Minnesota Renewable Hydrogen Roadmap

Progress Report to the 2012 Minnesota Legislature

Minnesota Department of Commerce
Division of Energy Resources

Background

Minnesota Session Laws 2007 statute 216B.813 created the Minnesota Renewable Hydrogen Initiative. In accordance with Subdivision 1 of that statute, the Department of Commerce (DOC) published a Renewable Hydrogen Roadmap[1], compatible with the United States Department of Energy's National Hydrogen Energy Roadmap and based on an assessment of marketplace economics and the state's opportunities in hydrogen, fuel cells, and related technologies to achieve the state's hydrogen goal of section 216B.8109, 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."

In accordance with 216B.813; the department must report to the legislature on the progress in implementing the road map by November 1 of each odd-numbered year, and include a slate of proposed pilot projects that contribute to realizing Minnesota's hydrogen economy goal.[2]

Minnesota Laws 2007, Chapter 57, Article 2, Section 3, Subd 6 appropriated $3,250,000 to fund a competitive grant program to implement the renewable hydrogen roadmap, and $750,000 for the purpose of preparing the hydrogen roadmap and making grants under Minn. Stat. 216B.813 for fiscal years 2008 and forward.

The roadmap and slate of proposed pilot projects was competed and remains available to the public on the Minnesota Department of Commerce website.[1,2]

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[1] "Minnesota Renewable Hydrogen Roadmap," Minnesota Department of Commerce. Available on DOC on-line document search tool; key words Energy/Hydrogen; https://www.cards.commerce.state.mn.us/CARDS

[2] "Hydrogen Commercialization Demonstration Projects" to accelerate the commercialization of renewable hydrogen and related technologies in Minnesota, Minnesota Department of Commerce. Available on DOC on-line document search tool; key words Energy/Hydrogen; Commerce Actions and Regulatory Documents Search https://www.cards.commerce.state.mn.us/CARDS

Minnesota Laws 2008, Chapter 363, Article 6, Section 3, Subd 4 reduced the amount allocated for competitive grants by $2,600,000.

The DOC subsequently issued a Request for Proposals for competitive grants under Minn. Stat. 216B.813. Grants were awarded to three projects totaling $344,576; biomass gasification for hydrogen-rich syngas ($150,000); syngas conditioning for selecting hydrogen ($149,125); and feasibly of renewable ammonia (fertilizer) from biomass gasification syngas ($45,450).

Minnesota Laws 2010, Chapter 215, Article 4, Section 5, Subd 2 cancelled all remaining funds (other than those required to complete these grant projects) and appropriated them to the general fund.

Compatibility with DOE’s National Hydrogen Energy Roadmap

Five DOE offices have been engaged in research and development (R&D) relevant to hydrogen production:

Hydrogen from Natural Gas

The Offices of Energy Efficiency and Renewable Energy (EERE) and Fossil Energy (FE) are working to reduce the cost of producing hydrogen via steam methane reforming. EERE is focused on distributed hydrogen production from natural gas and bio-derived liquid feedstocks and FE is focused on sub-centralized and centralized hydrogen production. Although hydrogen from natural gas is certainly a viable near-term option, it is not viewed by DOE as a long-term solution because it does not help solve the green house gas (GHG) or energy security issues.

Hydrogen from Coal

Research sponsored by the Office of Fossil Energy is focused on advancing the technologies needed to produce hydrogen from coal-derived synthesis gas and to build and operate a zero emissions, high-efficiency co-production power plant that will produce hydrogen from coal along with electricity.

Hydrogen from Nuclear Power

Research sponsored by the Office of Nuclear Energy (NE) is focused on developing the commercial-scale production of hydrogen using heat from a nuclear energy system. Key research areas include high-temperature thermochemical cycles, high-temperature electrolysis, and reactor/process interface issues.

Hydrogen from Renewable Resources

Research sponsored by EERE is focused on developing advanced technologies for producing hydrogen from domestic renewable energy resources that minimize environmental impacts. Key research areas include electrolysis, thermochemical conversion of biomass, photolytic and fermentative micro-organism systems, photoelectrochemical systems, and high-temperature chemical cycle water splitting.

Basic Research

In Office of Science's basic research program, a major emphasis will be placed on fundamental understanding of photoinduced water splitting that uses the energy of sunlight to separate water into hydrogen and oxygen by semiconductors or photocatalytic assemblies. To enable more efficient, lower-cost fossil-based hydrogen production, fundamental research in catalysis, membranes, and gas separation will be emphasized.

A primary benefit of a hydrogen fueled economy was to reduce GHG emissions and tailpipe pollutants. The potential for hydrogen to be a low GHG emitting fuel is dependent on the amount of GHGs emitted during hydrogen production. Virtually all of the hydrogen produced in the United States today comes from natural gas and coal. The cheapest and most common method of hydrogen extraction is steam methane reformation of fossil fuel. Hydrogen must be produced from carbon-neutral feedstocks to produce low life cycle GHG emissions. Although Minnesota has an abundance of renewable wind, solar and biomass resources, all fossil and nuclear fuel must be purchased from other locations and imported into the state. Based on an assessment of marketplace economics and Minnesota's competitive strengths to produce renewable low net GHG emission hydrogen for that marketplace, state efforts in the production of hydrogen from renewable resources were prioritized.[3]

Technology developments within the national hydrogen program have not progressed as quickly or successfully as anticipated in 2007. Hydrogen, like batteries, is an energy storage medium. Other advanced energy storage technologies have been successfully commercialized over the 2007-2011 time period which do not need the major investment in infrastructure that hydrogen requires. Although some market niches look promising, there is growing concern about the feasibility and merit of transitioning to the "hydrogen economy" as previously envisioned.

