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

FY 2013

PROGRESS REPORT FOR THE DOE

HYDROGEN AND FUEL CELLS PROGRAM

December 2013
DOE/GO-102013-4260

Approved by Sunita Satyapal, Director, Hydrogen and Fuel Cells Program

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Phone: (865) 576-8401
Fax: (865) 576-5728
E-mail: <mailto:reports@adonis.osti.gov>

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: (800) 553-6847
Fax: (703) 605-6900
E-mail: orders@ntis.fedworld.gov
Online ordering: <http://www.ntis.gov/ordering.htm>



Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Table of Contents

I.	Introduction	I-1
II.	Hydrogen Production	II-1
II.0	Hydrogen Production Program Overview	II-3
II.A	Electrolysis	II-11
II.A.1	Giner, Inc.: PEM Electrolyzer Incorporating an Advanced Low-Cost Membrane	II-11
II.A.2	National Renewable Energy Laboratory: Renewable Electrolysis Integrated Systems Development and Testing	II-15
II.A.3	Proton OnSite: High-Performance, Low-Cost Hydrogen Generation from Renewable Energy	II-18
II.A.4	Proton OnSite: Low-Cost Large-Scale PEM Electrolysis for Renewable Energy Storage	II-22
II.A.5	Proton OnSite: Economical Production of Hydrogen through Development of Novel, High Efficiency Electrocatalysts for Alkaline Membrane Electrolysis	II-26
II.A.6	Giner, Inc.: Unitized Design for Home Refueling Appliance for Hydrogen Generation to 5,000 psi	II-31
II.A.7	Proton OnSite: Hydrogen by Wire - Home Fueling System	II-35
II.A.8	Proton OnSite: Low-Noble-Metal-Content Catalysts/Electrodes for Hydrogen Production by Water Electrolysis	II-39
II.B	Solar Thermochemical	II-43
II.B.1	Argonne National Laboratory: Electrolyzer Development in the Cu-Cl Thermochemical Cycle	II-43
II.B.2	Science Applications International Corporation: Solar High-Temperature Water-Splitting Cycle with Quantum Boost	II-48
II.B.3	University of Colorado: Solar-Thermal Redox-Based Water Splitting Cycles	II-57
II.B.4	Sandia National Laboratories: Solar Hydrogen Production with a Metal Oxide-Based Thermochemical Cycle	II-62
II.B.5	Savannah River National Laboratory: Electrolyzer Development for the HyS Thermochemical Cycle	II-68
II.C	Photoelectrochemical	II-70
II.C.1	National Renewable Energy Laboratory: Semiconductor Materials for Photoelectrolysis	II-70
II.C.2	MVSystems, Incorporated: Photoelectrochemical Hydrogen Production	II-75
II.C.3	Midwest Optoelectronics, LLC: Critical Research for Cost-Effective Photoelectrochemical Production of Hydrogen	II-79
II.C.4	Lawrence Livermore National Laboratory: Characterization and Optimization of Photoelectrode Surfaces for Solar-to-Chemical Fuel Conversion	II-84
II.C.5	University of Nevada, Reno: Metal Oxide Semiconductor Nanotubular Arrays for Photoelectrochemical Hydrogen Generation	II-89
II.C.6	Los Alamos National Laboratory: Photoelectrochemical Material Synthesis at LANL	II-93
II.C.7	California Institute of Technology: Next-Generation Si Microwire Array Devices for Unassisted Photoelectrosynthesis	II-97
II.D	Biological	II-101
II.D.1	University of California, Berkeley: Maximizing Light Utilization Efficiency and Hydrogen Production in Microalgal Cultures	II-101
II.D.2	National Renewable Energy Laboratory: Biological Systems for Hydrogen Photoproduction	II-105
II.D.3	National Renewable Energy Laboratory: Fermentation and Electrohydrogenic Approaches to Hydrogen Production	II-108
II.D.4	J. Craig Venter Institute: Hydrogen from Water in a Novel Recombinant Oxygen-Tolerant Cyanobacterial System	II-113
II.D.5	National Renewable Energy Laboratory: Probing O ₂ -Tolerant CBS Hydrogenase for Hydrogen Production	II-116

