2009 REPORT ON STRATEGIC DEMONSTRATION PROJECTS TO ACCELERATE THE COMMERCIALIZATION OF RENEWABLE HYDROGEN AND RELATED TECHNOLOGIES IN MINNESOTA

RECOMMENDED PROJECTS

REPORT TO THE MINNESOTA LEGISLATURE

Minn. Stat. 216B.8109

MINNESOTA DEPARTMENT OF COMMERCE
OFFICE OF ENERGY SECURITY

Background

In 2005, the Minnesota legislature requested that the Minnesota Department of Commerce (DOC), "in consultation with appropriate representatives from state agencies, local governments, universities, businesses, and other interested parties, report back to the legislature by November 1, 2005, and every two years thereafter, with a slate of proposed pilot projects that contribute to realizing Minnesota's hydrogen economy goal as set forth in Minnesota Statute § 216B.8109." That goal, enacted in 2003, states "It is a goal of this state that Minnesota move to hydrogen as an increasing source of energy for its electrical power, heating, and transportation needs."

The first report, *Strategic Demonstration Projects to Accelerate the Commercialization of Renewable Hydrogen and Related Technologies in Minnesota, 2005,* concludes that, due to the state's strength in renewable energy, Minnesota has an opportunity to spawn the emergence of a new homegrown industry based on the production of renewable hydrogen. Given that the cost of producing renewable hydrogen in Minnesota is directly related to the cost of wind, solar, and bioenergy, the report recommends that the state build on the success of its existing renewable energy industries as a means to address not only hydrogen, but the state's greenhouse gas reduction and renewable energy goals.

Targeting products or end-use technologies that maximize use of existing infrastructure and renewable energy investments recognizes the importance of leveraging Minnesota's competitive advantage in renewable energy technologies while also creating value-added renewable hydrogen production strategies. Not only will this advance the state toward its goal of increasing the use of hydrogen, but it will also place Minnesota in a competitively advantageous position as a major producer of renewable hydrogen for a future hydrogen economy without incurring the risk and costs of pursuing projects that will only be successful if and when the infrastructure for a hydrogen economy develops.

The first report recommends that the state focus on demonstration projects that help convert a targeted technology, particularly one involving a Minnesota innovation or Minnesota-made components, into successful products. The emerging phase of a technology offers the best chance for a state government to influence business formation, and many renewable hydrogen and corollary system technologies are currently at their emerging stage. Support for homegrown innovations offers the potential to develop new business opportunities in the state and thus, may impact the state's economic performance. The first report concludes, "With strategic policy targeted at the development of cost-effective processes to produce hydrogen and other products from renewable fuels, Minnesota can translate its competitive edge into the expansion of its renewable fuels industry." (The Minnesota Office of Energy Security [OES] reports on pilot demonstration projects to advance commercialization of renewable hydrogen are available at: Hydrogen Strategic Demonstration Projects.

The projects included in the first report concentrate on identifying renewable hydrogen production methods and hydrogen end use applications—the components around which an integrated system would be designed—to place Minnesota in a competitively advantageous position over other states. A number of projects on the first slate were awarded federal or University of Minnesota Institute for Renewable Energy and Environment grants.

In 2007, OES developed a survey process to produce a second slate of projects. These projects again focused on emerging Minnesota technologies, business development opportunities, new Minnesota markets for renewable hydrogen and near term commercialization of hydrogen and related technologies. The 2007 focus was more targeted and included:

- areas in which Minnesota researchers and businesses have made advancements, have met project performance goals, and have begun development of a business plan with identification of markets and price points to guide the next project work phase;
- technologies and opportunities that offer other attractive co-benefits for the state, such as economic development, and provide for value-added use of a low-value resource or waste product, or an environmental benefit, etc.; and
- projects that offer opportunities to leverage state funds with private and/or federal funds toward commercialization of a technology, particularly ones where Minnesota interests play a role, either as an original equipment manufacturer or balance of parts, or as a provider of feedstock.

