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

A REPORT TO THE MINNESOTA LEGISLATURE

MINNESOTA DEPARTMENT OF COMMERCE

MINNESOTA DEPARTMENT OF COMMERCE
STATE ENERGY OFFICE
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Executive Summary

Hydrogen and fuel cells have the potential to solve several major challenges facing America that relate to energy, economics and the environment. To attain hydrogen's full benefits, however it must be produced using sustainable, renewable resources.

Other states have focused on producing hydrogen from coal or development of fuel cells. Few states are targeting renewable production of hydrogen, thus providing Minnesota with a window of opportunity to advance renewable hydrogen production methods. Local production of hydrogen using Minnesota native resources has the potential to stimulate job creation and economic development, as well as offer a prudent hedge against volatile energy prices and mitigate negative impacts of climate change.

The 2005 Minnesota legislature requested that the Minnesota Department of Commerce, "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 section 216B.013." 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 2005 Minnesota legislature requested that the Department of Commerce consider the following nonexclusive list of priorities in developing the proposed slate of pilot projects:

(1) demonstrate "bridge" technologies such as hybrid-electric, off-road, and fleet vehicles running on hydrogen or fuels blended with hydrogen;
(2) develop cost-competitive, on-site 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.
    (b) For all demonstrations, individual system components of the technology must 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 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

With these priorities, criteria, and issues taken into consideration, the Minnesota Department of Commerce began a public process to gather project ideas that address the legislative criteria. The department issued a public request for project ideas and received 50 project submissions from 25 different entities in response to that request.
This process helped the department identify a realistic range of demonstration project concepts and assess their fit and value in moving the state toward its goal of increasing hydrogen's use in the state. The first slate of projects concentrates on emerging technologies that offer near term commercial potential and provide opportunities to influence the state's economic performance. It includes the following list of renewable hydrogen production processes and end use applications. Projects from any of the production processes can be mixed and matched with ones from the end-use categories to create strategically important projects that would help speed commercialization and develop a hydrogen technology economy in Minnesota.

Recommended Priority Renewable Hydrogen Production Processes

- *Wind to Hydrogen by Electrolysis*- Assure adequate funding for the University of Minnesota WCROC wind to hydrogen demonstration and research on the effectiveness of storing hydrogen and using that hydrogen to produce electricity during periods of low wind.

- *Solar to Hydrogen by Electrolysis* - Weatherize a structure for the University of Minnesota Architecture building to house the University's solar to hydrogen demonstration project and convert it into a year-round, teaching, research and public demonstration facility.

- *Catalytic Conversion of Water-Rich Ethanol to Hydrogen from an Autothermal Reforming Process* – Scale up to monitor, test and verify Dr. Lanny Schmidt's process for producing hydrogen or hydrogen rich gases from ethanol

- *Hydrogen from Biodiesel By-product* – Demonstrate that hydrogen can be produced using low valued raw glycerol or other sugar rich waste that are by-products of various food processing plants.

- *Hydrogen from the Gasification of Wood, Crop, Food or Other Biomass Waste* - Gasification of residual biomass to produce hydrogen.

- *Purified Biogas from Anaerobic Digestion* – Complete the development of a simple process for purifying methane to be reformed into hydrogen in a fuel cell.

Recommended Priority Projects to Demonstrate End Uses of Hydrogen

A. *Hydrogen End Use Technologies - Fuel blended hydrogen*

Blending hydrogen with methane (or natural gas) 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.

- *Gas Turbines* - Burning a mixture of 12% hydrogen and 88% natural gas, with water injection to limit NOx to 25 ppmv.

- *Internal Combustion Engines (ICE)* - Blending 5-30% hydrogen with methane-fueled spark-ignited ICE generators

- *Methane/Syngas Powered Fuel Cells* -Methane produced through the anaerobic digestion of organic matter, particularly as produced from manure or by sewage treatments plants, can be reformed or filtered to obtain hydrogen.

- *Wind to Fuel Cell Storage* - Produce hydrogen from wind for use in a fuel cell or turbine when electricity demand exceeds the wind turbine's capacity to produce.

B. *Value-add Products from Hydrogen*

- *Anhydrous Ammonia* - Use the renewable hydrogen from one of the hydrogen production demonstration above to produce anhydrous ammonia.

- *University of Minnesota Diesel Research Center* – Equip center with instruments need for the testing of bio-fuels, hydrogen engines and power systems to meet EPA specifications.

The first slate of pilot projects to contribute in the near term to realizing Minnesota's hydrogen economy are projects that **would combine one of the above described hydrogen production processes with an appropriate end use product or power generation technology, also from the recommended list, into an integrated hydrogen energy system**. The selected production method and end-use application would determine the other systems components, such as the need and specifications for storage, transport, distribution and balance of systems components. Most of the above combinations of production processes and end use applications are worthy pilot projects for Minnesota to pursue. Because costs may be prohibitive, a selection process may be needed.

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

Background

Hydrogen has gained worldwide attention as one component in a set of solutions to meeting the future energy needs of the nation. As global demand for energy continues to increase, fossil fuel resources decline, leading to a rise in energy costs and spawning interest in alternative fuels. Hydrogen, an energy carrier rather than an energy source, is particularly attractive because it can be manufactured locally using water, wind, sun or biomass and is widely viewed as a secure, inexhaustible, emission-free fuel.

Hydrogen does not have to wait for the development of radically new technologies before it finds a market. In the near term, hydrogen can be used to enhance the performance and reduce emissions of conventional fuels. Hydrogen can be blended with other fuels at any point in the existing fuels distribution system, which makes hydrogen an attractive option in the on-going development of new fuels. Local production of hydrogen using Minnesota native resources has the potential to stimulate job creation and economic development, as well as offer a prudent hedge against volatile energy prices and help mitigate the negative impacts of climate change.

In Minnesota, interest in renewable hydrogen is driven by many of the same factors that are driving hydrogen and fuel cell development worldwide.

- Homeland security concerns due to dependence on fuels from unstable regions.
- Interruption of energy distribution systems due to human or natural causes.
- Impacts of fossil fuel emissions on public health, air and water quality.
- Climate change.
- Emerging global market in carbon credits.
- Price stability.
- Need to decrease the nation's trade imbalance.
- The potential for hydrogen to be produced locally, reducing the need for new transmission and pipeline systems.
- Regional economic development by adding value to native resources such as wind and biomass, and the business needs for more secure sources of reliable and price-stable energy.

