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The South Carolina Hydrogen Economy:

Capitalizing on the State's R&D Assets

Prepared for:

South Carolina Hydrogen Coalition and
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July 2005

1.0 INTRODUCTION

The great promise of a future hydrogen economy in the United States is captivating the interest of a growing number of individuals and organizations. In such an economy, hydrogen would be the primary source of energy for most transportation, industrial, commercial, and residential purposes. The advantages would include significant environmental and national energy security benefits. This changeover from our current fossil fuel-based economy would also have many far-reaching implications, and it would be accompanied by fundamental and dramatic shifts in how energy is produced, stored, transmitted, and used.

In 2002, the United States Department of Energy (DOE) completed an ambitious effort to produce a *"National Hydrogen Energy Roadmap,"* which outlined a long-term hydrogen research, development, and demonstration strategy for the nation. In 2003, a Committee of the National Research Council and National Academy of Engineering released an evaluation and review of DOE's Roadmap. These reports (and others cited in the Bibliography, Appendix II) describe the opportunities and technical challenges associated with developing a hydrogen economy. They also indicate that major investments will be needed during the next 50 years to realize the promise of a hydrogen economy and that the first wave of those investments are already flowing to major R&D projects in industry, research organizations, and universities today.

South Carolina has a limited window of opportunity to gain a significant share of these investments and to build a substantial new economic base. By beginning to act today, the state can capitalize on its existing R&D capabilities in order to enhance its ability to compete for the new jobs and wealth that will be created within a hydrogen economy over the longer term.

Although individual South Carolina research institutions have important capabilities related to a hydrogen economy, more than a dozen other states have already organized significant statewide efforts focused on establishing leadership positions in major hydrogen economy segments. Consequently, South Carolina organizations will need to act quickly, and on a concerted basis, to compete effectively with the other states that have already moved to advance their hydrogen economy-related efforts.

This *South Carolina Hydrogen Economy* report is intended to catalyze efforts in South Carolina over the next 24-36 months so that the state can effectively position itself to participate in a major way in a future hydrogen economy. This will require leaders from throughout the state to work together to achieve statewide R&D and economic development objectives.

The vision defined in the *South Carolina Hydrogen Economy* report is summarized in the following text box.

A Vision for Building South Carolina's Hydrogen Economy

By starting to take aggressive actions today, South Carolina will become a hydrogen economy leader in the United States over the next 10-20 years. As a first step, South Carolina organizations will exhibit the leadership to capitalize on their relevant research, development, demonstration, and entrepreneurial support capabilities, and they will establish and maintain comparative advantages that will lead to future jobs and economic opportunities in the state.

1.1 Background

The vision of a future hydrogen economy in the United States received considerable stimulus in the 2003 State of the Union address when President George W. Bush announced his support for a broad, multi-year "Hydrogen Fuel Initiative" and indicated his willingness to support the investment of $1.7 billion in hydrogen-related research over the next ten years. Many automobile and industrial organizations, as well as state economic development groups, took this message as a cue to begin accelerating their own hydrogen economy-related efforts.

Fully establishing a hydrogen economy in this country is clearly viewed as a long-term proposition requiring many fundamental technical and societal shifts. Nevertheless, the benefits of a hydrogen-based energy system have been perceived as so compelling by many that widespread interest in promoting a hydrogen economy has already been generated. These benefits include reduced dependence on foreign energy sources, greater domestic energy security, and improved environmental quality from reduced air pollution associated with transportation, industrial, and utility applications.

The transition to a hydrogen economy will require a significant investment. A new hydrogen supply and delivery infrastructure system will have to be put into place. New demand-side technologies that can convert hydrogen efficiently and cost-effectively to desired energy services will have to be developed. Throughout the United States, government and private-sector resources are starting to be committed to develop the hydrogen production, storage, and delivery technologies that will be needed to support a hydrogen economy. Efforts are also underway to commercialize fuel cells, hydrogen-fueled vehicles, and other hydrogen end-use technologies that will be required to meet society's needs. These continuing activities can potentially generate hundreds of billions of dollars in new economic opportunities in the United States during the next 50 years.

More than a dozen individual states have already recognized the significant economic and environmental opportunities that will accompany the transition to a hydrogen economy and they have begun considering the role they can play in this process. These state efforts have often led to the formulation of state-level "roadmaps" and studies of varying scope that describe how each particular state intends to increase: (1) R&D investments, (2) economic development activity, and/or (3) home-market demand for hydrogen-related products and services. Some studies focus only on fuel cell development, while others take a broader view of the hydrogen economy. It is clear that a number of states – such as California, Ohio, Michigan, Florida, New York, and Massachusetts – have already moved out aggressively to promote the use of fuel cells and hydrogen.

By comparison, South Carolina is a relative newcomer to the process of developing a collaborative statewide hydrogen initiative. Because of this, South Carolina organizations – both individually and collectively — are in danger of losing significant opportunities to other regions that have already organized major hydrogen-related initiatives.

South Carolina research organizations have significant capabilities that can be leveraged. While those capabilities are important, the state will also need to build a base of companies with hydrogen-related operations. Although some companies with major out-of-state interests in hydrogen have important facilities in the state, there are currently no commercial or industrial activities directly related to hydrogen. Corporate industrial involvement in South Carolina's efforts is vital because the economic benefits from hydrogen-related research are most likely to accrue to regions where research is applied, not necessarily where the research is just performed.

The state's economic development leaders have already identified hydrogen as a priority. A 2003 study commissioned by the South Carolina Competitiveness Council targeted hydrogen as one of the state's most promising industry clusters. The study prepared by Professor Michael Porter and the Monitor Company Group, L.P. indicated that Chemical Products were a high-ranking industrial cluster in the state *"due almost entirely to [*the*] Savannah River Site."* Among the strengths mentioned was the *"expertise in hydrogen technology at [*the*] Savannah River Site."* In addition, the study concluded that the Savannah River Site *"has the potential to act as an anchor in the cluster"* as well as an *"opportunity to partner with the auto cluster and USC's [*University of South Carolina's*] fuel cell researchers to develop fuel cell powered automobiles."*

This hydrogen economy report was commissioned about a year after the Porter/Monitor cluster study.

The study was prepared to analyze South Carolina's hydrogen economy assets and to identify initiatives that can leverage those assets to build a more extensive future hydrogen economy in the state.

1.2 Objectives of the Report

This report is intended as a short-term, strategically based hydrogen economy plan for the state of South Carolina.

The objective of the report is to identify a set of collaborative initiatives that can be undertaken within the next 24-36 months to mobilize the support needed to convert South Carolina research, academic, and industrial resources into economic development assets critical to creating a hydrogen economy.

The target audience is decision-makers and thought leaders from organizations in South Carolina that can potentially impact priorities and resources in order to accelerate the realization of economic development benefits associated with a vital hydrogen economy. This includes government officials, academic and industrial officials, economic developers, as well as business, technical, and financial leaders.

To accomplish the project's objective, the report focused on identifying and recommending proactive initiatives that can:

- Leverage the substantial collective hydrogen and fuel cell capabilities of the Savannah River National Laboratory (SRNL), South Carolina's research universities, institutions, and industry,

- Secure significant levels of near-term R&D and demonstration funding from government and industry, and

- Enhance South Carolina's economic development initiatives so as to position the state as a leader in the highly competitive race to capitalize on the opportunities that will be presented by a hydrogen economy.

2.0 HYDROGEN ECONOMY OPPORTUNITIES

This section begins by presenting a framework for the key elements of a hydrogen economy value chain. Such a framework is useful in defining some of the major business opportunities likely to be created. Although no one yet knows for certain precisely how or when a hydrogen economy will evolve, there are some trends currently apparent, and these are also discussed in this section. Finally, the section describes the major building blocks being used by other states in developing their hydrogen economy strategy to establish the basis for the recommendations presented in Section 5 of this report.

2.1 Hydrogen Economy Value Chain

Figure 1, shown below, was developed by DOE in its 2002 roadmap report to portray the various elements of the hydrogen economy value chain. It conveys the major activity areas that such an economy will have to address.

The value chain begins with the Production step in which hydrogen is produced for subsequent use from some source material. Following this step, there are several options for using the hydrogen. It may either be converted directly into energy in a Conversion step, or sent directly to either a Distribution system or a Storage system for subsequent conversion to energy. The nature of the Conversion step to energy will vary depending on the type of end-use Applications involved. The applications can range from stationary power production to transportation-related power generation to portable power for many uses.

Based on this high level description, Figure 2 presents a more detailed framework in pyramidical form encompassing the key elements of a hydrogen economy:

- Beginning at the top are the primary sources from which hydrogen is derived – such as water, biomass, natural gas, and coal. These constitute the basic chemical feedstocks from which hydrogen can be made.

- Next are the basic energy sources that can be used to produce hydrogen from the chemical compounds that contain it – natural gas, coal, nuclear power, and renewable energy (i.e., wind and solar).

- The next level highlights the fact that certain chemical extraction and processing methods are required in conjunction with the energy sources to yield the hydrogen product and that many options are potentially available, each with its advantages and disadvantages.

- Next, there are numerous options for distributing the hydrogen, depending on whether it is in gaseous or liquid form or in some solid chemical form. These options include pipelines, tanker trucks, small canisters, ships, and fueling stations.

- Depending on its ultimate use, hydrogen can be stored in a variety of forms before being used, including as a liquid or in pressurized tanks or as metal hydrides, chemical hydrides, glass

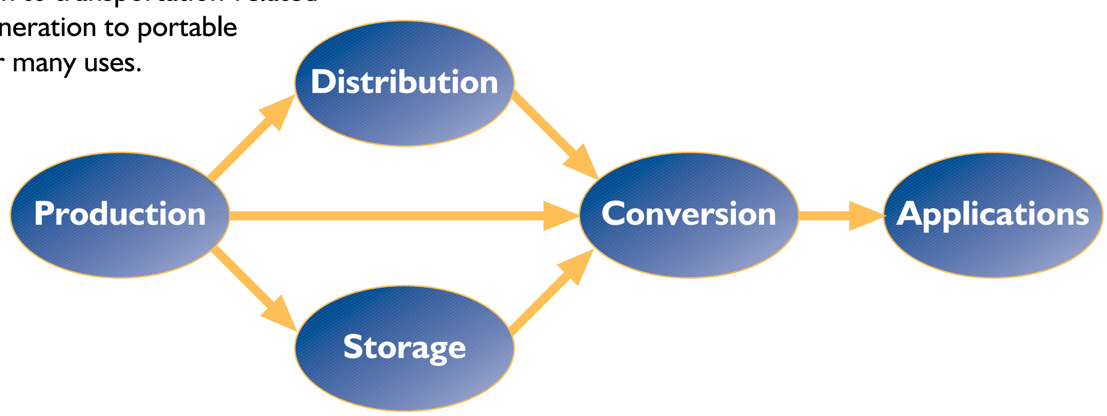


Figure 1 – Major Segments of the Hydrogen Economy Value Chain

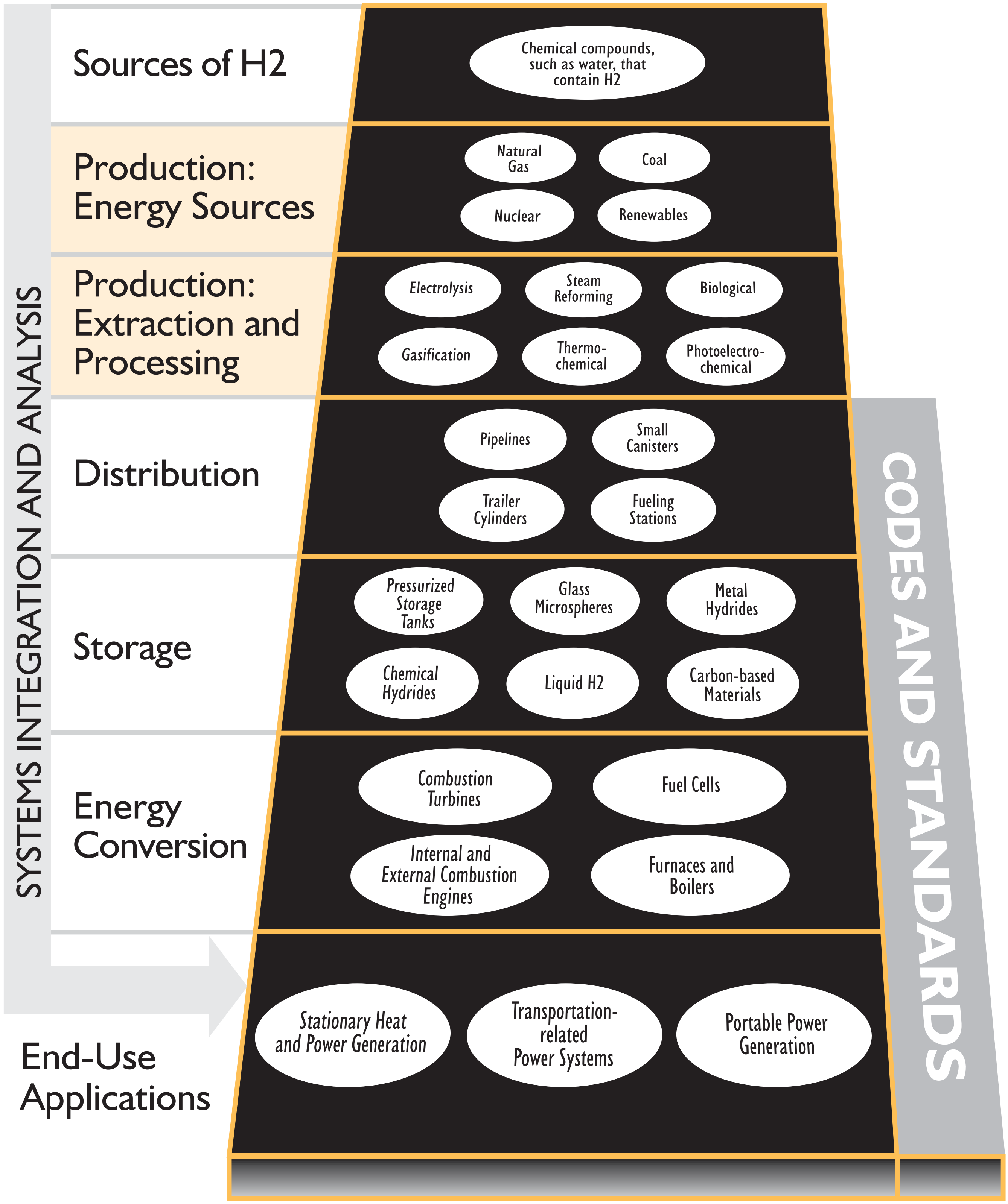


Figure 2 – Detailed Portrayal of the Hydrogen Economy Value Chain

microspheres, or carbon nanotubes.

- A number of technologies can be used to convert the hydrogen into energy, including fuel cells, combustion turbines, combustion engines, furnaces, and boilers.

- Finally, at the base of the pyramid, representing the ultimate end-product of the hydrogen economy, are the end-uses to which the hydrogen-derived energy can be put – stationary heat and power generation, portable power generation (smaller scale), and transportation-related power systems.

Figure 2 also indicates that considerable Systems Integration and Analysis will be required on the early elements of the value chain in order to produce practical end-use applications. The figure also indicates those elements were the development and application of Codes and Standards will ultimately be necessary.

2.2 Trends Impacting the Evolution of a Hydrogen Economy

There are significant technological, economic, and policy barriers that must be overcome to realize the full promise of a hydrogen economy. While hydrogen is the most common element in the universe, it is not freely available and must be chemically extracted from other compounds using some form of energy and processing technology, as indicated in Figure 2. Also, hydrogen has a much lower energy density than natural gas or liquid fuel, which complicates the logistics of distribution and storage. Finally, end-uses for hydrogen in the transportation, stationary power, and portable power sectors are still somewhat complex and expensive to supplant existing technologies that perform similar functions. While the transition to a "hydrogen economy" will fundamentally transform the United States energy system, the full transition is likely to require many decades.

There already exists a substantial world market for hydrogen for a range of applications. The world economy currently consumes about 42 million tons of hydrogen per year, about 60 percent of which is feedstock for ammonia production in the manufacture of fertilizer. Petroleum refining consumes another 23 percent, primarily to remove sulfur and upgrade heavier fractions into products. Another nine percent is used to produce methanol, with the remainder used in a variety of chemical, metallurgical, and space applications. The United States produces about 8.2 million tons of hydrogen per year, representing about $30 billion in value based on current production and delivery costs. About 7 million tons are consumed at the place of production (captured facilities), while the remaining 1.2 million tons is transported as "merchant" hydrogen. Hydrogen consumption in the United States for conventional use is expected to grow by as much as 10 percent per year in the near-term.

Much of the focus of the evolving hydrogen economy is on the transportation sector. Essentially all of the transportation-related uses of gasoline could potentially be replaced by hydrogen. Success in the transportation sector will be dependent on the development and commercialization of competitive fuel cell vehicles, requiring fuel cell systems that are lightweight and compact, reliable, flexible, and long lasting, and/or internal combustion engine systems that can store and burn liquid hydrogen effectively.

The use of hydrogen in stationary applications may also play an important role in a hydrogen economy. Many analysts have forecasted that distributed or on-site generation of electricity could represent a substantial market in the United States, especially in regions with comparatively high energy costs and air pollution problems. Competitive combined cycle gas turbines coupled with fuel cells and reciprocating engines tailored to use hydrogen could meet the future power needs of many commercial and industrial users. Additional opportunities exist in using hydrogen as a clean combustion fuel source in a variety of industrial boiler and process heater applications. The key to success in these markets will be to provide the required energy services in a manner competitive with conventional natural gas generation or combustion.

The 2003 National Academy of Sciences report laid out a potential sequence for the development of a hydrogen economy infrastructure. The starting point is the current hydrogen market, which relies on the reforming of fossil fuels, especially natural gas. The Academy projected a transition to a hydrogen system that would be accomplished initially through distributed production of hydrogen with conventional production technologies, avoiding many of the infrastructure barriers faced by central production and delivery. Small hydrogen production units located at dispensing stations or industrial sites would produce hydrogen through natural gas reforming or electrolysis. Distributed renewable energy systems could then provide electricity to on-site hydrogen production systems in certain parts of the country. A distributed transition such as envisioned by the Academy allows time for the market to develop while development of new production and delivery technologies are underway and before significant fixed investment is required.