The 2007 Minnesota legislature (MN § 216B.812) asked OES to consider the following nonexclusive list of priorities for the second slate; in the 2007 report:

(1) deploy "bridge" technologies such as hybrid-electric, off-road, and fleet vehicles running on hydrogen or fuels blended with hydrogen;
(2) lead to cost-competitive, on-site renewable hydrogen production technologies;
(3) demonstrate non-vehicle applications for hydrogen;
(4) improve the cost and efficiency of hydrogen from renewable energy sources; and
(5) improve the cost and efficiency of hydrogen production using direct solar energy without electricity generation as an intermediate step.
For all deployment projects that do not involve a demonstration component, individual system components of the technology should, if feasible, meet commercial performance standards, and systems modeling must be completed to predict commercial performance, risk, and synergies.

In addition, the proposed pilots should meet as many of the following criteria as possible:

(1) advance energy security;
(2) capitalize on the state's native resources;
(3) result in economically competitive infrastructure being put in place;
(4) be located where it will link well with existing and related projects and be accessible to the public, now or in the future;
(5) demonstrate multiple, integrated aspects of renewable hydrogen infrastructure;
(6) include an explicit public education and awareness component;
(7) be scalable to respond to changing circumstances and market demands;
(8) draw on firms and expertise within the state where possible;
(9) include an assessment of its economic, environmental, and social impact; and
(10) serve other needs beyond hydrogen development.

These priorities and criteria were taken under advisement in developing the 2009 slate of proposed pilot projects in this report.

2009 Process Used to Develop Slate of Renewable Hydrogen Projects

Public Input Survey

In July 2009, OES began a three-prong process to update its 2007 slate of projects by:

- reviewing a broad spectrum of international, federal, and state studies;
- issuing a call for information to stakeholders for project ideas; and
- organizing an expert advisory team to assist in setting goals, parameters, and specifications for a state renewable hydrogen grant program that would award grants to a number of pilot demonstrations that meet a set of performance requirements. Projects receiving awards will be the focus of the next slate of pilot demonstration projects. These projects will be profiled in the 2011 report.

An email survey was conducted to help identify renewable hydrogen and fuel cell technologies to include on the current slate. A request for information in July 2009 was sent to over 200 stakeholders who are participants in the Minnesota Renewable Hydrogen Initiative. The request was also sent to an additional list of over 600 other Minnesotans who are on OES's energy funding opportunities Listserve. However, given that the lists have some duplicate email addresses, OES estimates net requests were sent to approximately 500 interested parties. Recipients were instructed to provide information on renewable hydrogen projects on which they may be working and pass the request along to colleagues. The survey was designed to be simple, requesting that submitters include their names, potential partners, location (if already determined), and a short project description. The survey process was used in previous years to produce the slate of pilot projects and was conducted in a manner similar to other years.

OES received seven project ideas as a result of the request. Three project ideas came from one company and four project ideas came from the University of Minnesota. A breakdown of the quantity of projects submitted in response to 2005, 2007, and 2009 requests follows:

Table 1
Renewable Hydrogen Projects

Year	# Ideas	# Organizations
2009	7	2
2007	24	18
2005	50	25

Recognition of technical and economic barriers is commonly referenced as a key reason for the decline in projects, a trend mirrored across the country that follows the slowdown in technology advancement within the U.S. Department of Energy's (DOE) hydrogen vehicle program. Much of DOE's hydrogen program funding was invested in hydrogen transportation technologies. It is a program that has had to extend a number of important milestone dates because technologies were developing slower than expected. The Institute for Energy and Environment at the University of Minnesota also reports a decline in the number of renewable hydrogen projects that it receives from faculty for seed funding and cited they were observing far less interest in hydrogen in recent years. This general decline in interest in hydrogen technologies is not expected to reverse unless significant breakthroughs occur. However, many interested parties remain optimistic. Minnesota's strategy to build on the success of its existing renewable energy industries positions the state to take advantage of new opportunities as they occur. It is a strategy that will address not only hydrogen but the state's greenhouse gas reduction and renewable energy goals as well,

The following is a short description of the project ideas that were submitted in response to the request for project ideas.