Table of Contents

II.	Hydrogen Production (Continued)	
II.E	Distributed Bio-Derived Liquids	II-119
II.E.1	National Renewable Energy Laboratory: Distributed Bio-Oil Reforming	II-119
II.E.2	Pacific Northwest National Laboratory: Biomass-Derived Liquids Distributed Reforming	II-124
III.	Hydrogen Delivery	III-1
III.0	Hydrogen Delivery Program Overview	III-3
III.1	Argonne National Laboratory: Hydrogen Delivery Infrastructure Analysis	III-11
III.2	Mohawk Innovative Technologies, Inc.: Oil-Free Centrifugal Hydrogen Compression Technology Demonstration	III-16
III.3	Hexagon Lincoln: Development of High-Pressure Hydrogen Storage Tank for Storage and Gaseous Truck Delivery	III-21
III.4	Savannah River National Laboratory: Fiber Reinforced Composite Pipeline	III-25
III.5	Sandia National Laboratories: Hydrogen Embrittlement of Structural Steels	III-29
III.6	FuelCell Energy, Inc.: Electrochemical Hydrogen Compressor	III-33
III.7	Oak Ridge National Laboratory: Vessel Design and Fabrication Technology for Stationary High-Pressure Hydrogen Storage	III-37
III.8	Lawrence Livermore National Laboratory: Rapid High-Pressure Liquid Hydrogen Refueling for Maximum Range and Dormancy	III-42
III.9	Sandia National Laboratories: Polymer and Composite Material Performance in Hydrogen	III-46
III.10	Concepts NREC: Development of a Centrifugal Hydrogen Pipeline Gas Compressor	III-48
III.11	Pacific Northwest National Laboratory: Investigation of H ₂ Diaphragm Compressors to Enable Low-Cost Long-Life Operation	III-53
IV.	Hydrogen Storage	IV-1
IV.0	Hydrogen Storage Program Overview	IV-3
IV.A	Testing and Analysis	IV-11
IV.A.1	Argonne National Laboratory: System Analysis of Physical and Materials-Based Hydrogen Storage Options	IV-11
IV.A.2	Strategic Analysis, Inc.: Hydrogen Storage Cost Analysis	IV-18
IV.A.3	H ₂ Technology Consulting LLC: Best Practices for Characterizing Engineering Properties of Hydrogen Storage Materials	IV-24
IV.B	Engineering – HSECoE	
IV.B.1	Savannah River National Laboratory: Hydrogen Storage Engineering Center of Excellence	IV-29
IV.B.2	Pacific Northwest National Laboratory: Systems Engineering of Chemical Hydrogen Storage, Pressure Vessel, and Balance of Plant for Onboard Hydrogen Storage	IV-38
IV.B.3	United Technologies Research Center: Advancement of Systems Designs and Key Engineering Technologies for Materials-Based Hydrogen Storage	IV-46
IV.B.4	Los Alamos National Laboratory: Chemical Hydride Rate Modeling, Validation, and System Demonstration	IV-53
IV.B.5	National Renewable Energy Laboratory: System Design, Analysis, Modeling, and Media Engineering Properties for Hydrogen Energy Storage	IV-57
IV.B.6	General Motors Company: Thermal Management of Onboard Cryogenic Hydrogen Storage Systems	IV-63
IV.B.7	Ford Motor Company: Ford/BASF-SE/UM Activities in Support of the Hydrogen Storage Engineering Center of Excellence	IV-67
IV.B.8	Oregon State University: Microscale Enhancement of Heat and Mass Transfer for Hydrogen Energy Storage	IV-71
IV.B.9	Hexagon Lincoln: Development of Improved Composite Pressure Vessels for Hydrogen Storage	IV-76