Currently, hydrogen for use as an energy storage medium needs to be considered along other energy storage technologies. Minnesota's current renewable energy and GHG reduction policies places the state in a position to produce renewable hydrogen should the market for it become cost competitive. Investing to decrease cost of solar, wind and biomass-based energy production is consistent with these polices, and can provide for economic and energy security benefits that are independent – though supportive – of a renewable hydrogen economy. As the following information from DOE's 2011 Interim Update on the National Hydrogen Energy Program provides, progress is being made although significant technical and economic challenges remain.

Technology Status
U.S. DOE Hydrogen Program

DOE Hydrogen Production Sub-Program Summary[4]

Approach

A portfolio of feedstocks and technologies for hydrogen production will be necessary to address energy security and environmental needs. This program element addresses multiple feedstock and technology options for hydrogen production for the short and long

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[3] Minnesota Renewable Hydrogen Roadmap Report to the Minnesota Legislature, April 2011. Available on DOC on-line document search tool; key words Energy/Hydrogen; https://www.cards.commerce.state.mn.us/CARDS

[4] 2010 Annual Progress Report for the DOE Hydrogen Program summarizes the hydrogen and fuel cell R&D activities and accomplishments for FY 2010. Published in February 2011, the full document is very large; each technical report is available as an individual Adobe Acrobat PDF. http://www.hydrogen.energy.gov/annual_progress10.html and U.S. DOE Hydrogen Program, 2011 Interim Update: Technical Plan – Hydrogen Production http://search.nrel.gov/cs.html?url=http%3A//www1.eere.energy.gov/hydrogenandfuelcells/mypp/pdfs/production.pdf&charset=utf-8&qt=url%3Aeere.energy.gov/hydrogenandfuelcells/+%7C%7C+hydrogen+cost+targets&col=eren&n=6&la=enhttp://

term. The research focus for the near term is on distributed reforming of natural gas and renewable liquid fuels, and on electrolysis to meet initial lower volume hydrogen needs with the least capital equipment costs. For the long-term, research is focused on renewable feedstocks and energy sources, with emphasis on centralized options to take advantage of economies of scale when an adequate hydrogen delivery infrastructure is in place.

Objectives

Reduce the cost of hydrogen to $2.00-$4.00/gge1 (delivered) at the pump. This cost is independent of the technology pathway and takes into consideration a range of assumptions for fuel cell electric vehicles (FCEVs) to be competitive with hybrid electric vehicles (HEVs). Those considerations include a range of gasoline prices and fuel economies. Technologies are being researched to achieve this goal in timeframes relative to their current states of development. Target timelines are currently under review. Current targets follow:

By 2012, reduce the cost of distributed production of hydrogen from biomass-derived renewable liquids to $3.80/gge (delivered) at the pump. By 2017, reduce the cost of distributed production of hydrogen from biomass-derived renewable liquids to <$3.00/gge (delivered) at the pump.

By 2012, reduce the cost of distributed production of hydrogen from distributed water electrolysis to $3.70/gge (delivered) at the pump. By 2017, reduce the cost of distributed production of hydrogen from distributed water electrolysis to <$3.00/gge (delivered) at the pump.

By 2012, reduce the cost of central production of hydrogen from wind water electrolysis to $3.10/gge at plant gate ($4.80/gge delivered). By 2017, reduce the cost of central production of hydrogen from wind water electrolysis to <$2.00/gge at plant gate (<$3.00/gge delivered).

By 2012, reduce the cost of hydrogen produced from biomass gasification to $1.60/gge at the plant gate (<$3.30/gge delivered). By 2017, reduce the cost of hydrogen produced from biomass gasification to $1.10/gge at the plant gate ($2.10/gge delivered).

By 2017, develop high-temperature thermochemical cycles driven by concentrated solar energy to produce hydrogen with a projected cost of $3.00/gge at the plant gate ($4.00/gge delivered) and verify the potential for this technology to be competitive in the long term.

Develop advanced renewable photoelectrochemical and biological hydrogen generation technologies. By 2018, verify the feasibility of these technologies to be competitive in the long term.

Distributed Production Pathway

Distributed production of hydrogen may be the most viable approach for introducing hydrogen as an energy carrier. It requires less capital investment for the smaller capacity of hydrogen needed initially, and it does not require a substantial hydrogen transport and delivery infrastructure.

Two distributed hydrogen production technologies that have good potential for development are:

1. reforming of natural gas or liquid fuels, including bio-derived liquids, such as ethanol and bio-oil, and
2. small-scale water electrolysis located at the point of use (i.e., refueling stations or stationary power generation sites).