Project Ideas Submitted in Response to 2009 Renewable Hydrogen Survey

Organization: The Toro Company

The Toro Company has previously been involved in or is currently involved in three hydrogen related projects. These projects have focused on using fuel cell technology in their commercial groundskeeping vehicles, because groundskeeping vehicle applications have a relatively modest onboard H_2 storage requirement. If a viable solution can be found for storing more hydrogen onboard, larger power applications (such as rotary mowers) could be pursued. The current turf applications require fuel cells in the 5-8 kW categories. Proton Exchange Membrane (PEM) fuel cell technology has been identified as the best mobile solution and is teamed with a 48V battery pack (or a bank of ultra-capacitors) to power the electric-drive machine, with

the fuel cell maintaining a sufficient state-of-charge. The battery pack can supply up to 20 kW intermittently to handle peak loads, while onboard hydrogen is carried in a lightweight, 5000 psi composite tank.

Project 1: Integration of PEM Fuel Cell with Ultracapacitors into a Riding Greensmower

Summary: A Hydrogenics 7 kW PEM fuel cell was integrated with ultra-capacitors into a Toro riding greensmower. This was believed to be one of the earliest applications for fuel cell technology in grounds equipment.

Project 2: Toro – New York State Energy and Research Development Authority (NYSERDA) Fuel Cell Demonstration Project

Summary: Three PEM fuel cell groundskeeping vehicles are being developed by the Toro Corporation for NYSERDA which concluded in October 2009. These vehicles are based on the Toro Workman platform utilizing an 8 kW fuel cell and battery pack, along with a 74 liter/ 1.8 kg H_2 tank. Problems with this technology are associated with H_2 refueling. Compressing the H_2 to the required 5000 psi is also difficult.

Project 3: Integration of an onboard methanol reformer into a Toro grounds-keeping fuel cell vehicle

Summary: The Toro Company is subcontracting with Idatech, an Oregon-based fuel cell company, to integrate an onboard methanol reformer and fuel cell into a Toro Workman utility vehicle. The reformer will convert liquid methanol, which has a high fuel energy density, into the much lower density hydrogen onboard the vehicle. An onboard reformer gives the potential of carrying a significant amount of fuel (methanol) on the vehicle, and eliminates the problem of high pressure hydrogen refueling. This project is set for completion in 2010.

Organization: University of Minnesota

Department of Bio-products and Bio-systems Engineering

Project 1 Title: Distributed Nonthermal Plasma (NTP) Assisted Ammonia Production

Summary: A laboratory-scale prototype has been developed which produces ammonia from hydrogen and nitrogen via a catalytic assisted NTP process at atmospheric temperature and pressure. Currently Minnesota corn farmers spend over $300 million a year to purchase ammonia fertilizers from other states and countries and the ammonia is produced at high temperatures and pressures (300 – 600°C and 150 – 300 x 10^5 Pa), which is not feasible for a distributed system. This system is designed for use on farms and distributed to areas where a wind turbine would power an electrolyzer to produce the hydrogen needed and

would also provide the needed energy to power the plasma. The lab-scale plasma has shown ammonia output concentrations of up to 12%. Further funding is needed to scale up the project.

Project 2 Title: Biogas Production and Utilization from an Anaerobic Digester
This project's focus was to clean up biogas to pipeline quality and then use the clean biogas for operating a PEM fuel cell manufactured by Plug Power. Biogas is produced by the breakdown of organic matter in the absence of oxygen. In this case, the organic matter was manure from a dairy farm in Princeton, Minn. Pipeline quality biogas (>90% methane) production is the same process that the natural gas industry uses (removal of CO_2 and H_2S), however, the commercialization of this process at community and farm scale levels of gas flow is needed. The H_2 from the PEM fuel cell reformer was also stored in high-pressure tanks for use off the farm. The research phase of this project has been completed and further funding is needed for commercialization. Building a commercial process will require good control of the low flow rates of biogas and water, control of the operating pressures, automation of the control process, and verification and improvement of the system efficiencies. Fairly large quantities of water are currently used in the CO_2 removal. The reduction or reuse of the water will vastly improve the efficiency of the system. The system is designed to incorporate newer CO_2 and H_2S technologies as they are developed. A replenishment of funds is needed to continue the project.

