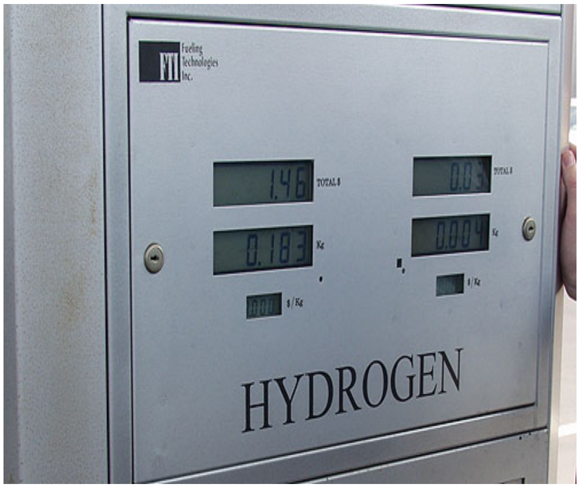

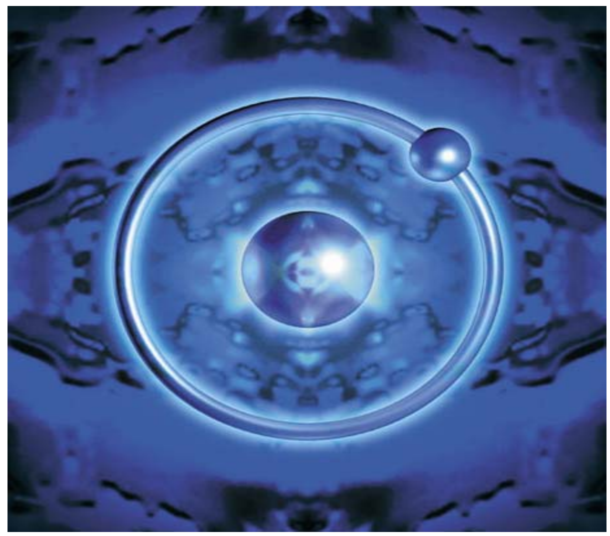

Policy Paper

The Hydrogen Economy and South Carolina's Role

--Is hydrogen the panacea that will solve our energy and pollution problems for future transportation needs?--

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1) Retrieved July 20, 2007 from http://www.edmunds.com/advice/alternativefuels/articles/102059/article.html.
2) Retrieved July 20, 2007 from http://enviro.org.au/enews.asp.
3) Retrieved July 20, 2007 from http://www.h2wales.org.uk/HRU.html.
4) Retrieved July 20, 2007 from www.rise.org.au/info/Res/hydrogen/index.html.

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> The energy and environmental problems facing the nation and the world, especially global warming, are far too serious to risk making policy mistakes that misallocate scarce resources.[1]
>
> Joseph J. Romm
> *Author and former USDOE official*
> *in hydrogen and fuel cell research.*

Introduction

America is dependent on foreign oil imports to meet its transportation needs. This puts the United States in a precarious and potentially dangerous situation given the geo-political volatility of mainly overseas petroleum suppliers (mainly in the Middle East[2] [3]).

Additionally, oil is a finite substance. While its supplies have not peaked, they are expected to do so sometime before 2040.[4] In the meantime, alternative vehicular fuels and technologies must be pursued. This is necessary not only for energy supplies and security reasons but also to address the effects of air pollution and greenhouse emissions.

Hydrogen offers a possible long-term solution for a sustainable energy system that would address America's future transportation requirements, including others such as stationary power generation and portable power generation. South Carolina and other states are investing resources in the research and development of a hydrogen economy, in the main, for vehicular fuel cell purposes.

Such an investment poses many challenges and risks. To meet these issues, public policymakers must make important choices in the near and long terms. Research and development efforts must offer realistic expectations on the pathway to energy self-sufficiency.

Hydrogen and its potential must be understood. Public policy must be based on this understanding. According to a 2005 RAND report:

> Decision makers in the public and private sectors do not have all the information they need for determining whether to invest in hydrogen research or to make investments in infrastructure that would be needed to use hydrogen as a source of energy. Decision makers also lack information to help them decide whether to formulate policies that will hasten the development of hydrogen as a viable energy source.[5]

Though far from definitive, this paper aims to provide *some* information and data to assist in making sense of a hydrogen economy and its policy implications.

Overview of the Emerging Hydrogen Economy

The emerging hydrogen economy (H_2 E) is a topic of growing interest and importance. The literature covering the budding H_2 E alone is prolific. The prestigious *Wall Street Journal*, *The Economist*, *Scientific American*, and numerous other sundry public magazines and journals have reported extensively on the subject matter. Add to this seemingly innumerable research papers, scientific studies, and web-based analyses and it becomes obvious, even to the casual observer, that the literature is indeed comprehensive.[6] Given this fact, it should be noted that the following narrative is based on a general review of much of this literature.

The H_2 Basics

What is hydrogen? The first element on the periodic table, basic hydrogen or H_2, is a simple chemical element consisting of one electron and one proton.[7] It is colorless and odorless and can be found nearly everywhere in nature—e.g., water, natural gas, biomass, etc.—but is extremely uncommon in its pure atomic state. Further, hydrogen is flammable and/or explosive in the range of 4.0-93.9% in air.[8]

To produce hydrogen, it must be separated from its natural state or “compound structure” such as water or natural gas. There are several ways to extract H_2 including steam reformation and electrolysis. H_2 can then be converted into energy or electricity to power anything from small appliances or devices to cars.[9]

What are fuel cells? Fuel cells are electrochemical devices which convert various substances, including H_2, into electricity. There is an assortment of fuel cell technologies in existence and others are being developed. The aim of current R&D in hydrogen research is to make fuel cells more efficient, cost-effective and productive in generating electricity (e.g., to power automobiles, buses, etc.). One such emphasis is placed on the development of polymer electrolyte membrane (PEM) fuel cells. PEM fuel cells use hydrogen fuel and oxygen from the air to produce electricity and are the preferred H_2 conversion apparatus for vehicles.[10] [11] [12]

What is the current status of the hydrogen production? Internationally, hydrogen production today is a large-scale commercial industry. H_2 is produced mainly to manufacture ammonia for fertilizers and to convert crude oil into gasoline. Globally, today, approximately 50 million tons are produced annually. In the United States, 8.2 million tons are now produced.

