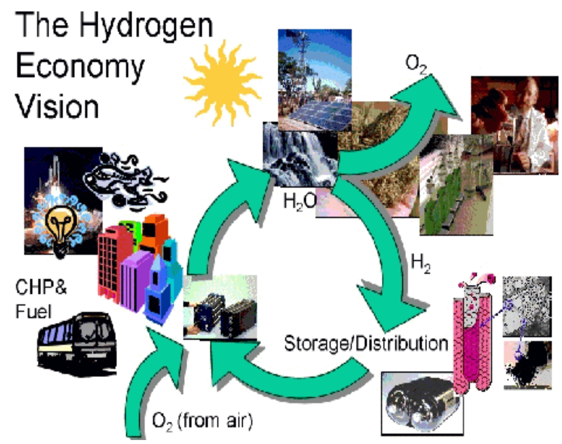
2.2.2 INTEGRATED HYDROGEN ENERGY SYSTEMS

Technology Description



Like 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, it could be produced directly from renewable resources. In the meantime, 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.

The vision for a hydrogen economy is based on a clean and simple cycle: separate water into hydrogen and oxygen using renewable energy such as solar. Use the hydrogen to power a fuel cell, where hydrogen and oxygen (from air) recombine to produce electrical energy, heat, and water to complete the cycle. This process produces no particulates, no carbon dioxide, and no pollution.

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 is likely to 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. 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.

Technology Status/Applications

- Today, hydrogen is primarily used as a chemical feedstock in the petrochemical, food, 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 use about 90 billion m^3 (3.2 trillion ft^3) of hydrogen yearly. 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 (HFC&IT) Program is to make a transition to a hydrogen-based energy system in which hydrogen will join electricity as a major energy carrier. Furthermore, much of 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 70%-80% 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 – including truck, rail, and barge delivery of liquid or compressed gas – will provide the most cost-effective hydrogen until demand increases and additional infrastructure is developed.
- *Use*: Small demonstrations by domestic and foreign auto and bus companies have been undertaken. 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

- By 2005: (1) develop auxiliary equipment (including sensors) that enable the use of hydrogen as a fuel and energy carrier; (2) investigate material compatibility and durability issues, as well as evaluate network capacity related to distribution of hydrogen; (3) install refuelers in key locations; and (4) adopt codes and standards for hydrogen systems.
- By 2010: (1) define a cost-effective hydrogen delivery infrastructure; (2) verify technologies that reduce the delivery cost of hydrogen for distances less than 200 miles to less than $.70/kg; and (2) verify technologies that reduce the moving and handling cost of hydrogen within the refueling station or power generation facility to less than $.60/kg.
- By 2015: (1) verify technologies to deliver hydrogen from the point of production to the point of use for a cost of less than $1/kg.

RD&D Challenges

- Codes and standards must be developed and implemented; appropriate supporting research and modeling are needed to validate system designs and operating procedures.
- Enabling technologies such as sensors need to be developed and commercialized.
- Infrastructure can be developed step-wise for the near-term, but eventually must be widespread and cost-effective. Thoughtful development schemes are needed to maximize the value of the investment.

RD&D Activities

- DOE's HFC&IT Program is carried out by national laboratories, universities, and the private sector, including CRADA collaborations between industry and the labs, and cost-shared industry-led efforts.
- The overall strategy of the HFC&IT 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 HFC&IT Program, as well as specific project objectives determined by peer review.

Recent Progress

- A complex integrated demonstration project is operated by SunLine Transit (Thousand Palms, California). The project includes both fossil- and renewable-hydrogen production, compressed gas storage and hydrogen use for transportation (public transit), and stationary power (educational displays). The refueling facility is open to the public and provides pressurized and liquid hydrogen, hydrogen/natural gas blends, and natural gas. The transit fleet includes buses running on hydrogen/natural gas blends and an Xcellsis fuel cell bus.
- A number of hydrogen/fuel cell personal vehicles (modified golf carts) have successfully been operated by Palm Desert (California), in conjunction with the Schatz Energy Research Center/Humboldt State University and with support from the DOE HFC&IT Program.
- 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).

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) timeframe to deploy these technologies for both stationary and vehicular applications. These companies include ExxonMobil, Shell, Texaco, BP, General Motors, Ford, Daimler-Chrysler, Toyota, Honda, United Technology Corporation Fuel Cells, Ballard, Air Products, and Praxair.
- To address the key barrier of perceived safety, the DOE initiated a successful effort to have the International Code Council (ICC) form a special committee to develop provisions specific to hydrogen for incorporation into its model building, fire, and fuel gas codes, which the ICC will publish for adoption by local jurisdictions throughout the United States. The ICC model codes will incorporate standards for hydrogen components and equipment being developed by leading organizations, such as the Society of Automotive Engineers and the International Standards Organization.
- The DOE completed a technology vision and roadmapping effort with industry to develop a framework for public-private partnerships to develop and deploy a national hydrogen infrastructure. The report was unveiled on November 12, 2002, by the Energy Secretary.