Ultimately, the Academy anticipates the construction of a nationwide pipeline distribution system similar to that used for natural gas to be built during the 2030 to 2050 period.

In the long term, central plant production of hydrogen using coal or nuclear energy will dominate as long as carbon sequestration for coal costs remain within an expected range and there are no major breakthroughs in renewable technologies to produce hydrogen at competitive costs.

2.3 Building Blocks of State Hydrogen Economy Strategies

Beginning in the 1970s, a number of states began encouraging residential and business users to use alternative energy technologies. Some states started to fund alternative energy research and commercialization efforts in the 1980s and 1990s. While initial efforts leading towards a hydrogen economy began over 30 years ago, the most significant statewide economic development efforts have only gained momentum within the last five years. Now, more than a dozen states have developed visible initiatives for promoting the expansion of hydrogen and/or fuel cell clusters within their respective regions. In addition, others are starting similar programs and pursuing significant legislative programs.

Appendix IV provides a brief overview on some specific types of state initiatives that are underway. It is important to note that all of the leading state-level hydrogen economy initiatives are constructed using the same set of four building blocks shown in Figure 3. The blocks are described below to provide a strategic framework for constructing South Carolina's hydrogen economy strategy in accordance with the recommendations that will follow in this report.

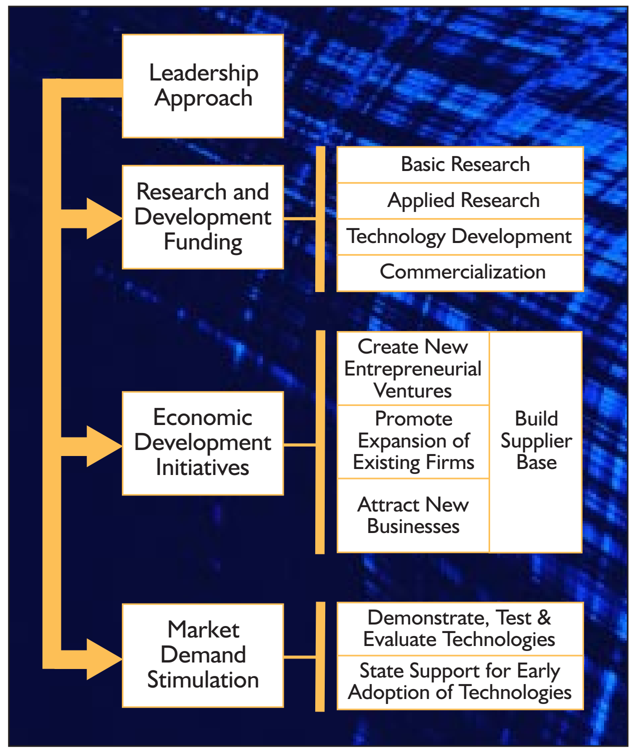


Figure 3 – Major Building Blocks of A Hydrogen Economy Strategy

Leadership Approach

In many states implementing hydrogen strategies, the governor has taken a visible lead in promoting the hydrogen cluster as a top economic development priority. State agencies are often integrally involved in hydrogen economy initiatives, and some states have passed or have introduced large-scale legislative packages. Almost all leading states have established partnerships that highlight industry involvement with universities and state government.

The form and function of the leadership organizations involved in hydrogen economy initiatives varies from state to state. The four most prevalent types of lead organizations are:

- Organizations that provide purely strategic direction and monitor progress made toward state goals,
- Not-for-profit or quasi-public organizations that provide specific economic development and/or market development services,
- State agencies that coordinate all activities related to the defined initiatives, and
- A mix of state agencies and public/private partnerships that are responsible for specific "hydrogen economy" programs or initiatives.

Research and Development Funding

A number of states have established funds that are specifically targeted to increase R&D activities related to renewable energy, hydrogen, and/or fuel cell technologies. Many of these funds are either targeted toward building stronger industry partnerships, expanding programs focused on commercializing/demonstrating technologies, and/or developing the capacity of small entrepreneurial firms. Also, various states have invested more broadly to build university capacity to support basic and applied research.

All of the leading states within the hydrogen economy arena are aggressively pursuing federal research funds to build their hydrogen and fuel cell programs. In many cases, the influence of congressional delegations has had a significant impact on funding levels for both universities and national laboratories.

Economic Development Initiatives

Most of the leading states already have a base of existing hydrogen or fuel cell companies within their borders. The most forward-looking states are attempting to leverage that base of companies to create an industry cluster. To accomplish this objective, states are taking three developmental steps:

1. **New Product Development** – Early-stage product-development and technology commercialization initiatives are currently the most prevalent economic development activities. These initiatives involve industry and either research universities or state manufacturing technology centers. Projects include both multi-company collaborative efforts and proprietary product development projects, which may include more extensive commercialization components.

2. **New Venture Development** – A few states have set aside modest amounts of funding specifically for new venture development services and venture capital targeted to firms offering new renewable energy technologies. However, most states integrate these services into broader technology-based entrepreneurship programs.

3. **Industrial Recruitment** – Most state efforts have focused on two areas: (1) recruiting out-of-state companies to participate in demonstration or technology development projects, and (2) aggressively marketing the state's capabilities.

A few states are also actively engaged in supplier development programs that encourage in-state manufacturers to adapt and expand existing product lines to incorporate new hydrogen or fuel cell products. These programs provide manufacturing-related support services and training to help the suppliers to develop new product lines.

Market Demand Stimulation

State programs designed to stimulate market demand fall into two general categories: (1) programs to encourage residential and business consumers to become early adopters of emerging technologies, and (2) demonstration projects. Primary examples of programs to encourage early adoption include the following:

- The development of uniform and streamlined regulations, including hydrogen-related codes and standards;

- State incentive programs for early technology adopters, including incentives such as grants, rebates, tax credits/exemptions, and loans;

- Power generation incentives and state regulations mandating that electric power generators produce a minimum percentage of their power using renewable energy sources, and

- Public education programs that provide potential consumers with information on the benefits of early adoption.

Demonstration programs are also geared to promote early market acceptance of technologies. These programs can: (1) provide selected technologies with increased visibility, (2) develop systems to support increased technology utilization, and/or (3) provide valuable testing/evaluation information. Most importantly, however, demonstration projects attract corporate partners because companies – especially homegrown firms – are more likely to locate operations in regions that develop early-stage markets.

The primary examples of state demonstration programs designed to promote early adoption of hydrogen technologies include the following:

- Direct government support for either of the following two types of demonstration programs: (1) installations of discrete technologies, such as fuel cells, or (2) development of extensive hydrogen infrastructure systems, such as the "hydrogen highway" networks of motor vehicle refueling stations,

- Tax and financial incentives to support the use, development, and/or demonstration of technologies, and

- State and local government procurement programs aimed at creating a market for commercial-grade products that are just beginning to build a market base.

In many states, incentives and support for demonstration projects are linked to programs promoting the use of technologies that offer environmental benefits.

3.0 HYDROGEN-RELATED R&D CAPABILITIES OF SOUTH CAROLINA ORGANIZATIONS

Described in this section are the current hydrogen-related capabilities of South Carolina R&D organizations in a number of specific areas critical to the development of safe and affordable hydrogen economy-related technologies. The capabilities are described by organization, and the focus is on R&D capacity since organizations in the state currently operate almost exclusively in this arena. The section also indicates technical areas where multiple South Carolina organizations have the potential to support substantial collaborative R&D or demonstration initiatives in major segments of the hydrogen economy value chain.

3.1 South Carolina Organizations with Major Hydrogen-Related R&D Capabilities

South Carolina began building broad-based capabilities many years before the term "hydrogen economy" was coined. Because of its defense-related mission associated with early operations of the Savannah River Site (SRS), the Savannah River Laboratory (now known as SRNL) became a hub for hydrogen research beginning in the 1950s. Then, in the early 1980s, the University of South Carolina (USC) began assembling a core team of hydrogen-related researchers. At the same time, Clemson University established an advanced materials-related R&D program associated with fuel cell systems, and it has more recently expanded its hydrogen storage and production research.

Even though South Carolina organization's have been engaged in hydrogen-related R&D for an extended period, this is not widely recognized outside the state. Other regions have been much more aggressive and competitive in attracting the R&D resources needed to build a hydrogen economy. Significant levels of new federal and industrial dollars are now flowing, and to date South Carolina's research institutions have been only moderately successful in competing for these new R&D funds.

Federal Funding for Hydrogen-Related R&D

The United States Department of Energy, which has the federal government's largest hydrogen R&D budget, is expected to spend $227 million this year on its Hydrogen Fuel Initiative and spend $9 million on its nuclear hydrogen initiative.

A few agencies such as the United States Department of Defense, the National Science Foundation (NSF), and the Department of Transportation (DOT) also fund hydrogen-related research but on a much smaller scale.

During the last three years, the state's research institutions have attracted approximately $28 million to $30 million per year in federal funding for hydrogen-related research. However, almost 90 percent of those dollars have gone to SRNL's defense mission.

Recent funding commitments by the State of South Carolina, which are targeted to support selected R&D programs that demonstrate clear economic development benefits, should help the state become more competitive. For example, based on provisions of the South Carolina Research Act, the state has allocated a portion of its lottery revenues for university-based centers of excellence. One of the centers that has been funded at USC is devoted to hydrogen-related R&D. Moreover, through the South Carolina Research Act and from other state sources, South Carolina has demonstrated a willingness to invest in R&D-related capital projects, including expenditures for land, buildings, and equipment.

The state funding is essential for building the base of university faculty and related resources that are needed to enhance the state's competitiveness. It also positions the universities to take advantage of collaborative funding opportunities flowing to SRNL from federal and industrial sources.

Federal research facilities, especially national laboratories, have been the hubs for a relatively high percentage of federal government funding for hydrogen-related research. SRNL, which only recently became a national laboratory, is slowly building its research funding base for hydrogen economy initiatives. However, on a longer-term basis, SRNL has the potential to attract very large levels of funding, if it secures an expanded mission in one or more areas that are strategically important to DOE and industrial sponsors.

Yet, while federal and state government dollars will continue to be vital, they will not be sufficient if South Carolina plans to build its hydrogen economy. South Carolina will not become a significant player until it expands its base of hydrogen-related companies. Currently, the lack of hydrogen-related commercial and industrial activity is one of the state's biggest challenges in developing a hydrogen economy.

Figure 4 on the right spotlights: (1) the location of organizations in South Carolina currently engaged in hydrogen economy-related R&D, and (2) hydrogen-related R&D operations established by research institutions to promote collaboration with industry.

There are also a range of other South Carolina organizations that either currently have or could potentially develop resources integral to the growth of a hydrogen economy in the state. Summaries on all of these organizations are provided in the following sections. These summaries provide information on the following three types of organizations:

- Research institutions – including SRNL and the state's universities,
- Private-sector organizations – including companies with operations in South Carolina that can potentially provide hydrogen-related goods or services, and
- Supportive organizations – including groups that can provide services or resources that can contribute to the growth of the state's hydrogen economy.

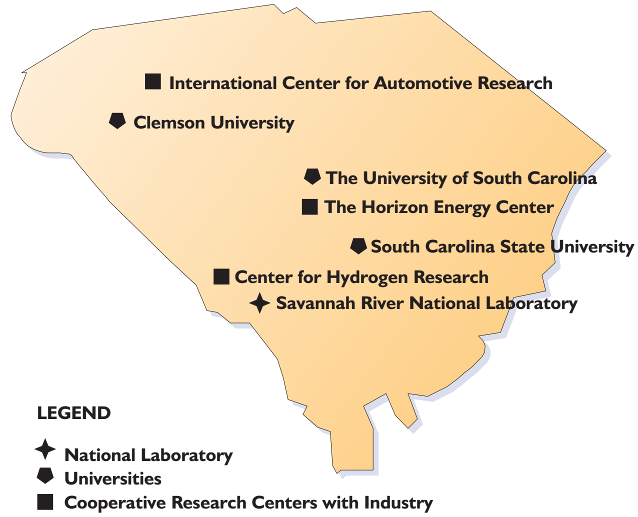


Figure 4 – Location of South Carolina's Hydrogen-related Research and Development Centers

3.1.1 Research Institutions

Current major hydrogen and/or fuel cell-related programs at SRNL, USC, Clemson University, and South Carolina State University (SCSU) are briefly discussed in this section. However, limited information is provided on some of the general crosscutting research initiatives, such as non-hydrogen-specific nanotechnology programs, that could potentially be integrated into hydrogen-related R&D programs.

The Savannah River National Laboratory

In May 2004, SRNL became the newest DOE national laboratory. The laboratory, previously known as the Savannah River Technology Center (and before that as the Savannah River Laboratory), was established in 1951. It is located on the Savannah River Site (SRS) near Aiken, South Carolina.

SRNL's research staff is comprised of approximately 900 workers, including more than 90 hydrogen-related scientist, engineers, and technicians. As a result, it is believed that SRNL currently employs more hydrogen related-technology workers than any other research facility in the United States and – possibly – the world.

The majority of SRNL's resources are devoted to projects involving tritium, an isotope of hydrogen, that support the DOE Office of Environmental Management and the National Nuclear Security Administration (NNSA).[1] Other projects include work for the United States Army, Nuclear Regulatory Commission, the United States Environmental Protection Agency, and the International Atomic Energy Agency. Today, the laboratory has an annual operating budget of $139 million, including approximately $25 million from NNSA in funding for tritium-related R&D.

SRNL has been engaged in large-scale hydrogen-related R&D longer than any other federally funded research organization. SRNL has over 50 years of experience in developing and applying hydrogen technology. This work is related to both its national defense activities as well as its recent activities with DOE hydrogen programs. The laboratory's initial hydrogen-related mission focused on the design, development, and demonstration of tritium production facilities at SRS.

SRNL continues to expand its hydrogen-related R&D activities for both defense and commercial applications. As a part of this effort, SRNL has taken the lead on developing a hybrid sulfur-based process for hydrogen production. At very high-temperatures (950 to 1,000 degrees C), this process thermochemically splits water into hydrogen and oxygen. In addition, SRNL has extensive experience in hydrogen separation technology and processes.

SRNL also has 25-plus years of expertise in metal hydrides, complex hydrides, and other solid-state hydrogen storage. Hydrides, which are beds of powdered metals that store hydrogen like a sponge, make it possible to store hydrogen in an easy-to-handle, stable solid form. SRNL, which is a team member in DOE's Center for Excellence for Metal Hydride Development, has developed and patented several hydrogen-storage devices using hydride beds. The laboratory is also engaged in hydrogen storage R&D and engineering projects involving chemical hydrides, glass microspheres, and carbon-based materials.

The Center for Hydrogen Research in Aiken, SC

The Center for Hydrogen Research, located two miles from SRS in Aiken, SC, was established as a unique facility to promote collaborative research, development, testing, and commercialization of hydrogen-related technologies.

When it is completed in October 2005, approximately 40 SRNL hydrogen research staff members will join other academic and university researchers in the new 60,000-square-foot laboratory and office building. SRNL staff members will occupy approximately half the space in the building.

As an immediate benefit of the center, SRNL is in the process of establishing cooperative research agreements with major automobile companies, who are expected to locate personnel within the facility.

Aiken County invested $10 million for building construction, and the region's Economic Development Partnership will be responsible for operations, commercialization activities, and marketing.

In addition, SRNL has been involved in hydrogen transport-related research and is currently partnering with Concurrent Technologies Corporation (*CTC*) on an applied research project focused on issues, such as the use of advanced materials to build pipelines and their components, pipeline integrity, and the co-transmission of hydrogen with natural gas. Additional information on *CTC* is provided in Section 3.1.2.

SRNL has also worked to develop codes and standards for hydrogen-related applications. The development and adoption of codes and standards for the distribution, storage, and conversion of hydrogen will be crucial to the commercial and consumer acceptance of hydrogen-related technologies.

[1] Tritium, which is an isotope of hydrogen, is a vital ingredient in the production of nuclear weapons.

SRNL has been active in teaming with academic and industrial partners to advance hydrogen technology, and it established the Hydrogen Technology Laboratory (HyTech) in 1995 to support these activities. Many of HyTech's programs support dual-use (i.e., military and private sector) applications. HyTech has participated in projects to convert public transit and utility vehicles for operation on hydrogen fuel. Two major projects include the H2Fuel Bus and an Industrial Fuel Cell Vehicle. Both of these projects were funded by DOE and cost shared by industry. HyTech has also conducted extensive R&D associated with other hydrogen technologies, including membrane filters for hydrogen separation, doped carbon nanotubes, storage vessel design and optimization, hydrogen compressors, and sensors for measuring hydrogen concentrations.

Presently, SRNL is working to expand its hydrogen-related activities, especially in non-defense sectors. As a part of this effort, it has plans to establish some operations in the new Center for Hydrogen Research (see text box on the previous page), which will be devoted to collaborative hydrogen-related research involving SRNL, industry, and academic institutions.

The University of South Carolina

Beginning in the 1980s, USC began building nationally recognized R&D capabilities in fuel cells and hydrogen-related electrochemical devices. USC has subsequently developed significant R&D capabilities related to hydrogen storage and production.

During the past three years, USC has attracted $10 million in federal funding for fuel cell and hydrogen-related research. More than 25 faculty, staff members, Ph.D. students, and postdoctoral fellows are actively engaged in this research on a full- or part-time basis.

In addition, USC recently secured $6 million in state funding for hydrogen and fuel cell research, which includes: (1) a $1 million annual appropriation for fuel cell and hydrogen research, and (2) $5 million in state funds to establish a center of excellence related to hydrogen storage and electrochemical sensors. Advancements in sensor-related technologies are critical to the development of fuel cells, storage systems, and distribution systems.

The additional resources that will accompany the centers of excellence will help to expand existing R&D capabilities. USC is already known as one of the nation's leading academic institutions involved in electrochemical and mathematical modeling research related to hydrogen, fuel cells, and energy storage devices. The two core organizations at USC that are leading this effort are highlighted in the following paragraphs:

- **The National Science Foundation Industry/University Cooperative Research Center for Fuel Cells** – The nation's only NSF-funded fuel cell center was established at USC in 2003 and it has already attracted 15 industrial partners. The center's mission is focused on pre-competitive research that involves faculty, students, and

USC Research Campus and Expanded Strategic Research Initiatives in Columbia, SC

In mid May, USC announced that it had secured a package of state, federal and private funding to build the $32 million Horizon Center, which is a two-building complex devoted to research and development related to the next generation of energy technologies. The Horizon Center will be one of the anchors within the university's new 200-acre research campus in Columbia, SC. The Horizon Center will include offices, laboratories, classrooms, and facilities that support cooperative research with industry.