Worldwide, nearly 80% of H_2 is produced currently from natural gas (methane[13]) through a process known as steam methane reforming (SMR).[14] Ninety percent is produced by SMR in the United States. Essentially, SMR separates H_2 from natural gas and releases carbon dioxide (CO_2) as a byproduct. Among current technologies, SMR is the least expensive process in producing pure hydrogen.[15]

What is the future for hydrogen? Given the facts of high crude oil and gasoline prices, our oil dependence on countries abroad, the inevitable peak and decline of oil supplies, and the effects of greenhouse emissions, the United States and other countries around the world are increasingly looking towards alternative fuels and advanced technology vehicles. Hydrogen, as an alternative fuel source, and hydrogen-powered vehicles are possible solutions, albeit long-term ones, to the problems associated with the growing oil crisis. The transition to the so-called emerging "hydrogen economy" is a term used, in a larger sense, to denote the potential transformation of the United States energy system to "end-use" H_2 applications.[16] [17]

> A hydrogen economy is a hypothetical future economy in which the primary form of stored energy for mobile applications and load balancing is hydrogen. In particular it is discussed as a method for replacing the petroleum based hydrocarbon fuels currently used in automobiles.[18]

Furthermore, many barriers exist and must be overcome before an H_2 E can be fully realized. Technological problems and costs are the main hurdles. These are associated with hydrogen production and lack of infrastructure (fuel delivery, storage, and conversion). Others include marginal business investment, competition from other alternative fuel technologies (ethanol, biomass, etc.), lack of public awareness, consumer preferences or demand, and the oil industry's tendency to maintain the status quo as long as possible to maximize profits.

Despite these challenges, the federal government and most state governments are advancing initiatives in hydrogen research and development, particularly for transportation purposes. For example, in January 2003, President Bush announced the Hydrogen Fuel Initiative (HFI)[19] in his State of the Union Address. This program was authorized by the Energy Policy Act of 2005[20] and supported by the Advanced Energy Initiative of 2006.[21] HFI initially was appropriated $1.2 billion, and for FFY 2007, the president is recommending increased funding for hydrogen technology research by $46 million over current levels.[22] [23]According to the president's assessment:

> If the research is successful and market introduction begins in 2020, hydrogen fuel cell vehicles have the potential to reduce our demand for oil by over 11 million barrels per day by 2040. America currently imports between 10 and 11 million barrels of oil daily.[24]

Most state governments, including several municipalities, are also undertaking initiatives in H_2 research and development. According to an extensive report published in October 2006 by the Breakthrough Technologies Institute, 47 states "have some sort of fuel cell or hydrogen legislation, demonstration or activism taking place today."[25] These R&D efforts are multi-faceted and fall within eight categories: 1) Plans and Strategies, 2)

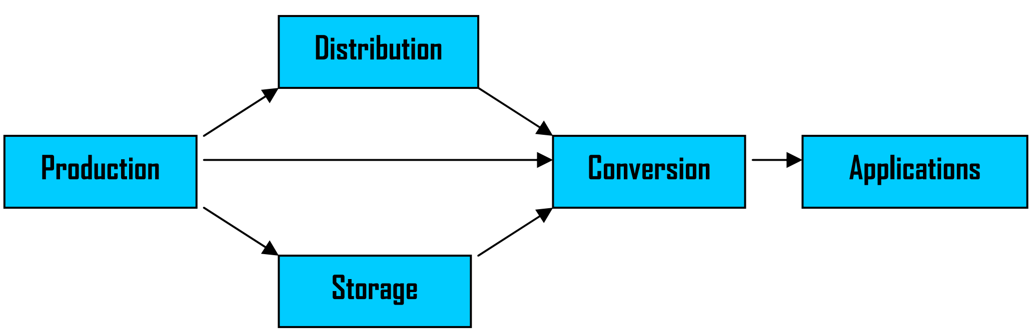
Standards and Regulations, 3) Public Agency Policies and Purchasing Programs, 4) Incentives and Market Stimulation, 5) Partnerships (alliances of government, business and/or academia that are working together to develop hydrogen and fuel cell policy and are fostering research and demonstration activities), 6) RD&D Support (grants, loans and facility space to support hydrogen and fuel cell research, development and demonstrations), 7) Emerging Business Support (financial incentives and business incubators to attract and nurture start-up hydrogen and fuel cell businesses), 8) State and Locally-Supported Demonstrations (fuel cell demonstrations supported or funded by state or municipal governments).[26] Based on an analysis of United States Department of Energy (USDOE) literature, those key states that are heavily involved in hydrogen initiatives include Arizona, California, Connecticut, Florida, Hawaii, Michigan, Ohio, and South Carolina.[27] [28]

So, bottom line, when will the transition to a transportation system (marketplace) based on hydrogen possibly occur? According to the vast majority of experts and scientists in the field of H_2 research and development, the answer is not for several decades. For example, the National Academy of Sciences predicts that the development of a hydrogen economy infrastructure may be attainable between 2030 and 2050.[29] The USDOE states that market introduction of personal vehicles could happen sometime between 2030 and 2040.[30] Bill Summers, program manager for the Savannah River National Laboratory, states that "hydrogen fuel cells for passenger vehicles could go into mass production in vehicles by 2020."[31] Similarly, Jon Van Zee, director of South Carolina's Fuel Cell Center states that "We have time. We don't have to get to a hydrogen economy in five years, but we do need to do research that will facilitate the technology 15 years from now."[32]

Analytical Framework: The Hydrogen Energy System

To understand the emerging hydrogen economy, especially as a fuel carrier for vehicles, it is important to grasp the major segments of a hydrogen energy system. These segments—as defined by the USDOE—include production, delivery, storage, conversion, and end-use applications.