University of Minnesota College of Design

Project Title: Production of Hydrogen from a Solar Photovoltaic (PV) Energy Source
Summary: This current PV system has been operational since 2004, producing hydrogen via an electrolyzer, which is supplied with power from PV arrays. The hydrogen is then stored in a pressure vessel and is coupled to a fuel cell, which can produce electricity on demand. The current solar hydrogen fuel cell generation / electricity generation system is capable of producing an average of 33 scfh of hydrogen when powered by a 5 kW amorphous silicon PV array. The PV array is now obsolete and this obsolescence contributes significantly to the overall system efficiency of only 12.8%. To increase the efficiency of the system to a targeted 31%, the obsolete PV arrays would need to be replaced and modifications to the electrolyzer would also need to be made. Consistent service failures have been experienced with proton exchange membrane (PEM) fuel cells from several manufacturers. The researchers believe that solid oxide fuel cells (SOFC) are better suited to this application. A future use for the hydrogen produced from the electrolyzer is also to co-power internal combustion (IC) engines in retrofitted gasoline vehicles. This approach has not been tested at this

laboratory, but it has been accomplished by numerous other researchers and is not novel.

Review of National Studies and Renewable Hydrogen Advisory Committee

In addition to the survey, OES conducted a literature search and reviewed relevant status reports and national program assessments (including U.S. DOE, U.S. General Accounting Office, and the Board on Energy and Environmental Systems of the National Research Council and other industrial, academic and international hydrogen related reports). The office also assembled a team of experts to act as an advisory committee (see below for MN Statute 216B.813 Subd. 2) to assist with development of the grants process to provide funding assistance for strategic renewable hydrogen and related end-use technology demonstration projects.

> 216B.813 *Subd. 2.**Grants.***
> *(a) The commissioner of commerce shall operate a competitive grant program for projects to assist the state in attaining its renewable hydrogen energy goals. The commissioner of commerce shall assemble an advisory committee made up of industry, university, government, and nongovernment organizations to:*
> *(1) help identify the most promising technology deployment projects for public investment;*
> *(2) advise on the technical specifications for those projects; and*
> *(3) make recommendations on project grants.*
> *(b) The commissioner shall give preference to project concepts included in the department's most recent biennial report: Strategic Demonstration Projects to Accelerate the Commercialization of Renewable Hydrogen and Related Technologies in Minnesota.*

The renewable hydrogen grants advisory committee was formed in April 2009. Its members included industry technical experts in hydrogen technologies as well as energy technology commercialization specialists. The members included: Dr. Mark Debe, Manager of 3M's fuel cell program; Owen Hopkins, Managing Director of Entegris' Renewables & Environment division; Jim Sebesta, CEO in Residence at the University of Minnesota's Venture Center and former founder and president of Sebesta Blomberg & Associates engineering firm; Ken Brown, Bio-energy Program Manager at the Minnesota Office of Energy Security; and Linda Limback, Research Coordinator for the Minnesota Office of Energy Security. Both Dr. Debe and Owen Hopkins have extensive experience with the national level hydrogen programs, having participated on a federal level with the U.S. Department of Energy's hydrogen vehicle program. Jim Sebesta is the founding engineer of a local engineering firm and expert in technology transfer with a focus on engineering and energy technologies. The two senior OES staff members have approximately 20 years of experience each developing, evaluating and facilitating a wide range of energy related programs and projects. All members of the committee have experience with development of requests for projects, development of projects and

proposals in response to RFPs, and in evaluation of proposals that are submitted to RFPs.