In addition, the university has announced that it will recruit approximately 250 net new faculty members over the next five years. USC is focusing much of its recruitment activity to support its four strategic research priority areas, which include the *next generation of energy technologies*, biomedical, nanotechnology, and the environment.

industry members. Center personnel are particularly well skilled in designing proton exchange membrane (PEM) fuel cell systems and modeling their performance. The center is also expanding its capacity to perform simulations on solid-oxide and direct-methanol fuel cell systems. Emphasis on integrated fuel cell systems is a feature that distinguishes this fuel cell program from research initiatives at other academic institutions. The center's integrated approach involves basic and applied research related to solid-state hydrogen storage materials, fuel cell-related devices, the interface between the device and the fuel cell, fuel cell materials, and power distribution and conditioning systems.

- **The Center for Electrochemical Engineering** – Many of the USC faculty members who are a part of this 10-year-old center are also members of the fuel cell center team. This center's faculty and staff have extensive experience in the design and optimization of electrochemical systems using mathematical models. Moreover, in addition to the research discussed within the preceding summary on the fuel cell center, the center's faculty members have been involved in other complementary areas, such as: (1) the synthesis and characterization of catalysts and other electrochemically active materials for both fuel cells and the production of hydrogen, and (2) the development and testing of materials used in hydrogen production-related sulfur-dioxide depolarized electrolyzers. In the past, some research was conducted on interconnects and components of direct methanol, molten carbonate, and sodium-oxide fuel cells. This center has attracted both industrial and federal research dollars, including a number of fuel cell-related Small Business Innovation Research grants.

Other fuel cell-related optimization R&D is also underway in both the departments of electrical and mechanical engineering. As an example, USC researchers have developed a virtual test bed (VTB), which is a comprehensive simulation and virtual prototyping environment for advanced electric power systems. Among a wide range of other applications, the test bed has been utilized to assess the use of fuel cells in the propulsion systems of U.S. Navy vessels.

Next Energy Initiative

USC is leading the Next Energy initiative, which is a collaborative effort involving the state's major hydrogen economy stakeholders. This initiative is developing a long-term plan for capitalizing on the transition from fossil fuels to alternative energy sources.

The Next Energy project will recommend approaches for building an infrastructure that supports economic development activities. That infrastructure will include plans for developing:

- world-class energy research programs,
- technology commercialization initiatives,
- state policies that support the development and adoption of alternative energy technologies, and
- related economic development initiatives.

The Next Energy plan is scheduled for completion in September 2005.

USC is also involved in hydrogen production- and purification-related projects, including research related to liquid fuel reformer methods. In addition, DOE has funded one USC faculty member for five years as a leading scientist on issues related to the nuclear production of hydrogen. This person is considered one of the nation's top researchers in high-temperature nuclear technologies and advanced nuclear fuels. USC's nuclear program, which is a part of the Department of Mechanical Engineering, was established in 2003.

Clemson University

Clemson University's current R&D initiatives related to hydrogen are focused on advanced materials. Researchers are engaged in a broad range of advanced materials research projects that have direct applications for improved hydrogen storage systems, fuel cells, and next-generation power systems.

Research teams have a particular interest in carbon fibers for structures, heat transfer applications, and hydrogen storage. Much of this effort is directed to basic and applied research on modeling fiber and film processes, smart blending, supercritical extraction, and surface modifications.

As an example of hydrogen storage research, early tests conducted by Clemson researchers indicated that palladium-doped porous carbon materials can absorb and store hydrogen at near liquid densities. In other storage-related projects, researchers are investigating carbon structures composed of concentric spheres of buckyballs.

In addition, Clemson researchers have attracted both federal and industrial sponsors for research related to the use of fluorinated fuel cell electrolytes. This research, which has continued for more than 20 years, is focused on improving the high-temperature performance, durability, and life of fuel cell membranes. Clemson has one of the only academic laboratories in the United States outfitted for handling tetrafluoroethylene, which is a key ingredient for making fluorinated membranes for fuel cells.

Clemson chemists are also developing nanocomposite fuel cell electrodes and carbon-based nanosponges that have may enhance the performance of fuel cells. Furthermore, Clemson's research in fuel cell electrode catalysts takes advantage of the university's combined expertise in electrochemistry, electrode materials (especially carbon), polymer materials, and catalysis.

In addition to this materials-related research, Clemson also has projects underway in the following areas related to hydrogen:

- **Thermochemical Production of Hydrogen** – Fundamental thermodynamic studies are in progress on a thermochemical process for producing hydrogen.
- **Renewables** – A collaborative research project with SRNL is focused on developing photobiological processes for producing hydrogen.
- **Gas Turbines** – Clemson's Advanced Gas Turbine Center has conducted some research on using hydrogen fuels in turbines.

The South Carolina Institute for Energy Studies at Clemson University

In 1981, the South Carolina General Assembly established the South Carolina Institute for Energy Studies to promote energy-related research and development that involve South Carolina academic institutions, federal partners and industry. The Institute, which resides at Clemson, has managed numerous projects involving Clemson research teams. The Institute could also play a more extensive role in managing projects that involve multiple institutions.

Advanced Materials Research at Clemson University

Clemson is nationally recognized for its materials-related research capabilities, especially in the area of carbon-based materials. Because of this resident expertise and the university's partnerships with industry, Clemson was awarded an NSF Engineering Research Center for Advanced Engineering Fibers and Films in 1998.

Moreover, to support a broad range of interdisciplinary research in materials, Clemson has established an Advanced Materials Research Laboratory where university and industry researchers have access to electron microscopy equipment, laser and instrumentation labs, advanced visualization tools, advanced testing equipment, and modeling tools. Advanced materials are one of three top research priority areas at Clemson.

From a hydrogen production standpoint, a Clemson chemist recently received a grant from DOE to collect and analyze thermodynamic data on reactions in the sulfur-iodide process. The chemist is collaborating with SRNL on the project. The sulfur-iodine process is being investigated in the United States and overseas as one of the more promising processes for producing hydrogen via thermochemical water-splitting. Few United States-based academic research teams are engaged in this type of thermodynamic study.

Clemson researchers are also working with SRNL on approaches for producing hydrogen using photobiological processes. A portion of this work has leveraged discoveries on hydrogen-producing microorganisms by SRNL's Environmental Biotechnology section.

In addition to these electrochemical and biochemical research activities, Clemson has established the International Center for Automotive Research (ICAR) in Greenville to significantly expand Clemson's collaborative automotive-related research with industry (see text box on the right). Clemson officials indicate that, eventually, the ICAR campus will include a wide range of research and testing facilities, including a fuels laboratory with an emphasis on hydrogen-based research. Research projects are also planned for optimizing the design of vehicles to accommodate fuel cells, hydrogen storage systems, and new hydrogen-fueled internal combustion engines.

South Carolina State University

The Clyburn Transportation Center, located on the campus of South Carolina State University (SCSU) in Orangeburg, South Carolina, was established to conduct research, education, and technology transfer programs related to intermodal transportation systems. The center has the capacity to support transportation-related demonstration and testing initiatives, including projects associated with hydrogen-powered vehicle fleets, related fueling systems, and fuel cells. The center's staff is exploring opportunities for partnering with SRNL to design and implement programs to: (1) test hydrogen containers, and (2) develop a demonstration project involving hydrogen-powered transit busses.

International Center for Automotive Research at Greenville, SC

Clemson University has attracted $115 million in public- and private-sector support to develop a 400-acre automotive research campus in Greenville and to hire automotive-related researchers.

The campus, which was christened in November 2004, will initially include a new graduate engineering center and research/ testing facilities. The campus is expected to grow into a "technopolis" containing many academic, R&D, commercial and residential tenants.

Construction has already started on the first building. The Information Technology Research Center will house cooperative research programs involving Clemson, BMW, IBM, and Microsoft.

In addition, BMW and its suppliers have pledged $15 million to endow two chair positions that will be focused on vehicle systems integration. Moreover, Michelin North America has pledged $3 million for an endowed chair in vehicle electronics systems integration.

Plans for ICAR include explicit provisions for promoting the development of energy-related innovations for vehicles and the subsequent commercialization of those technologies.

In addition, SCSU is offering an undergraduate degree in Nuclear Engineering in cooperation with the University of Wisconsin – Madison. This program could have a positive impact if nuclear facilities are used to produce hydrogen in South Carolina.

3.1.2 Private-Sector Organizations

A number of private-sector organizations in South Carolina have substantial expertise that could be leveraged to: (1) expand applied research opportunities in the state, and/or (2) convert South Carolina's research assets into products and services that have commercial potential. The most prominent of these organizations are highlighted in the following sections.

Westinghouse Savannah River Company

Westinghouse Savannah River Company (WSRC), which currently operates SRS under contract with DOE, is recognized as a world leader in managing nuclear materials. Of the more than 10,000 employees now at SRS, approximately 570 personnel are assigned to tritium-related programs.

From 1953 to 1988, SRS was the sole facility in the United States engaged in producing tritium and plutonium. At its peak, SRS operated five nuclear production reactors, and SRS has been one of only two nuclear production sites designated by DOE. Because of the site's historical role in nuclear production, SRS is a leading contender to attract future DOE-funded and/or industry-funded nuclear operations for hydrogen production.

In addition, WSRC's parent company is the Washington Group International (WGI), and WGI's Energy and Environment Business is headquartered in Aiken. WGI is one of the world's largest firms engaged in the engineering, design, and construction of nuclear facilities. WGI also provides similar services for fossil fuel and alternative energy technologies.

Concurrent Technologies Corporation

CTC is a national independent nonprofit applied R&D organization with 35 locations across the United States, including four offices in South Carolina. *CTC* specializes in teaming on multi-client projects to solve complex technical problems. *CTC* has extensive experience in working with DOE and DOD. *CTC* is leading a DOE-funded research, development, and testing initiative focused on technologies related to pipelines and other hydrogen-transmission systems. SRNL is one of the project team members, and *CTC* is considering locating additional personnel in Aiken to collaborate with SRNL.

In addition, since 1998, *CTC* has operated the Fuel Cell Test and Evaluation Center (FC*Tec*), which is based in Johnstown, Pennsylvania. The center's 20-person staff works with the leading fuel cell producers and major users to demonstrate, test, and evaluate fuel cell systems. FC*Tec* offers a unique set of test equipment and services and includes over 35,000 square feet of space. The center has worked extensively with organizations within the DOD and other federal government agencies, but it also serves a wide range of private-sector clients.

Also, *CTC's* Technology Management Directorate's operations represent a potential asset in developing hydrogen and fuel cell technologies. These operations, headquartered in Greenville, are engaged in active technology transfer, technology commercialization, and technology road mapping projects for both federal and private-sector clients. A portion of these projects focus on alternative energy technologies.

Other South Carolina Companies with Hydrogen-Related Operations

Two companies with facilities located in the state are world leaders in developing and commercializing hydrogen and fuel cell-related technologies:

- **BMW** – The automaker, which maintains primary North American production facilities near Greenville, recently announced that it had produced the world's first production-based hydrogen car. The current sedans have a bivalent drive that runs on liquid hydrogen as well as gasoline. Future models will feature hydrogen-only internal combustion systems with fuel cell power for the auxiliary power systems. The research for these innovations is taking place in Munich, Germany. BMW officials have indicated that a sufficient network of fueling stations is expected to be in place in Europe by 2010, and this may spur increased consumer demand for hydrogen-powered vehicles. Also, because BMW is building strong research relationships with Clemson University, expanded South Carolina R&D opportunities related to hydrogen and fuel cell-powered vehicles are possible.

- **GE Energy** – GE Energy, headquartered in Atlanta, Georgia, is one of the world's leading suppliers of power generation and energy delivery technology. GE Energy provides equipment, service, and management solutions across the power generation, oil and gas, transmission and distribution, distributed power, and energy rental industries. A key research and development program at GE is developing solid-oxide fuel cell technology and integrating it with a gas turbine to realize megawatt-class hybrid power generation systems. These systems will be compatible with a variety of fuels including hydrogen. GE is also developing advanced hydrogen fuel combustion technologies for use in heavy-duty gas turbines. GE Energy's Gas Turbine Center of Excellence for Engineering and Manufacturing, which is located in Greenville, is engaged in a wide range of technology development initiatives. This will include systems and gas turbine development of the fuel cell hybrid systems. In addition, as fuel cell hybrid systems get closer to commercialization, testing and production could also potentially be conducted at GE's Greenville campus.

In addition, a number of chemical and carbon materials companies, which are headquartered elsewhere but have operations in South Carolina, are manufacturing materials for fuel cell membranes or fuel cell components at out-of-state facilities. There are currently no private-sector commercial operations that are based in South Carolina that are involved in the development or production of hydrogen or fuel cell-related products.

Electric and Gas Utilities

South Carolina is a nuclear-friendly state, which is potential positive factor when DOE and private-sector firms consider locations for nuclear-based hydrogen production facilities. Nuclear facilities generate 56 percent of South Carolina's electric power compared with 20 percent nationally, and all three of South Carolina's investor-owned utilities operate nuclear reactors. Moreover, two utilities are considering options for building new reactors in the state.

Although South Carolina's investor-owned utilities are involved in very limited renewable energy projects, Santee Cooper, which is the power generator for the state's electric cooperatives, is interested in participating in renewable energy projects that provide value to their consumers.

Hydrogen Production and Consumption

Kemira Oyj is the leading producer of sodium chlorate in the southeastern United States and the second largest in the United States. The company's two North American sodium chlorate production facilities are located in Eastover, South Carolina, and Augusta, Georgia. At each of these facilities, Kemira produces approximately 10 million pounds per year of high-quality hydrogen "by-products" as a part of their sodium chlorate production process. Although each facility utilizes a high percentage of their hydrogen by-products for internal operations, more than 1 million pounds per facility could be made available to conduct validation, testing, and demonstration activities related to fuel cell technologies. Kemira's Eastover facility is located less than 25 miles of USC's fuel cell research center, and the Augusta facility is located within 25 miles of the Center for Hydrogen Research.

There are currently no major industrial consumers of hydrogen in South Carolina. However, because South Carolina is among the leading manufacturing states, high levels of demand are probable once hydrogen becomes cost competitive with fossil fuels. In today's market, fertilizer producers represent the largest end-market for hydrogen and one of the nation's largest fertilizer producers is located in Augusta.

3.1.3 Other Supportive Organizations

A number of other organizations in South Carolina that are positioned to support hydrogen and/or fuel cell-related initiatives are highlighted in the following sections:

South Carolina Hydrogen Coalition – SCH_2C was founded in 2002 to provide a forum for academic, industry, and government leaders from throughout the state to collaboratively develop strategies and tactics designed to significantly enhance South Carolina's ability to compete for the jobs and wealth that will be created within a hydrogen economy. The organization will play a leadership role in promoting and organizing initiatives that support statewide priorities related to the hydrogen economy.

South Carolina Energy Office – The South Carolina Energy Office is engaged in activities designed to promote the use of energy-efficient technologies, the adoption of alternative energy sources, and the enhancement of environmental quality. The Energy Office, which resides within the South Carolina Budget & Control Board, provides technical and financial assistance for energy conservation, energy information services, and support for initiatives that promote the use of clean, renewable energy resources.

FuelCellSouth – This not-for-profit organization, which is based in Columbia, was established to foster awareness and create market opportunities for fuel cell industry growth in the southeastern United States. Along with other activities, the organization sponsors an annual conference that brings together individuals from academia, industry, and government who are actively engaged in fuel cell and hydrogen-related work. FuelCellSouth also hosts regional forums and is working with regional groups on potential fuel cell-related demonstration projects.

United States Military Bases – Currently, a fuel cell is being demonstrated at the fire station on the McEntire Air National Guard base in Eastover. Recent fuel cell demonstration projects have also been conducted at Fort Jackson in Columbia and Shaw Air Force base in Sumter. Furthermore, Fort Jackson, which is the United States Army's largest entry-training center, is a strong candidate for future demonstration projects. Fort Jackson officials have expressed an interest in demonstration projects related to: (1) hydrogen production using landfill gases, and (2) distributed power generation. In addition to Fort Jackson, opportunities may also exist for conducting demonstration projects in partnership with Shaw or one of the three other major military installations in the state.

York Technical College — The Center for Alternative Energy Transportation Electric Vehicle Program resides on the York Technical College campus in Rock Hill, South Carolina. The center focuses on: (1) developing and demonstrating electric vehicle technologies, and (2) developing and delivering related education/training programs. The center is the only DOE-funded Alternative Fuel Vehicle center of excellence operated by a two-year institution. The center is well positioned to partner on demonstration projects with the four-year colleges involved in automotive, transportation and fuel cell-related research.

The Hollings Manufacturing Extension Partnership (MEP) – The Hollings MEP is a not-for-profit organization, affiliated with the Department of Commerce's National Institute of Standards and Technology. The partnership's sole purpose is to provide small and medium-sized manufacturers with services to enhance their competitiveness. The program is active in supplier development initiatives.

The South Carolina Research Authority (SCRA) – SCRA, which is headquartered in Columbia, manages contract R&D projects that can include governmental agencies, universities, and/or industry. In addition, SCRA often partners with South Carolina research universities, and it was recently authorized to manage Technology Innovation Centers at the state's research universities.[2] SCRA also manages a system of three research parks located near the state's research universities. Although SCRA is not currently engaged in hydrogen or fuel cell projects, it could be a resource in helping to build collaborative research projects involving in-state universities.

The South Carolina Department of Commerce and Local Economic Development Organizations – The Department of Commerce operates industry recruitment, existing business expansion, community development, and small business programs. The state agency works closely with local economic development officials in all four areas. The Department of Commerce is also charged with providing strategic leadership in developing the resources and strategies needed to enhance South Carolina's competitiveness.

[2] For more information on the Technology Innovation Centers, refer to 4.1.1 of this report.