Of these technologies, small-scale natural gas reformers are the closest to meeting the hydrogen production cost targets. Research will focus on applying the latest small-scale natural gas reforming systems to reform renewable liquid feedstocks at a competitive hydrogen cost. Distributed reforming using bio-derived liquids offers dramatically lower net greenhouse gas emissions. The second research focus is on small-scale electrolyzers for splitting water. To be cost competitive the cost of electricity needs to be under $.04/kWH to provide hydrogen at under $3.25/gge. Electrolyzers present the opportunity for non-carbon-emitting hydrogen production when a renewable electricity source such as wind or hydro power is used without grid backup. Regarding use of hydrogen in fuel cell vehicles, this does not include the increase in cost for changing vehicles from internal combustion engine/electric hybrid to fuel cell power plants.

Technical Challenges

The overarching technical challenge to hydrogen production is reducing cost. Estimates of the delivered cost of hydrogen using currently available technology for all production feedstocks is considerably higher than that required for hydrogen to be a cost-competitive primary energy carrier.

The capital costs of current water electrolysis systems, along with the high cost of electricity in many regions, limit widespread adoption of electrolysis technology for hydrogen production. Water electrolyzer capital cost reductions and efficiency improvements are required along with the design of utility-scale electrolyzers capable of grid integration and compatible with low-cost, near-zero emission electricity sources. Electrolytic production of hydrogen, where coal is the primary energy resource, will not lead to carbon emission reduction without development and use of carbon sequestration technologies.

Hydrogen can be produced from biomass either by distributed reforming of bio-derived liquids or through gasification or pyrolysis of biomass feedstocks. The costs of currently available bio-derived liquids such as ethanol or sugar alcohols (e.g., sorbitol) need to be reduced. Significant improvements in ethanol reforming and improved technologies need to be developed for other bio-derived liquids to reduce the capital and operating costs for this distributed production option to become competitive. The efficiencies of biomass gasification, pyrolysis and reforming need to be increased and the capital costs need to be reduced by developing improved technologies and approaches.

High-temperature, solar-driven, thermochemical hydrogen production using water-splitting chemical cycles is in an early stage of research. Research is also needed to cost-effectively couple the thermochemical cycles with advanced concentrated solar energy technology. If these efforts are successful, high-temperature thermochemical processes may provide a clean, efficient, and sustainable route for producing hydrogen from water.

Photoelectrochemical hydrogen production (direct water splitting), also in an early stage of development, depends on a breakthrough in materials development and could require large areas of land. Research in this area is progressing on three fronts: (1) the study of high-efficiency materials in order to attain the fundamental understanding needed for improving lower-efficiency lower-cost materials; (2) the study of low-cost durable materials in order to attain the fundamental understanding needed for modifying higher-efficiency lower-durability materials; and (3) the development of multifunction devices incorporating multiple material layers to achieve efficient water splitting.

Biological hydrogen production is in an early stage of research and presents many technical challenges, beginning with bioengineering of microorganisms that can produce hydrogen at high rates. Some of the challenges are related to increased light utilization efficiency, increased rate of hydrogen production, improved continuity of photoproduction, and increased hydrogen molar yield. The advantages of biological hydrogen production are that high-purity water is not required and toxic or polluting by-products are not generated.

Table 1. DOE cost reduction targets for 2015.

Pathway	Status[x]	2015 Percent Decrease Cost Reduction Target*
Distributed Water Electrolysis Hydrogen Production (grid)	$4.80/gge	38%
Central Wind Water Electrolysis	$5.90/gge	66%
Distributed Production of Hydrogen from Bio-Derived Renewable Biological Liquids	$4.40/gge	32%
Distributed Production of Hydrogen from Natural Gas	$3.00/gge	30%
Non-distributed Biomass Gasification/Pyrolysis Hydrogen Production	$2.00/gge	15%

[x] Gasoline gallon equivalent (gge) is the amount of alternative fuel it takes to equal the energy content of one liquid gallon of gasoline.
*Targets are in process of being reevaluated.

Hydrogen Production Funding - The FY 2010 appropriation for hydrogen production provided $41 million for continued hydrogen production research. The President’s FY 2011 budget request for EERE includes $12.8 million for hydrogen production research.

DOE Hydrogen Delivery Sub-Program Summary[5]

Introduction

Hydrogen must be transported from the production site to the end user (e.g., a fueling station or stationary power site) or produced on-site. It also must be compressed, stored, and dispensed at refueling stations or at stationary power generation sites. Due to hydrogen's relatively low volumetric energy density, the transportation, storage, and final delivery of hydrogen as an energy carrier currently entail significant costs and inefficiencies. The Hydrogen Delivery sub-program activity focuses on developing technologies to reduce the cost and increase the energy efficiency of hydrogen delivery, to enable the widespread use of hydrogen as an energy carrier.

Three potential delivery pathways are being considered: gaseous hydrogen (trucks or pipelines), liquid hydrogen (trucks), and novel solid or liquid hydrogen carriers (trucks or pipeline).