Figure 1.
The Hydrogen Energy System



Production

Again, though hydrogen is plentiful in the universe, it rarely exists in its natural form on earth. As such, it must be extracted or produced from sources like natural gas, coal, water, or biomass compounds. The methods of H_2 production vary according to the source used, but all require energy of some type, including electricity, heat or light.[33]

For instance, fossil fuels (natural gas, coal and petroleum) are used to produce hydrogen via thermo-chemical processes.[34] These processes are mainly two: steam reformers and partial oxidation[35] (autothermal production). Steam reforming is the most prevalent method accounting for around 95% of H_2 production in America. Currently, steam reforming is the most efficient commercial technology utilized. Its method of production is as follows:

> Steam reforming is a thermal process, typically carried out over a nickel-based catalyst that involves reacting natural gas or other light hydrocarbons with steam. This is a three-step process that results in a mixture of hydrogen and carbon dioxide, which is then separated by pressure swing adsorption, to produce pure hydrogen.[36]

H_2 can also be extracted from water (a "renewable" source) using electrolysis. This method, however, is not presently efficient or cost-effective, in particular, for transportation purposes. Today, considerable research and development is underway to change this situation.[37]

It is envisioned by supporters of a hydrogen economy, including the USDOE and South Carolina researchers and key policymakers, that H_2 could become a principal energy carrier for vehicles supplanting the existing petroleum-based energy system. Ideally, H_2 would be produced in refineries or fueling stations using direct and renewable advanced conversion techniques.

Still, several current challenges to H_2 production present themselves. According to the USDOE, these include the following:

> • Hydrogen production costs are expensive.
> • Low demand inhibits development of production capacity.
> • Current technologies produce large quantities of carbon dioxide and are not optimized for making hydrogen as an energy carrier.
> • Advanced hydrogen production methods need development.
> • Public-private production demonstrations are needed.[38]

Given these challenges, the implications are clear. In terms of H_2 production, research and development must be focused on reducing and achieving efficiencies. Alternative methods of production to current technologies using fossil fuels must be developed that are both renewable and CO_2 emission free. And private sector entities must aggressively collaborate with public R&D efforts (including demonstration projects) and, equally important, invest heavily in H_2 production.[39]

Delivery

Once hydrogen is produced, it is delivered for purposes of end-use applications (except in those cases where H_2 is produced and used onsite). For its uses today, it is transported in high pressure cylinders, cryogenic tanks, and tube trailers by trains, trucks, barges and ships. H_2 is also transported via pipelines in a few cases.

Delivery within a 200 mile radius is usually by cylinders or tube trucks. Other delivery in the range 1,000 miles is typically by cryogenic tanks via trains, barges or ships. Delivery by pipelines is limited to large H_2 production facilities located in the states of California, Indiana, Louisiana and Texas.

For future transportation purposes, hydrogen could ideally be delivered by pipeline to areas of high demand. Additionally, some scientists believe that it may be feasible to produce H_2 onsite at fueling stations eliminating the need for distribution.

Many scientific, institutional, and market obstacles to delivery of hydrogen are, however, recognized. These include:

- An economic strategy is required for the transition to a hydrogen delivery system. (Current investments in delivery systems need to be justifiable beyond 2020 to support adequate returns on investment.)
- Full life-cycle costing has not been applied to delivery applications.
- Hydrogen delivery technologies cost more than conventional fuel delivery.
- Current dispensing systems are inconvenient and expensive. (Customers expect the same degree of convenience, cost performance and safety as with conventional fuels).[40]

As such, steps need to be taken to overcome these obstacles to H_2 delivery. Emphasis should be placed on strategic planning, costing estimates, and consumer desires.

Storage

Hydrogen can be stored as a liquid, gas, or in a solid form. Storage of H_2 is an issue affecting all components of the hydrogen energy framework—production through end-use. Since H_2 is a light or low density element, storage must be compact. To achieve this, several alternatives are possible. For example, H_2 gas can be compressed into high pressure cylindrical and quasi-conformable tanks. This is currently the most advanced and preferred method. Furthermore, liquid H_2 can be stored in cryogenic containers and elliptical containers. And finally, still requiring advanced R&D, solid state H_2 storage—

which is considered the safest method—can be achieved through metal or chemical hybrids, carbon absorption (nanotubes), and glass microspheres.[41]

Hydrogen storage technology for vehicles is currently not optimal. Mainly, cost, efficiency and safety issues must be addressed. This is the focal point of present R&D work.

> The ultimate hydrogen storage system for meeting manufacturer, consumer, and end-user expectations would be low in cost and energy efficient, provide fast-fill capability, and offer inherent safety. Hydrogen storage systems need to enable a vehicle to travel 300 to 400 miles and fit in an envelope that does not compromise either passenger space or storage space.[42]

Conversion

Hydrogen can be converted into an energy carrier in two ways: combustion or electrochemically by fuel cells. Combustion applications are similar to those used by engines today using gasoline or natural gas. Demonstration vehicles are being tested by today by automobile manufacturers such as Ford and BMW.[43]

Fuel cells again use the chemical energy of H_2 to produce electricity and, therefore, power engines. According to the USDOE, fuel cells are more efficient than internal combustion engines.[44] [45] Fuel cells are also advantageous for mobile applications in that they are quiet and can avoid heat-to-power cycles.[46]

There are several fuel cell types. These types can be categorized (Figure 2) by three criteria: electrolyte, operating temperature, and level of hydrogen purity.[47]

Figure 2.
Summary of Fuel Cell Types[48]

Fuel Cell	Electrolyte	Operating Temperature (°C)	Sensitivities to Hydrogen Purity
Proton Exchange Membrane	Solid organic polymer poly-perfluorosulfonic acid	60-100	High sensitivities to impurities, must have <10 ppm CO
Alkaline	Aqueous solution of potassium hydroxide soaked in a matrix	90-100	High sensitivity to carbon dioxide
Phophoric Acid	Liquid phosphoric acid soaked in a matrix	175-200	Sensitive to CO
Molten Carbonate	Liquid solution of lithium, sodium and/or potassium carbonates, soaked in a matrix	600-1000	Low sensitivity to CO, Hydrogen/carbon monoxide mixtures can be used. CO_2 is required
Solid Oxide	Solid zirconium oxide to which a small amount of ytrria is added	600-1000	Low sensitivity to CO, Hydrogen/carbon dioxide/ methane mixtures can be used

Source: United States Department of Energy.