3.2 R&D Capabilities within Major Hydrogen Economy Segments

On the most discrete level, it may appear that South Carolina organizations are engaged in R&D programs focused on a variety of separate scientific areas. However, once these capabilities are bundled into major categories, it becomes readily apparent that there are tremendous synergies among these R&D programs in specific targeted areas. In many cases, the R&D programs at one institution fill a void or complement initiatives at other institutions. Figure 5 groups South Carolina's most significant hydrogen-related technical capabilities by organization within each of the major segments of the hydrogen economy value chain.

The summary that begins on the following page describes how these capabilities are interrelated.

		SRNL & SRS	USC	Clemson	CTC	Industry*
Production	Energy Source	● Nuclear; Photobiological	● Nuclear; Renewables	● Photobiological		
Production	Extraction Process	● Thermochemical; Electrolysis	● Electrolysis; Fuel Reforming	● Thermochemical		● **Kemira** Hydrogen By-Product
Distribution		● Hydrogen Infrastructure			● Hydrogen Infrastructure	
Storage		● Solid-state Systems	● Solid-state Systems	● Carbon-based Systems		
Conversion			● PEM Fuel Cells	● Fuel Cell Materials	● Fuel Cells	● **Chemical Companies** Fuel Cell Membranes And Components
End-Use Applications	Stationary Power Generation					● **GE Energy** Combustion Turbines
End-Use Applications	Transportation			● **ICAR** Site Under Development		● **BMW** HydrogenVehicles
End-Use Applications	Portable Power Generation					

* Industrial R&D by these companies is taking place in out-of-state facilities

Figure 5 – Segments of the Hydrogen Economy Value Chain Where South Carolina Organizations Have Major Current R&D Initiatives

3.2.1 Hydrogen Production— Energy Sources

Currently, 95 percent of the nation's hydrogen is produced using natural gas with most of the remainder produced by coal. These resources are not present in South Carolina. Because there are cost and efficiency issues associated with transporting hydrogen, those regions that have a large number of natural gas production facilities are currently among the leading hydrogen producers. However, as the cost of fossil fuels increases, other types of non-fossil fuel alternatives for generating hydrogen will become attractive, especially because of the environmental benefits associated with using either nuclear or renewable energy technologies.

Nuclear technology offers several important benefits. From an energy security standpoint, the United States can reduce its reliance on energy imports by increasing its nuclear generation capacity, because nuclear reactors are fueled with uranium and major uranium resources are available in the United States and Canada. Furthermore, nuclear facilities do not produce carbon dioxide or other air pollution emissions. Nuclear energy also potentially represents a less costly option for the large-scale production of hydrogen than other alternative energy technologies.

Even so, researchers at SRNL estimate that, if the technology were operational today, the cost of producing hydrogen using advanced nuclear water-splitting technologies would probably be about 1.5 times greater than production methods that employ today's most commonly used natural gas alternative. Although there are numerous economic and technical hurdles that need to be overcome before the nuclear production of hydrogen is viable, nuclear power is expected to play an important role in hydrogen generation within the next 25 years.

As this technology evolves, South Carolina is well positioned to be a leader in advanced high-temperature nuclear R&D. SRNL and USC are both engaged in research related to high-temperature nuclear reactors. Clemson has capabilities related to high-temperature materials, including ceramics. Furthermore, the Washington Group and several other nuclear systems design, construction, and management firms are located in the Carolinas.

In addition to nuclear energy, South Carolina is well positioned to produce hydrogen using two other types of renewable energy resources – biomass and landfill gases. The state – and the southeastern United States in general – has relatively large supplies of timber and agricultural-based biomass. In addition, the South Carolina Energy Office has identified 30 landfills with significant methane gas-to-energy potential.

However, because biomass and landfill gas are typically not cost competitive as fuels, they are not currently utilized on a significant scale. On the positive side, Clemson, USC, and SRNL all are engaged in various research projects related to biomass or renewable energy resources.

3.2.2 Hydrogen Production — Extraction and Processing

Currently, natural gas is the most common and cheapest feedstock for hydrogen production. However, the hydrogen produced from natural gas is much more expensive than the cost of gasoline with an equivalent energy content.

There are a number of other methods for producing hydrogen, and South Carolina organizations are actively engaged in R&D activities related to the following three production options:

- **Thermochemical** – SRNL and Clemson University are both examining thermochemical processes for splitting water using high-temperature nuclear reactors. Researchers at Clemson have a lot of expertise in examining the thermodynamic characteristics of such processes.
- **Electrolysis** – SRNL and USC have expertise in optimizing the sulfur-dioxide depolarized electrolyzers used to separate hydrogen from the sulfur compounds used in high-temperature hydrogen production.
- **Biological** – SRNL and Clemson are collaborating on R&D related to photobiological processes for producing hydrogen. USC has been developing biomass plants as an energy source, and a researcher at the Medical University of South Carolina has patented a microbial fuel cell for energy production.

3.2.3 Hydrogen Distribution

The comparatively high cost associated with distributing hydrogen is a significant impediment to the adoption of hydrogen both for today's industrial applications and for the applications envisioned in the future. Because it is a highly diffusive gas with low-volumetric energy density, building a hydrogen pipeline infrastructure is currently much more capital intensive than similar fossil fuel systems. Plus, there are still many technological hurdles that must be addressed to create pipelines that prevent leakages and avoid long-term embrittlement.

Because of these difficulties, the over-the-road shipment of cryogenic liquid hydrogen is expected to represent the primary distribution option for filling depots and refueling stations for motor vehicles during the near-term. Unless significant advancements are made in pipeline-related technologies, this may be the primary distribution option for an extended period.

Advancements in pipeline technologies are important, however, because they have the potential to significantly reduce the costs and improve the logistics for distributing hydrogen from large centralized processing facilities. Consequently, to address the technical challenges associated with pipelines, SRNL and *CTC* recently initiated a research program to develop more effective materials and technologies.

In addition, Clemson has extensive materials-related capabilities that are well aligned with the R&D needs for improving the hydrogen distribution infrastructure, and Clemson faculty have held a number of working group sessions to examine materials-related issues associated with pipelines. In addition, USC researchers have published extensively on the coatings needed to protect materials from hydrogen.

3.2.4 Hydrogen Storage

Many consider the current lack of cost-effective and efficient storage technologies to be the greatest limitation in converting to a hydrogen economy.

Codes and Standards

SRNL also provides another resource that is essential to the adoption of hydrogen-related storage and distribution technologies. They have developed extensive hydrogen-related codes, standards, and safety expertise. Since standardized and safe approaches for utilizing hydrogen are essential before consumers will adopt these technologies, SRNL's expertise is an important resource.

Historically, hydrogen has been stored as a high-pressurized gas or a cryogenic liquid. The current alternatives for on-board high-pressure gaseous storage tanks are much too large and expensive for automotive applications. The low-temperature process used to liquefy and store hydrogen has been adopted by BWM, but more efficient systems for liquified storage are still an R&D objective.

To overcome these hurdles, new solid materials are being studied and developed at SRNL and USC that can store and then liberate the hydrogen. Some of the R&D programs underway in South Carolina have focused on these new materials. South Carolina institutions have substantial R&D capabilities related to many of the most promising solid-state storage materials – especially materials used in stationary and transportation applications. In addition, BMW is a leader in developing technologies for liquefied hydrogen storage.

3.2.5 Energy Conversion

South Carolina's hydrogen-related energy conversion capabilities have focused on gas turbines and fuel cells. GE Energy is expected to commercialize a combined cycle fuel cell and gas turbine system later in this decade. The highly efficient turbines are expected to be a cost-effective alternative for smaller distributed energy applications.

The R&D at USC and Clemson has focused on PEM fuel cells, which are the most promising type of fuel cells for transportation applications. Fuel cells are an attractive power generation option in transportation applications because they can be more efficient as an energy conversion device than an internal combustion engine. However, fuel cells are much more costly to operate than internal combustion engines, degrade relatively quickly, and do not work well in freezing weather.

For example, PEM fuel cells currently cost more than $1,000 per kilowatt, and these fuel cells can be purchased with warranty protection assuring an operating lifetime of more than 1,000 hours. By comparison, a vehicle's internal combustion engine costs approximately $35 per kilowatt and it generally operates for 5,000 hours or more.

3.2.6 End-Use Applications of Hydrogen

Transportation and stationary power generation systems are expected to become the primary applications of hydrogen technology within the next 15 years. These are also the two applications that have attracted the largest share of federal and industrial hydrogen-related research funds.

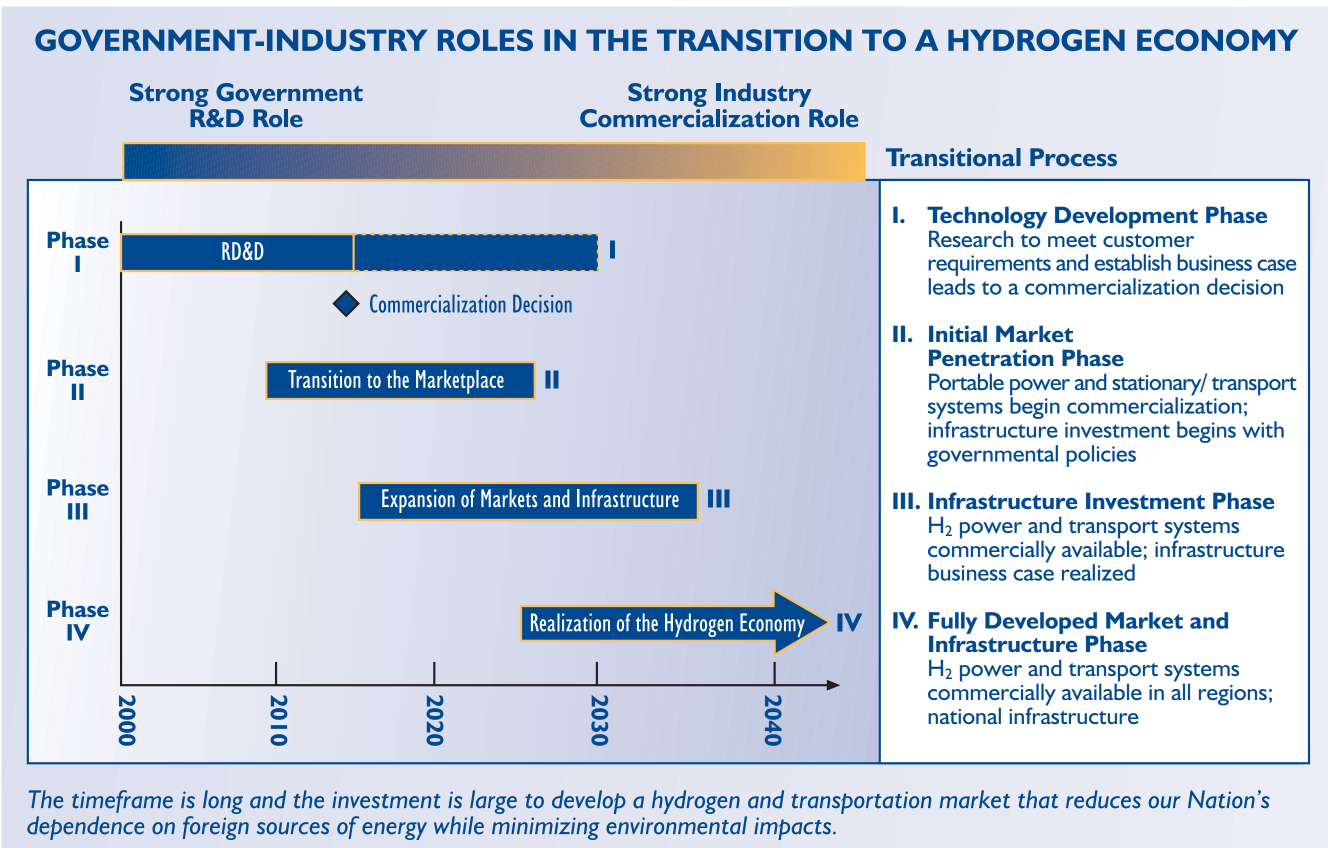
For each of these applications, companies with major facilities in South Carolina are among the world's most innovative and aggressive adopters of hydrogen-related technologies. On the transportation side, BMW is already developing hydrogen powered vehicles in Europe. At the same time, the Clemson ICAR program is expected develop R&D programs with BMW and other companies that address issues related to energy-related vehicle propulsion systems and vehicle electrical auxiliaries.

On the stationary power front, as mentioned earlier, GE Energy is a leading developer of power systems related to hydrogen, especially combustion turbine/ fuel cell combined-cycle power plants.

4.0 ECONOMIC DEVELOPMENT CONTEXT FOR THE REPORT

This section provides the economic development context for the report and provides the basis for the recommendations presented in Section 5.

In the introduction to its 2004 *Hydrogen, Fuel Cell & Infrastructure Technologies Program* plan, DOE explained that the transition to a hydrogen economy is expected to include four major phases. Figure 6, which appeared in the DOE report, provides a timeline that depicts the projected duration for each of the transitional phases. As of 2005, we are presently in Phase I, the Technology Development Phase. The start of Phase II, the Initial Market Penetration Phase, is not expected until around 2010, while Phase III, the Infrastructure Investment Phase, which will involve the expansion of markets and infrastructure is not anticipated to begin until around 2015. Widespread realization of a hydrogen economy is not expected to become evident until around 2025, when Phase IV, the Fully Developed Market and Infrastructure Phase, begins.



SOURCE: "Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-year Research, Development and Demonstration Plan," United States Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC, 2004

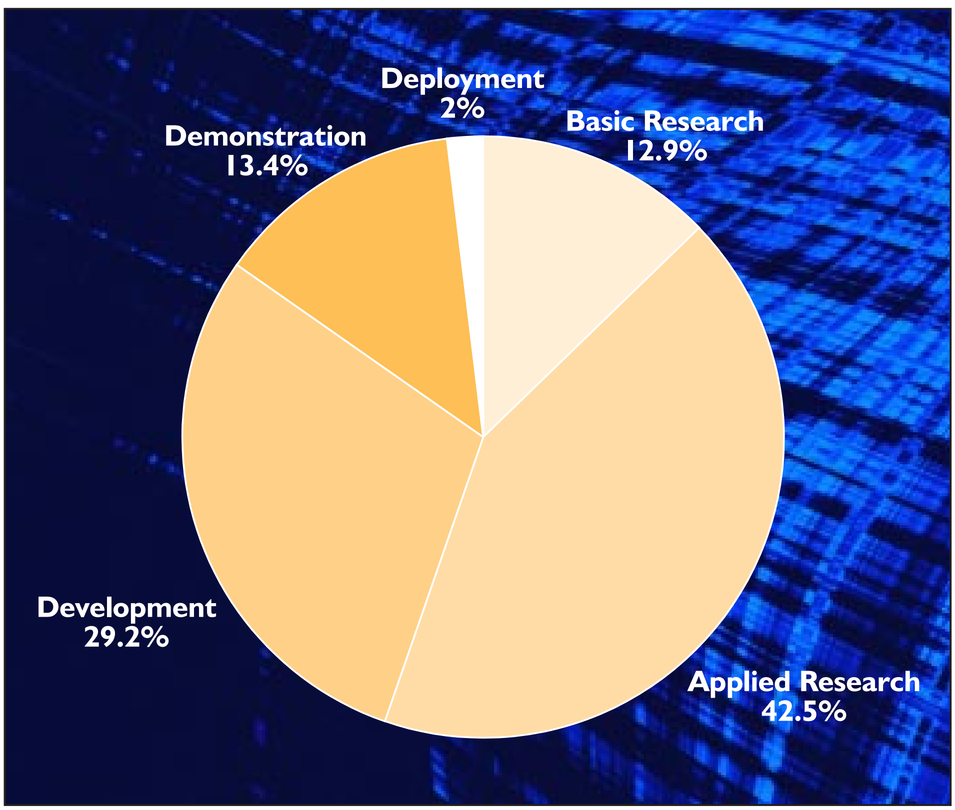
Figure 6 – U.S. Department of Energy's Timeline for the Transitional Phases to a Hydrogen Economy

The DOE report indicated that each new phase will offer an expanded set of economic opportunities, which build on the cumulative technical and economic advancements of previous phases. From an economic development prospective, this means that state and local hydrogen strategies must unfold in a series of customized stages that take advantage of the opportunities in each phase.

Overall, the strategies outlined in this *South Carolina Hydrogen Economy* report focus on opportunities in the R&D phase because – during Phase I – R&D spending is expected to account for the vast majority of all federal and industry funding for hydrogen economy projects. As indicated in Figure 7 below, nearly 85 percent of DOE's fiscal year 2005 budget for hydrogen initiatives is targeted to basic and applied R&D. Industry R&D spending patterns are following a path that is parallel to the federal government's.

South Carolina's objective during the R&D phase should be to attract the types of federal and industry R&D investments that lay the foundation for building a hydrogen economy over a longer term. Today's R&D investments will create significant economic activity by increasing industry partnerships and expanding R&D-related employment levels within the state. Yet, it is clear that the major long-term opportunities for attracting hydrogen economy jobs and wealth will materialize once hydrogen-related goods and services begin flowing into the marketplace.

However, South Carolina cannot wait to begin building hydrogen economy-related programs. Unless South Carolina gains a foothold during today's R&D phase, other more proactive states will have gained the competitive edge as a hydrogen economy begins to grow.



SOURCE: DOE Assistant Secretary David Garman's testimony before the Committee of Science, U.S. House of Representatives, March 3, 2004

Figure 7 – U.S. Department of Energy Fiscal Year 2005 Budget Allocation for Hydrogen Initiatives by Segment

4.1 Economic Development Framework for South Carolina

Provided below is a framework for a technology-based economic development infrastructure to enhance South Carolina's capacity to build a strong hydrogen-based industry cluster.[3] This framework emphasizes opportunities in Phase I – or the Technology Development phase – in DOE's hydrogen economy timeline.

Discussion is provided on: (1) current South Carolina technology-based economic development initiatives, and (2) economic development opportunities within each major segment of an economic development infrastructure, as listed below:

- Promoting establishment and growth of entrepreneurial firms,
- Supporting companies with existing operations in the state, and
- Providing the state with the comparative advantages needed to attract new industrial and service operations.

One other topic will also be discussed - the importance of building local-market demand for hydrogen products in order to stimulate economic development.

4.1.1 Promoting Entrepreneurial Ventures

On a comparative basis, South Carolina has had limited success in nurturing rapidly growing technology-based ventures. As a result, during the last 30 years, only a handful of South Carolina start-up firms have grown into major technology companies that serve national and international markets. According to the *2004 State Technology and Science Index* published by the Milken Institute, South Carolina ranked 39th among all states in the level of entrepreneurial activities and risk capital.

