

Table of Contents

Introduction	1
Organization of the Report.....	1
Overview of the Hydrogen Program	2
Office Overviews and Updates	11
Introduction to the AMR Peer Review Process and Methodology... ..	17
Hydrogen Production Technologies – 2023	24
Subprogram Overview.....	24
Project Summaries	27
Hydrogen Production	27
Project #P-148: HydroGEN Overview: A Consortium on Advanced Water-Splitting Materials.....	27
Project #P-170: Benchmarking Advanced Water-Splitting Technologies: Best Practices in Materials Characterization	32
Project #P-179: BioHydrogen (BioH ₂) Consortium to Advance Fermentative Hydrogen Production	36
Project #P-184: Scalable and Highly Efficient Microbial Electrochemical Reactor for Hydrogen Generation from Lignocellulosic Biomass and Waste.....	40
Project #P-196: H ₂ NEW Consortium: Hydrogen from Next-Generation Electrolyzers of Water	45
Project #P-197: Advanced Manufacturing Processes for Gigawatt-Scale Proton Exchange Membrane Water Electrolyzers.....	51
Project #P-198: Enabling Low-Cost Proton Exchange Membrane Electrolysis at Scale Through Optimization of Transport Components and Electrode Interfaces	55
Project #P-199: Integrated Membrane Anode Assembly and Scale-up.....	59
Project #P-200: Low-Cost Manufacturing of High-Temperature Electrolysis Stacks	63
Project #P-201: Automation of Solid Oxide Electrolyzer Cell and Stack Assembly	67
Project #P-202: Novel Microbial Electrolysis Cell Design for Efficient Hydrogen Generation from Wastewaters.....	71
Project #P-203: Novel Microbial Electrolysis System for Conversion of Biowastes into Low-Cost Renewable Hydrogen.....	76
Project #P-204: Hydrogen Production Cost and Performance Analysis	81
Production—HydroGEN Seedling	85
Project #P-190: A Multifunctional Isostructural Bilayer Oxygen Evolution Electrode for Durable Intermediate-Temperature Electrochemical Water Splitting	85
Project #P-191: Perovskite–Perovskite Tandem Photoelectrodes for Low-Cost Unassisted Photoelectrochemical Water Splitting	89

Project #P-192: Development of Composite Photocatalyst Materials That Are Highly Selective for Solar Hydrogen Production and Their Evaluation in Z-Scheme Reactor Designs 94

Project #P-193: Highly Efficient Solar Water Splitting Using Three-Dimensional/Two-Dimensional Hydrophobic Perovskites with Corrosion-Resistant Barriers 98

Hydrogen Infrastructure Technologies – 2023 102

Subprogram Overview..... 102

Project Summaries 105

Hydrogen Infrastructure 105

Project #H2-041: H2@Scale Cooperative Research and Development Agreement: California Research Consortium (Reference Station, Fueling Performance Test Device, Station Cap Model) 105

Project #IN-001a: Hydrogen Materials Compatibility Consortium (H-Mat) Overview: Metals 108

Project #IN-001b: Hydrogen Materials Compatibility Consortium (H-Mat) Overview: Polymers.... 113

Project #IN-015: Optimizing the Heisenberg Vortex Tube for Hydrogen Cooling 117

Project #IN-016: Free-Piston Expander for Hydrogen Cooling 120

Project #IN-019: Ultra-Cryopump for High-Demand Transportation Fueling 123

Project #IN-020: Self-Healable Copolymer Composites for Extended-Service Hydrogen-Dispensing Hoses 127

Project #IN-021: Microstructural Engineering and Accelerated Test Method Development to Achieve Low-Cost, High-Performance Solutions for Hydrogen Storage and Delivery 131

Project #IN-022: Tailoring Carbide-Dispersed Steels: A Path to Increased Strength and Hydrogen Tolerance 135

Project #IN-025: Hydrogen Delivery Technologies Analysis 140

Project #IN-026: Tailoring Composition and Deformation Modes at the Microstructural Level for Next-Generation Low-Cost, High-Strength Austenitic Stainless Steels..... 143

Project #IN-029: Reducing the Cost of Fatigue Crack Growth Testing for Storage Vessel Steels in Hydrogen Gas 147

Project #IN-030: Micro-Mechanically Guided High-Throughput Alloy Design Exploration toward Metastability-Induced Hydrogen Embrittlement Resistance 151

Project #IN-034: HyBlend: Pipeline Cooperative Research and Development Agreement (CRADA) Cost and Emissions Analysis 154

Project #IN-035: HyBlend: Pipeline Cooperative Research and Development Agreement (CRADA) Materials Research and Development 158

