

2002

Annual Progress Report

HYDROGEN, FUEL CELLS AND INFRASTRUCTURE TECHNOLOGIES PROGRAM



*U.S. Department of Energy,
Energy Efficiency and Renewable Energy*

A C K N O W L E D G E M E N T

WE WOULD LIKE TO EXPRESS OUR SINCERE APPRECIATION TO
ARGONNE NATIONAL LABORATORY AND QSS GROUP, INC.,
FOR THEIR ARTISTIC AND TECHNICAL CONTRIBUTIONS IN
PREPARING AND PUBLISHING THIS REPORT.

IN ADDITION, WE WOULD LIKE TO THANK ALL OUR PROGRAM
PARTICIPANTS FOR THEIR CONTRIBUTIONS TO THE PROGRAMS
AND ALL THE AUTHORS WHO PREPARED THE PROJECT
ABSTRACTS THAT COMPRISE THIS REPORT.

**U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585-0121**

FY 2002

**Progress Report for Hydrogen, Fuel Cells, and
Infrastructure Technologies Program**

**Energy Efficiency and Renewable Energy
Office of Hydrogen, Fuel Cells, and Infrastructure Technologies**

Approved by Steven Chalk

November 2002

CONTENTS

I. Introduction.....	1
II. Hydrogen Production and Delivery	19
A. Biological Processes.....	21
1. Biological Water Gas Shift Development, <i>National Renewable Energy Laboratory</i>	21
2. Maximizing Photosynthetic Efficiencies in H ₂ Production in Microalgal Cultures, <i>University of California Berkeley</i>	27
3. Efficient H ₂ Production Using Enzymes of the Pentose Phosphate Pathway, <i>Oak Ridge National Laboratory</i>	33
4. Bio-H ₂ Production from Renewable Organic Wastes, <i>Iowa State University</i>	38
5. Photobiological Algal H ₂ Production, <i>National Renewable Energy Laboratory</i>	42
B. Biomass-Based.....	49
1. H ₂ Production by Catalytic Reforming of Pyrolysis Vapors, <i>National Renewable Energy Laboratory</i>	49
2. Supercritical Water Partial Oxidation, <i>General Atomics</i>	59
3. Biomass-Derived H ₂ from a Thermally Ballasted Gasifier, <i>Iowa State University</i>	63
4. Techno-Economic Analysis of H ₂ Production by Gasification of Biomass, <i>Gas Technologies Institute</i>	68
C. Fossil-Based.....	71
1. Production of H ₂ by Superadiabatic Decomposition of H ₂ Sulfide, <i>Gas Technologies Institute</i>	71
2. Thermal Dissociation of Methane Using a Solar-Coupled Aerosol Flow Reactor, <i>University of Colorado</i>	76
3. Thermocatalytic CO ₂ -free Production of H ₂ from Hydrocarbon Fuels, <i>Florida Solar Energy Center</i>	83
4. Novel Catalytic Fuel Processing Using Micro-channel Steam Reforming and Advanced Separations Technology, <i>InnovaTek</i>	87
5. ITM Syngas and ITM H ₂ : Eng. Dev. of Ceramic Membrane Reactor Systems for Converting..., <i>Air Products and Chemicals Inc.</i>	92
6. Integrated Ceramic Membrane System for H ₂ Production, <i>Praxair</i>	97
7. Low Cost H ₂ Production Platform, <i>Praxair</i>	102
8. Effects of Fuel Constituents on Fuel Processor Catalysts, <i>Argonne National Lab.</i>	106
9. Separation Membrane Development, <i>Westinghouse Savannah River Tech. Center</i>	111
10. Defect-free Thin Film Membranes for H ₂ Separation & Isolation, <i>Sandia National Laboratories</i>	115
11. DFMA Cost Estimates of Fuel-Cell/Reformer Systems at Low/Medium/High Production Rates, <i>Directed Technologies</i>	120
D. Electrolytic Processes.....	125
1. Photoelectrochemical Systems for H ₂ Production, <i>National Renewable Energy Laboratory</i> ..	125
2. Photoelectrochemical H ₂ Production, <i>University of Hawaii</i>	130
3. Photoelectrochemical H ₂ Production Using New Combinatorial Chemistry Derived Materials, <i>University of California Santa Barbara</i>	136
4. Combinatorial Discovery of Photocatalysts for H ₂ Production, <i>SRI International</i>	144