Fiscal Year (FY) 2010 Technology Status

Current costs for the transport of hydrogen range from $2 to $8/gasoline gallon equivalent (gge) and are dependent on the quantity of hydrogen and the distance that the hydrogen is transported. Pipeline transport costs are at the lower end of the cost range and are also dependent on transport distance and quantities. These transport costs do not include compression, storage, and dispensing at fueling sites, which can add $2–3/gge of hydrogen. Progress toward current goals and targets is summarized below.

Project Category	**Goal (Targets to be met by 2020)***	**Status****
Tube Trailers	Reach H_2 delivery cost target of $1/gge. Reduce capital cost to <$200,000 Increase capacity to 1,100 kg through the use of carbon fiber or low-cost glass fiber.	$2.85–$3.15/gge (high volume demand projection. Completed system design for 1,100 kg capacity with glass fibers and small-scale prototype development. Completed testing of carbon fiber tank with a capacity of 600 kg.
Pipelines	Reach H_2 delivery cost target of $1/gge. Decrease cost/mile to <$490,000.	$2.20–$2.35/gge (high volume demand projection). Cost/mile (steel): $1M/mile; cost/mile (fiber reinforced plastic): $600,000/mile.
Liquefaction	Reach H_2 delivery cost target of $1/gge. Decrease installed capital cost to $100M. Increase energy efficiency to 87%.	$2.70–$2.90 (high volume demand projection). Installed capital cost: $170M. Energy efficiency: 40%.
Compression	Reduce capital cost to $6.2M (transmission compression). Increase energy efficiency to >98%. Cost contribution: $0.25/kg H_2.	Centrifugal pipeline package cost: $4.5M (projected). Energy efficiency: 98% (projected). Cost contribution: $0.60/kg H_2.
Bulk Storage	Reduce cost of storage tank to $300/kg H_2 stored. Increase volumetric capacity to >0.035 kg H_2/liter of storage volume.	Storage tank cost: $820/kg H_2 stored. Volumetric capacity: 0.025 kg H_2/liter of storage volume.
Carriers	Show a viable carrier material (liquid, non-toxic). Decrease delivery cost contribution to <$1/gge. Increase carrier H_2 content to 13.2% by weight.	N-ethylcarbazole delivery cost: $4.75. N-ethylcarbazole H_2 content by weight: 5.8%.

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[5] 2010 Annual Progress Report for the DOE Hydrogen Program summarizes the hydrogen and fuel cell R&D activities and accomplishments for FY 2010. Published in February 2011 http://www.hydrogen.energy.gov/annual_progress10.html

Hydrogen Delivery

Argonne National Laboratory estimates that hydrogen pipelines will cost an additional 45-75% more than natural gas pipelines, depending on method used.[6]

Table 2. Hydrogen Delivery Status and Target

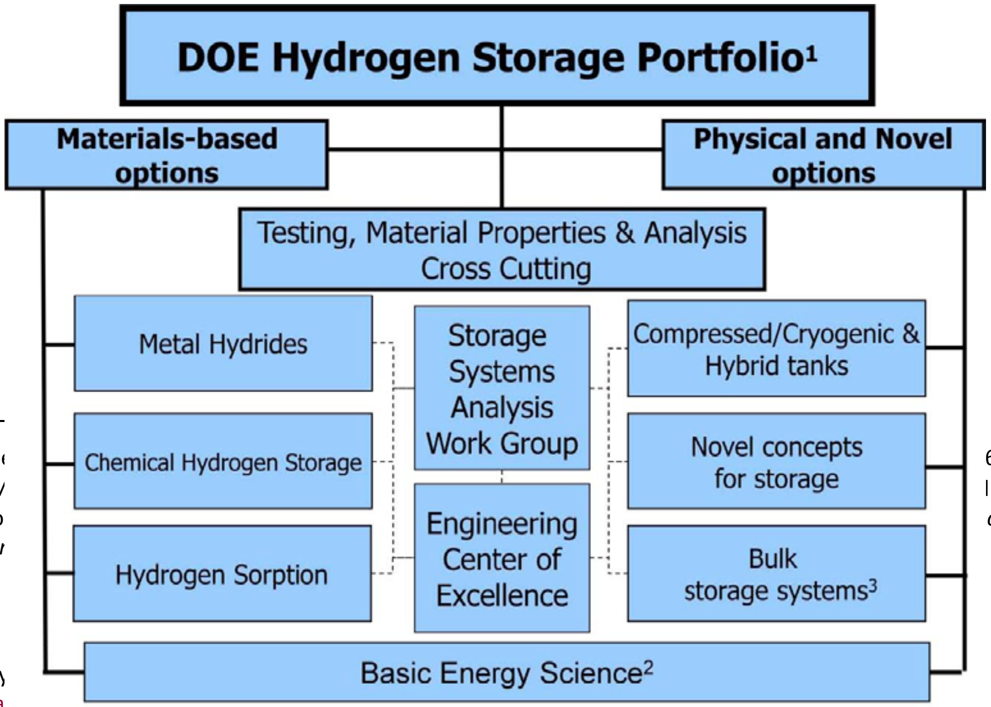
Delivery Method	Status	Target
Pipeline to Station (350 bar)	\$3/gge	Target < \$1/gge, from point of production
Pipeline & Truck to Station	\$5/gge	Target < \$1/gge, from point of production
Liquid Truck to Station	\$3.2/gge	Target < \$1/gge, from point of production

DOE Hydrogen Storage Sub-Program Summary[7]

Hydrogen storage is a key enabling technology for the advancement of hydrogen and fuel cell power technologies in transportation, stationary, and portable applications.