While many of these factors can be addressed through the development of renewable fuels, hydrogen holds promise--despite the technical obstacles and infrastructure barriers it must overcome. But hydrogen is only as clean as its source and method of production. To attain hydrogen's full energy, environmental and economic benefits, it must be produced using sustainable, renewable resources.

Positioning Minnesota for Competitive Advantage

Minnesota's economy will be substantially affected by the outcome of the competition between states to determine which ones will play a lead role in the hydrogen and fuel cell industries. Minnesota's current leadership in renewable energy has worthy, national recognition. Lesser known is the leadership role that Minnesota's manufacturers of fuel cell components and power generation technologies play on a national level in developing the hydrogen economy. These two industries share a common interest in hydrogen; one as the potential producer of hydrogen and the other as a potential consumer.

Today, most hydrogen is produced from natural gas, a non-renewable energy. This offers Minnesota a window of opportunity to advance renewable hydrogen production methods. Much of the economic fortune of hydrogen development in Minnesota may be determined by how much will be made from renewable resources, as well as the role that Minnesota takes in developing the processes to convert native resources such as wind and biomass into renewable hydrogen.

Few state governments are strategically positioning themselves to develop renewable fuels or renewable hydrogen. Of the states with initiatives, most are targeting production from coal or development of fuel cell technologies--particularly for the transportation sector--and those associated hydrogen fueling systems. Minnesota has focused on the near term (within about five years) and has had tremendous success in the development of its home-grown, renewable fuels like ethanol and biodiesel. The success of Minnesota's renewable energy industry places it in a competitively advantageous position to develop hydrogen from renewable feedstock. 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. Minnesota has the opportunity to spawn the emergence of a new home-grown industry based on the production of renewable products and hydrogen.

Minnesota's Existing Commitment to Hydrogen

Minnesota government has shown strong support for moving the state toward a hydrogen economy. The legislature enacted legislation, Minnesota Statute 216B.013, which 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". Since that enactment, the Minnesota Department of Commerce has launched the Minnesota Renewable Hydrogen Initiative. The initiative has outlined the components for a state-level roadmap to move toward hydrogen as an increasing source of fuel, to guide development of renewable production and to identify many critical uses for hydrogen. The Department also authored a report on hydrogen entitled "The Hydrogen Potential: Hydrogen Technology and Minnesota Opportunities" that provides a good background into the issues surrounding the development of a hydrogen economy. The report also highlights the areas of technological development that look most economically and technologically promising for Minnesota. (See: www.commerce.state.mn.us)

The Minnesota Department of Trade and Economic Development (now known as the Minnesota Department of Employment and Economic Development) has also shown interest in renewable hydrogen and fuel cells. At the request of the legislature, it authored a report entitled "Developing the Hydrogen Economy in Minnesota" that recommended a number of actions the State should take to attract businesses in the hydrogen, fuel cell and renewable energy industries. One of these recommendations was to fund "Energy Innovation Projects." In response to the recommendation, the 2005 Minnesota legislature requested that the Minnesota Department of Commerce, 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 section 216B.013." This report is in response to the legislature's request.

Legislative Request for Priority Slate of Hydrogen Demonstration Projects

The 2005 legislature drafted a set of priorities and criteria that the Minnesota Department of Commerce should take into consideration in determining a project's inclusion on this slate to ensure that the resulting demonstration projects have the greatest benefit to the State. The language that specifies those criteria is as follows:

"The Department of Commerce must consider the following nonexclusive list of priorities in developing the proposed slate of pilot projects:

(1) demonstrate "bridge" technologies such as hybrid-electric, off-road, and fleet vehicles running on hydrogen or fuels blended with hydrogen;

(2) develop cost-competitive, on-site 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.
    (b) For all demonstrations, individual system components of the technology must meet commercial performance standards and systems modeling must be completed to predict commercial performance, risk, and synergies.
(1) In addition, the proposed pilots should meet as many of the following criteria as possible: advance energy security;
(2) capitalize on the state's native resources;
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(4) be located where it will link well with existing and related projects and be accessible to the public, now or in the future;
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The following section discusses some of the relevant issues that pertain to the above criteria.

Commercial Performance Standards and System Modeling

The reasons governments sponsor demonstration projects of new technologies run the gamut from simply increasing public awareness of a technology to attempting to influence growth of an industry based on that technology. Demonstrations that help convert a targeted technology with potential to add value to the region's assets into a successful product have the greatest potential to influence improvement in regional economic performance. Successful technology transfer is difficult and depends on many factors including the match of the technology to the region's assets, wise targeting of appropriate technologies and the stage of the technology within its life cycle. 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.

According to the Minnesota Department of Trade Economic Development's report, "Developing the Hydrogen Economy in Minnesota", "…during the emerging stage, development is influenced by technological opportunities created by government intervention. Technological opportunities that fit within the state's science base frequently lead to the first business in that industry." The National Governors Association has a similar assessment, "Technology and innovation drive the creation of new companies. Studies of company formation consistently show that a vital fraction of start-ups are founded around spun-off university developed technology." The emerging stage of renewable energy development within the hydrogen and fuel cell arena provide the best opportunity to maximize benefit from government investments. Minnesota has already experienced success at influencing this stage of development as seen in the rise of its ethanol and bio-diesel industries, and this experience can translate directly to developing a renewable hydrogen industry.

Demonstration projects are an essential phase of technological development. They provide an opportunity for a new process or technology to be scaled up, optimized and monitored to provide the data needed to assess and verify it. Scaled up demonstrations are essential testing phases in developing a technology system, by providing the opportunity to evaluate and validate a system in the context of real-world operating conditions. Data collected from the demonstrations determines whether targets have been met under realistic operating conditions, provides feedback on progress and on how to efficiently manage the research elements of the system and make system improvements if needed.

Advance Energy Security

Most energy systems that rely on the production of renewable energy and, eventually renewable hydrogen, are expected to be located close to the resource and near the point of end use for the energy. These systems will be distributed across the country rather than built as large centralized plants. Distributed systems include technologies such as biomass-based generators, combustion turbines, concentrating solar power and photovoltaic systems, fuel cells, wind turbines, microturbines, engine/generator sets, and storage and control technologies.

