Small Business Innovation Research (SBIR) Projects

SBIR PHASE II (OFFICE OF SCIENCE, BASIC ENERGY SCIENCES)

Diode Laser Sensor for Contaminants in Hydrogen Fuel

Southwest Sciences, Inc.
1570 Pacheco Street, Santa Fe, NM 87505

Low concentrations of contaminants in hydrogen fuel can foul or damage fuel cells in hydrogen fuel cell vehicles. Currently there is infrequent monitoring of hydrogen quality at filling stations. There is no instrumentation available to perform this function at the station. In this project, a diode laser instrument is being developed that will be able to perform these measurements at filling stations. The sensor will provide fast measurements so that each vehicle fill can be monitored. In the Phase II project, a prototype was constructed to measure common hydrogen contaminants, carbon monoxide, ammonia, water vapor, and hydrogen sulfide. The system performance was demonstrated at SAE levels for these contaminants. The measurements typically take 10 seconds for each contaminant. In Phase IIB, the shortcomings of the Phase II prototype will be addressed. The issues include zero drift and contaminant absorption by the sample chamber. After fixing these issues, the prototype instrument will be tested at the California state quality assurance laboratory. The developed system will be installed at hydrogen stations to monitor fuel quality. It will also be useful for troubleshooting problems in the hydrogen supply chain. The analyzer will be essential to establishing a reliable hydrogen supply for the fuel cell vehicle market, which is expected to dramatically increase over the next decade.

Novel Fluorinated Ionomer for Proton Exchange Membrane Fuel Cells

Giner, Inc.
89 Rumford Avenue, Newton, MA 02466-1311

Commercial proton exchange membrane (PEM) fuel cell technology typically relies on the same type of ionomer in the catalyst layer as is used for the fuel cell membrane. However, the desired properties for the ionomer in the catalyst layer and the ionomer used in the membrane should be different. This results in poor fuel cell performance. The overall objective of this Phase I project is to design, synthesize, and characterize a novel fluorinated ionomer for PEM fuel cell cathode; the ionomer can improve the fuel cell performance under low-platinum and high-power operations. Novel fluorinated ionomers were developed; they have enhanced oxygen permeability by three times. The ionomers were integrated with the fuel cell catalyst to make fuel cell electrodes that tremendously improved fuel cell performance. We will further improve the ionomer properties and scale up their production. The ionomer will be integrated with other optimal components to maximize fuel cell performance. Selective ionomer will also be delivered to original equipment manufacturers for commercialization. The successful completion of this project will improve the performance and durability of PEM fuel cells, significantly reducing the cost of hydrogen vehicles. This will lead to a widespread deployment of hydrogen vehicles, which will relieve the nation’s heavy dependence on imported oil and reduce air pollutants.

Controlled Porosity and Surface Coatings for Advanced Gas Diffusion Layers

Physical Sciences, Inc.
20 New England Business Center, Andover, MA 01810-1077

Polymer electrolyte membrane fuel cells (PEMFCs) are a leading candidate for an alternative energy source for light-duty vehicles; however, their current performance is inadequate for this application. Gas diffusion layers (GDLs) are a critical component of the PEMFC that contribute significantly to the overall performance. Improving the properties of GDLs will allow for wide-scale adoption of the PEMFC and thus enhanced U.S. energy security and reduced greenhouse gas emissions. The objective of this project is to develop a novel and cost-effective process to produce carbon-based GDLs. Phase II will demonstrate scale-up of the process demonstrated in Phase I. This readily tailored process results in controllable transport properties, enhanced electrical conductivity, and durability that will enable enhanced PEMFC performance. During the Phase I effort, a carbon-based GDL with transport properties equivalent to and electrical conductivity two times superior to commercial Sigracet 10AA GDLs was demonstrated. The process developed facilitates tailoring of the transport properties and durability of the final product at 80% of the cost of current commercial GDLs. The objective of the Phase II project is to scale up production of the GDLs and optimize performance based upon testing at the component level and in fuel cell stacks. Fuel cell performance testing and demonstration of a cost-effective, versatile production process will highlight the ability to use the advanced GDLs in PEMFCs at a reduced cost.

