

CONTENTS

I	Introduction.....	3
II	Hydrogen Production and Delivery Sub-Program	7
II.0	Production and Delivery Sub-Program Overview	9
II.A	Distributed Production Technologies	13
II.A.1	Ceramic Membrane Reactor Systems for Converting Natural Gas to Hydrogen and Synthesis Gas (ITM Syngas)	13
II.A.2	Integrated Ceramic Membrane System for Hydrogen Production.....	18
II.A.3	Low-Cost Hydrogen Production Platform.....	23
II.A.4	Autothermal Cyclic Reforming Based Hydrogen Generating and Dispensing System	28
II.A.5	Novel Catalytic Fuel Reforming	32
II.A.6	Water-Gas Shift Membrane Reactor Studies	37
II.A.7	Hydrogen Production from Biomass Reformation.....	41
II.B	Separations.....	47
II.B.1	Defect-Free Thin Film Membranes for H ₂ Separation and Isolation	47
II.B.2	Inorganic Membrane Porous Support Tube Fabrication	53
II.B.3	Pyrochlore/Perovskite Proton Transport Membranes	56
II.B.4	A Photopolymerization/Pyrolysis Route to Microstructured Membranes	60
II.C	Biomass Gasification/Pyrolysis	65
II.C.1	Hydrogen from Biomass – Catalytic Reforming of Pyrolysis Streams.....	65
II.D	Photobiological Production	71
II.D.1	Maximizing Photosynthetic Efficiencies and Hydrogen Production in Microalgal Cultures	71
II.D.2	Biological Systems for Hydrogen Photoproduction	75
II.D.3	Algal H ₂ Production Systems: Creation of Designer Alga for Efficient and Robust Production of H ₂	82
II.D.4	Hydrogen Reactor Development and Design for Photofermentation and Photolytic Processes.....	87
II.E	Photoelectrochemical Production	91
II.E.1	Photoelectrochemical Systems for H ₂ Production	91
II.E.2	Photoelectrochemical Hydrogen Production	96
II.E.3	Discovery of Photocatalysts for Hydrogen Production	102
II.E.4	Photoelectrochemical Hydrogen Production Using New Combinatorial Chemistry Derived Materials	106
II.F	Electrolysis	113
II.F.1	High-Temperature Solid-Oxide Electrolyzer System	113
II.F.2	Renewable Electrolysis Integrated System Development and Testing	119
II.F.3	Alkaline, High-Pressure Electrolysis.....	123
II.F.4	Hydrogen Production – Increasing the Efficiency of Water Electrolysis (New Project).....	126
II.F.5	Low-Cost, High-Pressure Hydrogen Generator (New Project).....	128
II.F.6	Hydrogen Generation from Electrolysis (New Project)	132

CONTENTS (Continued)

II Hydrogen Production and Delivery Sub-Program (Continued)

II.G	High-Temperature Thermochemical Processes	135
II.G.1	High Efficiency Generation of Hydrogen Using Solar Thermochemical Splitting of Water*	135
II.H	H ₂ Delivery	141
II.H.1	Hydride Based Hydrogen Compression	141
II.H.2	Hydrogen Permeability and Integrity of Hydrogen Transfer Pipelines (New Project)	146
II.I	Analysis	149
II.I.1	Moving Toward Consistent Analysis in the Hydrogen, Fuel Cells and Infrastructure Technologies Program: Hydrogen Analysis (H ₂ A)	149
II.I.2	Hydrogen Transition Modeling and Analysis: HYTRANS v. 1.0	154
II.I.3	WinDS-H2 Model and Analysis	157
II.I.4	Technical and Economic Studies of Regional Transition Strategies toward Widespread Use of Hydrogen Energy	161
II.I.5	Hydrogen Production in a Greenhouse Gas Constrained Situation	167
II.I.6	Fuel Choice for Fuel Cell Vehicles: Hydrogen Infrastructure Costs	172