Distributed energy technologies are playing an increasingly important role in the nation's energy portfolio. They can be used to meet baseload power, peaking power, backup power, remote power, and power quality, as well as cooling and heating needs. Distributed energy also has the potential to mitigate congestion in transmission lines, reduce the impact of electricity price fluctuations, strengthen energy security, and provide greater stability to the electricity grid. Most projects involving renewable energy in Minnesota will be located near the distributed resource and, by their very nature as distributed systems, will help advance energy security and address this legislative criterion.

Distributed renewable energy projects, including hydrogen systems, are likely to be connected through microgrids, which easily integrate alternative energy production, such as wind or biomass projects, into the electricity network. In a recently release report, “Microgrids: Power Systems for the 21st Century”, researchers from the University of Southampton in the United Kingdom have projected that these networks “could make substantial savings and cuts to emissions without major changes to lifestyles.”(http://www.raeng.org.uk/news/publications/ingenia/issue24/Markvart_Arnold.pdf) According to lead researcher, Dr Tom Markvart, "This would save something like 20 percent to 30 percent of our emissions with hardly anyone knowing it." In smaller networks, like microgrids, technologies to store unused power can be easily introduced --something that is difficult in large networks. Microgrids will also increase efficiency by decreasing line losses and microgrid configurations can more easily be designed to prevent outages from spreading across a large region, enhancing the security of the entire energy network.

Capitalize on the State’s Native Resources and Link Well with Existing Projects

The native and renewable resources that currently offer the best potential for Minnesota’s investment are solar, wind, and biomass. Hydro energy projects may also offer potential for hydrogen production, especially during off-peak hours when demand for electricity is low.

A number of efforts around the state to produce renewable hydrogen and use it in fuel cells have already begun. The current efforts focus on wind and biomass as the resource. These projects provide a platform on which Minnesota has the opportunity to influence the development of renewable hydrogen production. A short discussion of Minnesota’s renewable resources and some of the current projects that relate to hydrogen or fuel cells within each of the resource categories follows.

Solar

Solar resources for creating renewable energy are available everywhere in the United States, although some areas receive less sunlight than others, depending on the climate and seasons. The greatest solar resources in the nation are located in the southwestern states, where sufficient solar energy falls on an area of 100 miles by 100 miles to provide all of the nation's electricity requirements. Minnesota has more annual solar energy potential than Houston, Texas, and nearly as much as Miami, Florida. Most solar energy technologies, however, are in direct competition with traditional electricity, and the relatively high cost of producing electricity from solar energy technologies compared to other energy sources is currently a barrier to its widespread use.

Current Solar Related Hydrogen Projects in Minnesota

The University of Minnesota already has a 5 kW PV solar powered water-to-hydrogen system in operation at the architecture building on the Minneapolis campus. The

University is interested in housing this system within a structure and converting into a small testing and demonstration center for these technologies. In the field of direct solar, Dr. Jane Davidson, also from the University of Minnesota, is researching high-temperature thermolysis of hydrogen sulfide, a process that shows promise.

Wind

The availability of wind power varies across the United States. Areas with the best wind resources include portions of North Dakota, Texas, Kansas, South Dakota, Montana, Nebraska, Wyoming, Oklahoma, Minnesota, Iowa, Colorado, New Mexico, California, Wisconsin, and Oregon. Roughly 6 percent of the contiguous U.S. land area has sufficient wind resources for wind turbines. Yet according to the U.S. Department of Energy, the potential electric power from these sufficient wind areas is surprisingly large. If developed, wind energy has the potential to supply more than one and a half times the current electricity consumption of the United States. Technology under development today will be capable of producing electricity economically from areas in many regions of the country. Minnesota is one of the leaders in developing its wind energy resource and, according to Pacific Northwest National Laboratory, Minnesota has the potential to generate 657 billion kWh.

But wind is intermittent. Storage is needed to realize its full potential. Configuring wind with an electrolyzer to produce hydrogen and coupling the system with a fuel cell or generator set offers the potential to store and dispatch wind power. Projects that test storage strategies for wind systems need to be developed and their efficiencies measured before the manufacturing sector can begin the level of production that will bring costs down.

Current Wind Related Hydrogen and Fuel Cell Projects in Minnesota

The University of Minnesota's West Central Research and Outreach Center has plans to establish a full-scale wind-to-hydrogen system at the Morris campus, and use the hydrogen to produce value-added products in addition to fuel. When built, this system would also demonstrate hydrogen's value as a storage medium for excess wind power.

Biomass

Biomass power is the second largest source of renewable electricity in the U. S. (after hydroelectric power), making up 19 percent of the total renewable electricity, or 76 percent of the non-hydro renewable electricity. (EIA, 2004). Recent advances in biomass technologies provide the means to convert the biomass to hydrogen, which can then be used as a fuel or as a component in products such as ammonia-based fertilizers. Anaerobic digestion, appropriate for food processing, municipal water treatment sludge, and manure, is also part of the biomass landscape. Digesters that produce hydrogen as one of their phases are currently commercially available and methane, itself, can be reformed into hydrogen.

A recent report from the U.S. National Renewable Energy Laboratory calculates that there are enough agricultural residues in the state that, if collected and fed to the most efficient conversion technologies available, could produce over 70 percent of the total electricity needed in the state. If that same residue was converted into renewable hydrogen and used in a fuel cell, the hydrogen could replace up to 65 percent of gasoline that Minnesota currently uses. Thanks to state government leadership, energy from wind and ethanol is at or near market-par with non-renewable sources of energy today. Claiming the value from agricultural residue can be another near-term success, while special energy crops may be part of Minnesota's future landscape.

Minnesota has many industrial processors in the ethanol, bio-fuels, food processing and paper industries that are prime candidates for hydrogen production using the bio-refining concept. Hydrogen production to offset purchased energy or as a value-added product offers great potential for these sites because waste feedstock is readily available. Food processing that involves hydrogenation also offers a particularly attractive opportunity because such plants have an immediate use for the hydrogen that they could produce.

Current Biomass Related Projects in Minnesota

ETHANOL. Dr. Lanny Schmidt, in the University of Minnesota's Chemical Engineering and Material Science department, has realized a major break-through in the use of a Rhodium-Cerium catalyst for potentially cost competitive hydrogen production from ethanol. The technology is ready for its next phase of development, a scaled up demonstration.

BIODIESEL. Virent Energy Systems, Inc. from Wisconsin has contacted Minnesota and Iowa biodiesel plants to obtain waste glycerol for conversion to syngas and hydrogen. A project placing this conversion technology at a Minnesota facility would demonstrate leadership in two important areas; biodiesel and renewable hydrogen.