General Techniques for Increasing Packing Density of Metal-Organic Frameworks for Enhanced Volumetric Storage of Hydrogen

NuMat Technologies
8025 Lamon Avenue, Skokie, IL 60077

Current hydrogen fuel cell electric vehicles (FCEVs) on the market rely on high-pressure hydrogen, 700-bar, storage systems to store and deliver hydrogen for use in the fuel cell. Bringing hydrogen to high pressures and storing hydrogen at high pressure requires sophisticated compressors and specialized carbon wrapped tanks. This high-pressure constraint makes FCEVs challenging and expensive to implement at scale, with costs passed onto the end user. This cost is coupled with safety concerns, with equipment failure in the supply chain leading to the release of high-pressure flammable gas that would present significant hazards. Therefore, alternative technologies that could facilitate the storage of hydrogen at lower pressure are required if hydrogen cars are going to be widely adopted by the public. Porous materials, in particular metal-organic frameworks (MOFs), have been highlighted as materials that could be used to store and deliver hydrogen at lower pressures in FCEVs. One of the key drawbacks that is often overlooked in the academic literature is their poor volumetric packing. Volumetric packing is of critical importance for fuel tank applications where storage space is limited. Therefore, to realize the potential of MOFs, the packing density must be optimized. The purpose of this SBIR project is to develop generalizable techniques for increasing the volumetric packing density of MOFs. The methods developed are transferable to other MOFs, are scalable, and will occur with no loss of performance. In Phase I work, NuMat successfully evaluated several packing techniques on a small scale optimizing the volumetric packing density of several MOFs. The goal of 80% packing density was achieved. Under Phase II, NuMat proposes to transition these formation techniques to commercial scales, identifying and validating the required equipment. The results achieved here will allow for MOFs to be implemented in FCEV storage systems, which could bring reductions in the cost of these systems and improvements in safety. Removing high-pressure constraints currently in place would simplify storage systems. This work is also broadly applicable to a wide range of volumetric storage challenges that are commercially relevant including the storage of light hydrocarbons for transportation, oxygen storage for medical applications, and safe transportation and delivery of toxic gases.

Novel Membranes for Electrochemical Hydrogen Compression Enabling Increased Pressure Capability and Higher Pumping Efficiency

Xergy, Inc.
299 Cluckey Drive Suite A, Harrington, DE 19952-2374

Adoption of hydrogen as an energy vector inevitably necessitates the infrastructure of technologies to enable distribution and storage of hydrogen. Xergy's technological contribution addresses the need to efficiently compress hydrogen gas using electrochemical compression. Compared to traditional mechanical hydrogen compressors, electrochemical compressors should have significantly lower capital expense and operational expenses. Technical features of electrochemical compression are a solid-state system capable of providing the most efficient compression while being vibration free and noiseless. This makes electrochemical compression more reliable and require less maintenance than conventional mechanical systems. A core component of electrochemical hydrogen compressors is a solid-state ionic membrane that conducts protons. In this program, Xergy, along with its partner Rensselaer Polytechnic Institute (RPI), is developing a more advanced membrane that exhibits high proton conductivity, very high tensile strength, and the ability to operate at elevated temperatures with minimal humidification requirements. In the SBIR Phase I effort, Xergy and RPI synthesized four different ion-pair membranes and developed composite structures for testing. After considerable performance testing, physical modeling, and durability reviews, the team down-selected to one membrane system, and subsequently tested single-cell electrochemical compressors to demonstrate operational feasibility and prepare for larger-scale systems suitable for prototyping. In Phase II, Xergy and RPI aim to scale up ionomer and membrane production and build pre-commercial prototypes for validation. Merchant, bulk hydrogen demand is currently a $135 billion U.S. industry and is growing at an 8% compound annual growth rate. Electrochemical hydrogen compression fills a vital technological gap in hydrogen supply and storage.

Multi-Functional Catalyst Support

pH Matter, LLC
6655 Singletree Dr., Columbus, OH 43229-1120

Hydrogen fuel cells are of interest for automotive applications because they produce zero emissions. However, fuel cells currently suffer from the high cost associated with precious metal electrode materials and long-term durability issues associated with voltage transients. In the proposed project, pH Matter will synthesize and demonstrate the performance of next-generation fuel cell electrode catalysts. The materials will outperform current precious metal catalysts in terms of cost, efficiency, and durability during operation. The unique properties of these materials allow them to be chemically resistant to degradation mechanisms suffered by traditional catalysts.

Novel Hydrocarbon Ionomers for Durable Proton Exchange Membranes

NanoSonic, Inc.
158 Wheatland Drive, Pembroke, VA 24136-3645

The objective of this project is to develop and demonstrate high-temperature hydrocarbon-based membranes that meet the chemical, thermal, and mechanical properties necessary for the demanding environments within a fuel cell vehicle. The approach involves the synthesis of novel, high-molecular-weight aromatic hydrocarbon membranes that possess polar moieties along the polymer backbone and pendant quaternary ammonium groups. During Phase I of this SBIR program, NanoSonic has manufactured a new class of durable, free-standing high-temperature hydrocarbon-based polymer electrolyte membranes as a low-cost alternative to expensive perfluorosulfonic acid ionomer-based membranes. The ionomers are mechanically tough and display high dimensional stability and low swelling. These innovative, structurally robust membranes exhibit fuel cell performance at 120°C with zero humidification. During the Phase II program, a series of novel phosphoric acid-imbibed poly (thioether benzonitrile) copolymers shall be evaluated per DOE's 2020 technical targets for membranes for transportation applications.