The Hydrogen Storage Program element will include on-going analysis to examine the system level performance, the lifecycle cost, energy efficiency, and environmental impact of the technologies, any changes in the system-level requirements that might alter the technical targets, and the progress of each technology development effort toward achieving the technical targets.

Funding for hydrogen storage RD&D will be scaled down according to measurable progress—as technical and cost targets are met or missed, funding for particular technological approaches will be adjusted. When all performance, safety and cost targets are met, hydrogen storage RD&D funding will end as appropriate. If specific performance issues remain at that time, RD&D could be extended if the risk of the continued effort is justified by the potential benefit.



1. Coordinated by DOE Energy Efficiency and Renewable Energy, Office of Hydrogen, Fuel Cells and Infrastructure Technologies
2. Basic science for hydrogen storage conducted through DOE Office of Science, Basic Energy Sciences
3. Coordinated with Delivery Program element

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Table 3. Current Hydrogen Storage Status and Targets

Storage	Status; system cost ($/kWh)	2015 Target $/kWh
350 bar	17 -18	~15.5
700 bar	18 -25	~23
Mat.-based	14 -19	~15.6
Liquid H2	22 -36	~8

DOE Fuel Cells Sub-Program Summary

Introduction

The Fuel Cells sub-program supports research, development, and demonstration of fuel cell technologies, focusing on the development of fuel cells and fuel cell systems for use in a variety of stationary, portable and transportation applications, with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications. Early market penetration is targeted through the development of fuel cell technologies and systems for portable-power applications, auxiliary power units (APUs), and specialty applications such as material handling equipment. Fuel cell technologies already provide sufficient performance and durability to be competitive with alternative technologies in some of these applications, while in others relatively modest improvements are required. The expansion of fuel cells into applications and markets that have more stringent technical and cost requirements is also being pursued.

FY 2010 Technology Status

Major challenges in the advancement of fuel cell technology are reduction of cost and improvement of durability. Air, thermal, and water management are also key issues for enhancing fuel cell performance. Fuel cells are approaching their targets for power density and specific power, but further progress is required to achieve system packaging requirements necessary for commercialization. Efforts continue to evaluate, understand, and mitigate degradation mechanisms through modeling and experimental validation by the national laboratories, universities, and fuel cell developers. While hydrogen is the fuel of choice for automotive applications, stationary applications would benefit from technology improvements permitting fuel flexibility.

The cost of a hydrogen-fueled 80-kWe fuel cell power system projected for high volume production (500,000 units/year) has been estimated to be $51/kW (Assuming 2010 technology for an 80-kW System projected on High-Volume Manufacturing not yet in place (500,000 units/year). Although the target of $45/kW for 2010 was not met, considerable progress has been made over time. $51/kW represents a $22/kW (30%) reduction from the 2008 cost of $73/kW; and $10/kW (16%) reduction from the 2009 cost of $61/kW. Cost reductions resulted from simplified architecture and reduction in stack component costs through ongoing R&D efforts.

One hundred and seven projects funded by DOE completed final reports in 2010, the most recent year for which results are available. Three of those projects were in Minnesota, two with 3M and one with Cummins Power Generation.

Membranes

3M Company, Minnesota: Membranes and MEAs for Dry, Hot Operating Conditions[8], Steven Hamrock

Project Introduction

Proton exchange membrane fuel cells (PEMFCs) represent a promising power source for a variety of applications. While many breakthroughs have been made over the last few years in the development of PEMFCs, technical and economic barriers for their commercialization still exist. Key areas where improvements are still needed are in expanding the temperature range and lowering the humidification requirements of the stack [1]. Requirements of system size, efficiency, performance, start-up and cooling mean that fuel cells must be able to run robustly and exhibit adequate durability under a wide variety of operating temperatures, including temperatures up to 120ºC. They must also be able to do this with little or no external gas humidification (i.e., “dry”), and during start-up, shut-down, or periods of lower stack temperatures, they must run in the presence of, and be stable to, some liquid water in the gas channels. Unfortunately, operation under these hot, dry conditions seriously compromises both the conductivity and durability of the ionomer membrane.

Project Conclusions

The focus of this project has been to develop new polymers and new stabilizing or conductivity enhancing membrane components to provide a membrane which can meet all DOE 2010 and 2015 targets including both conductivity and durability. We have also focused on gaining a better understanding of structure property relationships relevant to conductivity and durability to aid in this development. We have met all of the DOE membrane targets with at least one of the materials tested, and our new PFIA ionomer met the 30ºC and 80ºC conductivity targets, has nearly met the 120ºC conductivity target (>100 mS/cm above 40% RH), has come very close to meeting all conductivity targets and has come very close to meeting all durability targets as well.