WOOD AND CROP WASTE. A gasification plant that is planned for the University of Minnesota at Morris will use crop waste (corn stover) to produce heat, electricity, syngas and/or hydrogen. The University of Minnesota Duluth's Coleraine Lab has obtained a grant to develop a gasification project that will convert wood waste to hydrogen.

MANURE. Haubenschild Dairy, near Cambridge, MN, recently installed a reformer to convert biogas from an anaerobic manure digester into methane and ultimately into hydrogen for use in a proton electron membrane (PEM) fuel cell.

BIOMASS DENSIFICATION. The Center for BioRefining at the University of Minnesota has developed a biomass/hydrolysis process that converts waste biomass, such as corn stover, into bio-oil which can be used to make polymers for products and hydrogen-rich gas.

Hydro

Minnesota generates about 1 percent of its electricity using hydro power but, according to the Idaho National Laboratory, could site an additional 26 small hydropower projects, representing a hydropower potential of 56 additional MW. The study also identified about 200 low power (< 1 MW) potential projects representing a hydropower potential of 49 MW. But few new hydro projects are anticipated. Dynamic scheduling of off peak, baseload hydro power turbines could generate hydrogen through electrolysis. There are also a few micro hydro technologies on the horizon that do not entail damming rivers and those technologies may eventually proliferate. Micro hydro offers a potential for hydrogen production but the size of these projects is so small that they do not offer sizable production capability.

Economically Competitive Infrastructure

Hydrogen end-use applications have vastly different infrastructure development needs. Most portable, micro, and stationary applications use existing infrastructure with little need for adaptation and at low access costs. Transportation applications, on the other hand, call for new kinds of distribution networks and fueling stations, even if the fuel is a hydrogen blend. Without federal funding, the infrastructure costs associated with hydrogen transportation applications pose barriers to developing hydrogen vehicle markets and to developing demonstration projects involving fuel cell vehicles. Portable and stationary applications do not carry the high associated infrastructure costs or the risks associated with such costs.

Multiple Integrated Aspects of Hydrogen Infrastructure

Energy systems have three main components: production, distribution, and the final end use. In addition, systems frequently involve an energy storage component that allows the energy to be dispatched on demand. There are many other components that make up the entire life cycle of renewable energy systems. In biomass systems, for example, these components could include growing, harvesting and pre-processing feedstock, as well as the disposal of waste products. The components of an integrated hydrogen energy system examined in this report are limited to the processes, technologies and system requirements from the production of renewable hydrogen to the end use application.

A major barrier to the development of a renewable hydrogen industry is the lack of new hydrogen end use markets. Today hydrogen is used primarily as a coolant for utilities and in chemical and other industrial processes. Its use as an energy carrier is very limited. Demand for hydrogen must grow in order to spawn new production facilities and create the efficiencies that will bring costs down. Currently there are a very limited number of energy technologies--such as fuel cells--that require the use of hydrogen, and those technologies are still in a stage of relative infancy.

Markets for Minnesota renewable hydrogen must be developed to create demand. Scientists at the University of Minnesota's West Central Research and Outreach Center have a potential solution. They are working on a demonstration project to produce hydrogen from wind, which they intend to expand (if funding becomes available) to produce anhydrous ammonia fertilizer. Investments in such technologies and processes to cost-competitively produce fertilizers, hydrogenated oils and other marketable products from renewable hydrogen offer Minnesota a potential to bring renewable products to market today--without waiting for hydrogen energy technologies to proliferate. If Minnesota can develop renewable hydrogen-based products and convert its locally produced power generators and engines to run on renewable hydrogen and blends, a renewable hydrogen industry will emerge, ready to sell to other energy markets when demand materializes.

Draw on Firms and Expertise within the State

There are many institutions and businesses in Minnesota that are actively involved in the development stage of renewable energy processes and fuel cell technologies. One major player is the University of Minnesota (UMN). Like all major research universities, UMN tends toward deep research into the scientific and engineering principles that go into the development of an innovative technology, rather than the applied research to commercialize a technology. Businesses and manufacturers, on the other hand, focus on applied research and the commercialization stages of a technology. The State has supported some initiatives, like UMN's "Initiative in Renewable Energy and the Environment" that is fostering partnership between these two very different components of innovation. Such partnerships are crucial to moving an innovation out of the laboratory and to the market.

University of Minnesota

The University of Minnesota's "Initiative in Renewable Energy and the Environment" has created an unprecedented level of research by top faculty in renewable energy research. Renowned faculty such as Dr. Lanny Schmidt, with his desktop demonstration of an efficient process to produce hydrogen from ethanol, as well as many other researchers, are making major advancements in technologies and processes that are helping to increase Minnesota's efficiency at producing and using renewable energy. And teams like the scientists at the West Central Research and Outreach Center, who are building Minnesota's first wind to hydrogen system, are experimenting at the pre-commercial stage of this emerging industry. Remembering the message from the National Governor's Association that "studies of company formation consistently show that a vital fraction of start-ups are founded around spun-off university developed technology," it is important to keep the University of Minnesota as a resource in this emerging industry.

Minnesota Businesses, Cooperatives and Agricultural Producers

Minnesota has a large number of businesses that have a stake in renewable energy. These businesses cover a range of products and services that are currently involved or have the potential to be involved in renewable energy. Development of renewable energy can have an impact on business formation and expansion across a broad spectrum of sectors and distribute wealth over a vast area of the state. The impact may be felt greatest in rural areas where agriculture producers, food processors, the ethanol and bio-fuels producers, farmer cooperatives, and communities have opportunities to collect and harvest fuels, as well as produce and market energy.

Government and Citizens

Minnesota has been a leader in setting policy for development of a homegrown renewable fuels and energy industry. It has invested resources wisely and supported its investments with policies that built a competitive fuel industry. But the market--Minnesota citizens--played an important role. Minnesotans have proved to be early adopters of practices and products that have environmental advantages, and, at the same time, provide benefits to the state economy.

Hydrogen Demonstration Project Report Input Process

With the preceding priorities, criteria, and considerations in mind, the Minnesota Department of Commerce began a public process to identify a full range of demonstration project concepts, assessing their fit and priority for moving the state toward its goal of increasing hydrogen's use in the state.