IV.	Hydrogen Storage (Continued)	
IV.C	Materials – Sorption	IV-80
IV.C.1	National Renewable Energy Laboratory: Hydrogen Sorbent Measurement Qualification and Characterization	IV-80
IV.C.2	HRL Laboratories, LLC: Room Temperature Hydrogen Storage in Nano-Confined Liquids	IV-84
IV.C.3	Lawrence Berkeley National Laboratory: Hydrogen Storage in Metal-Organic Frameworks	IV-89
IV.C.4	Oak Ridge National Laboratory: The Quantum Effects of Pore Structure on Hydrogen Adsorption	IV-93
IV.C.5	Northwestern University: Metallation of Metal–Organic Frameworks: En Route to Ambient Temperature Storage of Molecular Hydrogen	IV-99
IV.C.6	National Renewable Energy Laboratory: Weak Chemisorption Validation	IV-103
IV.C.7	Pennsylvania State University: Hydrogen Trapping through Designer Hydrogen Spillover Molecules with Reversible Temperature and Pressure-Induced Switching	IV-107
IV.D	Materials – Metal Hydrides	IV-112
IV.D.1	Northwestern University: Design of Novel Multi-Component Metal Hydride-Based Mixtures for Hydrogen Storage	IV-112
IV.D.2	Delaware State University: Hydrogen Storage Materials for Fuel Cell-Powered Vehicles	IV-121
IV.D.3	National Institute of Standards and Technology: Neutron Characterization in Support of the DOE Hydrogen Storage Sub-Program	IV-126
IV.E	Materials – Chemical	IV-131
IV.E.1	Los Alamos National Laboratory: Fluid Phase Chemical Hydrogen Storage Materials	IV-131
IV.E.2	Hawaii Hydrogen Carriers, LLC: Development of a Practical Hydrogen Storage System Based on Liquid Organic Hydrogen Carriers and a Homogeneous Catalyst	IV-135
IV.E.3	University of Oregon: Novel Carbon(C)-Boron(B)-Nitrogen(N)-Containing H ₂ Storage Materials	IV-140
IV.E.4	Brookhaven National Laboratory: Aluminum Hydride: the Organometallic Approach	IV-146
IV.E.5	Savannah River National Laboratory: Electrochemical Reversible Formation of Alane	IV-150
IV.F	Advanced Tanks	IV-154
IV.F.1	Oak Ridge National Laboratory: Lifecycle Verification of Polymeric Storage Tank Liners	IV-154
IV.F.2	Oak Ridge National Laboratory: Melt Processable PAN Precursor for High-Strength, Low-Cost Carbon Fibers	IV-160
IV.F.3	Oak Ridge National Laboratory: Development of Low-Cost, High-Strength Commercial Textile Precursor (PAN-MA)	IV-165
IV.F.4	Pacific Northwest National Laboratory: Synergistically Enhanced Materials and Design Parameters for Reducing the Cost of Hydrogen Storage Tanks	IV-171
V.	Fuel Cells	V-1
V.0	Fuel Cells Program Overview	V-3
V.A	Catalysts	V-9
V.A.1	3M Company: Durable Catalysts for Fuel Cell Protection during Transient Conditions	V-9
V.A.2	National Renewable Energy Laboratory: Extended, Continuous Pt Nanostructures in Thick, Dispersed Electrodes	V-14
V.A.3	Argonne National Laboratory: Nanosegregated Cathode Catalysts with Ultra-Low Platinum Loading	V-19
V.A.4	Brookhaven National Laboratory: Contiguous Platinum Monolayer Oxygen Reduction Electrocatalysts on High-Stability Low-Cost Supports	V-26
V.A.5	Los Alamos National Laboratory: The Science and Engineering of Durable Ultra-Low PGM Catalysts	V-31
V.A.6	Los Alamos National Laboratory: Engineered Nano-Scale Ceramic Supports for PEM Fuel Cells	V-37