CONTENTS (Continued)

II. Hydrogen Production and Delivery (Continued)

D. Electrolytic Processes (Continued)

5. Low Cost, High Efficiency Reversible Fuel Cell Systems, *Technology Management Incorporated* 148
6. High-Efficiency Steam Electrolyzer, *Lawrence Livermore National Laboratory* 152
7. Enabling Science for Advanced Ceramic Membrane Electrolyzers, *Los Alamos National Laboratory* 156
8. H₂ Production Through Electrolysis, *Proton Energy* 161

E. Hydrogen Fueling Systems and Infrastructure 166

1. Development of a Turnkey Commercial Hydrogen Fueling Station, *Air Products and Chemicals, Inc.* 166
2. Autothermal Cyclic Reforming-Based Fueling System, *GE Energy* 170
3. Development of a Natural Gas to Hydrogen Fuel Station, *Gas Technologies Institute* 175
4. Distributed H₂ Fueling Systems Analysis, *Directed Technologies Inc.* 179
5. Technical Analysis: Integrating a H₂ Energy Station into a Federal Building, *TIAX* 184

F. Crosscutting Hydrogen Production and Delivery Analysis 189

1. Hydrogen Technical Analysis, *TIAX* 189
2. Hydrogen Infrastructure Studies, *Longitude 122 West* 194

III. Hydrogen Storage. 199

A. High Pressure Tanks 201

1. H₂ Composite Tank Program, *Quantum Technologies Inc.* 201
2. H₂ Storage Using Lightweight Tanks, *Lawrence Livermore National Laboratory* 205
3. Hydrogen Storage in Insulated Pressure Vessels, *Lawrence Livermore National Laboratory* 210
4. Advanced Thermal H₂ Compression, *Ergenics Inc.* 213
5. Development of a Compressed Hydrogen Gas Integrated Storage System for Fuel Cell Vehicles, *Johns Hopkins University/Lincoln* 218
6. Low Permeation Liner for Hydrogen Gas Storage Tanks, *Idaho National Energy and Environmental Laboratory* 223

B. Carbon Materials 226

1. Hydrogen Storage in Carbon Single-Wall Nanotubes, *National Renewable Energy Laboratory* 226
2. Doped Carbon Nanotubes for H₂ Storage, *Westinghouse Savannah River Tech. Center* 231
3. Hydrogen Storage in Metal-Modified Single-Walled Carbon Nanotubes, *California Institute of Technology* 235

C. Hydrides 239

1. Catalytically Enhanced H₂ Storage Systems, *University of Hawaii* 239
2. Complex Hydrides for Hydrogen Storage, *Florida Solar Energy Center* 244
3. High-Density Hydrogen Storage Demonstration Using NaAlH₄-Based Complex Compound Hydrides, *UTC Fuel Cells* 247
4. Standardized Testing Program for Emergent Chemical Hydride and Carbon Storage Technologies, *Southwest Research Institute* 251

CONTENTS (Continued)

III. Hydrogen Storage (Continued)

C. Hydrides (Continued)

5. H₂ Fueled ICE Scooter with On-Board Metal Hydride Storage, *Energy Conversion Devices* . . . 255
6. Hydride Development for Hydrogen Storage, *Sandia National Laboratories* 260

IV. Fuel Cells 265

A. Transportation Power Systems 267

1. Atmospheric Fuel Cell Power System for Transportation, *UTC Fuel Cells* 267
2. Fuel Cell Systems Analysis, *Argonne National Laboratory* 270
3. Fuel Cell Vehicle Systems Analysis, *National Renewable Energy Laboratory* 275
4. Cost Analyses of Fuel Cell Stacks/Systems, *TIAX* 279

B. Stationary Power Systems 283

1. Alkaline Fuel Cell Development, *Oak Ridge National Laboratory* 283
2. Development of Advanced, Low-Cost PEM Fuel Cell Stack and System Design for Operation on Reformate, *Teledyne* 285
3. Proton Exchange Membrane Fuel Cell Power System on Ethanol, *Caterpillar* 290
4. Fuel Cell Distributed Power Package Unit: Fuel Processing Based on Autothermal Cyclic Reforming, *GE* 294
5. R&D on an Ultra-Thin Composite Membrane for High-Temperature Operation in PEMFCs, *Fuel Cell Energy, Inc.* 297