The Minnesota Department of Commerce conducted a public process to gather project ideas that addressed the legislative criteria set forth in Minnesota 2005 Session Laws, Chp. 97, Article 13, Sec. 2, Subd 2. The Department made a public request for citizens, businesses, academic researchers, and other stakeholders to submit project ideas. The Department issued an electronic request for projects to over 250 participants in the Minnesota Renewable Hydrogen Initiative. Each participant was asked to forward the call for project ideas to others who might be interested.

The Department received 50 project submissions from 25 different entities. Faculty and staff at the University of Minnesota submitted 16 of the project ideas. The University of Minnesota was mentioned as a partner or potential partner on another 5 proposals. Fifteen proposals were submitted by out of state businesses, including one from Canada, and many of these included an in-state partner.

The project ideas scanned cover the scope of renewable hydrogen system components. Some demonstration projects covered the full scope of a hydrogen energy system from production, purification, storage, transport, and use. Others focused on one element of the process, such as the production aspect. Most of the project ideas addressed areas of technological and process development that the Department's Minnesota Renewable Hydrogen Initiative had previously assessed as having good potential for the state.

The project submissions promised a range of benefits to the state. Some were primarily directed at creating public awareness and conditioning the market for acceptance. These projects tended to be ones that relied on commercially available components and contained little or no research or systems optimization tasks. Other innovative project ideas were primarily in the realm of research with few, if any, demonstrated results. A few submissions proposed to scale up a technology that has already been verified in the laboratory but had not yet been tested on a real life scale. The data from these demonstrations would provide the systems integration knowledge for optimization and would verify economic projections. These projects contained research elements and frequently involved industry and university partnerships.

Below are brief descriptions of the project proposals that were submitted:

1. **Develop and test hydrogen blended with syngas from methane to fuel a lean-burn engine for either electricity or mechanical use**.

2. **Internal Combustion Engine (ICE) Generation Sets Operating on Hydrogen**. Renewable hydrogen for an ICE to produce electricity or mechanical power.

3. **Natural Gas-Fueled Honda Civic**. At a state agency.

4. **Hydrogen-Fueled Honda Civic**. At a state agency.

5. **Renewable Hydrogen Transportation Pilot Project**. Hydrogen from wind used in a fuel cell taxi.

6. **Hydrogen-Fueled ICE for Residential Electricity Generation**. Develop, install and test an 8-10 kW residential electric generator fueled by hydrogen.

7. **Hydrogen Production from Water Using Solar Thermal Energy**. Produce hydrogen from water using a low-temperature solar thermal process (100 degrees Centigrade).

8. **Hydrogen Town**. Deploy hydrogen and fuel cells in multiple applications in a given location.

9. **Fuel Cell-Powered Uninterruptible Power System (UPS).**

10. **Hydrogen Refueling Station.** Natural gas, DME or ethanol used as the feedstock.

11. **Soy Diesel-fueled 1 KW Generator for Residential, Farm or Other Off-grid Application**.

12. **Field to Fuel**: Assess a range of crops for their hydrogen production potential.

13. **Integrated Large-scale Hydrogen Production and Use Demonstration Plant**. Develop a large-scale hydrogen production plant to test performance, environmental impacts and commercial viability. Include storage, fueling, and range of end-use options.

14. **High Flux Solar Simulator**. Develop a high flux solar simulator as a unique platform for solar thermo-chemical research.

15. **Hydrogen-Rich Gases to Enhance Engine Performance**. Test various hydrogen-rich gas blends on engine performance.

16. **Biorenewable Production of Hydrogen from Ethanol**. Demonstrate biorenewable production of hydrogen by converting an ethanol and water mix directly to hydrogen.

17. **International Renewable Hydrogen Transmission Demonstration Facility**. Build and test a gaseous hydrogen pipeline as a way to collect and transport dispersed renewable energy.

18. **Economic Development via Energy Independence**. Build demonstration project with Duluth to test hydrogen technologies and help power the city. Feed

performance information into the Community Renewable Energy Model developed by UMD in order to improve the deployment of the technologies.

19. **Hydrogen Highway Electrification & Lighting Project**. Install solar PV arrays in the highway median to light the highway.

20. **Predict Hydrogen Demand in Minnesota**. In both urban and rural areas.

21. **Hybrid-Fuel Cell Power for Industrial Lift Trucks**. Beta-test fuel cell fork lifts at a Minnesota warehouse.

22. **Fuel Cell Pilot Project**: Deploy up to 20 units.

23. **Develop scaled-up biomass-to-hydrogen facility using new technology**.

24. **5 kW Regenerative Fuel Cell System for Telecomm Back-up and/or Peak-shaving Power.**

25. **Regenerative Fuel Cell System for Uninterruptible Power Supply (UPS).**

26. **Renewable Hydrogen Fueling Station using PEM Electrolysis**.

27. **Hybrid-Electric Hydrogen Powered fleet**. Minnesota as the cold-weather testing site for 5 hydrogen-powered Priuses.

28. **Integrated Wind Turbine & Ethanol Fuel Cell to Demonstrate Firm Power**. Ethanol fuel cell to track output of wind turbine & provide power difference between a specified fixed output and the wind turbines current output.

29. **Optimal Design of Hydrogen Infrastructure in the Upper Midwest**. Quantify the carbon-neutral hydrogen production capacity in the Upper Midwest, model optimal infrastructure design, identify costs, energy use, and emissions from various options.

30. **eP-Olympia Hydrogen-powered Ice Resurfacer Demonstration**. Demonstrate a hydrogen-powered ice-resurfacer and the necessary hydrogen production and fueling infrastructure; build education/outreach campaign based on it.

31. **Hydrogen Outreach & Education Program**. Develop comprehensive modular hydrogen and fuel cell education and outreach program.

32. **Intelligent Design of Hydrogen Refueling Infrastructure in Minnesota**. Identify renewable hydrogen supply and estimate demand; identify costs, energy use and emissions, and model optimal infrastructure.

33. **On-site Hydrogen Generation Using Sunflower Hull Gasification.** Gasify waste sunflower hulls at processing site to produce high purity syngas (H2 & CO) for market.

34. **Hydrogen-Fueled Auxiliary Power Generation for Mobile Use (e.g., on Trucks)**. Replace current diesel auxiliary power system in large trucks with fuel cell to reduce emissions during idle time.

35. **Hydrogen Production from Biomass at Digester Sites**. Construct an integrated model, which could be replicated, that makes use of sewage treatment or manure digester gas that is now being flared. Use it in an ICE.