The vision for H_2 energy conversion vehicles is a complex one and poses it own set of challenges.[49] The H_2 internal combustion engine car has the potential to be achievable sooner than those vehicles powered by fuel cells. However, many experts in the field of hydrogen R&D believe there are a number of issues associated with combustion such as the high cost of hydrogen and the life-cycle of the vehicle,[50] including those cited above.

The challenges facing conversion today, as highlighted by the USDOE, are durability, reliability and cost.

- No single fuel cell technology has met the criteria for performance, durability, and cost.
- Fuel cells require enhanced materials, membranes, and catalysts to meet both engineering and cost criteria.
- Research is needed to fill critical knowledge gaps.
- Market and institutional barriers hinder development of cost-competitive hydrogen conversion devices.[51]

Hydrogen R&D is necessary to make conversion methods, either of a combustion or fuel cell type, practicable. Preferably, both industry and government should work vigorously together to maximize vehicular H_2 conversion technologies for commercial purposes.

Applications

End-use applications for H_2 apply to stationary, portable, and transportation devices. In particular, regarding transportation end-use applications, these would obviously include automobiles, buses, trucks, trains, and watercraft devices such as boats or ships. According to the literature, almost every major carmaker has developed a H_2 vehicle prototype—General Motors, Ford, Chrysler, BMW, Honda, Hyundai, Nissan, and Toyota.[52] [53] Major oil companies are also conducting hydrogen R&D—BP America, Chevron Corporation, ConocoPhillips, Exxon Mobil Corporation, and Shell Hydrogen.

Public-private collaborative efforts are also being pursued. For example, FreedomCAR[54] [55] is a formal partnership program between the USDOE and automakers and fuel companies. Their aim is "to jointly conduct technology road mapping, determine technical requirements, suggest research and development (R&D) priorities, and monitor the R&D activities. Technology road mapping includes identification of existing barriers and challenges, technology-specific R&D goals (including cost targets) and milestones to progress toward the overall partnership goals."[56]

Significant efforts are in progress to make H_2 vehicles efficient and cost-effective. These are clearly in research and development as well as in demonstration. Public transportation, such as bus systems, is seen as promising initial end-use application.

Nevertheless, the obstacles to widespread vehicular usage are daunting. End-use applications are not affordable or practical today. Production, storage and delivery compound these problems for reasons cited above. To realize transportation hydrogen applications these and other obstacles must be overcome.

- Transportation, stationary and portable applications require technological and engineering solutions.
- Customers must accept hydrogen technologies and fuel cell vehicles. (The first vehicles are likely to fall short of consumer expectations (e.g., range, cold-weather applications, etc.)[57]

South Carolina Hydrogen Organizations and Programs

Over the past few years, South Carolina has established a number of organizations and programs to research and develop hydrogen-related technologies. These R&D efforts have been related in many cases to fuel cell technologies, e.g., proton exchange membranes (PEMs). However, other R&D efforts have concentrated on H_2 production, storage and delivery aspects. Transportation as an end-use application has additionally been a focus. Other organizations have also been created to promote collaboration and public awareness.

The Savannah River National Laboratory

In 2004, the Savannah River National Laboratory[58] (SRNL) was established at the Savannah River Site[59] near Aiken, South Carolina. Funded by the federal government (USDOE), it has an annual operating budget of $139 million and a research staff of some 90 persons.

SRNL has eight programmatic or "competency" areas, one of which is called "Hydrogen & Tritium Science & Technology." According to SRNL, "it is working on the technologies to not only make H_2 vehicles a reality in the future, but to make hydrogen an important part of the nation's overall energy strategy, powering our homes and industries."[60]

H_2 production. SRNL is developing thermo-chemical processes for separating hydrogen from carbon monoxide and other hydrocarbon gases. SRNL is also studying biological resources (e.g., microalgae[61]) to produce hydrogen. Additionally, these production methods are being examined for purposes of reducing production costs and increasing efficiencies.

H_2 storage. SRNL is also developing and patenting hydrogen storage devices, specifically metal hybrids. These hybrids make it possible to store H_2 safely in a solid and stable form. Other storage technologies are being tested as well. These include alanates[62] that possess storage capabilities like those of metal hybrids but are lighter and more appropriate for H_2 vehicles. Further, carbon nanostructures or nanotubes and microspheres are being experimented with for storage purposes.[63]

H_2 delivery. SRNL is working with Concurrent Technologies Corporation[64] to research technologies for pipeline delivery. R&D for transporting hydrogen with natural gas is also being studied.[65]

The Center for Hydrogen Research

The Center for Hydrogen Research (CHR) is located two miles from SRS in Aiken, South Carolina. CHR is a new facility[66] established "to accelerate the development of hydrogen as a viable alternative energy source by bringing together scientists from the national lab with researchers from universities, research institutes and the private sector."[67]

Currently, CHR is a facility with a total 60,000 square feet, 12,000 of which is available lab space ready to be fitted for specific research needs. It should be noted also that CHR has some 80 researchers or scientists with approximately half coming from SRNL.