V.	Fuel Cells (Continued)	
V.A	Catalysts (Continued)	
V.A.7	National Renewable Energy Laboratory: Tungsten Oxide and Heteropoly Acid-Based Systems for Ultra-High Activity and Stability of Pt Catalysts in PEM Fuel Cell Cathodes	V-44
V.A.8	Illinois Institute of Technology: Synthesis and Characterization of Mixed-Conducting Corrosion Resistant Oxide Supports	V-50
V.A.9	Northeastern University: Development of Novel Non-PGM Electrocatalysts for Proton Exchange Membrane Fuel Cell Applications	V-54
V.A.10	General Motors Company: High-Activity Dealloyed Catalysts	V-61
V.A.11	University of South Carolina: Development of Ultra-Low Platinum Alloy Cathode Catalyst for Polymer Electrolyte Membrane Fuel Cells	V-68
V.A.12	Los Alamos National Laboratory: Non-Precious Metal Fuel Cell Cathodes: Catalyst Development and Electrode Structure Design	V-74
V.B	Membranes	V-79
V.B.1	Giner, Inc.: Dimensionally Stable High Performance Membrane	V-79
V.B.2	FuelCell Energy, Inc.: High-Temperature Membrane with Humidification-Independent Cluster Structure	V-83
V.B.3	Ion Power Inc.: Corrugated Membrane Fuel Cell Structures	V-86
V.C	MEA Integration	V-90
V.C.1	3M Company: High-Performance, Durable, Low-Cost Membrane Electrode Assemblies for Transportation Applications	V-90
V.C.2	Argonne National Laboratory: Rationally Designed Catalyst Layers for PEMFC Performance Optimization	V-95
V.D	Degradation Studies	V-98
V.D.1	Los Alamos National Laboratory: Durability Improvements through Degradation Mechanism Studies	V-98
V.D.2	Nuvera Fuel Cells, Inc.: Durability of Low-Platinum Fuel Cells Operating at High Power Density	V-104
V.D.3	Los Alamos National Laboratory: Accelerated Testing Validation	V-109
V.D.4	National Renewable Energy Laboratory: Analysis of Laboratory Fuel Cell Technology Status – Voltage Degradation	V-116
V.D.5	Ballard Power Systems: Development of Micro-Structural Mitigation Strategies for PEM Fuel Cells: Morphological Simulations and Experimental Approaches	V-121
V.E	Impurities	V-129
V.E.1	National Renewable Energy Laboratory: Effect of System Contaminants on PEMFC Performance and Durability	V-129
V.E.2	Hawaii Natural Energy Institute: The Effect of Airborne Contaminants on Fuel Cell Performance and Durability	V-135
V.F	Transport Studies	V-141
V.F.1	Lawrence Berkeley National Laboratory: Fuel Cell Fundamentals at Low and Subzero Temperatures	V-141
V.F.2	Giner, Inc.: Transport in PEMFCs	V-147
V.F.3	General Motors Company: Investigation of Micro- and Macro-Scale Transport Processes for Improved Fuel Cell Performance	V-153
V.F.4	Nuvera Fuel Cells, Inc.: Transport Studies Enabling Efficiency Optimization of Cost-Competitive Fuel Cell Stacks	V-159
V.G	Balance of Plant	V-162
V.G.1	Dynalene Inc.: Large-Scale Testing, Demonstration and Commercialization of the Nanoparticle-Based Fuel Cell Coolant (SBIR Phase III)	V-162

V. Fuel Cells (Continued)

- V.G Balance of Plant (Continued)
 - V.G.2 Tetramer Technologies, LLC: New High-Performance Water Vapor Membranes To Improve Fuel Cell Balance-of-Plant Efficiency and Lower Costs V-166
 - V.G.3 Eaton Corporation: Roots Air Management System with Integrated Expander V-170
- V.H Analysis/Characterization. V-175
 - V.H.1 Argonne National Laboratory: Fuel Cells Systems Analysis V-175
 - V.H.2 Strategic Analysis, Inc.: Fuel Cell Transportation Cost Analysis. V-181
 - V.H.3 Oak Ridge National Laboratory: Characterization of Fuel Cell Materials. V-186
 - V.H.4 National Institute of Standards and Technology: Neutron Imaging Study of the Water Transport in Operating Fuel Cells V-193
 - V.H.5 National Renewable Energy Laboratory: Enlarging the Potential Market for Stationary Fuel Cells Through System Design Optimization V-199
 - V.H.6 Battelle: Stationery and Emerging Market Fuel Cell System Cost Analysis - Material Handling Equipment. V-203
 - V.H.7 Lawrence Berkeley National Laboratory: A Total Cost of Ownership Model for Design and Manufacturing Optimization of Fuel Cells in Stationary and Emerging Market Applications V-207
 - V.H.8 Los Alamos National Laboratory: Technical Assistance to Developers V-212
- V.I Portable Power V-216
 - V.I.1 Arkema Inc.: Novel Materials for High Efficiency Direct Methanol Fuel Cells V-216
 - V.I.2 Los Alamos National Laboratory: Advanced Materials and Concepts for Portable Power Fuel Cells V-220
- V.J Stationary Power V-227
 - V.J.1 InnovaTek: Power Generation from an Integrated Biomass Reformer and Solid Oxide Fuel Cell (SBIR Phase III Xlerator Program) V-227
- V.K Bipolar Plates V-231
 - V.K.1 TreadStone Technologies, Inc.: Low-Cost PEM Fuel Cell Metal Bipolar Plates V-231
- V.L Alkaline Fuel Cells V-235
 - V.L.1 National Renewable Energy Laboratory: Advanced Ionomers and MEAs for Alkaline Membrane Fuel Cells V-235
- V.M Cross-Cutting V-238
 - V.M.1 University of Connecticut: Improving Fuel Cell Durability and Reliability V-238
- V.N Basic Energy Sciences Fuel Cell Research. V-243
 - V.N.1 University of Chicago: Computer Simulation of Proton Transport in Fuel Cell Membranes V-243
 - V.N.2 Clemson University: Fluoropolymers, Electrolytes, Composites and Electrodes V-247
 - V.N.3 Lehigh University: Gas Transport Across Hyperthin Membranes. V-251
 - V.N.4 University of Texas: Theory-Guided Design of Nanoscale Multi-Metallic Catalysts For Fuel Cells V-254
 - V.N.5 Columbia University: Structure-Property Relationship in Metal Carbides and Bimetallic Alloys V-257
 - V.N.6 University of New Mexico: Nanostructured Catalysts for Hydrogen Production from Renewable Feedstocks V-260
 - V.N.7 University of Texas at Austin: Fundamental Structure/Property Studies of Gas Separation Membrane Polymers. V-264
 - V.N.8 Georgia Institute of Technology: Precisely Tunable High Performance Carbon Molecular Sieve Membranes for Energy Intensive Separations V-268
 - V.N.9 University of Southern California, Los Angeles: Nanoporous Membranes for Hydrogen Production: Experimental Studies and Molecular Simulations V-273