III Hydrogen Storage Sub-Program 177

III.0	Hydrogen Storage Sub-Program Overview	179
III.A	Compressed/Liquid H ₂ Tanks	183
III.A.1	Low-Cost, High-Efficiency, High-Pressure Hydrogen Storage	183
III.A.2	Optimum Utilization of Available Space in a Vehicle through Conformable Hydrogen Vessels	186
III.A.3	Next-Generation Physical Hydrogen Storage	190
III.B	Chemical Hydrides	195
III.B.1	Low-Cost, Off-Board Regeneration of Sodium Borohydride	195
III.B.2	Hydrogen Storage: Radiolysis for Borate Regeneration	200
III.B.3	Chemical Hydride Slurry for Hydrogen Production and Storage	205
III.B.4	Design and Development of New Carbon-Based Sorbent Systems for an Effective Containment of Hydrogen	210
III.C	Metal Hydrides	215
III.C.1	Catalytically Enhanced Hydrogen Storage Systems	215
III.C.2	Hydride Development for Hydrogen Storage	220
III.C.3	High Density Hydrogen Storage System Prototype Using NaAlH ₄ Based Complex Compound Hydrides	230
III.C.4	Discovery of Novel Complex Metal Hydrides for Hydrogen Storage through Molecular Modeling and Combinatorial Methods	235
III.C.5	Sub-Nanostructured Non-Transition Metal Complex Grids for Hydrogen Storage	239
III.C.6	Complex Hydride Compounds with Enhanced Hydrogen Storage Capacity (New FY 2004 Project)	243

CONTENTS (Continued)

III	Hydrogen Storage Sub-Program (Continued)	
III.D	Carbon Materials	245
III.D.1	Hydrogen Storage in Carbon-Based Materials	245
III.E	Testing	253
III.E.1	Standardized Testing Program for Emergent Chemical Hydride and Carbon Storage Technologies	253
IV	Fuel Cells Sub-Program	259
IV.0	Fuel Cells Sub-Program Overview	261
IV.A	MEAs and Catalysts	265
IV.A.1	Integrated Manufacturing for Advanced Membrane Electrode Assemblies	265
IV.A.2	Development of High-Temperature Membranes and Improved Cathode Catalysts	270
IV.A.3	Advanced MEAs for Enhanced Operating Conditions	277
IV.B	Membranes and MEAs	285
IV.B.1	High-Temperature Membranes	285
IV.B.2	Electrodes for Hydrogen-Air PEM Fuel Cells	291
IV.B.3	High-Temperature Polymer Membranes	297
IV.B.4	Development of Polybenzimidazole-based, High-Temperature Membrane and Electrode Assemblies for Stationary and Automotive Applications	301
IV.B.5	Enabling Commercial PEM Fuel Cells with Breakthrough Lifetime Improvements ..	306
IV.B.6	MEA and Stack Durability for PEM Fuel Cells	311
IV.B.7	Development of a Low-Cost, Durable Membrane and Membrane Electrode Assembly for Stationary and Mobile Fuel Cell Application	315
IV.B.8	Development of Novel Water-Gas-Shift Membrane Reactor	319
IV.B.9	Montana PEM Membrane Degradation Study, Year 1 Report*	324
IV.B.10	Development of Higher-Temperature Membrane and Electrode Assembly for Proton Exchange Membrane Fuel Cell Device*	328
IV.B.11	Polymer Blend Proton Exchange Membranes	333
IV.B.12	High Temperature Polymer Electrolytes Based on Ionic Liquids	338
IV.B.13	New Polyelectrolyte Materials for High-Temperature Fuel Cells, Membrane Electrode Assemblies and Enhanced Selectivity	342
IV.C	Catalysts.....	349
IV.C.1	New Electrocatalysts for Fuel Cells	349
IV.C.2	Low-Platinum Catalysts for Oxygen Reduction at PEMFC Cathodes	355
IV.C.3	Low Platinum Loading Catalysts for Fuel Cells	360
IV.C.4	Development, Characterization and Evaluation of Transition Metal/Chalcogen-Based Cathode Catalysts for PEM Fuel Cells	365
IV.C.5	Novel Approach to Non-Precious Metal Catalysts	368
IV.C.6	Novel Non-Precious Metals for PEMFC: Catalyst Selection through Molecular Modeling and Durability Studies	373
IV.C.7	Non-Precious Metal Electrocatalysts	379
IV.C.8	Development of High-Performance, Low-Pt Cathodes Containing New Catalysts and Layer Structure	382

CONTENTS (Continued)

IV Fuel Cells Sub-Program (Continued)