Additionally, CHR is funded and operated entirely by Aiken County government which invested $10 million for building construction. CHR belongs to the South Carolina Hydrogen and Fuel Cell Alliance.[68] Members of the alliance include the S.C. Department of Commerce, major research universities, and leading businesses and manufacturers.[69] [70]

In terms of R&D research, and similar to that of SRNL, CHR has three core competencies that include: production, storage, and conversion.

H_2 Production. Researchers with CHR and SRNL[71] are well-versed in producing hydrogen and tritium, the radioactive isotope used in national defense. Even so, concentration in producing hydrogen *outside* of a nuclear reactor for commercial application is CHR's main focus.

H_2 Storage. CHR is additionally centered on solid-state storage. This focus is aimed to create greater safety, compact size, and convenience of storage—all critical requirements for H_2 vehicles.

H_2 Conversion. Further, CHR scientists are examining safer and more efficient ways of extracting hydrogen from water or other compounds that are aimed to be commercially practical.

The University of South Carolina

The University of South Carolina is spotlighting four research areas: alternative energies or H_2 advanced technology, nanotechnology, biotechnology, and environmental sciences. Innovista[72] is a district or area adjacent to USC that is envisioned to be the hub for these research areas.

USC is home to the National Science Foundation (NSF)—Industry/University Cooperative Research Center for Fuel Cells. NSF tapped USC to be its only center for H_2 fuel cell research in 2003.

According to USC, it is working in collaboration with several industrial partners to advance the technology and commercialization of fuel cells by performing research in five main areas: 1) fuel cell design, 2) fuel cell performance, 3) hydrogen storage materials, devices and distribution systems, 4) new catalysts for hydrogen production and for fuel cell electrodes, and 5) motor design and power conditioning.

As mentioned earlier, USC hydrogen research is concentrating on the proton exchange membrane fuel cell. Also, research in the use of solid oxide fuel cells[73] is being conducted.

In addition to the fuel cell research, USC is developing improved technologies for generating and storing hydrogen. One such project is probing ways to produce hydrogen in a very pure form because hydrogen impurities can damage fuel cells.[74]

Figure 3.
The Horizon Center
Future Center for Next Generation Energy Technologies[75]

Source: University of South Carolina.

Clemson University

Clemson University (CU) is another higher education institution in South Carolina conducting research into hydrogen technologies, principally with regard to advanced materials.[76] CU is looking at improved H_2 storage, fuel cells, and eventually, end-use applications.

CU hydrogen storage research is centered mainly on the carbon-related materials. One example is research being conducted that involves doped carbon nanotubes.[77] The aim here is to increase significantly storage capacity.

CU is also conducting research related to fluorinated fuel cell electrolytes.[78] If successful, this research would improve the performance and durability of H_2 fuel cells. Other fuel cell research at CU involves nanocomposite fuel cell electrodes and carbon nanosponges.

Moreover, in terms of end-use applications, the International Center for Automotive Research or Clemson-ICAR,[79] located in Greenville, South Carolina, is working with other CU researchers in developing carbon fuel cell materials (mentioned above) that could make hydrogen a practical fuel for cars.

Other South Carolina Hydrogen Organizations

Several organizations have formed to foster collaboration and public awareness relating to a hydrogen economy. These catalyst or partnership organizations include:

EngenuitySC. It is a strategic council composed of both public and private sector members.[80] EngenuitySC is a nonprofit organization fostering the growth and expansion of a knowledge-based economy in the Midlands. One of its areas of chief concern is the development of hydrogen fuel cells. One of its main programs to-date is the Greater Columbia Fuel Cell Challenge.[81]

South Carolina Hydrogen and Fuel Alliance. Formed in 2006, the alliance is a non-profit organization promoting the use of hydrogen and fuel cell technologies.[82] Its chief collaborative partners include the Savannah River National Laboratory, the University of South Carolina, Clemson University, South Carolina State University, and the Center for Hydrogen Research.

South Carolina Hydrogen Coalition. The coalition was established in 2002 as a non-profit located in Aiken, South Carolina. It too fosters the promotion of hydrogen and fuel cells. In conjunction with the South Carolina Energy Office[83] it issued an important report in 2005 entitled, "The South Carolina Hydrogen Economy: Capitalizing on the State's R&D Assets" (prepared by Concurrent Technologies Corporation).[84]

South Carolina Next Energy Initiative. The initiative is described as a working group consisting of leaders in South Carolina businesses, higher educational institutions, and politics. The goal of this group is to determine how the state can take a leadership role in the development of energy sources that will replace fossil fuels, especially hydrogen.[85] In 2005, the initiative issued a report delineating a strategic plan for a state H_2 economy.[86]

USC Columbia Fuel Cell Collaborative. Created in 2005, this is a collaborative organization consisting of the University of South Carolina, the City of Columbia and EngenuitySC. The principal aim is "to create and execute a plan for how Columbia can set the standard for large scale use and implementation of fuel cell applications by partnering with industry from the entire supply chain around this technology."[87]

South Carolina Policy Initiatives: Concluding Remarks

> South Carolina is on the cutting edge of hydrogen research, and hydrogen holds the potential to be the new fuel for the 21st century.[88]
>
> Lindsay Graham
> *U.S. Senator (R-S.C.)*

> Right now South Carolina is on the edge of what could become a multi-trillion dollar industry over the next 20 years—the beginning of a hydrogen revolution.[89]
>
> Bobby Harrell
> *Speaker of the S.C. House of Representatives*

For better or worse, some South Carolina key policymakers are betting on a future hydrogen energy economy and they want the Palmetto State to be among those in the H_2 economy lead, especially with regard to R&D in the short-term.

This is evidenced by a large influx of millions of federal, state, and local dollars. For example, the state appropriated $3.6 million in recurring monies in FY 2007-08 for hydrogen projects. Other appropriated state dollars for the same period include $1 million for fuel cell research at USC and $400,000 to the South Carolina Hydrogen and Fuel Cell Alliance. The State of South Carolina has also allocated more than $200 million in research chairs in academia for research. This is complementary to $175 million in other federal and state dollars now allocated to H_2 research in the state.