Industry Cluster-Based Economic Development as an Engine for Growth

Industry Cluster initiatives are designed to create jobs and wealth by expanding the base of complementary businesses and support organizations within a region.

This is achieved through collaboration among companies within the targeted cluster, research organizations, academic institutions and government. Because of this collaboration, the organizations can more effectively exchange industry-specific knowledge, share specialized resources, and build regional buyer-supplier relationships.

As a result, the quality of the workforce, the levels of entrepreneurship, and the amount of innovation all rise. This creates a critical mass of talent and ideas that allows companies within the industry cluster to grow at an accelerated rate.

South Carolina was also ranked 43rd in its proportional share of science and technology workers, which is important since these are the workers most needed during an R&D-intensive start-up phase.

However, South Carolina is now taking additional steps to upgrade the resources available for entrepreneurs. For example, the recently enacted Life Science Act and Venture Capital Investment Act created two funds – the South Carolina Venture Capital Fund and the South Carolina Technology Innovation Fund. The $50 million venture fund is authorized to invest up to $5 million in equity, near-equity, or seed capital per transaction. The Technology Innovation Fund will provide small grants to support research and technology transfer initiatives associated with the technology incubators located at the state's research universities.

[3] See the text box on the right for more information on the importance of industry clusters.

In addition, the state legislature recently authorized the creation of three Technology Innovation Centers. The new statute provides $6 million per year to staff centers at the state's research universities. The personnel assigned to the Innovation Centers are expected to focus on technology commercialization and other economic development activities related to university intellectual property.

Still, South Carolina's recent investments are relatively modest when compared to the funds allocated by other states that are implementing hydrogen economy initiatives. For example, Ohio has announced plans to spend $103 million over three years on its fuel cell initiatives, and Michigan has committed $56 million to promote the growth of "next energy" industries. More details on these and other selected state initiatives appear in Appendix IV.

4.1.2 Supporting Existing Businesses

There are currently no existing hydrogen-related commercial or industrial operations in the state, with the exception of the Kemira Oyj sodium chlorate production facility in Eastover that produces hydrogen gas as a by-product. As the base of companies begins to grow, however, new hydrogen-related companies will need a range of cluster-specific services. Expanded education and training programs will probably represent the most important resource. In some industry segments, such as nuclear technology, these programs are highly specialized.

Specialized services will also be needed in one or more of the following areas:

- Financing,
- Physical infrastructure, and
- Regulatory infrastructure.

Companies looking to expand into a hydrogen market may also need manufacturing-related support services. For example, in-state service providers, such as the manufacturing extension partnership, could provide supplier development services that encourage in-state manufacturers to adapt and expand existing product lines so that they include new hydrogen or fuel cell products. These programs can provide specialized manufacturing-related support services and training.

Importance of Linking Technology-Based Entrepreneurship with the State's Core Economic Development Mission

Technology-based economic development initiatives are more effective when they are integrated into the core missions of a region's primary state and local economic development programs. Historically, most economic development programs have focused on attracting large capital investments from both out-of-state companies building new facilities in the region and firms that are expanding their existing operations.

While these investments are still important, a strategy that focuses primarily on attracting large capital investments will not specifically address South Carolina's greatest weakness in building a hydrogen economy. The state's most evident liability is its lack of a strong base of high-level technical, scientific, and management executives with experience building high-growth firms.

Regions that have a critical mass of management talent are most successful in nurturing start-up firms and expanding existing homegrown firms. Without access to this management talent, much of the intellectual property generated by South Carolina's hydrogen-related R&D activities will migrate to other regions.

4.1.3 Recruiting New Industrial and Service Operations

During the early R&D-intensive period before significant markets begin to materialize, the primary economic development opportunities will be generated by: (1) securing the private- and public-sector funding to expand research organizations, (2) recruiting partners to work with in-state research organizations, and (3) working with companies that are commercializing technologies. South Carolina's traditional tax-reduction incentives are not useful in any of these instances because companies will typically not generate significant taxable revenues during the R&D phase.

Opportunities to attract or recruit new industrial facilities and service operations will begin to emerge later in this decade. For South Carolina, the handful of companies in the state that have major interests in hydrogen outside the state could potentially be early candidates to locate new hydrogen-related operations. This includes GE Energy, BMW, and a number of chemical companies.

New opportunities will also arise as the transition-to-market phase begins (i.e., Phase II in DOE's timeline). During this phase, the federal government and industry will begin to invest in commercial-scale production facilities. States that are competing for the larger scale-up facilities should be prepared to make significant investments that would include financing for: (1) the required matching funds for federal grants, (2) project-related infrastructure (i.e., roads, water, etc.) and site-preparation expenses, and (3) incentives to attract the industrial and service-sector participants in the project.

4.1.4 Stimulating Local-Market Demand

As hydrogen products and related services begin to appear in the marketplace, those regions that have established local markets for hydrogen-related products will have a significant comparative advantage in developing their hydrogen economies. For example, new start-up firms will be more likely to locate in regions where there are local buyers for their goods and services. In addition, the initial investments to build the hydrogen production and distribution infrastructure will also flow to areas where there are strong local markets.

To stimulate local-market demand, a number of states have established financial incentives to promote the early adoption of technologies, and they have implemented demonstration projects.[4] In contrast, according to information listed on the Database of State Incentives for Renewable Energy, South Carolina is one of the few states that has not implemented any incentives to promote the early adoption of renewable energy technologies.

Technology demonstration projects are also important because, typically, early adopters will accept an emerging technology only after they receive credible evidence from respected sources that the technology provides significant economic and technical benefits in a working environment. In South Carolina, a fuel cell demonstration project is currently underway at a dormitory on the USC campus in Columbia, but there have been few other state-funded alternative energy demonstration activities.

[4] See Appendix IV for details on the incentive programs in selected other states.

5.0 RECOMMENDATIONS

The recommendations in this report are intended to significantly enhance South Carolina's ability to secure increased levels of federal and industry funding for R&D initiatives that involve multiple in-state research institutions. These recommendations were developed with input from stakeholders throughout the state and with guidance from the project's Advisory Group.

Based on the feedback received from stakeholders, the following five strategic parameters were identified as the guiding characteristics that should underlie and be reflected in each recommendation:

- **Long-Term Impact** – Even though initiatives can be started in the near-term, they must lead to creating major long-term assets for attracting business investments and improving the competitiveness of South Carolina R&D institutions. Further, the initiatives must focus on building capacity in hydrogen economy segments that are strategically important to prospective federal and industry partners.

- **Superior Capabilities** – To compete successfully for federal and industry funding needed to build programs that will have a lasting impact, South Carolina R&D organizations must focus on broad segments of the hydrogen value chain where they can clearly demonstrate they have unique and/or superior capabilities.

- **Adaptability** – By focusing on broader technology segments that are adaptable to evolving circumstances, South Carolina increases its opportunities to leverage the range of capabilities provided by in-state partners. In contrast to initiatives that focus on very narrow technology segments, R&D institutions will have more flexibility in adapting broad-based programs as the hydrogen economy evolves in a non-linear and uncertain manner.

- **Increased Recognition** – Currently, South Carolina's hydrogen-related capabilities are not widely recognized outside of the state. In addition to increasing the flow of information about the hydrogen economy in the state, South Carolina can enhance its reputation by: (1) developing world-class R&D capabilities, (2) conducting and reporting on world-class R&D projects, and (3) participating in high-profile R&D and demonstration projects with industry. These activities will increase the state's visibility, which will place South Carolina in a more favorable position as its organizations compete for industry and federal investments.

- **Opportunities for Collaboration** – Expanding the level of collaboration among R&D, industry and government organizations in South Carolina is a fundamental part of the strategy. The recommendations in this report are focused on major R&D areas where collaborative efforts involving multiple organizations will help attract higher levels of government and industrial funding than might be available through the efforts of any single organization.

Keeping these characteristics in mind, a total of five recommendations were developed in the following four areas:

- Focusing state leadership,
- Pursuing high-payback R&D programs,
- Stimulating local-market demand, and
- Enhancing state economic development initiatives.

The five recommendations are discussed in the sections that follow.

5.1 Focused State Leadership

RECOMMENDATION #1

South Carolina should put into place a focused and collaborative leadership structure to define and implement South Carolina's hydrogen economy priorities. This should include establishing a lead laboratory for each major segment of the hydrogen economy value chain.

The South Carolina Department of Commerce is currently working with stakeholders in the state to develop a focused and collaboritive leadership structure to ensure that high-priority hydrogen economy initiatives are implemented in South Carolina. For this effort to succeed, the state's primary stakeholders must commit financial resources and provide the leadership necessary to improve South Carolina's ability to compete in the hydrogen economy.

It is essential that the stakeholders develop a joint vision, mission, goals, and objectives for South Carolina's hydrogen economy initiatives. And – most importantly – it is vital that the efforts undertaken regarding hydrogen economy objectives be pursued collaboratively to ensure that the state's overall hydrogen economy objectives are achieved.

Statewide efforts should include plans and initiatives to: (1) significantly increase the level of federal and industrial R&D investments targeted to major hydrogen initiatives in the state, (2) stimulate local-market demand for hydrogen-related goods and services, and (3) promote economic development.

To accomplish the state's R&D-related objectives, the state should establish a Lead Laboratory Process to maximize major funding opportunities available for collaborative efforts involving USC, Clemson, SCSU, and/or SRNL. This process should provide a framework for pursuing and managing major hydrogen-related research programs. Based on the Lead Laboratory structure, a specific institution would be selected to take a leadership role in developing a research agenda in a given technical area.

The Lead Laboratory would work closely with the other organizations to develop a research plan with specific goals, utilizing the strengths and capabilities of each institution to best accomplish the research objectives. The research agenda would be defined to address the critical challenges and opportunities that will lead to eventual commercial applications. The Lead Laboratory is also charged with developing a funding strategy to secure financial support for the research activities, again using the appropriate capabilities and relationships of the other institutions.

5.2 High-Payback R&D Programs

Two recommendations involve R&D programs. The first recommendation, related to hydrogen production, represents South Carolina's greatest opportunity for securing substantial long-term R&D funding related to the hydrogen economy. It builds on the thermochemical and nuclear R&D capabilities at SRNL and the state's research universities.

In the second recommendation, five target technology areas are identified. In each of these areas, two or more South Carolina R&D organizations have developed significant capabilities, and future federal funding has been allocated for initiatives. These are all areas that present significant opportunities for attracting federal and industrial investments.

5.2.1 Thermochemical Hydrogen Production

RECOMMENDATION #2

As its top hydrogen economy priority, South Carolina should pursue and secure DOE and industrial support to ensure that South Carolina is:

(1) the leader in developing the thermochemical water-splitting processes for producing hydrogen, and

(2) the location selected for the first commercial-scale high-temperature nuclear facility that produces hydrogen using a thermochemical process.

SRNL studies indicate that large quantities of hydrogen could be produced at competitive prices by using a high-temperature chemical water-splitting process. The water-splitting process reacts effectively at temperatures in the range of 950 degrees to 1,000 degrees Centigrade. To achieve the temperatures needed to drive the thermochemical process, soon-to-be demonstrated high-temperature gas cooled nuclear reactors are under development.[5]

SRNL already has extensive and broad-based expertise in conducting the R&D associated with the high-temperature thermochemical processes for producing hydrogen. Both USC and Clemson are also engaged in related research. Because of the unparalleled level of expertise in the state, South Carolina should work with DOE to ensure that SRNL is designated as the leader in the research, process development, and testing of these thermochemical processes. SRNL should also expand its partnerships with USC and Clemson to perform this work.

Furthermore, South Carolina should also immediately develop and subsequently implement an aggressive campaign designed to obtain funding for the billion dollar-plus nuclear facility that will be used to produce hydrogen commercially once the thermochemical process is successfully demonstrated.

Successfully competing for this investment will require the active collaboration of state government, the state research universities, SRNL, and state industrial leaders. It will also require the united support of the state's federal congressional delegation.

Currently, DOE's Nuclear Hydrogen Initiative (NHI) plan indicates that DOE anticipates providing funds to construct a prototype thermochemical hydrogen production facility by 2017. The prototype facility, which is currently slated for the Idaho National Laboratory, would demonstrate the commercial potential of the high-temperature hydrogen production technology. Based on this timetable, the construction of a full commercial-scale system could begin by 2020. However, this timetable is contingent on advancing the thermochemical process from laboratory scale to full commercial scale, and that will require the successful completion of considerable R&D and scale-up activities.

More information on both the thermochemical process and the nuclear facility are provided in the following sections.

[5] Other options, such as high-temperature central receivers heated by focused solar energy, may be able to support the thermochemical water-splitting process. R&D is still being conducted on this technology.

Developing the thermochemical process — By the end of 2008, DOE is expected to select a thermochemical process for a megawatt-scale pilot-plant evaluation. Several national laboratories, including SRNL, are expected to compete to conduct these trials. The national laboratory that conducts the thermochemical process pilot-plant evaluation will gain experience and an understanding about the process, and the selected laboratory will have a competitive advantage for future test facilities, including the larger engineering demonstration-phase system and the associated high-temperature nuclear reactor.

SRNL is currently conducting R&D related to both the Sulfur-Iodine (SI) and Hybrid Sulfur (HyS) thermochemical processes, which are widely regarded as the leading technologies. In addition, Clemson is performing thermochemical measurements related to SI, and USC is conducting R&D on a critical HyS component — the sulfur-dioxide depolarized electrolyzer. SRNL and the state universities also have expertise in materials science that could be applied to solving the very difficult materials issues associated with these systems. Furthermore, SRNL has strong capabilities in process scale-up and systems development, and it possesses the necessary personnel and facilities for performing the pilot-scale experiments.

There are seven major R&D initiatives associated with the thermochemical process development and demonstration. Total funding of $60 million is required during the next five years to successfully complete these initiatives, which are listed below. The listing also identifies the research organizations that would be involved in each of the initiatives:

- Completing thermodynamic studies on key chemical mixtures to determine their physical and chemical properties in order to permit system optimization and component design (Clemson and SRNL),

- Performing system analyses and modeling for thermochemical cycles and optimizing process design to achieve high overall efficiency (SRNL and USC),

- Performing materials studies to identify viable candidates to withstand harsh process environments (SRNL, USC, and Clemson),

- Constructing an engineering-scale component and subsystem test facility to perform engineering examinations and performance verification for major thermochemical processes, including both SI and HyS components (located at SRNL with technical support from USC, Clemson, and SCSU),

- Developing high performance, economically-viable designs for the sulfur dioxide-depolarized electrolyzer and performing verification testing (SRNL and USC), including development of improved PEM electrolytes (Clemson),

- Demonstrating the HyS cycle in a closed-loop, laboratory-scale system (SRNL), and

- Preparing a design for a multi-megawatt pilot-plant and a large-scale electrolyzer (SRNL and USC).

These initiatives would generate significantly expanded levels of activity at in-state research institutions and create R&D jobs. They would also lead to increased partnerships with both chemical and energy companies interested in working collaboratively on the development of commercial processes and products.

Building a commercial high-temperature nuclear reactor – Both DOE laboratories and industry are conducting extensive R&D on the high-temperature nuclear reactors needed to produce hydrogen via water-splitting. As mentioned earlier in this recommendation, DOE anticipates demonstrating the commercial potential of a prototype reactor for hydrogen production by 2017. The reactor would be operated in a test and demonstration mode, and it is not intended for continuous commercial operation. The commercial-scale reactor would be constructed once the technology is successfully demonstrated. Attracting the investments associated with the commercial-scale reactors should be South Carolina's top long-term hydrogen economy priority because of the potential economic benefits.

During the next 20 years, the commercial-scale reactor will probably represent the single largest hydrogen economy investment in the United States. SRS would be an ideal location for commercial reactor as well as the prototype reactor.

South Carolina's advantages include the following assets:

- Nuclear facilities currently generate 56 percent of South Carolina's total electric power, which means South Carolina has a higher percentage of nuclear power generation than any other state.

- Proposals have been made to establish a Nuclear Energy Park at SRS to host commercial nuclear power plants producing electricity and/or hydrogen, and two groups of electric utilities are currently considering SRS as a site for new next generation reactors.

- SRS, which is recognized as a world leader in handling nuclear materials, has a history of hosting nuclear production facilities, and it has an extensive security, emergency preparedness, and environmental monitoring infrastructure.

- SRS has a large buffer zone, a large and reliable supply of water, a trained and experienced work force, and it is located in a region with a high concentration of the types industrial companies that are heavy users of energy.

- USC and SCSU have a nuclear engineering degree programs, and USC has research expertise in advanced nuclear fuels and high-temperature reactors.

- Clemson has expertise in high-temperature materials and thermodynamics.

While securing funding for the commercial reactor should be South Carolina's primary long-term objective, the state should also seek to expand its research and university-level education programs related to high-temperature nuclear technology. Consequently, South Carolina should seek DOE funding for a university high-temperature research reactor at SRS.

Currently, a group of 17 southeastern universities, including USC and Clemson, are seeking DOE funding for a high-temperature research reactor. At present there are no high-temperature research reactors available to universities in the United States. Although the research reactor would not specifically support hydrogen production research, it would provide a resource that would enhance R&D capabilities related to high-temperature reactors.

If South Carolina continues to upgrade its university-based high-temperature nuclear research and the nuclear engineering programs at USC and SCSU, the state would significantly enhance its competitive position in attracting the federal and industrial investments needed to build the prototype and commercial-scale nuclear facilities.

Building these capital-intensive facilities would create a large number of engineering and construction-related jobs. More importantly, during the lifetime of this facility, a large number of knowledge-based workers would be needed for plant operations and continuing R&D. Potential industry partners include General Electric, Areva, General Atomics, and Westinghouse. The project could also expect to attract a base of nuclear technology suppliers and related spin-off companies.

5.2.2 Strategic R&D Areas

RECOMMENDATION #3

South Carolina should pursue major R&D initiatives in selected strategic hydrogen economy technology areas where South Carolina institutions have significant core capabilities.

Five technology areas are discussed in this recommendation. Stakeholders in the state should work collaboratively to pursue initiatives in those areas that have the greatest potential for securing federal and industrial funding. By mounting a united effort that focuses on a small number of program areas strategically important to the state, South Carolina can marshal the in-state resources and political support needed to increase the probability of successfully competing for major projects.