The advisory committee spent two months reviewing materials, deliberating over outcomes and assessing opportunities in Minnesota. Members also contacted key principal investigators of funded research for current project status information and to assess if results merited next phases. The advisory committee developed a set of goals to address if a project is to receive funding from OES's renewable hydrogen grant program. The goals provide the state with a set of criteria to identify projects that offer greater public benefit. They are a key element of an RFP issued by OES in compliance with MN Statute 216B.813 *Subd. 2* in November 2009 and will guide the development of future slates of renewable hydrogen projects.

Goals for Minnesota Renewable Hydrogen Demonstration Projects

- Address a particular technical barrier related to commercialization of the production and/or use of renewable hydrogen and/or related technologies.
- Utilize an industry base within the state for support and expertise to build on an area of particular strength within the state's renewable hydrogen research and development community.
- Determine current economic viability and simple payback period of method(s) used for the production and/or use of renewable hydrogen, and identify improvement needed to become cost-competitive with traditional products.

Please note that OES's renewable hydrogen grants RFP issued on November 9, 2009, does not target funding for pilot projects that would produce hydrogen from wind turbines via electrolysis. The state is currently participating in developing such a project at the University of Minnesota West Central Research and Outreach Center. This project is one of the key hydrogen projects in the state. Eliminating the category of wind energy for hydrogen via electrolysis from the RFP is not a statement negating the importance of this project. It is, in fact, quite the opposite. The full project includes development of a reactor that will then turn the renewable hydrogen into anhydrous ammonia, a common fertilizer used throughout the Corn Belt. Eliminating that category from the RFP protects the state from granting funds to a competing project until the results from the first project are realized. Consequently, although not listed in the current RFP, this category is included in the 2009 slate of projects.

2009 Slate of Renewable Hydrogen and Related End-Use Pilot Projects

Hydrogen Production Processes Category

The 2009 slate of recommended renewable hydrogen and related technology includes the following list of renewable hydrogen production processes and end-use applications.

Solar to Hydrogen by Electrolysis

Production of hydrogen from solar could provide an ongoing research platform for development and demonstration of electrolyzer technologies and hydrogen end-use technologies, such as gasoline/hydrogen co-fueled internal combustion engine vehicles or fuel cell applications. Educational institutions provide unique settings to build awareness and stimulate technology development, especially if demonstration projects are integrated into a program where they become a visible and important educational tool and curriculum in advancing the technology.

Hydrogen from Low-value By-products

Hydrogen production projects that use low-value, renewable by-products from commercial or industrial processes could be distributed around the state. A significant benefit to the state may be derived from producing high value hydrogen or hydrogen rich gas from low-value, renewable by-products produced, converted, and used on-site. Incorporation of high-value use of the hydrogen or hydrogen rich gas is of particular interest.

Hydrogen from Gasification of Wood, Crop, Food, or Other Biomass Waste

There are currently five (5) biomass gasification facilities in the state that can use syngas in place of natural gas to provide for process heating needs. A major problem regarding renewable hydrogen production from syngas is the need for improved hydrogen gas separation and purification. The problem is compounded when multiple feedstocks are used. Projects that focus on the separation and purification of hydrogen from gasification syngas produced from a variety of feedstocks are of particular interest so that technical and economic issues regarding production of hydrogen and value-added products are identified and benchmarked.

Biogas from Anaerobic Digestion

Minnesota has significant potential to produce biogas from anaerobic digestion of biosolids. Although removing sulphur, the major contaminate, is commercially viable, cleaning the biogas to the hydrogen purity recommended for a fuel cell is problematic given the specifications needed for fuel cells today. More contaminate tolerant fuel cells,

such as solid oxide fuel cells, can more cost effectively use cleaned biogas as fuel and operate at much higher temperatures to provide opportunities for heat recovery. Of interest are projects related to optimization of production and use of hydrogen rich gas from anaerobic digestion; particularly ones that would help reduce production costs, accommodate mixed streams of waste biosolids, improve hydrogen concentration, create new markets for renewable hydrogen, and/or lead to turnkey systems for the marketplace.