C. Fuel Processing Subsystem and Components 300

1. Next-Millennium Fuel ProcessorTM for Transportation Power System, *Nuvera* 300
2. Multi-Fuel Processor for Fuel Cell Electric Vehicle Applications, *McDermott* 305
3. Quick-Starting of Fuel Processors, *Argonne National Laboratory* 309
4. Microchannel Fuel Processor Development, *Pacific Northwest National Laboratory* 313
5. Plate-Based Fuel Processing System, *Catalytica* 320
6. Fuel Processors for PEM Fuel Cells, *University of Michigan* 325
7. Evaluation of Partial Oxidation Fuel Cell Reformer Emissions, *TIAX* 328
8. Catalysts for Autothermal Reforming, *Argonne National Laboratory* 332
9. Fuel Processing of Diesel Fuel for Auxiliary, *National Energy Technology Laboratory* 337
10. Testing of Fuels in Fuel Cell Reformers, *Los Alamos National Laboratory* 342
11. Sulfur Removal from Reformate, *Argonne National Laboratory* 348
12. Nanoscale Water Gas Shift Catalysts, *NexTech* 352
13. Water-Gas Shift Catalysis, *Argonne National Laboratory* 356
14. Transition Metal Carbide Water Gas Shift Catalysts, *University of Michigan* 360
15. Development of Novel Water-Gas-Shift Membrane Reactor, *University of Kentucky* 364

D. Fuel Cell Stack Subsystem and Components 369

1. R&D of a 50-kW, High-Efficiency, High Power Density, CO-Tolerant PEM Fuel Cell Stack System, *Honeywell* 369
2. Development of Comprehensive Computer Models for Simulation of Fuel Cell Systems, *University Of Miami* 373

CONTENTS (Continued)

IV. Fuel Cells (Continued)

D. Fuel Cell Stack Subsystem and Components (Continued)

3. High-Performance, Matching PEM Fuel Cell Components and Integrated Pilot Manufacturing Processes, <i>3M</i>	379
4. Design and Installation of a Pilot Plant for High-Volume Electrode Production, <i>Southwest Research Institute</i>	386
5. Integrated Manufacturing for Advanced Membrane Electrode Assemblies, <i>De Nora</i>	390
6. Development of High-Temperature Membranes and Improved Cathode Catalysts, <i>UTC Fuel Cells</i>	395
7. High-Temperature Membranes, <i>Case Western Reserve University</i>	400
8. Bacterial Cellulose Membranes, <i>Oak Ridge National Laboratory</i>	404
9. Nano-Particle Porous Oxide Electrolyte Membranes (POEMs) as Proton Exchange Membranes, <i>University Of Wisconsin</i>	408
10. Low-Platinum Catalysts for Oxygen Reduction at PEMFC Cathodes, <i>Naval Research Laboratory</i>	413
11. Low Platinum Loading Catalysts for Fuel Cells, <i>Brookhaven National Laboratory</i>	418
12. Development of High-Performance, Low-Pt Cathodes Containing New Catalyst and Layer Structure, <i>Superior MicroPowders</i>	423
13. New Electrocatalysts for Fuel Cells, <i>Lawrence Berkeley National Laboratory</i>	429
14. Electrodes for Polymer Electrolyte Membrane Fuel Cell Operation on Hydrogen/Air and Reformate/Air, <i>Los Alamos National Laboratory</i>	433
15. Nondestructive Study of the Water Transport Mechanism inside Operating PEM Fuel Cells Using Neutron Imaging Techniques, <i>National Inst. for Standards and Testing</i>	438
16. Direct Methanol Fuel Cells, <i>Los Alamos National Laboratory</i>	441
17. Development of Advanced Catalysts for Direct Methanol Fuel Cells, <i>NASA Jet Propulsion Laboratory</i>	447
18. Carbon Composite Bipolar Plates, <i>Oak Ridge National Laboratory</i>	451
19. Cost-Effective Surface Modification for Metallic Bipolar Plates, <i>Oak Ridge National Laboratory</i>	454
20. Scale-Up of Carbon/Carbon Composite Bipolar Plates, <i>Porvair Corporation</i>	458
21. Carbon Foam for Fuel Cell Humidification, <i>Oak Ridge National Laboratory</i>	463
22. Carbon Monoxide Sensors for Reformate-Powered Fuel Cells, <i>Los Alamos National Laboratory</i>	468
23. Electrochemical Sensors for PEMFC Vehicles, <i>Lawrence Livermore National Laboratory</i> ..	473
24. Development of Sensors for Automotive Fuel Cell Systems, <i>United Technologies Research Center</i>	476
25. Design & Development of New Glass-Ceramic Proton Conducting Membranes, <i>Iowa State University</i>	480
26. <i>Fuel Cell System Durability</i> , <i>Los Alamos National Laboratory</i>	485