Table x. 3M Progress towards Meeting Membrane Technical Targets

All membranes are 20 micron	**Units**	**3M 2010 Status**	**2010 target**	**2015 target**
Area Specific Resistance at 120°C (H_2O pp 40-80 kPa)	Ohm cm$_2$	0.038 (50 kPa) 0.02 (80 kPa) ***625 EW PFIA***	≤0.02	≤0.02
Area Specific Resistance at 80°C (H_2O pp 25-45 kPa)	Ohm cm$_2$	0.017 (25 kPa) 0.006 (44 kPa) ***625 EW PFIA***	≤0.02	≤0.02
Area Specific Resistance at 30°C (H_2O pp 4 kPa)	Ohm cm$_2$	0.03 (3.8 kPa) ***625 EW PFIA***	≤0.03	≤0.03
Area Specific Resistance at -20°C	Ohm cm$_2$	0.14 ***700 EW PFSA***	≤0.2	≤0.2
O_2 cross-over	mA/cm$_2$	<0.5	≤5	≤2
H_2 cross-over	mA/cm$_2$	<2	≤5	≤2
Durability Mechanical (%RH Cycle) Chemical (OCV)	Cycles Hours	10,000 ***625 EW PFIA*** 450 ***625 EW PFIA***	≥20,000 ≥500	≥20,000 ≥500
EW – equivalent weight; PFIA – perfluoro imide acid; PFSA – perfluoro sulfonic acid; RH – relative humidity; OCV – open circuit voltage				

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[8] 3M Company : Membranes and MEAs for Dry, Hot Operating Conditions[8], Steven Hamrock http://www.hydrogen.energy.gov/pdfs/progress10/v_d_2_hamrock.pdf

Catalysts

3M Company, Minnesota: Advanced Cathode Catalysts and Supports for PEM Fuel Cells[9]

Project Introduction

State-of-the-art proton exchange membrane (PEM) fuel cell electrocatalyst technology utilized in today's prototype fuel cell vehicles reveals limitations with respect to general durability and robustness under start-stop cycling, adequate performance with low PGM loadings, and low-cost manufacturability. To a large degree, these deficiencies are traceable to properties of the conventional carbon supported dispersed Pt catalysts in use today. The research and development of this contract are focused on overcoming these three most critical barriers for fuel cell MEA automotive deployment by using an alternative catalyst support and deposition method.

Project Conclusions

This project has met or exceeded the currently specified DOE electrocatalyst and MEA performance and durability targets for 2015 using the same MEA component set in 50 cm2 cell tests. Furthermore, the NSTF catalyst based MEAs used outside this project in original equipment manufacturer 400 cm2 (>20 cell) short stacks have generated specific power densities of <0.2 gPt/kW, successful 10°C cold and -20°C freeze-start [8], and lifetimes of 2,000 hours under various automotive system relevant cycling. Significant improvements in ORR activity with new alloys and processing methods were demonstrated and further improvements are anticipated. Probably the most significant advances this past year were understanding and improving major water management issues associated with the ultra-thin NSTF electrodes. Future work will be strongly focused on down-selecting and incorporating these advanced components into a robust, durable, high-performance, roll-good manufactured MEA containing no more than 0.2 mg/cm2 of PGM total for the final stack testing-deliverable.

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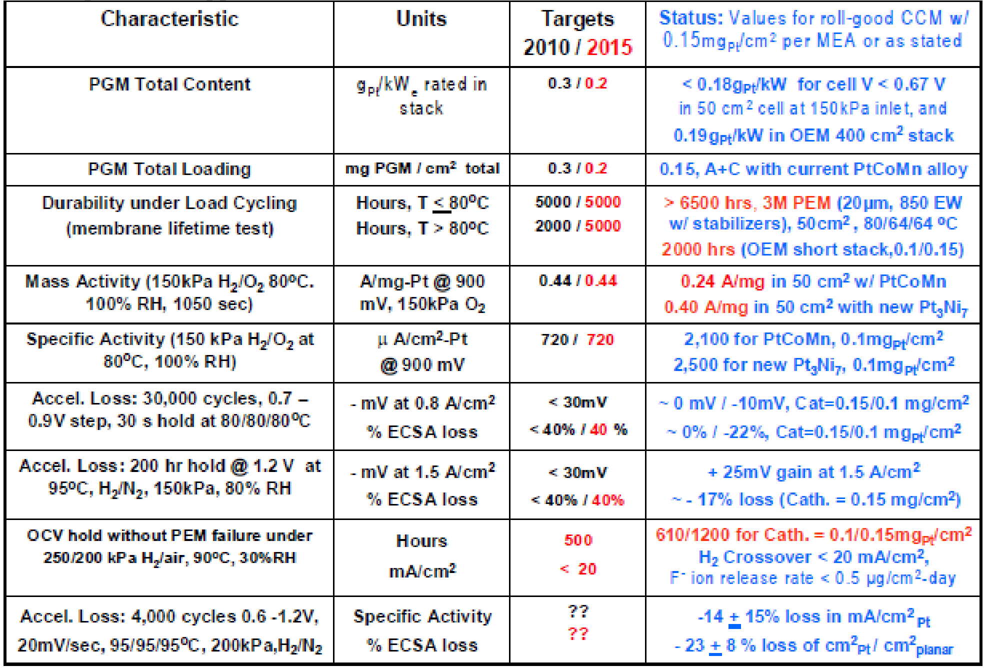
[9] 3M Company Advanced Cathode Catalysts and Supports for PEM Fuel Cells[9], Mark Debe
http://www.hydrogen.energy.gov/pdfs/progress10/v_e_1_debe.pdf

Table 1. Progress towards Meeting Technical Targets for Electrocatalysts and MEAs for Transportation Applications. (Values in red most recent.)