V.	Fuel Cells (Continued)	
V.N	BES (Continued)	
V.N.10	Argonne National Laboratory: Structure/Composition/Function Relationships in Supported Nanoscale Catalysts for Hydrogen	V-276
V.N.11	Brookhaven National Laboratory: Metal and Metal Oxide-Supported Platinum Monolayer Electrocatalysts for Oxygen Reduction	V-280
V.N.12	Brookhaven National Laboratory: Active Sites and Mechanism for the Water-Gas Shift Reaction on Metal and Metal/Oxide Catalysts	V-284
V.N.13	Oak Ridge National Laboratory: Fundamentals of Catalysis and Chemical Transformations	V-288
V.N.14	Pacific Northwest National Laboratory: Activation of Small Molecules with Bi-Functional Ambiphilic Catalyst Complexes	V-292
V.N.15	Pacific Northwest National Laboratory: Bio-Inspired Molecular Catalysts for Oxidation of Hydrogen and Production of Hydrogen: Cheap Metals for Noble Tasks	V-295
V.N.16	University of California, Santa Barbara: Platinum-Group Metal (PGM) Substituted Complex Oxide Catalysts	V-298
V.N.17	University of Connecticut: Porous Transition Metal Oxides: Synthesis, Characterization, and Catalytic Activity	V-301
V.N.18	University of Connecticut: Understanding the Effects of Surface Chemistry and Microstructure on the Activity and Stability of Pt Electrocatalysts on Non-Carbon Supports	V-305
V.N.19	Georgetown University: In Situ NMR/IR/Raman and ab initio DFT Investigations of Pt-Based Mono- and Bi-metallic Nanoscale Electrocatalysts: from Sulfur-Poisoning to Polymer Promoters to Surface Activity Indexes	V-309
V.N.20	Ohio State University: Investigation of the Nature of Active Sites on Heteroatom-Containing Carbon Nano-Structures for Oxygen Reduction Reaction	V-313
V.N.21	University of Pennsylvania: Oxide-Metal Interactions Studied on M@Oxide, Core-Shell Catalysts	V-318
V.N.22	University of Pennsylvania: Fundamental Studies of the Steam Reforming of Alcohols on PdZnO and Co/ZnO Catalysts	V-320
V.N.23	University of Pittsburgh: Theoretically Relating the Surface Composition of the Pt Alloys to Their Performance as the Electrocatalysts of Low-Temperature Fuel Cells	V-324
V.N.24	Rutgers University: Nanoscale Surface Chemistry and Electrochemistry of Clean and Metal-Covered Faceted Substrates: Structure, Reactivity and Electronic Properties	V-328
V.N.25	University of Texas: Correlation of Theory and Function in Well-Defined Bimetallic Electrocatalysts	V-331
V.N.26	Tufts University: Metal Ion Sites on Oxide Supports as Catalysts for the Water-Gas Shift and Methanol Steam Reforming Reactions	V-335
V.N.27	Virginia Tech: Hydrocarbon Oxidation, Dehydrogenation and Coupling over Model Metal Oxide Surfaces	V-340
V.N.28	Virginia Tech: Atomic Level Studies of Advanced Catalysts for Hydrodeoxygenation	V-343
V.N.29	University of Wisconsin: Atomic-Scale Design of Metal and Alloy Catalysts: A Combined Theoretical and Experimental Approach	V-347
VI.	Manufacturing R&D	VI-1
VI.0	Manufacturing R&D Program Overview	VI-3
VI.1	National Renewable Energy Laboratory: Fuel Cell Membrane Electrode Assembly Manufacturing R&D	VI-7
VI.2	W. L. Gore & Associates, Inc.: Manufacturing of Low-Cost, Durable Membrane Electrode Assemblies Engineered for Rapid Conditioning	VI-11
VI.3	Rensselaer Polytechnic Institute: Adaptive Process Controls and Ultrasonics for High-Temperature PEM MEA Manufacture	VI-17
VI.4	National Institute of Standards and Technology: Metrology for Fuel Cell Manufacturing	VI-23