The five areas are discussed below:

1. Advanced Materials and Systems for Hydrogen Storage – New hydrogen storage technologies are needed for motor vehicle applications if DOE design goals for efficient hydrogen fueled light vehicles are to be met. Most current experimental hydrogen-fueled light vehicles use compressed gas storage in high pressure canisters. However, there are major weight-related and safety issues associated with the compressed gas storage systems that have a sufficient capacity to achieve a vehicle driving distance comparable to current gasoline-fueled light vehicles. BMW has had notable success in incorporating a cryogenic liquid hydrogen storage system into their hydrogen fueled vehicles, and the company currently plans to continue this approach in their first production vehicles.

In the United States, DOE has taken a lead role in working with automakers and energy companies to develop critical technologies to support development of competitive hydrogen fueled vehicles through the FreedomCAR and Fuel Partnership projects. A key element of the overall DOE hydrogen program is storage technology development, with an emphasis on solid-state storage. DOE funding for hydrogen storage projects doubled from $11 million to $24 million between fiscal year 2003 and fiscal year 2004, and South Carolina research institutions have had a modest level of participation in these efforts.

Worldwide, BMW, Ford, General Motors, DaimlerChrysler, Honda, and Toyota are all investing substantial funds in hydrogen storage research. Energy companies such as BP, ChevronTexaco, ConocoPhillips, ExxonMobil, and Shell Hydrogen are also engaged.

SRNL, building on its decades-long experience in handling, purifying, and storing the hydrogen isotope tritium, has a very active program in hydrogen storage. SRNL is beginning to develop relationships with automobile manufacturers for collaborative research on solid-state hydrogen storage materials. Most of this activity is focused on complex metal hydrides, but work is also underway on other materials such as glass microspheres and carbon based materials.

The key factor facilitating the collaboration between SRNL and industry is the establishment of the Center for Hydrogen Research, described in Section 3.1.1 of this report. In addition to SRNL, USC has active research programs in metal hydrides. Clemson has major programs in carbon-based materials and has some work underway in hydrogen storage.

2. Integration of Storage and Energy Conversions Systems into Motor Vehicles – Advancements in hydrogen storage systems, hydrogen-powered internal combustion engines, and fuel cells will provide automakers with new opportunities to optimize space utilization within the vehicle and improve the operational efficiency of energy and storage systems. To accomplish these objectives, R&D is needed to address systems design and integration issues related to the vehicle compartments and energy-related components.

This provides opportunities for R&D related to developing onboard vehicle storage systems. While considerable federal R&D funding is being devoted to new solid-state storage materials, much less attention is being given to storage containers. To develop containers suitable for transportation applications, significant advancements will be needed in container materials and design. For example, improvements in container strength and weight must be achieved to meet DOE design goals.

Also, design concepts that permit conformance to vehicle shape and volume envelopes are needed, as well as better means of determining the structural and thermal loads imposed by the storage medium. It is important for the development of container systems to be closely coupled with development of the advanced storage media so that interactions between the two are understood and accommodated.

The capabilities of the state's research universities and SRNL in advanced materials, structural analysis, and hydrogen handling can be of major benefit in assisting auto manufacturers, smaller component manufacturers, and new start-up companies in developing state-of-the-art storage containers and incorporating them into vehicle designs. The materials and design studies, while initially focused on solid-state storage systems, can be expected to provide technology applicable to compressed gas and cryogenic storage systems as well. Development of a collaborative partnership between South Carolina research institutions and auto manufacturers and suppliers should provide significant economic development opportunities.

Similar design, integration, and optimization opportunities exist in incorporating fuel cells into light vehicles. Prototype vehicles, which have been recently introduced, are beginning to provide performance and reliability data, and several automobile companies have announced plans to have hydrogen/fuel cell vehicles available for sale by 2010. However, there is still considerable uncertainty as to when hydrogen-fueled light vehicles will become competitive on a cost and performance basis. Effective systems integration and optimization will play a key role in determining if and when these systems become truly competitive. USC with its fuel cell center and power conditioning capabilities, and the developing Clemson/ICAR automotive research capabilities can make major contributions with proper research emphasis in this area.

3. Stationary Fuel Cell Systems and Gas Turbines – GE Energy is developing combustion turbine/fuel cell combined-cycle power plants. Siemens Westinghouse Power Corporation and a number of Japanese companies are also working on similar products. Siemens Westinghouse demonstrated the world's first combination of a fuel cell and microturbine in 2002. There is still significant development work that must be completed on combined-cycle systems, however, before they are commercially available.

In addition to the R&D programs internal to individual companies, DOE's National Energy Technology Laboratory has developed a partnership with industry, national laboratories, and universities to examine issues related to the efficiency of solid-oxide fuel cells and fuel cell/turbine hybrid power generation systems. The fuel cells present the most critical cost and technical challenges. But, research issues related to the integration of the two systems are also important.

This appears to present an opportunity for collaboration between USC and GE Energy. USC is a leader in optimizing fuel cell systems and simulating advanced electronic power systems. For example, USC's virtual testbed system, which is a comprehensive simulation and virtual prototyping environment for advanced electric power systems, provides researchers with a tool for reducing costs of designing, testing, and evaluating the systems within electrical equipment.

4. Advanced Materials for a Hydrogen Infrastructure – New hydrogen pipeline and related distribution systems need to be developed to support large hydrogen production facilities, such as the large-scale nuclear hydrogen production facility described in Recommendation #2. Currently, the geographical coverage of hydrogen pipelines in the United States is very limited. Approximately 400 miles of these pipelines have been built, and nearly all of these pipelines are located near large refineries and chemical plants in states such as Indiana, California, Texas, and Louisiana. The longest hydrogen pipelines spans the 90-mile distance between Houston to Beaumont, Texas.

At this point, the comparative advantages and disadvantages between the most-often-used delivery options (truck, rail, and barge) and advanced pipeline infrastructures are poorly understood. This is predominantly because numerous materials-related issues still need to be resolved before these pipelines are viable.

Several of the most significant technical issues are outlined in the following paragraphs:

- **Hydrogen embrittlement** – Research is needed to identify optimum low-cost steel pipe alloys that will resist hydrogen embrittlement. Particular attention is needed for welding methods used to join pipes. In some cases, welding may accelerate hydrogen embrittlement, and improved welding methods may be required.

- **Valves, fittings, and seals** – Hydrogen leaks through pipe walls, valves, fittings, and seals more readily than natural gas because of the relatively small size of hydrogen molecules. Research is needed to develop advanced steels, coatings, seals, and other advanced materials that can resist hydrogen leakage.

- **Sensors and safety controls** – Innovative and affordable sensors and safety controls need to be developed for pipeline and other hydrogen delivery methods.

CTC and SRNL are currently collaborating on a hydrogen infrastructure project, and both USC and Clemson researchers have explored advanced materials-related issues associated with pipelines. Plus, DOE has funded R&D at SRNL to evaluate technologies and systems design issues related to using natural gas pipelines for the co-transmission of hydrogen. The materials issues cited above are major considerations with a combined natural gas and hydrogen system. Plus, in a co-transmission system, more efficient methods for separating the gas at high-purity levels must also be developed. A number of chemical and energy companies – including Air Products & Chemicals, United Technologies Research Center, Air Liquide, and the Gas Technology Institute – are active partners in current research programs with DOE.

5. Photobiological Production of Hydrogen – With DOE sponsorship, Clemson, SRNL, and four other universities are engaged in R&D related to the photobiological production of hydrogen. Conventional processes and technologies for the photobiological production of hydrogen have been the subject of basic and applied research for many years. However, research in South Carolina has uncovered novel approaches for direct photosynthesis, which produces hydrogen directly from water without carbon fixation. These approaches have the potential to overcome many of the technical and economic challenges that have limited market acceptance of biohydrogen production technologies.

There may also be opportunities to build on other biomass R&D at USC, Clemson, and the Medical University of South Carolina. Overall, biomass represents a large potential feedstock for producing hydrogen. Biomass is defined as organic matter that is available on a renewable basis through natural processes. Hydrogen, as well as other fuels, can be produced from biomass by both thermal and biological processes.

As is the case in the southeastern United States in general, South Carolina has a relatively large volume of agricultural and timber-based biomass. Consequently, advancements that improve the cost competitiveness of biomass technologies could potentially provide South Carolina with economic benefits.

5.3 Local-Market Demand

RECOMMENDATION #4

South Carolina should pursue and implement a range of hydrogen economy demonstration projects and incentives to promote the early adoption of hydrogen technologies in the state.

As mentioned in Section 4.1.4, initiatives that create local markets for hydrogen-related products and services can have positive economic development benefits. Consequently, South Carolina should develop incentive programs to encourage the early adoption of hydrogen-related technologies by government, business, and residential consumers (see Appendix IV for examples of state incentive programs).

The state should also consider funding technology demonstration programs, especially with companies that are already located in the state or are potential candidates to locate new operations in the state.

The text box below highlights a few examples of demonstration projects that have the potential to: (1) enhance South Carolina's reputation as a leader in hydrogen economy initiatives, (2) develop partnerships with companies that are producing hydrogen products, and (3) leverage educational and research programs at South Carolina's higher education institutions.

Examples of Potential Hydrogen-Related Technology Demonstration Projects

A Network of Hydrogen Fueling Stations for Transit Busses and Fleet Vehicles –Demonstration projects can lead to the development of the initial nodes of a vehicle refueling infrastructure in the state. That is important because public demand for hydrogen-powered vehicles will not materialize without a refueling infrastructure. The following three South Carolina organizations are interested in partnering on a project to demonstrate hydrogen fueling station technologies for transit buses and fleet vehicles:

- The Clyburn Transportation Center at SCSU, which was established to demonstrate, test, and evaluate transportation-related technologies,
- SRNL, which has developed and demonstrated hydrogen technologies for buses and utility vehicles, and
- York Technical College, which operates the Center for Alternative Energy Transportation Electric Vehicle Program.

Hydrogen from landfill gas – The South Carolina Energy Office has identified 30 potential landfill sites that are candidates for relatively large landfill-gas-to-energy (LGTE) projects. The methane gas collected from LTGE projects could be used to produce hydrogen. This hydrogen could be used in a variety of applications, including stationary fuel cell systems.

Distributed electric generation projects – Several organizations in the state are demonstrating stationary fuel cell systems. As combined-cycle fuel cell and turbine systems are commercialized by the end of the decade, there may also be opportunities to work with an in-state company, such as GE Energy, for a larger demonstration project.

5.4 Economic Development Initiatives

RECOMMENDATION #5

South Carolina should implement expanded hydrogen-related economic development initiatives that capitalize on the state's core R&D capabilities.

Section 4.0 of this report outlined a framework for developing an economic development infrastructure that will promote the growth of a hydrogen economy. The recommendations given below focus on initiatives to create economic development programs that can be started today but will have long-term benefits.

The recommendations in this section do not take the place of a comprehensive economic development strategy for building a hydrogen industry cluster in the state. A comprehensive longer-term strategy is needed, but it should be incorporated into a larger state economic development strategy for all technology sectors. The integrated approach allows for more efficient use of state resources and creates a more extensive set of services that could be shared by hydrogen economy initiatives and other technology-based economic development programs.

The recommendations outline initiatives in the following two areas:

- Promoting the establishment and growth of entrepreneurial ventures, and
- Expanding the industrial base.

5.4.1 Promoting Entrepreneurial Ventures

The newly created Technology Innovation Centers provide a structure to begin developing the support services needed to promote the establishment and growth of homegrown hydrogen-related companies in the state. An opportunity exists to incorporate this responsibility into the still-to-be-defined mission of the organizations.

However, the centers would need to focus on both technology issues and entrepreneurship. Consequently, the centers should develop an explicit linkage with the entrepreneurship programs at Clemson and USC. This would combine the Innovation Centers' expertise in technology-based programs with the capabilities embedded in university programs that are supporting the creation and expansion of entrepreneurial firms.

Once the overall mission for the Innovation Centers is defined, it will be important to reevaluate the funding levels allocated for the program. The Innovation Centers' current $6 million budget is not sufficient to provide adequate levels of service, especially in areas such as technology development and commercialization. This is especially true since the centers were established to provide services to support the development and commercialization of a broad range of technologies, not just hydrogen-related technologies.

Furthermore, from a hydrogen economy prospective, the Innovation Center support staff, who will be located at each of the research universities, should work collaboratively on statewide programs that support the collective hydrogen-related R&D capabilities at SRNL, USC, and Clemson. Consequently, as a prerequisite for the success of this hydrogen initiative, the support services provided by the Innovation Centers should be structured to advance statewide hydrogen economy objectives. To forge this linkage, the organization designated to lead the state's hydrogen economy initiatives should provide the strategic direction and oversight for hydrogen-related programs.

In addition, especially during the R&D-intensive first phase of the hydrogen economy, the hydrogen-related initiatives delivered through the Innovation Centers should focus on supporting activities at the Center for Hydrogen Research in Aiken, the Horizon Center in Columbia, and ICAR in Greenville. The Innovation Centers should assist with technology commercialization activities and help to attract companies that would locate within these research parks.

5.4.2 Expanding the Industrial Base

As discussed in Section 4.1.3, the three most promising areas where South Carolina has near-term opportunities for recruiting corporations that may locate operations in the state are:

- The existing industrial partners that are working with the state's R&D organizations,
- Companies that are candidates to work with the R&D organizations on major projects, and
- Companies that currently have facilities in the state but also have hydrogen-related initiatives underway at out-of-state facilities.

To begin recruiting activities targeting these companies, the state Department of Commerce (DOC) should identify appropriate site-location contacts within these firms and maintain communications with these individuals to ensure that industry members understand the state's capabilities and state economic developers understand the industry's needs. DOC should also consider developing financial incentive packages for attracting these firms, since the state's traditional tax incentives typically do not benefit companies that are conducting research or proceeding with commercialization.

In addition, there will be some opportunities to compete for investments in new facilities that will be constructed by firms that are not conducting R&D activities in collaboration with in-state partners. These opportunities will begin to increase as the nation transitions to a hydrogen economy. Consequently, DOC should start marketing activities to attract companies within industry segments that are beginning to introduce new products.

To support this activity, the state should develop market research and technology road mapping capabilities to provide the intelligence needed to identify and evaluate the strategic alternatives for achieving the state's science, technology, and economic development objectives.

APPENDIX I

List of Advisory Group Members

Note - The views expressed in this report do not necessarily reflect the individual views or priorities of the members of the Advisory Group.

- David L. Bodde, Ph.D., Senior Fellow, Spiro Center for Entrepreneurial Leadership, Clemson University

- Theodore Motyka, Ph.D., Manager, Hydrogen Technology Center, Savannah River National Laboratory

- Norbert Seyr, Powertrain Projects, BMW Group

- Ralph E. White, Ph.D., Dean of the College of Engineering and Information Technology, The University of South Carolina

APPENDIX II

Bibliography

Although a wide range of published reports, proprietary market research summaries, and web-based documents were reviewed while preparing this report, the bibliography given below includes only the six documents specifically cited in this report. A more general reference book on the subject of a hydrogen economy written for a less technical audience is *Ewing, Rex A., Hydrogen - Hot Stuff Cool Science, PixyJack Press, LLC.,* 2004.

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The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs; National Research Council and the National Academy of Engineering; The National Academies Press; Washington, DC; 2003.

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Nuclear Hydrogen R&D; United States Department of Energy, Office of Nuclear Energy, Science and Technology; Washington, DC; 2004.

Porter, Michael E., Ph.D., *South Carolina Competitiveness Initiative: Phase I Final Presentation*, Monitor Company Group, LP, Cambridge, MA, December 8, 2003.