36. **Hydrogen Production as Anchor for Business Incubator**. Use landfill gas to make hydrogen for both commercial and industrial hydrogen uses, and to fuel a high-temperature fuel cell to power the business incubator.

37. **On-site Demonstration of Hydrogen-Rich Gases to Enhance Engine Performance**. Emissions and performance testing of specific hydrogen fuel blends for use in engines for permitting process.

38. **Develop a Hydrogen Lab**. This would be a permanent structure at the University of Minnesota.

39. **Conversion of Animal Waste to Bio-Hydrogen Via Anaerobic Fermentation**. Technical and economic feasibility of producing hydrogen using anaerobic digestion, including an enriched culture for manure and new purification methods to boost hydrogen production.

40. **Plasma Generation of Hydrogen**. Development of low temperature atmospheric plasma process for generating hydrogen from ethanol and water at point of break.

41. **Phase 1: Wind Energy Storage and Electricity Production**. Adding stationary fuel cell to wind system for production of electricity.

42. **Phase 2: Value-added Wind to Energy &** B**ridge Technologies**. Testing feasibility of producing fertilizer from wind, water and air rather than natural gas; Hydrogen fueling station and hydrogen bridge vehicles.

43. **Phase 3: Hybrid Hydrogen Storage System**. Short pipeline and hythane turbine and heating system that can use blends of hydrogen and natural gas, with potential to use syngas from methane as well.

44. **Hydrogen Production from Biomass Gasifier and from Anaerobic Digester**. For use in fuel cell and hythane furnace.

45. **Hydrogen From Wind Using Radiant Heat Transfer -Catalytic cracking of H2O bonds**.

46. **Hydrogen Fuel Cell Demonstration Using Biomass-derived Glycerol as the Hydrogen Source**. Develop self-contained power generation system fueled from low-cost, bio-derived glycerol.

47. **H2 from Wind**. Test hydrogen production and energy storage of wind (plus biomass) to make wind dispatchable.

48. **Hydrogen Production and Storage for Wind**. Hydrogen production from wind for peak power.

49. **Solid Oxide Fuel Cell for H2 Boost for a Dual Fuel Diesel Truck.** H2 in a SOFC and fuel blended with soybean oil and corn oil in a retrofitted duel-fuel diesel truck.

50. **GM Duel Fuel H2/Gas Truck.** Demonstrate the performance and reliability of a conversion system for a GM truck that allows it to run on blends of gasoline and hydrogen.

Assessment Process

The request for project idea that the Minnesota Department of Commerce issued was a "request for information" process and not a "request for proposal process." The Department was particularly interested in determining the priority of production methods and hydrogen end use applications—the components around which an integrated system will be designed. Because some projects provided for full systems while others proposed innovations for only one component of a hydrogen energy system, the Department's review entailed some deconstruction of the project ideas into their component parts so each component could be assessed on its own merits. This way an individual component from one submission could be linked to a different project idea to create a model demonstration project that involves an entire integrated energy system where all components offered priority level opportunities for the state.

Minnesota Department of Commerce engineering staff carefully reviewed the component parts of each projects and assessed each component separately. Because some of the criteria were mutually exclusive and a number of projects only contained ideas for one component of an energy system, the department used a qualitative methodology for assessment. The team discussed the merits of each project component in the production category, storage category, distribution category and end-use category separately. Many of the guidance criteria in the legislative requirement for this report profile the need for cost effective steps leading to increased production and use of renewable hydrogen. The criteria, as a whole, calls for demonstration projects that have highest near-term potential to show economic benefit for the state. Consequently, the assessment team looked carefully at the technical maturity, economics and efficiencies of each idea during this stage of assessment.

The first slate of projects concentrates on emerging technologies that offer near term commercial potential and provide opportunities to influence the state's economic performance. Project components that fit these criteria typically have the ability to use current infrastructure which allow them to be useful to Minnesota now, and many of these projects can be upgraded easily to accommodate pure hydrogen technologies and markets when they arrive. The team reached consensus in drafting the following list of recommended renewable hydrogen production processes and end use applications that can be mixed and matched to create strategically important projects that would help speed commercialization and develop a hydrogen technology economy in Minnesota.

Recommended Priority Renewable Hydrogen Production Processes

- **Wind to Hydrogen by Electrolysis.** The University of Minnesota West Central Research and Outreach Center (WCROC) received funding to demonstrate the production of hydrogen from wind-powered electrolysis. WCROC scientists are currently seeking partnerships with Norsk Hydro, a Norwegian manufacturer of electrolyzers, and an engine or power generator company such as Cummins Power in Fridley. These partners will assist by providing equipment and working with the researchers to develop the system conversion and optimization function that is needed to power an ICE engine with hydrogen. The State should assist with funding if needed. Although the use of this renewable hydrogen will probably be in an ICE because of cost, the hydrogen could also be used to power a fuel cell. Given that a significant problem with obtaining maximum economic development from the state's wind power is it's variability, a demonstration project showing the effectiveness of storing hydrogen made during periods of high wind, and using that hydrogen to produce electricity through a fuel cell during periods of low wind, would demonstrate dispatchable of wind as a base-load or constant source of energy.

The state and University should also assist in developing the relationships that would involve more Minnesota businesses or cooperative partners such as a Minnesota engine or fuel cell component manufacturer into this effort and future efforts. Technology commercialization by a Minnesota interest is essential for Minnesota to realize full economic benefits from demonstration projects. Partnerships with Minnesota manufacturers, businesses, communities and cooperatives may help the transfer of the technology from demonstration stage to the marketplace. The State should request that demonstration projects include a business plan and involve such partnerships.

- **Solar to Hydrogen by Electrolysis**. The University of Minnesota has a 15 kW PV solar array that provides electricity for electrolyzing water into oxygen and hydrogen. The hydrogen is stored in a moderate pressure storage tank for use in a fuel cell to produce electricity. Although the system components are in place, they are located in a small, uninsulated building that does not permit research into the thermal cogeneration aspects of the plant essential for minimizing parasitic losses and allowing self-sustaining, year-round operation. $200,000 for a structure would allow for continued research into increasing the core efficiency of the plant from 12% (stored electricity out / renewable electricity in) to a projected 30% or better. This efficiency improvement technology is core to any successful renewable (wind, solar or biomass) hydrogen based energy system. In addition, the funding would allow the plant to be converted into a year-round, teaching, research and public demonstration facility with internet access. The information collected through full-year use of this project would complement and support a project demonstrating a dispatchable wind with use of similar technology at the University of Minnesota Morris campus (above).