IV.D Bipolar Plates	387
IV.D.1 Scale-Up of Carbon/Carbon Composite Bipolar Plates	387
IV.D.2 Cost-Effective Surface Modification for Metallic Bipolar Plates	391
IV.E Platinum Recycling	397
IV.E.1 Platinum Recycling Technology Development	397
IV.E.2 Platinum Group Metal Recycling Technology Development	401
IV.F Fuel Processing	405
IV.F.1 Advanced High-Efficiency Quick-Start Fuel Processor for Transportation Applications	405
IV.F.2 Fuel Processors for PEM Fuel Cells	411
IV.F.3 Microchannel Reformate Cleanup: Water Gas Shift and Preferential Oxidation	417
IV.F.4 Plate-Based Fuel Processing System	422
IV.F.5 Quick-Starting Fuel Processors - A Feasibility Study	427
IV.F.6 Rapid-Cold Start, On-Board, Microchannel Steam Reformer	432
IV.F.7 Water Gas Shift Catalysis	438
IV.F.8 Catalysts for Autothermal Reforming	443
IV.F.9 Selective Catalytic Oxidation of Hydrogen Sulfide	448
IV.F.10 Development of a 50-kW Fuel Processor for Stationary Fuel Cell Applications Using Revolutionary Materials for Absorption-Enhanced Natural Gas Reforming	453
IV.F.11 Effects of Fuel Composition on Fuel Processing	457
IV.F.12 Evaluation of Partial Oxidation Fuel Cell Reformer Emissions	461
IV.G Stationary Power Systems	465
IV.G.1 Advanced Buildings PEM Fuel Cell System	465
IV.G.2 150-kW PEM Fuel Cell Power Plant Verification	469
IV.G.3 Back-up/Peak-Shaving Fuel Cells	475
IV.G.4 Economic Analysis of Stationary PEM Fuel Cell Systems	479
IV.G.5 Residential Fuel Cell Demonstration by the Delaware County Electric Cooperative, Inc. (New Project)*	483
IV.G.6 Fuel Cell Operated Smart Home (New Project)*	485
IV.H Transportation Systems and Balance of Plant Components	487
IV.H.1 Fuel Cell Systems Analysis	487
IV.H.2 Fuel Cell Vehicle Systems Analysis	492
IV.H.3 Development of a Thermal and Water Management System for PEM Fuel Cells	496
IV.H.4 Fiber Optic Temperature Sensors for PEM Fuel Cells	502
IV.H.5 Cost and Performance Enhancements for a PEM Fuel Cell System	507
IV.H.6 Development and Testing of a Toroidal Intersecting Vane Machine (TIVM) Air Management System	510
IV.H.7 Development of Sensors for Automotive Fuel Cell Systems	514
IV.H.8 Sensor Development for PEM Fuel Cell Systems	520
IV.H.9 Low-Friction Coatings and Materials for Fuel Cell Air Compressors	525

CONTENTS (Continued)

IV Fuel Cells Sub-Program (Continued)

IV.H	Transportation Systems and Balance of Plant Components (Continued)	
	IV.H.10 Graphite-based Thermal Management System Components for Fuel Cell Power Systems.....	529
	IV.H.11 CO Sensors for Fuel Cell Applications	534
	IV.H.12 50-kW (net) Integrated Fuel Cell Power Systems.....	540
IV.I	Fuel Cell Characterization	545
	IV.I.1 Neutron Imaging Study of the Water Transport in Operating PEM Fuel Cells	545
	IV.I.2 Microstructural Characterization of PEM Fuel Cell Membrane Electrode Assemblies.....	549
	IV.I.3 PEM Fuel Cell Durability.....	555
	IV.I.4 Cost Analyses of Fuel Cell Stacks/Systems	561
IV.J	DMFC and SOFC	567
	IV.J.1 Direct Methanol Fuel Cells	567
	IV.J.2 Modeling and Control of an SOFC APU	575
	IV.J.3 Bipolar Plate-Supported Solid Oxide Fuel Cell	582
	IV.J.4 Advanced Catalysts for Direct Methanol Fuel Cells.....	586
V	Technology Validation Sub-Program	593
V.0	Technology Validation Sub-Program Overview	595
V.A	Power Parks Analysis	597
	V.A.1 Hawaii Hydrogen Power Park	597
	V.A.2 DTE Energy Hydrogen Technology Park	602
	V.A.3 Hydrogen from Biomass for Urban Transportation	607
	V.A.4 Validation of an Integrated System for a Hydrogen-Fueled Power Park	611
	V.A.5 Hydrogen Power Park Business Opportunities Concept Project.....	615
	V.A.6 Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems (New Project)*	620
V.B	Hydrogen and Fuel Cell Demonstration/Analysis	623
	V.B.1 Alkaline Fuel Cell-Battery Hybrid Systems with Ammonia or Methanol as Hydrogen Supply	623
	V.B.2 UNIGEN® Regenerative Fuel Cell for Uninterruptible Power Supply.....	628
	V.B.3 Fuel Cell Installation and Demonstration Project, Gallatin County, Montana*	632
V.C	System Analysis.....	637
	V.C.1 Controlled Hydrogen Fleet & Infrastructure Analysis	637
	V.C.2 Power Parks System Simulation.....	641
	V.C.3 Technology Validation: Fuel Cell Bus Evaluations	646
V.D	Refueling Technology Development and Demonstration	651
	V.D.1 Development of a Turnkey Hydrogen Fueling Station	651
	V.D.2 Development of a Natural Gas to Hydrogen Fuel Station.....	656
	V.D.3 Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements.....	661