APPENDIX III

List Of Individuals Interviewed

Savannah River National Laboratory

- Melvin R. Buckner, Ph.D., Program Manager, University and Nuclear Programs
- Robin Brigman, Ph.D., Environmental Sciences and Technology
- Gerald Hooker, Principal Technical Advisory, Hydrogen Technology
- Theodore Motyka, Ph.D., Manager, Hydrogen Technology
- John G. Simon, Senior, Ph.D., Advisory Consultant, Office of the Vice President
- William A. Summers, Ph.D., Program Manager, Hydrogen Technology
- George Wicks, Ph.D., Consulting Scientist, Immobilization Technology
- Clinton R. Wolfe, Ph.D., Manager, Strategic Materials Technology Department
- Todd Wright, Ph.D., Director, SRNL

University of South Carolina

- Michael D. Amiridis, Ph.D., Chairman, Department of Chemical Engineering
- Abdel-Moez Bayoumi, Ph.D., Chair, Department of Mechanical Engineering
- Anthony Boccanfuso, Ph.D., Director of Research and Economic Development, Office of the Vice President, and Managing Director, USC Research Foundation
- Thomas A Davis, Ph.D., Department of Chemical Engineering
- Travis Knight, Ph.D., Department of Mechanical Engineering, Nuclear Program
- Michael A. Matthews, Ph.D., Department of Chemical Engineering
- Harris Pastides, Ph.D., Vice President for Research and Health Sciences
- Branko N. Popov, Ph.D., Department of Chemical Engineering
- James A. Ritter, Ph.D., Department of Chemical Engineering
- John W. Van Zee, Ph.D., Department of Chemical Engineering
- John W. Weidner, Ph.D., Department of Chemical Engineering
- Ralph E. White, Ph.D., Dean of the College of Engineering and Information Technology

Clemson University

- David L. Bodde, Ph.D., Senior Fellow, Spiro Center for Entrepreneurial Leadership
- Stephen Creager, Ph.D., Department of Chemistry
- R. Larry Dooley, Ph.D., Associate Dean, College of Engineering and Science
- Luis Echegoyen, Ph.D., Department of Chemistry
- Dan D. Edie, Ph.D., Department of Chemical Engineering
- Michael S. Ellison, Ph.D., Interim Director, School of Materials Science and Engineering
- Robert T. Geolas, Executive Director, International Center for Automotive Research
- Lawrence P. Golan, Ph.D., Director South Carolina Institute for Energy Studies
- ohn M. Kennedy, Ph.D., Director, Center for Advanced Engineering Fibers and Films
- Joseph W. Kolis, Ph.D., Director of Special Projects, Office of the Vice President of Research
- Christian E.G. Przirembel, Ph.D., Vice President, Research and Economic Development
- Ya-Ping Sun, Ph.D., Department of Chemistry
- Mark C. Thies, Ph.D., Department of Chemical Engineering

South Carolina State University

- Clarence W. Hill, Ph.D., Director, Clyburn Transportation Center

Washington Group International
- Laurie J. Hollick, Senior Vice President Strategic Programs
- David A. Pethick, Vice President, Business Development

GE Power Systems
- Roger Schonewald, Manager, Technology External Programs

GE Research Laboratory
- Susan Townsend, Hydrogen Programs
- Michael Vanderwenken, Advanced Technology Business Development

BMW Group
- Norbert Seyr, Liaison Engineer for Research and Technology, Vehicle Technology Projects

Concurrent Technologies Corporation
- J. Steve Johnson, Director, Technology Management
- Robert J. Unger, Director, Fuel Cell Test and Evaluation Center

John Deere Corporation
- Peter Finamore, Manager, Research and Development, Advanced Energy Systems

Kemira Oyj
- R.C. Aizcorbe, Jr., Vice President and General Manager
- Austin D. Devaney, Commercial Manager
- Bob Jackson, Development Manager

Santee Cooper
- Tom Kierspe, Manager, Capital Projects
- Elizabeth A. Kress, Principal Engineer, Capital Projects

South Carolina Electric & Gas
- Stephen M. Cunningham, Manager, New Project Development

Progress Energy
- Joe Donahue Vice President Nuclear Engineering & Services

Duke Power
- Michael Crews, Director, Science and Technology Planning
- James C. Rogers, Director, Economic Development

Aiken Electric Cooperative
- Gary L. Stooksbury, Chief Executive Officer

Three Rivers Solid Waste Authority
- Colin Covington, General Manager

Fort Jackson
- Nick Autry, Mechanical Engineer, Engineering Services Division
- George I. Dibb, Engineering Manager, Engineering Services Division
- Byung-Joon Kim, Mechanical Engineer, Engineering Services Division

South Carolina Research Authority
- Rob Davis, Vice President, Technology Development
- Larry E. Druffel, Ph.D., President and Chief Executive Officer

York Technical College
- Edward F. Duffy, Ph.D., Vice President for Development
- Robert Kosak, Ph.D., Director, Energy Resource Center

South Carolina Energy Office
- John F. Clark, Director
- Richard I. Horton, Manager

Catawba Regional Council of Governments
- Wendy Bell, Senior Planner, Clean Cities Program Manager

South Carolina Forestry Commission
- Tim Adams, Resource Development Forester

South Carolina Department of Commerce
- Timothy N. Dangerfield, Chief of Staff
- Richard Fletcher, Project Manager

Economic Development Partnership
- Ernest S. Chaput, Special Projects
- Fred E. Humes, Director

South Carolina Technology Alliance
- Thomas E. Persons, Sr., President

Fuel Cell South
- James Barnhill, Partner
- Thomas Militello, Partner

Next Energy Initiative
- Neil McLean, Managing Partner, Sagacious Partners
- G. Larry Wilson, Chief Executive Officer, Treyls

Contacts with Organizations Outside of South Carolina

ICF Consulting
- Ted Egan, Director of Analysis
- James O. Gollub, Senior Vice President

National Hydrogen Association
- Jeffrey Serfass, President
- Patrick Serfass, Technical and Program Development Coordinator

APPENDIX IV

Policies in Selected States for Promoting the Growth of a Hydrogen Economy

Various states are investing in programs and implementing policies designed to secure a competitive advantage as a hydrogen economy grows. Six of these initiatives are summarized in this appendix.

- ***Ohio*** has committed $103 million over three years, including $75 million in financing to make strategic capital investments, $25 million for R&D and demonstration, and $3 million for worker training.

- ***California*** plans to invest at least $40 million in state and private funds to build hydrogen refueling stations during the next five years.

- ***Michigan*** has committed $56 million for its NextEnergy program, which is focusing its efforts on alternative energy technologies – especially for the automotive sector.

- ***Florida*** is among the states that has introduced legislation to provide extensive incentives for research, economic development, and market stimulation.

- Numerous other states, including ***New York*** and ***Massachusetts***, are spending tens of millions of dollars per year on incentives to stimulate the adoption of technologies.

More information is provided on each of these programs in the following sections. It is important to note that these programs only represent a sample of the state-level hydrogen economy initiatives that are presently underway within the United States. Furthermore, this small sample does not begin to convey the extent of the competition emerging from the Far East, Canada, and Europe.

California

There are many reasons why California is aggressively pursuing initiatives to promote the adoption of hydrogen-related technologies. California has: (1) more motor vehicles on the road than any other state, (2) a rapidly growing population with an ever-increasing demand for fossil-fuel energy, (3) relatively high electric power rates, and (4) regionally severe air pollution problems that may provoke United States Environmental Protection Agency-imposed sanctions. Three of the California programs designed to address these problems are highlighted in the following paragraphs:

- **Vision 2010** – The California Hydrogen Highway Network is a public-private partnership managed by the California Environmental Protection Agency (Cal/EPA) in coordination with state and local agencies. The group has installed 16 hydrogen refueling stations at a cost of $1 million per station, the state has committed to spend an additional $6.5 million in fiscal year 2005-2006, and a Cal/EPA blueprint calls for continued funding for at least the next five years. According to California officials, once the network is completed, every Californian will have easy and convenient access to hydrogen fueling stations.

- **The California Energy Commission's Public Interest Energy Research (PIER)** – PIER promotes energy research, technology development, demonstration, and technology commercialization projects. The program is also leading the effort to develop a broad climate-change research plan for California. PIER awards up to $62 million in grants annually.

- **California Fuel Cell Partnership** – The California Fuel Cell Partnership is a not-for-profit corporation comprised of automobile manufacturers, energy companies, fuel cell companies, and government agencies. The organization is active in the establishment of initiatives that promote the development and adoption of fuel cell vehicles and is currently engaged in a range of programs, including the following:
  - – Placing up to 300 fuel cell cars and buses into fleets,
  - – Promoting fuel stations to support the vehicle fleets,
  - – Ensuring 'common-fit' fueling protocols,
  - – Promoting practical codes and standards, and
  - – Enhancing public awareness.

In addition, there are several other related programs targeted to reducing fossil fuel emissions and promoting the adoption of renewable energy technologies, including hydrogen-related technologies. Examples of these initiatives are discussed below:

- **The Low-Emission Vehicle Program** – The California Air Resources Board (CARB) operates the Low-Emission Vehicle Program, which promotes the use of clean alternative energy technologies. This program focuses on various energy-related technologies, including hybrid electric vehicles, battery-powered electric vehicles, and fuel cell vehicles. The CARB also implemented and oversees the "Zero Emission Vehicle" mandate, which requires that 10 percent of all light-duty vehicles offered for sale in California effectively emit no tailpipe emissions. Similar regulations exist for buses, and these regulations are intended to increase the percentage of zero-emission buses to 15 percent by 2008.

- **Renewable Portfolio Standard** – The California Energy Commission implemented a statutorily mandated Renewable Portfolio Standard (RPS). The RPS is intended to increase the use of non-fossil fuels to 20 percent of statewide energy consumption by 2017. As part of this program, California has instituted various incentives to encourage consumers to purchase renewable energy and to promote distributed generation. Also, California has adopted Supplemental Energy Payments that compensates investor-owned utilities for above-market expenditures related to renewable energy power generation.

Connecticut

Two of the nation's largest fuel cell manufacturers and a number of start-up firms engaged in hydrogen-related R&D activities are based in Connecticut. State economic development officials and policy makers have initiated a number of programs to promote the growth of this cluster. For example, the Connecticut Clean Energy Fund, which is managed by a quasi-public agency, is charged with making equity and other investments to promote the development, demonstration, commercialization, and adoption of renewable energy technologies. Fuel cells are a priority area. The program is funded through a surcharge on Connecticut ratepayers' utility bills, and the fund has invested approximately $35 million since its inception in January 2000.

On a smaller scale, the New Energy Technology Program, which is operated by the Connecticut Office of Policy and Management, provides grants to small companies that are commercializing renewable energy-related technologies. The state provides five $10,000 grants per year.

To promote research, the Yankee Ingenuity Technology Competition provides up to $300,000 for selected collaborative research programs involving Connecticut universities and industry. Renewable energy research projects are among the program's top priorities. Also on the research front, the University of Connecticut received state and private funding to establish its Global Fuel Cell Center in 2001. The center has subsequently attracted more than $4.3 million in state, federal, and industrial research funding.

Connecticut also offers a number of regulatory and incentive programs designed to encourage the adoption of alternative energy technologies, such as:

- Regulations that require the state's electric utilities to enter into 10-year-plus contracts to purchase not less than 100 megawatts of renewable energy capacity, and
- Local property tax exemptions for renewable energy projects.

Florida

In March 2005, the Florida Hydrogen Business Partnership published *"Florida's Accelerated Commercialization Strategy for Hydrogen Energy Technologies,"* which included a variety of statewide recommendations for implementing hydrogen economy initiatives. The Governor bundled a number of these recommendations into the Florida Hydrogen Energy Technologies Act, which was introduced during the 2004-05 session. The legislation was unanimously approved by the Florida House of Representatives but was not considered by the Senate. The legislation is expected to be reintroduced during the 2005-06 session. The legislation currently includes the following provisions:

- Companies would be provided sales and use tax exemptions for hydrogen technology-related expenditures,
- Utilities would be provided with incentives for demonstrating and testing hydrogen-related technologies,
- The nation's first statewide siting standards for hydrogen fueling infrastructure would be established, and
- A $12.9 million matching grant program would be put in place to support research, development, demonstration, and commercialization projects.

In addition, a $15 million incentive program has been proposed to provide cash and tax credits for hydrogen-fueled vans and a fueling station.

Overall, Florida currently has 28 mobile and stationary hydrogen demonstration projects either underway, in development, or in planning stages. Also, a state government agency is purchasing eight of the world's first commercially available hydrogen shuttle busses.

Michigan

Michigan's NextEnergy initiative includes a broad range of economic development, research, and market development programs designed to promote the commercialization and adoption of alternative energy technologies. The programs underway in Michigan are summarized below:

- **NextEnergy Tax Incentives** – Companies locating or expanding alternative energy-related R&D or manufacturing operations in Michigan receive business and personal property tax exemptions.
- **NextEnergy Center** – The soon-to-be-opened, 40,000 square-foot facility is located in Detroit. The facility's power grid will include the use of fuel cells, advanced combustion engines, photovoltaic systems, and advanced solar systems. The building will also house a laboratory, incubator space, conference room, product demonstration area, office space, and exhibition area. The center will fund industry/university research and commercialization projects and develop other industry support services.
- **Michigan NextEnergy Zone** – Companies that locate in the 700-acre, state-owned site in Detroit operate virtually free of all state and local taxes.

- **Spurring NextEnergy Demand** – Companies receive grants and property tax exemptions to support the adoption of energy-efficiency and alternative energy technologies.

Massachusetts

The Commonwealth of Massachusetts offers a number of incentives designed to promote the development and use of renewable energy resources, including the initiatives described in the following paragraphs:

- $6 million has been allocated over three years to fund distributed renewable energy projects used by commercial, industrial, and institutional facilities.
- Up to $25 million will be provided in rebates and production incentives to electric power generators that meet or exceed minimum requirements for producing electricity using renewable resources.
- Inventors, who receive income from qualifying alternative energy patents, are allowed to deduct their related income from state personal income tax or corporate excise tax, if the product is manufactured within the Commonwealth.

New York

New York has taken action on number of initiatives designed to promote the development and use of renewable energy resources, including those described in the following paragraphs:

- Up to $50 million in tax credits over five years has been provided to offset 30 percent of the capitalized costs for corporate and residential "green buildings," which includes buildings that install "clean energy" technologies.
- $19 million per year has been allocated from the Systems Benefit Charge fund for demonstration projects involving emerging alternative energy technologies, including fuel cells.
- A 280-acre Saratoga Technology Energy Park is being created to promote "clean energy" technologies.
- Purchase of 10 percent of state government's energy from renewable energy resources has been committed.

Ohio

Ohio recently completed "*Ohio's Fuel Cell Roadmap*," which outlines the state's primary hydrogen economy strategy. The Ohio roadmap includes provisions for promoting the growth of a fuel cell cluster and stimulating demand for fuel cells and related products. The cornerstone for the fuel cell initiatives has been the Ohio Fuel Cell Initiative, established in 2002. As a part of the initiative, $103 million has been committed to support programs in the following three core areas:

1. Expanding the state's collaborative research capabilities at research institutions, such as Case Western Reserve University, Ohio University, Ohio State University, National Aeronautical Space Administration (NASA) Glenn Center, and the Air Force Research Laboratory at Wright-Patterson Air Force Base,
2. Participating in demonstration projects involving hydrogen and fuel cell infrastructure, and
3. Investing to attract new companies and expand existing fuel cell companies.

To date, more than $38 million of the funds have been awarded, primarily for R&D and demonstration projects.

The Fuel Cell Initiative is an integral part of the state's $1.1 billion Third Frontier Project, which focuses on a broad range of priority technology areas identified by the state. The Third Frontier program has provided funding for a number of projects including $18 million for the Power Partnership of Ohio, which is led by Case Western University in collaboration with other universities and private-sector partners. The program has also provided $4.4 million to the Fuel Cell Prototyping Center located at Stark State College.

Two other examples of recently funded projects are:

- $1.6 million for the Wright Center of Innovation for fuel cells led by Case Western Reserve University, and
- $600,000 Mound Technical Solutions to develop, manufacture, and market the next-generation modular Comprehensive Fuel Cell Test System. Collaborators on this project include the University of Dayton Research Institute, Cellex Power, Case Western Reserve University, EMTEC, Mound Community Improvement Corp., Sinclair Community College, and Battelle.

Much of the leadership for fuel cell initiatives in Ohio has come from the Ohio Fuel Cell Coalition, which was founded in 2003 with financial support from the Ohio Department of Development and industry. The coalition represents almost 70 private and public partners from Ohio's fuel cell industry.

PREFACE

During the past several years, various individual organizations in South Carolina have discussed approaches for defining and pursuing opportunities associated with the future emergence of a hydrogen economy in the United States. In an attempt to develop a more coordinated approach, the South Carolina Hydrogen Coalition (SCH_2C) was created in 2002 to provide a forum where the state's industrial, academic, governmental, and research organizations could develop collaborative approaches that can provide greater benefits to the state than initiatives by individual organizations acting alone.

In late 2004, the SCH_2C, with partial funding from the South Carolina Energy Office, commissioned Concurrent Technologies Corporation (*CTC*) to prepare a *South Carolina Hydrogen Economy* report. *CTC* is a national non-profit applied R&D organization headquartered in Johnstown, Pennsylvania, with four offices in South Carolina. *CTC* was selected to lead this effort because of its involvement in economic development initiatives in the state and because of its experience in working with the United States Department of Energy and its national laboratories. Furthermore, *CTC* is actively involved with a number of hydrogen economy issues and agreed to cost share in development of this report.

Work on the report started in early 2005. As a first step, SCH_2C formed an Advisory Group of knowledgeable individuals from interested organizations in South Carolina to advise the project team. Appendix I contains a list of the Advisory Group. The final views expressed in the report do not necessarily reflect the individual views or priorities of the members.

Project Methodology

The methodology used by *CTC* in preparing the *South Carolina Hydrogen Economy* report included the following four major components:

1. **Examine major trends driving the creation of a hydrogen economy** – Relevant literature from a wide range of sources was reviewed to provide a context for the analysis, conclusions, and recommendations presented in this report. The review provided information on the major trends affecting the emergence of a hydrogen economy in both the United States and the world. Appendix II contains a bibliography of the documents cited in this report.

2. **Identify and catalog South Carolina's hydrogen economy-related resources and capabilities** – With assistance from the Advisory Group, all major organizations and individuals in South Carolina that have, or are likely to have, significant current or near-term interest in any relevant aspect of a hydrogen economy or fuel cells were identified. Within the timeframe available, meetings or phone interviews were held with as many of these individuals as possible. Appendix III lists the individuals interviewed during the project and includes each person's affiliation. The purpose of the interviews was to secure information regarding specific hydrogen economy-related capabilities, resources, or interests in the state and to identify potential collaborative efforts.

3. **Review major economic development initiatives underway in other states pertaining to fuel cells and a hydrogen economy** – Hydrogen economy-related initiatives underway in a number of other selected states were reviewed to provide a perspective for comparing efforts in South Carolina. A summary of the findings regarding selected state programs appears in Appendix IV.

4. **Develop recommendations on major collaborative initiatives that can capitalize on South Carolina's assets related to a hydrogen economy** – Based on assimilating the above information, a set of recommendations was developed that can leverage the state's current hydrogen economy-related assets. At this stage, these assets are predominantly research and development (R&D) related. The recommendations identify proactive measures that can be pursued in South Carolina within the next 24-36 months with the appropriate support and funding.

Although these initiatives can be started in the near-term, they are intended to create long-lived assets that can position South Carolina to be a major player in the evolution of a hydrogen economy in the United States over the next 10-20 years. If successfully implemented, the recommended initiatives would have a major impact on moving South Carolina into a leading competitive position where it can attract the jobs and economic development that will be associated with an emerging hydrogen economy.

Acknowledgements

The SCH_2C, South Carolina Energy Office, and *CTC* provided the funding to support preparation of this hydrogen economy report. The project was conducted under the direction of Mr. Richard Begley, Director of the SCH_2C.

CTC staff participating in the project included:

- Dr. Edgar Berkey, Vice President, Research & Development, and Chief Quality Officer
- Mr. Garry Powers, Director of Economic Development Initiatives
- Mr. Steven Ostheim, Director, Energy Programs
- Ms. Eileen Schmura, Senior Mechanical Engineer
- Ms. Joanne Mekis, Graphic Designer
- Mr. Michael Hull, Graphic Designer

In addition, Energy and Environmental Analysis, Inc. of Washington, DC, provided market research and supporting information for the project.

The entire project team is grateful to all members of the Advisory Group, as well as to all individuals and institutions in South Carolina who were contacted during the course of the project. The level of cooperation on this hydrogen economy study and the widespread commitment among South Carolina's stakeholders to collaboratively achieve statewide objectives is a very positive indicator that South Carolina has the potential to successfully build a hydrogen economy in the state.