- **Catalytic Conversion of Water-Rich Ethanol to Hydrogen from an Autothermal Reforming Process.** Fast and efficient renewable reforming is one of the critical steps to producing hydrogen for the marketplace. Last year, Dr. Lanny Schmidt from the University of Minnesota used a simple laboratory reactor to successfully demonstrate that hydrogen or hydrogen rich gases can be produced from ethanol using a very efficient process. The next step in development of this technology is a scaled-up demonstration project to verify that the process will function as expected at a high level of on-going production. The state should support a scale-up demonstration of Dr. Schmidt's Rhodium-Cerium catalytic process to convert ethanol to hydrogen. If successful, this process has the potential to provide a value-added product for Minnesota ethanol producers and positively impact corn growers throughout the state. Project outcomes would provide the data to verify the concept on a commercial scale, demonstrate performance, and provide data for system optimization.

- **Hydrogen from Biodiesel By-product.** A Wisconsin company, Virent Energy Systems, has developed a process that uses low valued raw glycerol, a by-product of various food processing plants, to produce hydrogen. Minnesota is in a unique position to demonstrate this process because of the state's new emphasis on developing bio-diesel fuels and the resulting development of new biodiesel plants. The technology has good potential for producing hydrogen or hydrogen-rich gases from high-sugar containing waste waters as from cereal or bakery goods plants. Virent Energy Systems is interested in demonstrating this process in Minnesota.

- **Hydrogen from the Gasification of Wood, Crop, Food or Other Biomass Waste**. There are many different processes that look promising for the production of hydrogen from various sources of bio-waste through gasification technologies. Bio-waste that is already being collected (or can easily be collected) offers a good near-term resource for hydrogen production. Few gasifiers have been tested using crop and food wastes, so the gasification process alone provides an opportunity to produce renewable energy. Currently there are a few U.S. projects (one in Minnesota) that are attempting to produce hydrogen from gasification of wood. But other wastes provide good potential too, especially for a state that has agricultural, food processing and wood product waste. Gasification of residual biomass should be encouraged.

- **Purified Biogas from Anaerobic Digestion.** The University of Minnesota Biosystems & Engineering Department and the Haubenschild Farm purified biogas produced from the anaerobic digestion of manure. The biogas was then reformed into hydrogen to run a 5 kW PEM fuel cell. This was the first demonstration of using biogas to fuel a fuel cell in the nation and possibly in the world. The biogas clean-up process involved removing impurities (CO2, H2S and others) and reforming the methane component of the biogas into usable hydrogen fuel. The University engineers and the farmer-engineer, Dennis Haubenschild, are trying to develop a relatively inexpensive purification process that a farmer can easily operate by himself. The energy produced from this process can be used to supply electricity on the farm or for selling energy back to a utility. Funding for this project was limited, so only a few types of purification systems were tested. This project offers a number of potential benefits to dairy farmers and should be continued. If state funds are used, a Minnesota manufacturing partner with experience in filtration systems or with the ability to commercialize the process should be involved so that the business opportunity to develop this system for the market place is realized.

Recommended Priority Projects to Demonstrate End Uses of Hydrogen

Uses for hydrogen that involve blends and value added products offer Minnesota the best opportunities to move toward a hydrogen economy. Strategic investments in energy technologies that can use renewable energy and/or renewable hydrogen without needing expensive investments in infrastructure also provide the state an opportunity to influence the development of business expansion. The most promising near-term end uses are as follows:

A. Potential Hydrogen End Use Technologies - Fuel blended hydrogen

Blending hydrogen with methane (or natural gas) 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.

GAS TURBINES

Gas turbines 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.

COST COMPARISON FOR NO_x RETROFIT OPTIONS

	DLN Combustor	Hi Temp SCR	Liquid H_2	Steam Reformer
Capital Cost	$1,000,000	$2,750,000	$160,000	$2,250,000
NPV[1] of Increased Operating Cost	$0	$55,000	$705,000	$50,000
Credit for Increased Capacity ($200/kW)	$0	$30,000	-$200,000	-$500,000
NPV of Heat Rate Change	$0	-$10,000	$35,000	-$170,000
Total NPV	$1,000,000	$2,825,000	$700,000	$1,630,000
NO_x reduction, tpy	21	21	21	21
Cost of NO_x offsets, $/tpy	$47,600	$134,500	$33,300	$77,600

1 NPV = Net Present Value

The cost of natural gas and the need for expensive nitrogen oxide (NOx) emission control equipment are primary reasons for limited use of gas turbines.[i] NOx is formed during high temperature combustion processes from the oxidation of nitrogen in air; the higher the temperature, the more NOx formed. Burning a mixture of 12 percent hydrogen and 88 percent natural gas, with water injection to limit NOx to 25 ppmv, can achieve the needed NOx reductions at less cost than retrofitting a turbine with other NOx reduction methods. In addition, hydrogen blended with compressed natural gas (HCNG) produces less carbon monoxide as well as carbon, will increasing burning velocity, flame temperature and stability.[ii]

INTERNAL COMBUSTION ENGINES (ICE)

Blending 5 percent-30 percent hydrogen with methane-fueled spark-ignited ICE generators allows for leaner air/fuel mixtures that realize strong emissions reductions. Near the lean air/fuel limit for combustion of methane that is produced from anaerobic digestion or gasification, adding hydrogen reduces incomplete combustion products (carbon monoxide and hydrocarbons) while increasing engine torque and power. Tests show that a blend of approximately 20 percent hydrogen and 80 percent methane can reduce emissions of nitrogen oxides by 30 to 50 percent without affecting the performance and efficiency of an ICE natural gas engine.[iii]

10,000 Hythane Buses for Beijing

Brehon Energy plc has entered into a memorandum of understanding with four leading Chinese groups to convert 10,000 diesel buses in Beijing to run on HCNG – 20% hydrogen, 80% CNG. The project targets the conversion of the 10,000 buses prior to the start of the 2008 Olympic Games in Beijing.

In 2003, Cummins Westport worked with SunLine Transit Agency of California to test and develop HCNG technology.[iv] There are many benefits to this technology.[v]

- CNG engines used for both electricity generation and vehicles can be adapted to use HCNG with current technology.
- Existing CNG fueling facilities can be used as a springboard to develop the hydrogen infrastructure and related codes and standards.
- Natural gas and hydrogen come from predominantly domestic supplies thereby lessening dependence on imported oil.
- Natural gas and hydrogen blended fuels provides excellent emissions benefits today and pave the road for the use of hydrogen in the future.