It is further demonstrated by legislation at both the federal and state levels. At the federal level, for example, Congress passed the Energy Policy Act in 2005[90] which contains significant provisions for hydrogen and fuel cell research. President Bush is supportive of a hydrogen economy. In his 2003 State of the Union address he proposed "$1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles."[91] At the state level, the General Assembly passed S. 243,[92] the Hydrogen Infrastructure Act in 2007. Among its various provisions, not all related to hydrogen, are the following: 1) authorizes the South Carolina Research Authority to administer grants for the purpose of promoting the development of hydrogen; 2) requires state agencies to consider purchasing equipment and machinery operated by hydrogen or fuel cells; and 3) allows a sales tax exemption for equipment or machinery operated by hydrogen or fuel cells.[93] [94]

Still, some policymakers are skeptical or at least hesitant to bet on a full-fledged hydrogen economy and a transportation system dominated by H_2. For instance, Governor Mark Sanford, though an advocate of H_2 research, vetoed S. 243. His veto statement argued that:

> I think there are some issues related to hydrogen research that we believe need some deeper consideration… Hydrogen is still an unproven commercial endeavor and, as such, I believe we should be very measured and deliberate in taxpayer commitments. With hydrogen, we've been supportive in many areas, but it is our opinion that this bill goes beyond this zone of deliberate investment in unproven technology. One, we don't believe it's wise to put all your eggs in one basket… Two, we don't believe it's the role of government to "lead" the private sector… Finally, we believe that when government does invest in developing technologies, public monies should be matched with significant private investment.[95]

In terms of policy, there are both pros and cons—advocates and critics. A few of the pros and cons are summarized below.

Pros

- Hydrogen is an extremely clean fuel, producing few emissions when combusted directly or in combination with hydrocarbon fuels. When used in a fuel cell, the only byproducts are heat and water.[96]
- Hydrogen can contribute to economic growth through job development, investment opportunities, and the creation of a sustainable, secure energy supply.[97]
- Hydrogen is a versatile energy carrier that can be used to power nearly every energy need.[98]

Cons

- Although hydrogen can be procured through electrolysis, it is most commonly separated by a reforming process that uses natural gas and other fossil fuels. Supplies of natural gas are becoming tighter, and coal, one of the most feasible hydrogen feedstocks, is a source of major pollution. The technology to produce, store, and transport hydrogen power at a reasonable cost is not yet in place and likely will not be for some time.[99]
- The competition—more fuel-efficient internal combustion vehicles—is getting tougher, [including ethanol,[100] biomass, electric, and various hybrid vehicles].[101]
- [Oil companies are disposed to maintain the current petroleum energy system until it is exhausted to avoid R&D costs and maintain profits.][102] (Bracketed statements added.)

Given this, again the question arises as presented in the subtitle of this paper: "Is hydrogen the panacea that will solve our energy and pollution problems for future transportation needs?"

Perhaps.

Economic outcome—the widespread implementation of a hydrogen economy—will ultimately be decided by consumer preference and market conditions. Whether or not H_2 is the silver bullet for the transportation sector will be its viability in the global competitive marketplace. This is uncertain now. There are many unknown circumstances and caveats. Today, there are certainly no well-documented projections as to which alternative fuel or vehicle will prevail. In the end, the competing technologies will be price or cost driven.

In the interim, government policy initiatives and investments can influence what eventually happens in the short and long terms. In the short term, hydrogen research and development can provide venture capital and jobs. As time passes, depending on policy influences on technological progress and economic competition, H_2 may dominate partially or wholly the alternative fuel and vehicle marketplace.[103]

Figure 4.
Guiding Principles for Government Regarding H_2

Hydrogen R&D is necessary to make conversion methods, either of a combustion or fuel cell type, practicable. Governments should continue and expand a leadership role by setting realistic goals for investments and tracking and reporting progress and performance. They should continue to utilize universities and the national laboratories where appropriate to continue to research and develop breakthrough technologies and to support industry through cost-shared research and development contracts. Finally, federal and state government should proactively educate the public and increase its awareness about the new energy technologies and manage expectations.[104]

Source: United States Department of Energy.

ENDNOTES

[1] Romm, J. (2004). *The hype about hydrogen*. Washington, DC: The Island Press, p. 8.
[2] See http://library.thinkquest.org/20331/history/mideast.html.
[3] Venezuela is also an unstable area given President Chavez's recent political ideology and actions.
[4] Government Accountability Office. (2007, February). *Crude oil: uncertainty about future oil supply makes it important to develop a strategy for addressing a peak and decline in oil production*. Washington, DC: Author, p. 4.
[5] Bernstein, M. (2005). *RAND forum on hydrogen technology and policy: a conference report*. Santa Monica, CA: RAND Corporation, p. vii.
[6] The exception might only be with regard to emphasis placed on policy.
[7] See http://www.hydrogennow.org/Facts/whatishydrogen.htm.
[8] "Hydrogen is a clean energy carrier (like electricity) made from diverse domestic resources such as renewable energy (e.g. solar, wind, geothermal), nuclear energy, and fossil energy (combined with carbon capture/sequestration). Hydrogen in the long-term will simultaneously reduce dependence on foreign oil and emissions of greenhouse gases and criteria pollutants." Retrieved June 12, 2007 from http://www.energy.gov/energysources/hydrogen.htm.
[9] This extends to virtually any electrical entity including grids that supply power to residential and industrial complexes.

[10] "Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers." Retrieved June 8, 2007 from http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html#pem.

[11] Other production (extraction) methods, for example, include gasification, thermo-chemical, and biological processes.

[12] The University of South Carolina is conducting R&D into this technology and this will be discussed later.