Wind Energy to Hydrogen Via Electrolysis or Other Means

Wind to Hydrogen by Electrolysis. The large-scale demonstration at the University of Minnesota's West Central Research and Outreach Station (WCROC) where production of hydrogen from wind-powered electrolysis is underway deserves continued support. This project could be expanded to become a research platform for complementary research and pilot projects.

Value-Added Products and End Uses for Hydrogen

Anhydrous Ammonia

Currently some of the better opportunities for renewable hydrogen in Minnesota are in production of high-demand, value-added products such as anhydrous ammonia fertilizer. Products, like renewably produced anhydrous ammonia, have easy market entry because they fit into an extensive distribution and use system that has been in place for decades. These kinds of products do not depend on the development of new networks like most applications that involve use of hydrogen for fuel. Products produced from renewable hydrogen may even have a higher value than similar fossil fuel produced products because of the local jobs produced and the premium that the label "renewable" carries in the marketplace. If carbon reduction polices are implemented, there will be further value. Anhydrous ammonia produced from renewable hydrogen may also offer Minnesota another important opportunity in addition to the prospect of developing the first system to produce it—an opportunity to influence the development of a new manufacturing sector in the state.

The University of Minnesota was awarded grant funds and received bonding authority for WCROC to design and build a refinery to produce anhydrous ammonia from the renewable hydrogen. The commercial opportunities for production of anhydrous ammonia from renewable wind power are promising. Due to the rural benefits possible, use of renewable hydrogen to produce anhydrous ammonia is a priority area for Minnesota. The concept is technically feasible but the economics are uncertain. Minnesota's strategy to use wind power when it is at a low value (not useable by the grid) to produce the hydrogen needed for fertilizer could produce the economics needed for renewably produced anhydrous to be price competitive with current market prices and apply to other renewable products as well. The project has experienced delays due

to unforeseen issues including recently unresolved negotiations over royalty payments. Project success will also allow the investment to further serve the state as a research platform while producing performance data so that the process can be tested, optimized, and measured.

Economic Viability of Renewable Hydrogen for Anhydrous Ammonia

The economic viability of producing anhydrous ammonia from renewable hydrogen is a frequently overlooked but important component to assessment of WCROC's anhydrous project. Included in this slate is a plan that would provide financial analysis, market analysis, pricing, technology, maintenance and operator requirements, and regulatory assessment to support WCROC's anhydrous ammonia project. The study should provide detailed information on the manufacturing and transportation costs of production of anhydrous ammonia and identify components within renewable hydrogen production systems that can be improved to meet market price point goals for renewable anhydrous ammonia fertilizer.

Fuel Blended Hydrogen

Blending hydrogen with methane, gasoline, diesel, and other fuels represents a near-term opportunity to introduce hydrogen into the nation's fuel mix, typically reducing emissions, improving turbine or engine performance, and creating a near-term market for renewable hydrogen. Projects for hydrogen blends that would be of particular interest are:

- Gas turbines where the hydrogen/natural gas blending would play an important role in the generation of efficient, low-cost electric power and process heat for applications ranging from small 75-kilowatt (kW) distributed power systems up to 200 megawatt (MW) utility combined cycle power plants.
- Diesel Generators. In the Twin Cities Metropolitan area alone, stationary generators produce about 300 MW of power for peak shaving purposes. The largest of these generators is about 2 MW and many are in the range of a few hundred kW. Hydrogen blends for diesel generators could reduce emissions while increasing use of renewable fuels to help meet the state's renewable electricity goal.

Fuel Cell Niche Markets

Projects that demonstrate fuel cells in targeted specialty markets where fuel cells have the potential to offer tangible advantages over current technologies and require little infrastructure have easy market entry. Of particular interest are projects that support Minnesota companies/manufacturers and can achieve a competitive price point.