CONTENTS (Continued)

IV. Fuel Cells (Continued)

E. Air Management Subsystems	490
1. Turbocompressor for PEM Fuel Cells, <i>Honeywell</i>	490
2. Development and Testing of a High Efficiency Integrated Compressor/Expander based on Torroidal Intersecting Vane Machine Geometry, <i>Mechanology, LLC</i>	494
3. Turbocompressor for Vehicular Fuel Cell Service, <i>Meruit</i>	499
4. Motor Blower Technologies for Fuel Cell Automotive Power Systems, <i>UTC Fuel Cells</i>	503
5. Hybrid Compressor/Expander Module, <i>TIAX</i>	508
F. Crosscutting Fuel Cell Analysis and Demonstration	513
1. Precious Metal Availability and Cost Analysis for PEMFC Commercialization, <i>TIAX</i>	513
2. Assessment of Fuel Cell Auxiliary Power Systems for Onroad Transportation Applications, <i>TIAX</i> 517	517
3. Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles, <i>TIAX</i>	522
4. Fuel Cell R&D and Demonstration, <i>Los Alamos National Laboratory</i>	526
5. Advanced Underground Vehicle Power and Control Fuel Cell Mine Locomotive, <i>Vehicle Projects,</i> <i>LLC</i>	530

V. Integrated Hydrogen and Fuel Cell Demonstration/Analysis 535

A. System Analysis	537
1. Analysis of Hydrogen Production Using Ammonia and Ammonia-Borane Complex for Fuel Cell Applications, <i>Florida Solar Energy Center</i>	537
2. Well-to-Wheels Analysis of Energy and Emission Impacts of Fuel-Cell Vehicle Fuels, <i>Argonne</i> <i>National Laboratory</i>	543
3. Hydrogen and Fuel Cell Vehicle Evaluation, <i>National Renewable Energy Laboratory</i>	547
4. Power Parks System Simulation, <i>Sandia National Laboratory</i>	550
5. Process Analysis Work for the DOE Hydrogen Program - 2001, <i>National Renewable Energy</i> <i>Laboratory</i>	554
B. Integrated Hydrogen and Fuel Cell Demonstration	558
1. Real-World Demonstration of Fuel Cell Vehicles and Refueling Technology, <i>California Fuel Cell</i> <i>Partnership</i>	558
2. Filling Up With Hydrogen 2000, <i>Stuart Energy USA</i>	563
3. Hydrogen Reformer, Fuel Cell Power Plant, and Vehicle Refueling System, <i>Air Products and</i> <i>Chemicals, Inc.</i>	567

VI. Safety and Codes & Standards 571

A. Safety	573
1. Gallium Nitride Integrated Gas/Temperature Sensors for Fuel Cell System Monitoring for Hydrogen and Carbon Monoxide, <i>Peterson Ridge LLC</i>	573
2. Interfacial Stability of Thin Film H ₂ Sensors, <i>National Renewable Laboratory</i>	577
3. Micro-Machined Thin-Film H ₂ Gas Sensors, <i>Advanced Technology Materials Inc.</i>	581

CONTENTS (Continued)

VI. Safety and Codes & Standards (Continued)

B. Codes and Standards	585
1. H ₂ Infrastructure Activities Codes and Standards: Hydrogen Codes and Standards Outreach, National Hydrogen Association	585
2. Codes and Standards Analysis, University of Miami	591
3. Hydrogen Codes and Standards, National Renewable Energy Laboratory	595
4. SAE Fuel Cell Codes and Standards Initiative, Society of Automotive Engineers	598

VII. Conversion Devices 603

A. Turbines	605
1. Reduced Turbine Emissions Using H ₂ -Enriched Fuels, Sandia National Laboratories	605
B. Internal Combustion Engines	609
1. Internal Combustion Engines Research and Development, Sandia National Laboratories ..	609
2. HCNG Heavy Duty Vehicle Prime Mover, NRG Tech	613

Acronyms..... 619

Appendix A 625

Primary Contact List 637