VI.	Manufacturing R&D (Continued)	
VI.5	BASF Fuel Cell, Inc.: High-Speed, Low-Cost Fabrication of Gas Diffusion Electrodes for Membrane Electrode Assemblies	VI-27
VI.6	Quantum Fuel Systems Technologies Worldwide, Inc.: Development of Advanced Manufacturing Technologies for Low-Cost Hydrogen Storage Vessels	VI-30
VII.	Technology Validation	VII-1
VII.0	Technology Validation Program Overview	VII-3
VII.1	National Renewable Energy Laboratory: Technology Validation: Fuel Cell Bus Evaluations	VII-7
VII.2	National Renewable Energy Laboratory: Stationary Fuel Cell Evaluation	VII-11
VII.3	H2Pump LLC: Hydrogen Recycling System Evaluation and Data Collection	VII-15
VII.4	National Renewable Energy Laboratory: Hydrogen Component Validation	VII-18
VII.5	Proton OnSite: Validation of an Advanced High-Pressure PEM Electrolyzer and Composite Hydrogen Storage, with Data Reporting, for SunHydro Stations	VII-22
VII.6	National Renewable Energy Laboratory: Forklift and Backup Power Data Collection and Analysis	VII-26
VII.7	National Renewable Energy Laboratory: Fuel Cell Electric Vehicle Evaluation	VII-32
VII.8	National Renewable Energy Laboratory: Next Generation Hydrogen Infrastructure Evaluation	VII-36
VII.9	California Air Resources Board: Data Collection and Validation of Newport Beach Hydrogen Station Performance	VII-41
VII.10	California State University, Los Angeles: California State University Los Angeles Hydrogen Refueling Facility Performance Evaluation and Optimization	VII-43
VII.11	Gas Technology Institute: Performance Evaluation of Delivered Hydrogen Fueling Stations	VII-45
VIII.	Safety, Codes & Standards	VIII-1
VIII.0	Safety, Codes & Standards Program Overview	VIII-3
VIII.1	National Renewable Energy Laboratory: Fuel Cell Technologies National Codes and Standards Development and Outreach	VIII-7
VIII.2	National Renewable Energy Laboratory: Component Standard Research and Development	VIII-11
VIII.3	Los Alamos National Laboratory: Hydrogen Safety, Codes and Standards: Sensors	VIII-14
VIII.4	Sandia National Laboratories: R&D for Safety, Codes and Standards: Materials and Components Compatibility	VIII-22
VIII.5	Los Alamos National Laboratory: Hydrogen Fuel Quality	VIII-28
VIII.6	Sandia National Laboratories: R&D for Safety Codes and Standards: Hydrogen Release Behavior	VIII-33
VIII.7	Sandia National Laboratories: R&D for Safety Codes and Standards: Risk Assessment	VIII-39
VIII.8	Pacific Northwest National Laboratory: Hydrogen Emergency Response Training for First Responders	VIII-43
VIII.9	Pacific Northwest National Laboratory: Hydrogen Safety Panel and Hydrogen Safety Knowledge Tools	VIII-46
VIII.10	Zero Carbon Energy Solutions: International Partnership for Hydrogen & Fuel Cells in the Economy - Regulations Codes and Standards Working Group	VIII-51
VIII.11	National Renewable Energy Laboratory: NREL Hydrogen Sensor Testing Laboratory	VIII-55
IX.	Market Transformation	IX-1
IX.0	Market Transformation Program Overview	IX-3
IX.1	National Renewable Energy Laboratory: Direct Methanol Fuel Cell Material Handling Equipment Deployment	IX-7
IX.2	Pacific Northwest National Laboratory: Fuel Cell Combined Heat and Power Commercial Demonstration	IX-11
IX.3	Advanced Technology International: Landfill Gas-to-Hydrogen	IX-16