METHANE/SYNGAS POWERED FUEL CELLS

The methane produced through the anaerobic digestion of organic matter, particularly as produced from manure or by sewage treatments plants, can be reformed or filtered to obtain hydrogen. This type of hydrogen is being used in many locations to produce electricity from fuel cells. The same is true for Syngas produced by the gasification of organic matter such as wood waste and agricultural residue. The National Renewable Energy Laboratory projects that there is enough residual biomass and energy crops in the state that, if collected and fed to the most efficient conversion technologies available (such as biomass gasification), large percentages of the state’s need for electricity and hydrogen could be realized. The report “provides convincing evidence that Minnesota should further participate in such research and demonstration projects. This course of action would help ensure that the state maximizes value while benefiting from its significant renewable biomass resources.” [vi]

WIND TO FUEL CELL STORAGE

Minnesota has a significant wind resource but wind is not dispatchable. Producing hydrogen from wind when electric demand is low could enable that system to become a base load wind energy system. Electricity from the wind turbine can be used to produce hydrogen in an electrolyzer. The hydrogen can be compressed and stored in a pressure tank and during the peak-hours or when the wind is not blowing it can be converted back into electricity by means of a fuel cell.

B. Recommended Value-add Products from Hydrogen

Anhydrous Ammonia. Use the renewable hydrogen from one of the hydrogen production demonstration to produce anhydrous ammonia to prove the feasibility and verify the economics of producing fertilizer from renewable hydrogen, rather than natural gas. This project has the potential to spawn a renewably produced fertilizer industry in the state.

University of Minnesota’s Center for Diesel Research Biofuels and Hydrogen Instrumentation Facility. Although combustion and performance characteristics of hydrogen/compressed natural gas (HCNG) is well known, the characteristics of hydrogen blended with Minnesota fuels such as E85 and biodiesel is not. Without this information it is difficult for investors to move forward with the blending and engine modifications needed to increase use of these fuel blends. The state should encourage the University of Minnesota to build up its capacity for hydrogen engine and power system testing. The University presently houses the Diesel Research Center, which could be fully equipped to test a wider range of alternative fuels for approval by EPA. There are few official EPA emissions testing facilities in the nation and as interest in bio-fuel and hydrogen builds the demand for such testing will increase. A University-based, EPA approved testing facility specializing in such fuel blends is needed.

Demonstration Project Estimated Costs

A demonstration project for an integrated system can be expected to cost between $1 -$4 million dollars.

Priority Integrated Hydrogen Demonstration Projects for Minnesota

The Minnesota Legislature requested that the Minnesota Department of Commerce compile a slate of proposed projects that contribute to realizing Minnesota’s hydrogen economy goal and report back every two years on such projects. The first slate of projects developed by the Minnesota Department of Commerce targets projects that not only can contribute to the hydrogen economy goal but also provide good potential to influence business development and rural economic development in the state. It focuses on projects that have demonstrated proof of concept, are entering their pre-commercial stages of development, and will likely be developed in Minnesota, by or in partnership with Minnesota institutions or businesses that have an economic stake in their success.

The first slate of pilot projects to contribute in the near term to realizing Minnesota's hydrogen economy are projects that **would combine one of the above described** (beginning on page 14 of this report) **hydrogen production processes with an appropriate end use product or power generation technology, also from the recommended list, into an integrated hydrogen energy system**. The selected production method and end use application would determine the other systems components such as the need and specifications for storage, transport, distribution and balance of systems components. Most of the above combinations of production processes and end use applications are worthy pilot projects for Minnesota to pursue. Because costs may be prohibitive, a selection process may be needed.

Demonstration projects are more likely to have a broad impact on the state's economy if they are "learning demonstrations." Well-defined objectives that target goals such as efficiency, performance, emissions, economics, and other impacts that will move a technology toward meeting market conditions are important to the success of learning demonstrations.

A business plan that outlines strategies for commercialization once performance and other goals are met will help assure that a demonstration project is preparing the technology for the marketplace and that stakeholders understand the opportunities, costs, and barriers of entry to that market. Active partnerships involving the project's host site, as well as educational, research, business, and market sectors are equally important to maximizing benefit of a project.

Investments in strategic demonstration projects to accelerate commercialization of renewable hydrogen technologies can move Minnesota toward greater reliance on hydrogen and its benefits and they may also provide Minnesota with the opportunity to influence the emergence of a new industry.

The Minnesota Department of Commerce plans to review and update this slate of projects every two years.

[i] California Energy Commission, Alzeta Report on Low NOx Gas Turbine Combustors for Distributed Power Generation
http://www.energy.ca.gov/pier/final_project_reports/600-01-002.html
U.S. Dept. of Energy, "Cost Analysis of NOx Control Alternatives for Stationary Gas Turbines,"
http://www.eere.energy.gov/de/pdfs/gas_turbines_nox_cost_analysis.pdf

[ii] ASME technical paper 99-GT-115, presented at ASME Turbo Expo 1999.
http://www.asme.org
IFRF Combustion Journal, "Investigation of a gas turbine combustion system fired with mixtures of natural gas and hydrogen." Article No. 200207
http://www.journal.ifrf.net/library/december2002/200207Tomczak.pdf

[iii] HCNG reduces NO_x emissions by 95% relative to diesel. In tests between HCNG and CNG engines run by the Center for Transportation Technology and Systems, SunLine Transit Agency and Cummins Westport, the HCNG fueled engines reduced NO_x emissions by 50%, non-methane hydrocarbons by 58%, methane by 16%, total hydrocarbons by 23% and CO_2 by 7% (approximately 10 million tons per year). These reductions were achieved with no significant change in fuel efficiency between the HCNG and CNG-fueled engines.
http://www.cngvp.org/news_detail_arcihve_v1_8_28_03.html

[iv] Westport Innovations, Hydrogen Blended Natural Gas Program Overview
http://www.westport.com/pdf/WPT-HCNG_MED.pdf

[v] Cummins Westport Inc. HCNG emissions and performance benefits
http://www.cumminswestport.com/fuels/hcng.php

[vi] National Renewable Energy Laboratory "Minnesota Biomass-based Hydrogen and Electricity Generation Potential," February 2005
http://www.moea.state.mn.us/p2/forum/MNbiomass-NREL.pdf