Project #IN-036: Cost-Effective Pre-Cooling for High-Flow Hydrogen Fueling 164

Project #IN-037: Autonomous Fueling System for Heavy-Duty Fuel Cell Electric Trucks 168

Project #IN-039: Analytic Framework for Optimal Sizing of Hydrogen Fueling Stations for Heavy-Duty Vehicles at Ports 172

Project #IN-040: The HyRIGHT Project: 700 bar Hydrogen Refueling Interface for Gaseous Heavy-Duty Trucks 176

Project #TA-049: High-Pressure, High-Flow-Rate Dispenser and Nozzle Assembly for Heavy-Duty Vehicles 180

Hydrogen Storage.....	184
Project #ST-127: Hydrogen Materials Advanced Research Consortium (HyMARC) Overview.....	184
Project #ST-236: Low-Cost, High-Performance Carbon Fiber for Compressed Natural Gas Storage Tanks.....	191
Project #ST-237: Carbon Composite Optimization Reducing Tank Cost.....	195
Project #ST-238: Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks.....	198
Project #ST-240: Cost-Optimized Structural Carbon Fiber for Hydrogen Storage Tanks.....	202
Project #ST-241: First Demonstration of a Commercial-Scale Liquid Hydrogen Storage Tank Design for International Trade Applications	205
Fuel Cell Technologies – 2023	209
Subprogram Overview.....	209
Project Summaries	212
Project #FC-160: ElectroCat 2.0 (Electrocatalysis Consortium).....	212
Project #FC-317: Stationary Direct Methanol Fuel Cells Using Pure Methanol	219
Project #FC-323: Durable Fuel Cell Membrane Electrode Assembly through Immobilization of Catalyst Particle and Membrane Chemical Stabilizer	224
Project #FC-326: Durable Membrane Electrode Assemblies for Heavy-Duty Fuel Cell Electric Trucks.....	229
Project #FC-327: Durable High-Power-Density Fuel Cell Cathodes for Heavy-Duty Vehicles	236
Project #FC-330: High-Efficiency Reversible Solid Oxide System.....	241
Project #FC-331: A Novel Stack Approach to Enable High Round-Trip Efficiencies in Unitized Proton Exchange Membrane Regenerative Fuel Cells.....	245
Project #FC-333: Advanced Membranes for Heavy-Duty Fuel Cell Trucks	251
Project #FC-336: A Systematic Approach to Developing Durable, Conductive Membranes for Operation at 120°C	256
Project #FC-337: Cummins Proton Exchange Membrane Fuel Cell System for Heavy-Duty Applications.....	261
Project #FC-338: Domestically Manufactured Fuel Cells for Heavy-Duty Applications	267
Project #FC-339: M2FCT: Million Mile Fuel Cell Truck Consortium.....	274
Project #FC-344: Low-Cost Corrosion-Resistant Coated Aluminum Bipolar Plates by Elevated Temperature Formation and Diffusion Bonding	281
Project #FC-345: Development and Manufacturing for Precious-Metal-Free Metal Bipolar Plate Coatings for Proton Exchange Membrane Fuel Cells.....	286
Project #FC-346: Fully Unitized Fuel Cell Manufactured by a Continuous Process	292
Project #FC-347: Development of Low-Cost, Thin Flexible Graphite Bipolar Plates for Heavy-Duty Fuel Cell Applications.....	298
Project #FC-348: Fuel Cell Bipolar Plate Technology Development for Heavy-Duty Applications	303
Project #FC-349: Foil-Bearing-Supported Compressor–Expander	308

Project #FC-350: High-Efficiency and Transient Air Systems for Affordable Load-Following Heavy-Duty Truck Fuel Cells 312

Project #FC-351: Durable and Efficient Centrifugal Compressor-Based Filtered Air Management System and Optimized Balance of Plant..... 317

Project #FC-352: Leveraging Internal Combustion Engine Air System Technology for Fuel Cell System Cost Reduction..... 321

Project #FC-353: Fuel Cell Cost and Performance Analysis..... 325

Project #FC-363: Advanced Fuel Cell Vehicle DC-DC Converter Development 331

Systems Development and Integration – 2023..... 335

Subprogram Overview..... 335

Project Summaries 338

Project #SDI-001: Integrated Modeling, Techno-Economic Analysis, and Reference Design for Renewable Hydrogen to Green Steel and Ammonia 338

Project #SDI-002: Hydrogen Energy Storage System at Borrego Springs Toward a Hydrogen-Enabled 100% Renewable Microgrid 343

Project #SDI-004: Hydrogen Coach Bus Fueling Demonstration 347

Project #TA-001: Membrane Electrode Assembly Manufacturing Research and Development.... 351