Table of Contents

IX.	Market Transformation (Continued)	
IX.4	Hawaii Natural Energy Institute: Hydrogen Energy Systems as a Grid Management Tool	IX-19
IX.5	Plug Power Inc.: Ground Support Equipment Demonstration	IX-24
IX.6	Argonne National Laboratory: Fuel Cells as Range Extenders for Battery Electric Vehicles	IX-26
IX.7	National Renewable Energy Laboratory: Hawaii Hydrogen Initiative (H2I) Financial Scenario Analysis	IX-30
X.	American Recovery and Reinvestment Act	X-1
X.0	American Recovery and Reinvestment Act Activities	X-3
X.1	Delphi Automotive Systems, LLC: Solid Oxide Fuel Cell Diesel Auxiliary Power Unit Demonstration	X-7
X.2	Plug Power Inc.: Highly Efficient, 5-kW CHP Fuel Cells Demonstrating Durability and Economic Value in Residential and Light Commercial Applications	X-10
X.3	Plug Power Inc.: Accelerating Acceptance of Fuel Cell Backup Power Systems	X-13
X.4	Sprint Nextel: Use of 72-Hour Hydrogen PEM Fuel Cell Systems to Support Emergency Communications	X-16
XI.	Systems Analysis	XI-1
XI.0	Systems Analysis Program Overview	XI-3
XI.1	Oak Ridge National Laboratory: Worldwide Status of Hydrogen Fuel Cell Vehicle Technology and Prospects for Commercialization	XI-13
XI.2	University of California: Siting Strategies for Early H2 Refueling Infrastructure in California: Learning from the Gasoline Experience	XI-17
XI.3	University of California: Design and Economics of an Early Hydrogen Refueling Network for California	XI-21
XI.4	Oak Ridge National Laboratory: Analysis of Optimal Onboard Storage Pressure for Hydrogen Fuel Cell Vehicles	XI-25
XI.5	Argonne National Laboratory: Life-Cycle Analysis of Hydrogen Onboard Storage Options	XI-29
XI.6	Argonne National Laboratory: Employment Impacts of Infrastructure Development for Hydrogen and Fuel Cell Technologies	XI-33
XI.7	National Renewable Energy Laboratory: Pathway Analysis: Projected Cost, Well-to-Wheels Energy Use and Emissions of Current Hydrogen Technologies	XI-36
XI.8	National Renewable Energy Laboratory: Hydrogen from Biogas: Resource Assessment	XI-40
XI.9	Sandia National Laboratories: Global Hydrogen Resource Analysis	XI-44
XI.10	Argonne National Laboratory: Life-Cycle Analysis of Water Use for Hydrogen Production Pathways	XI-48
XI.11	National Renewable Energy Laboratory: Analysis of Fuel Cell Integration with Biofuels Production	XI-51
XI.12	National Renewable Energy Laboratory: Analysis of Community Energy	XI-56
XII.	Small Business Innovation Research	XII-1
XII.0	Small Business Innovation Research (SBIR) Hydrogen Program New Projects Awarded in FY 2013	XII-3
	Phase I Projects	XII-3
XII.1	Cryogenically Flexible, Low Permeability Thoraeus Rubber H2 Dispenser Hose	XII-3
XII.2	Hydrogen Leak Detector for Hydrogen Dispenser	XII-4
XII.3	Nanostructured Catalysts for Alkaline PEM Fuel Cells	XII-4
	Phase II Projects	XII-4
XII.4	Low-Noble-Metal-Content Catalysts/Electrodes for Hydrogen Production by Water Electrolysis	XII-4
XIII.	Acronyms, Abbreviations and Definitions	XIII-1

XIV. Primary Contacts IndexXIV-1

XV. Hydrogen Program Contacts XV-1

XVI. Project Listings by State XVI-1

XVII. Project Listings by OrganizationXVII-1