Characteristic	Units	Targets 2010 / 2015	**Status:** Values for roll-good CCM w/ 0.15mg$_{Pt}$/cm^2 per MEA or as stated
PGM Total Content	g$_{Pt}$/kW$_e$ rated in stack	0.3 / 0.2	< 0.18g$_{Pt}$/kW for cell V < 0.67 V in 50 cm^2 cell at 150kPa inlet, and 0.19g$_{Pt}$/kW in OEM 400 cm^2 stack
PGM Total Loading	mg PGM / cm^2 total	0.3 / 0.2	0.15, A+C with current PtCoMn alloy
Durability under Load Cycling (membrane lifetime test)	Hours, T $\leq$ 80°C Hours, T > 80°C	5000 / 5000 2000 / 5000	> 6500 hrs, 3M PEM (20µm, 850 EW w/ stabilizers), 50cm^2, 80/64/64 °C 2000 hrs (OEM short stack,0.1/0.15)
Mass Activity (150kPa H_2/O_2 80°C. 100% RH, 1050 sec)	A/mg-Pt @ 900 mV, 150kPa O_2	0.44 / 0.44	0.24 A/mg in 50 cm^2 w/ PtCoMn 0.40 A/mg in 50 cm^2 with new Pt_3Ni_7
Specific Activity (150 kPa H_2/O_2 at 80°C, 100% RH)	µ A/cm^2-Pt @ 900 mV	720 / 720	2,100 for PtCoMn, 0.1mg$_{Pt}$/cm^2 2,500 for new Pt_3Ni_7, 0.1mg$_{Pt}$/cm^2
Accel. Loss: 30,000 cycles, 0.7 – 0.9V step, 30 s hold at 80/80/80°C	- mV at 0.8 A/cm^2 % ECSA loss	< 30mV < 40% / 40 %	~ 0 mV / -10mV, Cat=0.15/0.1 mg/cm^2 ~ 0% / -22%, Cat=0.15/0.1 mg$_{Pt}$/cm^2
Accel. Loss: 200 hr hold @ 1.2 V at 95°C, H_2/N_2, 150kPa, 80% RH	- mV at 1.5 A/cm^2 % ECSA loss	< 30mV < 40% / 40%	+ 25mV gain at 1.5 A/cm^2 ~ - 17% loss (Cath. = 0.15 mg/cm^2)
OCV hold without PEM failure under 250/200 kPa H_2/air, 90°C, 30%RH	Hours mA/cm^2	500 < 20	610/1200 for Cath. = 0.1/0.15mg$_{Pt}$/cm^2 H_2 Crossover < 20 mA/cm^2, F$^-$ ion release rate < 0.5 µg/cm^2-day
Accel. Loss: 4,000 cycles 0.6 -1.2V, 20mV/sec, 95/95/95°C, 200kPa,H_2/N_2	Specific Activity % ECSA loss	?? ??	-14 ± 15% loss in mA/cm$^2_{Pt}$ - 23 ± 8 % loss of cm$^2_{Pt}$ / cm$^2_{planar}$

Auxiliary Power

Cummins Power Generation , Minneapolis Minnesota: Diesel-Fueled SOFC System for Class 7/Class 8 On-Highway Truck Auxiliary Power[10], Dan Norrick,

Introduction

With the onset of anti-idling legislation and the rising cost of fuel one potential early adopter for SOFC fuel cell technology is the on-highway truck APU application. First, an SOFC APU could provide the same electrical source as a conventional internal combustion engine-based APU. Second, it has the potential to improve exhaust emissions, fuel efficiency, reduced transmitted noise and vibration, and provide heating for both cabin and engine.

This project was directed at designing, building and demonstrating a ULSD-fueled SOFC APU installed in an on-highway truck to supply AC power for cabin loads, engine heating, and battery charging during rest periods.

Conclusions

During FY 2010 the project fabricated and • delivered the second generation of SOFC modules with significantly improved performance and stability. These modules were demonstrated and characterized on both hydrogen and reformed liquid fuels.

- Demonstrated the viability of a dry CPOX approach • at the stack and module level.
- Built and tested two complete 4-module sets for • testing.
- Completed conceptual design of higher-power • (~1 kWe) module.
- Completed SOFC APU unit fabrication and • demonstration.
- Project work completed in the second quarter of • FY 2010Discussion

At the conclusion of the SOFC APU project the technology may be seen to be approaching the necessary requirements for creating successful commercial implementation(s) in mobile power markets in the five- to ten-year range.