[13] Methane is a chemical compound with the molecular formula CH_4. It is the simplest alkane, and the principal component of natural gas. Retrieved July 26, 2007 from http://en.wikipedia.org/wiki/Methane.

[14] The SMR process is more fully explained online at http://en.wikipedia.org/wiki/Steam_reforming.

[15] However, the SMR process is designated as nonrenewable due to the use of natural gas.

[16] This includes not only the transportation sector but also in the stationary and portable sectors

[17] Again, even under ideal conditions and circumstances, this transformation would take decades.

[18] Retrieved June 9, 2007 from http://en.wikipedia.org/wiki/Hydrogen_economy.

[19] See http://www.hydrogen.energy.gov/presidents_initiative.html.

[20] See http://en.wikipedia.org/wiki/Energy_Policy_Act_of_2005.

[21] See http://www.whitehouse.gov/stateoftheunion/2006/energy/energy_booklet.pdf.

[22] Ibid.

[23] According to the Congressional Research Service (2007, January 2004), "Congress agreed to increase funding for hydrogen and fuel cell research from $185 million in FY2003 to $266 million in FY2004, $305 million in FY2005, and $335 million in FY2006. The Energy Policy Act of 2005 authorizes a total of $3.3 billion through FY2010 for fuel cell and hydrogen R&D." Retrieved June 15, 2007 from http://www.house.gov/delahunt/RL33564.pdf.

[24] Retrieved June 11, 2007 from http://www.hydrogen.energy.gov/presidents_initiative.html.

[25] Curtin, S. and Gangi, J. (2006, October). *State activities that promote fuel cells and hydrogen infrastructure development*. A report prepared for the California Air resources Board. Washington, DC: Breakthrough Technologies Institute, Inc., p. 5. Retrieved June 11, 2007 from http://fuelcells.org/info/StateActivity.pdf.

[26] Ibid.

[27] See http://www.eere.energy.gov/state_energy_program/projects_all_by_topic.cfm/topic=604.

[28] Regional areas of the United States have as well formed alliances for cooperation and mutual support of hydrogen R&D efforts. See pp. 222-230 of Op. Cit. Curtin, S. and Gangi, J. (2006, October).

[29] Berkey, E. and Powers, G. (2005, July). *The South Carolina hydrogen economy: capitalizing on the state's assets.* Prepared for the South Carolina Hydrogen Coalition and The South Carolina Energy Office. Johnstown, PA: Concurrent Technologies Corporation, p. 7.

[30] United States Department of Energy. (2002, February). *A national vision of America's transition to a hydrogen economy—to 2030 and beyond.* Washington, DC: Author, p. iv.

[31] Washington, W. (2007, June 10). Biodiesal could benefit S.C. *The State*. Retrieved June 11, 2007 from http://www.thestate.com/169/story/87353.html.

[32] University of South Carolina. (2006) Simple element, first-rate fuel. *Breakthrough 2006*. Columbia, SC: Author, p. 19.

[33] Op. Cit. United States Department of Energy. (2002, February), p. 4.

[34] Thermo-chemical processes are also used to make hydrogen from biomass. "Pyrolysis is a thermal decomposition process that occurs at moderate temperatures with a high heat transfer rate to the biomass particles and a short hot vapor residence time in the reaction zone. Several reactor configurations have been shown to assure this condition and to achieve yields of liquid product as high as 75% based on the starting dry biomass weight." Retrieved June 12, 2007 from http://www1.eere.energy.gov/biomass/pyrolysis.html.

[35] See http://www.freepatentsonline.com/6221280.html.

[36] Op. Cit. United States Department of Energy. (2002, February), p. 4.

[37] Of note, R&D efforts to make affordable and practical polymer electrolyte membrane (PEM) fuel cells may be the answer to fueling hydrogen vehicles in the future.

[38] United States Department of Energy. (2002, November). *National hydrogen energy roadmap*. Washington, DC: Author, pp. 8-9. [It should be noted that while this citation is from a 2002 document, the abundance of literature still affirms that these challenges are the same in 2007].
[39] According to the USDOE, an estimated 40 million tons of hydrogen would be necessary to fuel 100 million fuel cell automobiles.
[40] Op. Cit. United States Department of Energy. (2002, November), pp.13-14.
[41] They are glass bubbles ranging from 25 to 50 microns in diameter, with a thickness of about 1 micron used to store hydrogen. Retrieved June 14, 2007 from www.msu.edu/~svobodar/glossary.htm.
[42] United States Department of Energy. (2003, February). *Fuel cell report to Congress*. Washington, DC: Author, p. 43.
[43] Op. Cit. Romm, J. (2004), p. 116.
[44] Op. Cit. United States Department of Energy. (2002, November), p. 23.
[45] Op. Cit. Romm, J. (2004), p. 116-117.
[46] Op. Cit. United States Department of Energy. (2002, February), p. 7.
[47] Ibid.
[48] Retrieved June 22, 2007 from http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/vision_doc.pdf.
[49] For an excellent discussion of hydrogen fuel cells see United States Department of Energy. (2003, February). *Fuel cell report to Congress*. Washington, DC: Author. Retrieved June 15, 2007 at http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf.
[50] Op. Cit. Romm, J. (2004), p. 116.
[51] Op. Cit. United States Department of Energy. (2002, November), pp. 24-25.
[52] These prototypes are obviously very expensive. Toyota's FCX is, for instance, valued at over $1 million. Retrieved June 15, 2007 from http://www.iht.com/articles/2005/11/02/business/hydrogen.t.php.
[53] The number of hydrogen cars in the United States as January 2007 was 20. Retrieved June 15, 2007 from http://en.wikipedia.org/wiki/Hydrogen_vehicle.
[54] See http://www1.eere.energy.gov/vehiclesandfuels/index.html.
[55] See http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/fc_fuel_partnership_plan.pdf.
[56] Retrieved June 15, 2007 from http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/fc_partners.html.
[57] Op. Cit. United States Department of Energy. (2002, November), pp. 30-31.
[58] See http://srnl.doe.gov.
[59] Established originally in 1951, the current mission statement of the SRS is "to serve the nation through safe, secure, cost-effective management of our nuclear weapons stockpile, nuclear materials, and the environment." See http://www.srs.gov/general/srs-home.html.
[60] Retrieved June 18, 2007 from http://srnl.doe.gov/core6.htm.
[61] See http://www.fao.org/ag/ags/agsi/MICROALG.htm.
[62] See http://www.nwo.nl/nwohome.nsf/pages/SPES_5RUFNU.
[63] Retrieved June 19, 2007 from http://srnl.doe.gov/core6.htm#stor.
[64] See http://www.ctc.com.
[65] Op. Cit. Berkey, E. and Powers, G. (2005, July), p.12.
[66] It opened on February 13, 2006.
[67] Retrieved June 19, 2007 from http://www.scch2r.org.
[68] See http://www.schydrogen.org.
[69] See http://www.scch2r.org.
[70] See http://www.schydrogen.org/membership_members.html.
[71] According to CHR, "It is a strategic partnership and collaborative effort between the Aiken County Economic Development Commission and the Savannah River National Laboratory."
[72] See http://innovista.sc.edu.
[73] See http://www.fossil.energy.gov/programs/powersystems/fuelcells/fuelcells_solidoxide.html.
[74] It should be noted that USC is working in collaboration with its School of Engineering, the City of Columbia, and other South Carolina stakeholders in advancing H_2 initiatives.
[75] Retrieved June 20, 2007 from http://president.sc.edu/Research_Campus/Horizon_Center.html.
[76] In late 2006, for example, USDOE awarded $2 million to CU to fund hydrogen research, along with the Savannah River National Lab, to better understand impurities in the production of hydrogen and oxygen streams and the performance of hydrogen fuel cells.