- Due to Minnesota's manufacturing presence in landscape maintenance equipment, neighborhood vehicles, and off-road and water recreational vehicles, the state is in a competitive position to influence development of the electronics and control systems needed for niche market fuel cell vehicles/equipment. Supporting efforts by such manufacturers to develop the electronics and control systems needed for small, specialty vehicles would position the state for

successful participation in future specialty vehicle-related, fuel cell opportunities. Projects to develop and demonstrate use of electronics, electronic control systems, and other improvements as needed for fuel cell powered vehicles could provide a tangible market advantage, greater functionality, and superior economic advantage.

- There is a Minnesota presence in the development of contaminant tolerant fuel cells. A pilot project to optimize biogas-fueled, contaminate-tolerant fuel cells would present a unique opportunity to pair an emerging local technology with locally produced fuel. Biogas could be produced across the state through the anaerobic digestion of organic matter, manure or sewage treatment plants to obtain hydrogen-rich gas. The same is true for syngas produced by the gasification of organic matter such as wood waste and agricultural residue.

End-Use Technology System Integration Components and Distribution Technologies

Many of the near-term hydrogen production processes and end-use technologies need further development before integration into a complete system. Development of renewable hydrogen production processes will continue to be listed separately from end-use technologies on this slate until such time when both elements have been independently verified and tested, reducing risks and project costs while increasing potential for success and for easier system integration. When cost and performance data indicate that a particular integrated renewable hydrogen pilot system is on target to meet cost and performance goals as an integrated system, it will be included on the slate under a new category.

Focus for 2011 Slate of Pilot Projects for Renewable Hydrogen

The legislative charge in MN § 216B.812 is focused on hydrogen as the key component of renewable energy production. The slates of demonstration projects produced in response to this charge focus on inclusive, high-level areas where Minnesota may have near term commercialization opportunities. The OES RFP, issued in November 2009, identifies more specific technologies within the current slate of projects where strategic projects are ready for performance demonstrations.

Scientific development and break through research is needed if a low GHG hydrogen economy is to be reached. This type of research receives support through the University of Minnesota's Initiative in Renewable Energy and Environment, as well as from many federal research programs. The concept of a low GHG economy is an important one if hydrogen is to become a part of the energy mix. One of the more comprehensive assessments of the U.S. DOE's hydrogen program was undertaken in early 2008 in response to a congressional request and was conducted by the Committee on Assessment of Resource Needs for Fuel Cell and Hydrogen Technologies, Division on

Engineering and Physical Sciences, National Research Council of the National Academies. The results of its assessment were contained in the report, "Transitions to Alternative Technologies – A Focus on Hydrogen." It concludes that hydrogen as a transportation fuel can help lower GHG emissions over competing emerging alternative fuels after the year 2025 only if hydrogen is produced using low GHG emitting sources (Chap 2 on-line version, pg 22 & footnote #2, pg 9 at: http://books.nap.edu/openbook.php?record_id=12222&page=22).

In summary, due to the fact that viable production of renewable hydrogen is dependent on the cost of the renewable energy used to produce it, it is important to continue supporting state efforts to increase production efficiency and lower costs or firm up supply of its low GHG emission-producing renewable energy resources. Investments in renewable energy systems carry few of the risks entailed in a potential shift to a hydrogen economy. The state's energy-related legislative goals that directed strategy for participation in a potential hydrogen economy have been reinforced by events over time. It remains important to position the state for successful participation and economic benefit in energy-related opportunities that are not solely dependent on timing or implementation of a hydrogen economy.

Consequently, 2009 Strategic Demonstration Projects emphasize the need to:

- Support the state's fuel cell component suppliers.
- Utilize existing commercial markets for fossil fuel based hydrogen as a critical market entry point for renewable hydrogen.
- Support efforts by Minnesota manufacturers of off-road and service vehicles to develop the electronics and control systems needed for either battery or fuel cell powered systems.
- Build on the success of the state's existing renewable energy industries as a means to address not only hydrogen, but the state's greenhouse gas reduction and renewable energy goals.