Table x. Demonstrated Results Against Project Objectives

Objective	**Objectives**	**Demonstrated**
Operation on Liquid Fuel	ULSD	ULSD
Average Power (Net DC)	-	1,100 Watts
Average Power (Net AC)	-	820 Watts
Combined Heat and Power (CHP)	-	>4 kWatts
Peak Power (Net DC)	-	1,250 Watts
Specific Power (Net DC)	17 W/kg	9 W/kg
Power Density	8 W/L	3 W/L
Start-up Time (Cold)	1 hour	1 hour
Efficiency @ Rated Power	25% lower heating value	11% lower heating value
In-Vehicle Demonstration	Operation on a Class 8 Truck	Operation on Truck Hardware in Lab
DC - direct current; AC - alternating current		

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[10] Cummins Power Generation , Minneapolis Minnesota Diesel-Fueled SOFC System for Class 7/Class 8 On-Highway Truck Auxiliary Power, Dan Norrick http://www.hydrogen.energy.gov/pdfs/progress10/v_i_1_norrick.pdf

DOE Fuel Cells Sub-Program FY 2011 Plans

In FY 2011, the Fuel Cells sub-program will continue R&D efforts on fuel cells and fuel cell systems for several key applications, with a focus on further developing multiple fuel cell technologies using various fuels, which involves improving component properties. Support will continue for R&D needed to addresses critical issues with:

- Membranes
- Catalysts
- Electrodes
- Modes of operation
- Integration and component interactions such as water transport, sensors, and air compression that can lead to lower cost and lower parasitic losses.

Minnesota Renewable Hydrogen Grant Projects

Grants were awarded to three projects totaling $344,576 under the DOC grant program to "Demonstration Projects to Accelerate the Commercialization of Renewable Hydrogen and Related Technologies in Minnesota."

PROJECT TITLE: WEST CENTRAL MINNESOTA RENEWABLE AMMONIA PRODUCTION FEASIBILITY STUDY
Grant: $45,450
Match: $15,150
Total Project Cost: $60,600

Project Description: Swift Count Rural Development Authority to perform a feasibly study and create a business plan for planning, constructing, and operating a renewable anhydrous ammonia production plant in west central Minnesota using locally available biomass. Biomass to be gasified, and hydrogen and air used in ammonia reactor to produce renewable fertilizer for use on local farms, who in turn, supply the plant with biomass feedstock.

Project completed: The anhydrous ammonia plant is expected to produce approximately 44,000 tons of anhydrous ammonia annually from 95,000 tons of corn stover. Ash, a by-product of anhydrous ammonia production, specifically the corn stover gasification process, is expected to be produced at a rate of approximately 92 pounds per ton of corn stover processed, or approximately 4,350 tons annually. The process requires 930 million standard cubic feet per hour (scfh) of nitrogen to react with the hydrogen to produce the anhydrous ammonia. The nitrogen will be purchased from a third-party supplier. The process requires 19,580,000 kWh of electricity annually.

PROJECT TITLE: DEMONTRATION PROJECT FOR SMALL-SCALE GASIFICATION OF SEED SCREENINGS TO PRODUCE RENEWABLE ELECTRICITY AND SYNTHETIC DIESEL
Grant: $150,000
Match: $851,000
Total Project Cost: $1,001,800

Project Description: Pembina Trail Resource Conservation & Development with Agricultural Utilization Research Institute (AURI) to install and demonstrate a small-scale 75kW biomass gasifier (Biomax 75) to synthesize gas to run a genset to produce renewable electricity for the Roseau, Minnesota School District, and secondly, utilize hydrogen from gasifying low value grass screenings and demonstrate synthetic diesel production.
Project in progress.

PROJECT TITLE: GASIFIED BIOMASS SYNGAS CONDITIONING TO OPTIMIZE RENEWABLE HYDROGEN PRODUCION
Grant: $150,000
Match: $851,000
Total Project Cost: $1,001,800

Project Description: Atmosphere Recovery, Inc. (ARI) Eden Prairie, MN to construct advanced syngas cleanup system and demonstrate results of hydrogen conditioning, and test bench for use in a small-scale gasifier.
Project in progress.

CONCLUSION

Based on an assessment of marketplace economics and Minnesota's competitive strengths, the most prudent investments that the state can make for the state’s hydrogen goal [Minn. Stat. 216B.8109] to “move toward increasing use hydrogen for its electrical power, heating, and transportation needs,” is to invest in technologies that will increase the efficiency and lower costs of renewable energy production. Thereby making the cost of producing renewable hydrogen more competitive compared to hydrogen produced from non-renewable sources. This approach is both consistent with findings of the national hydrogen program and complements Minnesota's competitive strengths in the production of renewable energy. The potential for production of renewable ammonia or other high-value products from gasification of renewable biomass is one example of this strategy.

Secondly, although Minnesota does not have fuel cell manufactures, it does have some fuel cell component suppliers. Should funds become available again, complementing funding provided through federal programs would serve to leverage investments toward solving challenges they face in producing technically and economically viable fuel cells.

In fulfillment of its legislative charge, the DOC will continue to encourage promising hydrogen developments within the state and national program, however, the Department respectfully considers that it is important to do so in the context of the full range of developing energy efficiency, energy storage and renewable energy technologies available.

Because the law was changed to divert all funds previously appropriated to carry out 216B.813, the Department is unable to continue activities specified under this statute.