Columbia, SC
July 2005

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EXECUTIVE SUMMARY

This "*South Carolina Hydrogen Economy*" report was commissioned by the South Carolina Hydrogen Coalition and the South Carolina Energy Office for two major purposes: (1) to identify the hydrogen economy-related resources currently in the state, and (2) to develop recommendations on some near-term, strategically-based steps that the state can take to capitalize on its assets and gain a significant share of the anticipated jobs and wealth that will be generated by an emerging hydrogen economy. In conducting this project, the major trends driving the emergence of a hydrogen economy in the United States were examined and some of the major hydrogen economy-related economic development initiatives being undertaken by other states were reviewed.

Based on these assessments, but especially on the present early stage of evolution of a hydrogen economy, the report presents five major recommendations intended to capitalize on South Carolina's research and development (R&D) assets. The recommended actions can all be started within the next 24-36 months, but they are designed to position the state to become a hydrogen economy leader over the longer term.

Emerging Hydrogen Economy Opportunities

The United States, along with other industrialized nations, has begun to increase its investments in a series of hydrogen economy-related initiatives. These actions are driven by concerns associated with dwindling petroleum reserves, increasing concentrations of greenhouse gases in the atmosphere, and a growing dependence on foreign sources of fossil fuel-related energy. For example, the United States plans to allocate $1.7 billion for hydrogen economy-related research over the next ten years. At the same time, an increasing number of companies from throughout the industrialized world – especially those involved with vehicle manufacturing and energy – are investing in the development of hydrogen technologies at an accelerating pace.

Industrial demand for hydrogen is also increasing. Currently, more than $30 billion of hydrogen is produced in the United States annually, predominantly for fertilizer production and petroleum refining. This market is currently growing at 10 percent per year. These growth rates would be further bolstered if hydrogen becomes cost competitive for a range of general energy and transportation applications. For example, one estimate indicates that the amount of hydrogen currently produced in the United States would need to increase by a factor of four to replace the petroleum currently consumed by motor vehicles, aircraft, and other modes of transportation.

As defined by the United States Department of Energy (DOE) and shown in Figure ES-1, the hydrogen economy value chain contains five major segments: Production, Distribution, Storage, Conversion, and End-Use Applications. There are major economic opportunities associated with each of these segments. The changeover from using fossil fuels to using hydrogen in our society will fundamentally transform the way energy in the United States is produced, stored, distributed, and used. However, the full transition to a hydrogen economy is expected to take 50 years or more, so much of the investment in the early years will be devoted to R&D activities. For example, DOE has allocated 85 percent of its $230 million-plus hydrogen economy budget in fiscal year 2005 for R&D. In additions, DOE has indicated that it anticipates that R&D will consume the vast majority of all hydrogen economy-related spending for at least the next 5 to 10 years. Thus, it is important to understand South Carolina's relevant R&D assets related to the emergence of a hydrogen economy.

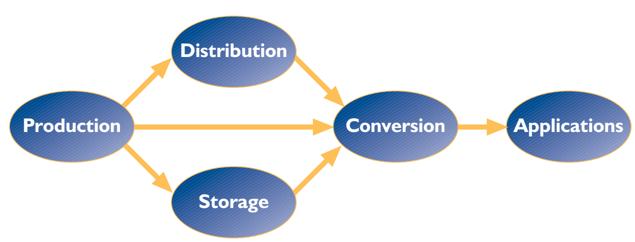

Figure ES-1 — Major Segments of the Hydrogen Economy Value Chain

Many States are Aggressively Pursuing Hydrogen Economy Opportunities

To compete more effectively for an increased share of the investments being made toward a hydrogen economy, a number of states are already implementing programs, initiatives, and partnerships involving research institutions, industry, and government. As the text box on the right indicates, these state efforts typically include four building blocks: (1) leadership approach, (2) R&D funding, (3) economic development initiatives, and (4) market demand stimulation.

Examples of six state hydrogen economy strategies that include provisions within each of these building blocks are briefly discussed below.

- Ohio has committed $103 million over three years for fuel cell-related initiatives.
- California plans to invest more than $40 million during the next five years to build hydrogen-fueling stations and is investing equally large amounts on programs to develop and deploy alternative energy technologies.
- Michigan has allocated $56 million for the state's NextEnergy Program, which is focusing its efforts on alternative energy technologies – especially for the automotive sector.
- Florida has recently completed a comprehensive strategy that calls for extensive incentives to promote hydrogen-related economic development.
- Numerous states, including New York and Massachusetts, are spending millions of dollars per year on incentives to stimulate the development and adoption of hydrogen and fuel cell technologies.

South Carolina's Capacity to Compete

South Carolina has the capacity to compete for hydrogen economy investments primarily because it has built significant relevant R&D capabilities over the past 50 years. South Carolina began building its hydrogen-related R&D base in 1951 when the federal government established the Savannah River Site (SRS) near Aiken, South Carolina. SRS was constructed to produce and separate the basic materials used in the fabrication of nuclear weapons, including tritium, an isotope of hydrogen that is a vital ingredient in such weapons. Because of this defense mission, SRS became a hub for hydrogen-related research.

Then, in the early 1980s, the University of South Carolina (USC) began assembling a nationally recognized team of fuel cell and hydrogen researchers. At about the same time, Clemson University was building a research base in advanced materials, which has increasingly included hydrogen economy-related applications.

Thus, the state has been involved in hydrogen-related research for a longer time than most regions of the United States. Moreover, South Carolina is currently attracting $25-30 million per year in federal funding for hydrogen-related R&D. Even so,

Four Building Blocks of State Hydrogen Economy Strategies

The leading state-level hydrogen economy strategies are typically constructed using the following four building blocks:

Leadership Approach – Industry, universities, and state government are collaboratively defining state-level priorities and working together to ensure their implementation efforts are focused.

R&D Funding – States are funding basic and applied R&D, technology development, and commercialization programs, especially collaboratively with industry.

Economic Development Initiatives – Programs have focused on new venture creation, expansion of existing firms, and recruiting new businesses.

Market Demand Stimulation – States are providing incentives for the early adoption of alternative energy technologies and demonstration projects.

the state's hydrogen-related capabilities are barely recognized outside of the state. The state's hydrogen initiatives have lacked visibility primarily for four reasons:

- SRS's defense mission contributes approximately 90 percent of the current funding received in the state for hydrogen-related R&D. Much of this work is classified. Consequently, a large portion of the research findings have not been reported in the open literature.
- South Carolina has been only moderately successful to date in attracting the faster growing hydrogen economy investments for applications such as hydrogen-powered vehicles and electricity generation facilities.
- The state has just begun to define and develop a series of hydrogen-related economic development initiatives, but efforts to implement a comprehensive statewide program are still at an early stage.
- The state lacks a base of industrial companies that currently have commercial hydrogen-related operations.

Nevertheless, as indicated by recent investments in hydrogen and other technology-based economic development programs, South Carolina has begun to invest in initiatives that offer significant economic opportunities for the state. See the text box on the right for more details.

Recent Initiatives Have Expanded South Carolina's Ability to Compete for Hydrogen Economy Investments

A number of the recent initiatives in South Carolina that have enhanced the state's ability to compete for hydrogen economy investments are listed below.

R&D Funding – USC was awarded $6 million in state funding, including a $1 million annual appropriation, for hydrogen R&D with industry.

R&D-Related Economic Development – USC has begun construction on a new $32 million center that includes facilities for collaborative energy-related research with industry. A new Center for Hydrogen Research in Aiken, which is scheduled to be completed in October, will leverage hydrogen R&D generated by SRNL, industry, and the state's universities. Clemson University has attracted public and private support for development of the International Center for Automotive Research (ICAR) at Greenville. South Carolina State University has established the Clyburn Transportation Center. In addition, the state is investing $3 million per year for Technology Innovation Centers to convert university intellectual property into economic development assets.

New Venture Development – State funding was provided for venture capital and new venture development.

South Carolina's Hydrogen-Related R&D Capabilities

This section highlights the R&D capabilities of South Carolina organizations in each major segment of the hydrogen economy value chain that was illustrated in Figure ES-1. South Carolina has significant capabilities in each value chain segment. In many cases, there are potential synergies among research programs being conducted. At the same time, the capabilities at each institution often fill voids associated with initiatives at other institutions. The text box on the following page describes the research institutions. The discussion below is by value chain segment.

Hydrogen Production – South Carolina has significant R&D strengths related to hydrogen production using high-temperature thermochemical processes. Although numerous technical hurdles must still be overcome before the nuclear production of hydrogen is viable, nuclear power is expected to play an important role in hydrogen generation within 25 years. As the technology evolves, South Carolina is well positioned to be a leader in development of both advanced high-temperature nuclear technology and the thermochemical process for hydrogen production. SRNL, USC, and Clemson are all involved in related research. In addition, the Washington Group International (WGI) and several other nuclear systems design, construction, and management firms are located in the Carolinas.[1]

South Carolina also has capabilities in generating hydrogen using renewable energy resources. For example, both Clemson and SRNL also are working on a novel approach for producing hydrogen using photobiological processes.

Hydrogen Distribution – SRNL and Concurrent Technologies Corporation (*CTC*) recently initiated a collaborative research program to develop more effective materials and technologies to address the numerous technical challenges associated with the development of a large-scale hydrogen pipeline system.[2] In addition, Clemson's extensive materials-related capabilities are well aligned with the research needs for improving the hydrogen infrastructure, and USC has published extensively on the coatings needed to protect materials from hydrogen.

Hydrogen Storage – Many consider the current lack of cost-effective and efficient storage technologies as the greatest limitation in converting to a hydrogen economy. South Carolina has extensive R&D capabilities focused on solving the storage challenges. For example, SRNL has 25-plus years of expertise in solid-state hydrogen storage technology research, development, and demonstration. Hydrides, which are beds of powdered metals that can store hydrogen like a sponge, make it possible to store hydrogen in an easy-to-handle solid form. USC also has expertise in solid-state storage, while Clemson has experience

[1] WGI is the parent company of the Westinghouse Savannah River Company, which currently operates SRS under contract to DOE. WGI is one of the world's largest firms engaged in the engineering, design and construction of nuclear facilities. The company's Energy and Environment Business is headquartered in Aiken.

[2] *CTC* is a nonprofit applied R&D organization with expertise in advanced energy, fuel cells, hydrogen, and technology transitioning. *CTC* has four offices in South Carolina, including the headquarters of its Technology Management Directorate in Greenville. *CTC* operates the Fuel Cell Test and Evaluation Center for the United States Department of Defense in Johnstown, Pennsylvania.

South Carolina Research Institutions With Hydrogen-Related R&D Capabilities

Savannah River National Laboratory (SRNL) is the newest DOE national laboratory, and it is part of SRS operations. Although the majority of SRNL's $139 million annual budget is devoted to defense-related research, SRNL is increasing non-defense-related hydrogen research with industry. More than 90 hydrogen-related scientists, engineers and technicians are employed at SRNL, which is believed to be more than any other research site in the United States and – possibly – the world.

The University of South Carolina has hydrogen and fuel cell activities centered in a nationally recognized electrochemical engineering group. USC secured support for a National Science Foundation (NSF) Industry/University Cooperative Research Center for Fuel Cells. In addition, DOE has funded USC's nuclear engineering programs related to nuclear-driven production of hydrogen.

Clemson University's current research initiatives related to hydrogen are focused in advanced materials. In addition, Clemson has established the International Center for Automotive Research (ICAR) with explicit provisions for research, development, and commercialization activities related to optimizing the design of vehicles to accommodate fuel cells, hydrogen storage systems, and new hydrogen-fueled internal combustion engines.

South Carolina State University (SCSU) has the Clyburn Transportation Center, which is involved in research, education and technology transfer programs related to intermodal transportation systems. The center is planning programs related to hydrogen storage and distribution systems.

with carbon-based storage materials. At the same time, BMW is a leader in developing storage systems for liquid hydrogen.

Energy Conversion – South Carolina's energy conversion-related R&D activities are focused on fuel cells. USC has nationally recognized R&D capabilities related to proton exchange membrane (PEM) fuel cell systems, which are among the most promising types of fuel cells for motor vehicle and smaller distributed-energy applications. Clemson is also engaged in fuel cell materials research.

End-Use Applications – Transportation and stationary power generation systems are expected to become primary applications for hydrogen technology. BMW and GE Energy, which both have major facilities in South Carolina, are among the world's most innovative and aggressive adopters of hydrogen-related technologies. For example, BMW is already developing hydrogen-powered vehicles in Europe. In the market for stationary power systems, GE Energy is a leading developer of power systems related to hydrogen, especially combustion turbine/fuel cell combined-cycle power plants. Both companies are currently conducting their hydrogen-related R&D outside of the state, but future South Carolina production operations are possible.

Recommendations

As mentioned earlier in this document, during the next 5-10 years, R&D expenditures are expected to represent the bulk of all investments in a hydrogen economy. Consequently, the recommendations in this report focus predominantly on identifying the opportunities where South Carolina has the greatest probability of securing significant levels of new research-related federal and industry funding. These opportunities will also position South Carolina to involve additional industry partners and will ultimately help generate homegrown companies and attract corporate investments from outside the state.

While the report's recommendations are focused on R&D initiatives, R&D programs alone are not sufficient to generate long-term economic development benefits. The jobs and wealth that will be created by a hydrogen economy will accrue predominantly to regions where technology is applied rather than where research is conducted. Consequently, for South Carolina to successfully compete for hydrogen economy investments, a united group of industry, academic, and government leaders must come together. They must work collectively, cooperatively, and collaboratively to promote economic development opportunities and to stimulate local-market demand for hydrogen-related goods and services. The state's major stakeholders have already started the process of building an alliance to achieve these objectives. Their ultimate level of success will significantly affect the state's ability to accomplish the recommendations that are summarized in the remainder of this section.

Recommendation #1 – Focused State Leadership

South Carolina should put into place a focused and collaborative leadership structure to define and implement South Carolina's hydrogen economy priorities. This should include establishing a lead laboratory for each major segment of the hydrogen economy value chain.

The South Carolina Department of Commerce is currently working with stakeholders in the state to develop the leadership structure to ensure that high-priority hydrogen economy initiatives are implemented in the state. For this effort to succeed, the state's primary stakeholders must commit the financial resources and provide the leadership necessary to improve South Carolina's ability to compete in a hydrogen economy. Statewide efforts should include initiatives to: (1) increase the level of federal and industrial R&D funding targeted to major hydrogen initiatives in the state, (2) stimulate local-market demand for hydrogen-related goods and services through technology demonstrations, and (3) implement targeted economic development programs.

To accomplish the state's R&D-related objectives, the state should establish a *Lead Laboratory Process* for the major South Carolina research institutions in areas related to hydrogen R&D. This process would identify a specific institution to take a leadership role regarding each given technical area and would require them to collaborate with the others in pursuing and managing major hydrogen-related research programs. The objective would be to maximize major funding opportunities available for collaborative efforts involving USC, Clemson, SCSU, and/or SRNL.

Recommendation #2 – Thermochemical Hydrogen Production

As its top hydrogen economy priority, South Carolina should pursue and secure DOE and industrial support to ensure that South Carolina is:

(1) the leader in developing the thermochemical water-splitting processes for producing hydrogen, and

(2) the location selected for the first commercial-scale high-temperature nuclear facility that produces hydrogen using a thermochemical process.

SRNL, USC, and Clemson have extensive and broad expertise in conducting the R&D associated with the high-temperature thermochemical processes for producing hydrogen. Furthermore, research is underway at USC and SRNL on the high-temperature nuclear technologies for producing the process heat necessary to drive these thermochemical processes.

Consequently, South Carolina should immediately pursue an aggressive co-ordinated campaign to ensure that South Carolina is the leader in developing the thermochemical process. As a next step, South Carolina should work to ensure that the first billion dollar high-temperature nuclear facility for producing hydrogen is located in the state at SRS. Successfully competing for these investments will require the active collaboration of state government, the state research universities, SRNL, and state industrial leaders. It will also require the support of the state's federal congressional delegation. These initiatives are important because they may represent the largest single investment in the hydrogen economy over the next 20 years.

Recommendation #3 – Strategic R&D Areas

South Carolina should pursue major R&D initiatives in selected strategic hydrogen economy technology areas where South Carolina institutions have significant core capabilities.

South Carolina has substantial R&D capabilities in the five strategic areas listed below. Stakeholders in the state should work collaboratively to pursue initiatives in those areas that have the greatest potential for securing federal and industrial funding.

- Advanced Materials and Systems for Hydrogen Storage.
- Integration of Storage and Energy Conversions Systems into Motor Vehicles.
- Stationary Fuel Cell Systems and Gas Turbines.
- Advanced Materials for a Hydrogen Infrastructure.
- Photobiological Production of Hydrogen.

Recommendation #4 – Local-Market Demand

South Carolina should implement a range of hydrogen economy demonstration projects and incentives to promote the early adoption of hydrogen technologies in the state.

Initiatives that create local markets for hydrogen-related products and services can have positive economic development benefits. Consequently, South Carolina should develop incentive programs to encourage the early adoption of hydrogen-related technologies by government, business, and residential consumers.

The state should also consider funding technology demonstration programs, especially with companies already located in the state or who are potential candidates to locate new operations in the state. As examples, demonstration projects could include a network of hydrogen fueling stations for transit buses and fleet vehicles, hydrogen production systems using landfill gas, or rural distributed electric generation projects using fuel cells.

Recommendation #5 – Economic Development Initiatives

South Carolina should implement expanded hydrogen-related economic development initiatives that capitalize on the state's core R&D capabilities.

In order to move quickly to leverage the state's hydrogen-related R&D capabilities, more extensive programs are need to:

(1) Promote the establishment and growth of entrepreneurial ventures that capitalize on the intellectual property generated in South Carolina, and

(2) Expand the state's industrial base.

South Carolina also should develop a comprehensive technology-based economic development strategy. Many of the provisions in a broad-based strategy would have significant benefits in promoting the growth of the state's hydrogen cluster.

Conclusion

South Carolina has a limited window of opportunity to gain a significant share of the jobs and wealth created by the hydrogen economy. By acting today to develop and implement a hydrogen economy initiative, the state can capitalize on its existing R&D capabilities and gain momentum. By waiting, other states that have organized large statewide hydrogen economy efforts will have gained a substantial competitive advantage. South Carolina needs to act quickly, and on a concerted basis, to compete effectively in the emerging hydrogen economy.