CONTENTS (Continued)

V	Technology Validation Sub-Program (Continued)	
V.D	Refueling Technology Development and Demonstration (Continued)	
V.D.4	Hydrogen Refueling Technology	664
V.D.5	Research and Development of a PEM Fuel Cell, Hydrogen Reformer, and Vehicle Refueling Facility	668
V.D.6	Praxair Hydrogen Fueling Station at LAX – Small-Footprint H ₂ Capability at the Corner Filling Station	674
V.D.7	Hydrogen Filling Station*	677
V.D.8	Hydrogen Fuel Project - H ₂ Fuel (New Project)*	680
V.E	Vehicle Demonstrations	683
V.E.1	Hydrogen and Natural Gas Blends – Converting Light and Heavy Duty Vehicles	683
V.E.2	Fuelcell-Powered Front-End Loader Mining Vehicle*	685
V.E.3	Global Assessment of Hydrogen-Based Technologies*	689
VI	Safety and Codes & Standards Sub-Program	695
VI.0	Safety, Codes and Standards Sub-Program Overview.....	697
VI.1	Hydrogen Codes and Standards.....	699
VI.2	Electrochemical Sensors for PEMFC Vehicles	705
VI.3	Interfacial Stability of Thin Film Hydrogen Sensors	711
VI.4	Codes and Standards Analysis.....	715
VI.5	Hydrogen Safety, Codes and Standards Research and Development	721
VI.6	Cooperative Industry-Government Hydrogen Safety Study (New Project)	728
VI.7	Hydrogen Safety	732
VI.8	Evaluation of Integrated Hydrogen Systems	739
VI.9	Management of International Energy Agency Hydrogen Implementing Agreement Secretariat	743
VI.10	Combustion of Hydrogen in Air under Simulated Accident Conditions (New Project).....	750
VII	Education Sub-Program	753
VII.0	Education Sub-Program Overview	755
VII.1	Determine Baseline Knowledge of Hydrogen and Fuel Cells.....	759
VII.2	Fuel Cell Demonstration with On-site Generation of Hydrogen (New Project)*	762
VII.3	Washington State Fuel Cell Education and Demonstration Program (New Project)*	763
VII.4	Lansing Community College Alternative Energy Initiative (New Project)*	767
VII.5	Shared Technology Transfer Project (New Project)*	768
VII.6	Montana Hydrogen Futures Project (New Project)*	770
VIII	Cross-Cutting Reports	771
VIII.1	Advanced Manufacturing Technologies for Renewable Energy Applications (New Project)*.....	773
VIII.2	Clean Energy Research (New Project)*	775
VIII.3	Fuel Cell and Hydrogen Research (New Project)*	777

CONTENTS (Continued)

VIII Cross-Cutting Reports (Continued)

VIII.4	Adapting Planar Solid Oxide Fuel Cells for Use with Solid Fuel Sources in the Production of Distributed Power (New Project)*	779
VIII.5	Developing Improved Materials to Support the Hydrogen Economy (New Project)*	781
VIII.6	New York State Hi-Way Initiative (New Project)*	782
VIII.7	Vermont Renewable Hydrogen Production and Transportation Fueling System (New Project)*	784
IX	Acronyms and Abbreviations	787
X	Hydrogen Program Contacts	797
XI	Index of Primary Contacts	801