[77] See Zidan, R. and Rao, A. (2002). *Doped carbon nanotubes for hydrogen storage*. From the proceedings of the 2002 USDOE Hydrogen Program Review. Washington, DC: USDOE. Retrieved June 20, 2007 from http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/32405b29.pdf.
[78] See http://americanhistory.si.edu/fuelcells/basics.htm.
[79] See http://www.clemson.edu/autoresearch.
[80] See http://www.engenuitysc.com.
[81] See http://www.fuelcellchallenge.com.
[82] See http://www.schydrogen.org/index.html.
[83] See http://www.energy.sc.gov.
[84] Op. Cit. Berkey, E. and Powers, G. (2005, July).
[85] See http://www.clemson.edu/scies/NextEnergyInitiative.htm.
[86] See http://www.engenuitysc.com/client_resources/home/next%20energy%20strategy%209-29-05%20final_a.pdf.
[87] Retrieved June 21, 2007 from http://www.fuelcellchallenge.com/client_resources/Fuel%20Cell%20Challenge%20Two%20Page%20Document.pdf.
[88] Retrieved June 18, 2007 from http://www.senate.gov/~lgraham/index.cfm?mode=presspage&id=243010.
[89] Retrieved June 18, 2007 from http://mooreschool.sc.edu/moore/research/Publications/BandE/bande53/53n3/technology.html.
[90] See http://www.hydrogenassociation.org/policy/energyBill_2005.pdf.
[91] Retrieved June 22, 2007 from http://www.cnn.com/2003/ALLPOLITICS/01/28/sotu.transcript.
[92] According to newspaper accounts, "the legislation pumps up to $7 million into hydrogen fuel cell research, gives $300 state tax credits for consumers buying electric, hybrid or ethanol powered cars and gives breaks to people building ethanol and biodiesel facilities. Cost: $9.5 million." Retrieved June 22, 2007 from http://www.thestate.com/312/story/98691.html.
[93] See http://www.scstatehouse.net/cgi-bin/query.exe?first=DOC&querytext=HYDROGEN%20INFRASTRUCTURE&category=Summary&session=117&conid=2956457&result_pos=0&keyval=1170243.
[94] According to *The State*.com, posted July 8, 2007, the S.C. Research Authority is seeking its first projects for funding under the S.C. Hydrogen Infrastructure Act by the end of July 2007. "The act establishes a $15 million fund to promote the development of a hydrogen economy." Retrieved July 17, 2007 from http://www.thestate.com/business/story/112772.html.
[95] Retrieved June 22, 2007 from http://www.scgovernor.com/uploads/upload/S.243.pdf.
[96] Retrieved June 22, 2007 from http://www.cecarf.org/Programs/Fuels/Fuelfacts/HydrogenFacts.html.
[97] Retrieved June 22, 2007 from http://www.hydrogenassociation.org/pdf/keyHydrogenMessages.pdf.
[98] Retrieved June 22, 2007 from http://www.newfuelsnow.com/hydrogen.
[99] Retrieved June 22, 2007 from http://www.cecarf.org/Programs/Fuels/Fuelfacts/HydrogenFacts.html.
[100] See *The Economist* (2007, July 14th-20th). Congress debates climate change: full of sound and fury. Vol. 384 No. 8537, pp. 32-33. Also see U.S. Environmental Protection Agency. (2007, April). Regulatory impact analysis: renewable fuel standard program. Washington, DC: Author. Retrieved July 20, 2007 from http://epa.gov/otaq/renewablefuels/420r07004.pdf.
[101] Op. Cit. Romm, J. (2004), p. 145.
[102] Meckler, L. (2007, April 2). Fill up with ethanol? One obstacle is big oil. *The Wall Street Journal*. p. A1.
[103] In other words, H_2 may find its own niche or it may fall to competing technologies. Also, parallels to H_2 have been drawn to those, for instance, which occurred in the 1970s with the competition between Beta and VHS recorders, and the eventual dominance VHS making BETA recorders obsolete. And today, interestingly enough, the predominance of digital recorders are replacing VHS systems.
[104] See http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fc_report_congress_feb2003.pdf.