Project #TA-016: Fuel Cell Hybrid Electric Delivery Van..... 356

Project #TA-017: Innovative Advanced Hydrogen Mobile Fueler 360

Project #TA-018: High-Temperature Electrolysis, Stack, and Systems Testing 363

Project #TA-028: Demonstration of Electrolyzer Operation at a Nuclear Plant to Allow for Dynamic Participation in an Organized Electricity Market and In-House Hydrogen Supply 367

Project #TA-035: Power Electronics for Electrolyzer Applications to Enable Grid Services 372

Project #TA-037: Demonstration and Framework for H2@Scale in Texas and Beyond 375

Project #TA-039: Solid Oxide Electrolysis System Demonstration 380

Project #TA-042: Next-Generation Hydrogen Station Analysis..... 384

Project #TA-043: Solid Oxide Electrolysis Cell Stack Development and Manufacturing 388

Project #TA-044: System Demonstration for Supplying Clean, Reliable, and Affordable Electric Power to Data Centers Using Hydrogen Fuel..... 392

Project #TA-045: Waterfront Maritime Hydrogen Demonstration Project 397

Project #TA-048: Advanced Research on Integrated Energy Systems (ARIES)/Flatirons Facility – Hydrogen System Capability Buildout..... 401

Project #TA-052: Solid Oxide Electrolysis Cells Integrated with Direct Reduced Iron Plants for Producing Green Steel..... 405

Project #TA-053: Grid-Interactive Steelmaking with Hydrogen (GISH)..... 411

Project #TA-056: Ultra-Efficient Long-Haul Hydrogen Fuel Cell Tractor 416

Project #TA-057: High-Efficiency Fuel Cell Application for Medium-Duty Truck Vocations..... 420

Project #TA-058: Freight Emissions Reduction via Medium-Duty Battery Electric and Hydrogen Fuel Cell Trucks with Green Hydrogen Production via a New Electrolyzer Design and Electrical Utility Grid Coupling 423

Project #TA-059: Medium-Duty Vehicle Total Cost of Ownership and Target Development..... 427

Project #TA-060: Offshore Wind to Hydrogen – Modeling, Analysis, Testing, and International Collaboration Work..... 430

Project #TA-062: Validation of Interconnection and Interoperability of Grid-Forming Inverters Sourced by Hydrogen Technologies in View of 100% Renewable Microgrids 433

Project #TA-065: Total Cost of Ownership Analysis of Hydrogen Fuel Cells in Off Road Heavy-Duty Applications – Preliminary Results..... 436

Analysis, Codes and Standards – 2023 441

Subprogram Overview..... 441

Project Summaries 444

 Systems Analysis 444

 Project #SA-174: Life Cycle Analysis of Hydrogen Pathways..... 444

 Project #SA-178: Cradle-to-Grave Transportation Analysis..... 447

 Project #SA-181: Global Change Analysis Model Expansion – Hydrogen Pathways..... 450

 Project #SA-186: Updates to National Energy Modeling Systems to Include Hydrogen Module .. 453

 Safety, Codes and Standards..... 457

 Project #SCS-001: Component Failure Research and Development 457

 Project #SCS-005: Research and Development for Safety, Codes and Standards: Material and Component Compatibility 461

 Project #SCS-010: Research and Development for Safety, Codes and Standards: Hydrogen Behavior 465

 Project #SCS-011: Hydrogen Quantitative Risk Assessment 469

 Project #SCS-019: Hydrogen Safety Panel, Safety Knowledge Tools, and First Responder Training Resources 474

 Project #SCS-021: National Renewable Energy Laboratory Hydrogen Sensor Testing Laboratory 479

 Project #SCS-022: Fuel Cell and Hydrogen Energy Association Codes and Standards Support . 484

 Project #SCS-028: Hydrogen Education for a Decarbonized Global Economy (H2EDGE)..... 488

 Project #SCS-030: MC Formula Protocol for H35HF Fueling 492

 Project #SCS-031: Assessment of Heavy-Duty Fueling Methods and Components 496

 Project #SCS-033: Risk Assessments of Design and Refueling for Hydrogen Locomotive and Tender 500

 Project #SCS-H2042: Hydrogen Contaminant Detector 505

Appendix A: 2023 Hydrogen Program Review Summary.....510

Appendix B: 2023 Hydrogen Program Annual Merit Review and Peer Evaluation Meeting Attendee List527

Appendix C: Evaluation Forms578

Appendix D. List of Projects Presented but Not Reviewed593

Appendix E. Funding Opportunity Announcements and Selections – Examples ...604