New Approaches to Improved Polymer Electrolyte Membrane Electrolyzer Ion Exchange Membranes

Tetramer Technologies, LLC
657 South Mechanic Street, Pendleton, SC 29670-1808

Electrolyzer systems produce high-value hydrogen on demand and on site via electrochemically splitting water. This Phase IIB project is directed at lowering electrolyzer cell costs while improving performance of the membrane. Tetramer Technologies, LLC has developed a new membrane molecular architecture, which during Phase II demonstrated equivalent or better performance to the current Nafion materials at 50% lower cost. These attributes directly address the DOE electrolyzer cost and performance targets. Key attributes of Tetramer's technology vs. the current Nafion electrolyzer membranes are improved physical performance properties, 50% lower hydrogen permeability, and equal or higher conductivity. This technology will provide thinner membranes that can lower costs and increase performance directly through decreased ionic resistance and indirectly through the reduction of the overall cell potential. The Phase IIB activities are focused on optimizing membrane performance, further lowering costs, scaling up manufacturing of the down-selected polymer membrane material, and initializing commercialization, culminating in the demonstration of the Tetramer membranes in stacks in prototype electrolyzer system units.

Flexible Barrier Coatings for Harsh Environments

GVD Corporation
45 Spinelli Place, Cambridge, MA 02138-1046

Many reliability problems stem from plastic and elastomer seals employed in hydrogen systems that leak and degrade because of the extreme-temperature, high-pressure, and high-wear hydrogen environments. There is a critical need for improved materials that can enable seals to operate reliably at both extreme temperatures (-40°C ≤T ≥200°C) and high hydrogen pressures (>875 bar). Materials also need to withstand harsh environmental wear from repeated use. GVD Corporation proposes to utilize hydrogen gas barrier coatings deposited on such seals to shield them from hydrogen permeation and enable reliable, long-term operation. These barrier coatings are based on GVD's novel thin film vapor deposition technology. In GVD's process, an inorganic-organic multilayer barrier coating is fabricated from the vapor phase and grown directly on the surface of the elastomer seal. The coating deposits uniformly and conformally over three-dimensional seals and gaskets. Furthermore, these coatings are highly flexible and stable at 200°C. In Phase I and II, GVD demonstrated technical feasibility of the concept by depositing flexible, well-adhered barrier and lubricious coating stacks on elastomeric and rigid substrates. These coatings survived temperatures up to 200°C while reducing permeability to helium by >60% (equivalent to a 70%–90% reduction in hydrogen permeability). During Phase IIA, GVD will optimize these materials for large-scale manufacturing and for use in hydrogen dispensers.

SBIR PHASE I (OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY)

PVDF-Film for Robust Online Assessment of Composite Tanks (PROACT)

Advent Innovations, Ltd.
612 Dutchmans Creek Trail, Irmo, SC 29063-8331

To stimulate the U.S. economy and global competitiveness there is a push to reduce dependence on foreign oil imports and establish a domestic power and fuel industry using efficient, reliable clean energy technologies. A promising development is the introduction of fuel cell electric vehicles using hydrogen, which can achieve significantly higher efficiencies than combustion engines resulting in overall less energy use. The hydrogen is stored in high-pressure composite tanks, commonly referred to as composite overwrapped pressure vessels. Damage to the composite overwraps can result from pressure loads over time, environmental-induced degradation in operation, or accidental mechanical impacts. To ensure the structural health of the composite overwraps and prevent unexpected failure, online/real-time monitoring of the tank would be beneficial. In this project, an intelligent sensor system will be developed and specifically optimized for composite overwrapped pressure vessels. The sensor will be integrated with composite tanks to continuously monitor the structural health. During Phase I, structural health monitoring sensors will be developed to be conformable to the composite tanks and will utilize thin, flexible material such as polyvinylidene fluoride (PVDF) films to measure dynamic strain (impacts, vibration, transient stress waves, and deformation). The films will be porous so as to allow resin to flow when embedding during the filament winding and composite curing process and ensure structural integrity. The system will use both passive and active sensing modes to detect damage and degradation on demand to ensure robust and comprehensive online monitoring of composite overwrapped pressure vessels. In addition to fuel cell vehicle hydrogen tanks, the structural health monitoring sensors could also be utilized for composite tanks used in applications such as natural gas vehicles, rocket motors, self-contained breathing apparatuses used by first responders or recreational divers, containers for chemical or hazardous material storage, and many others.

Onboard Monitoring Method for Detection of Damage to Carbon Fiber Composite Overwrap on Hydrogen Fuel Tanks

TDA Research, Inc.
12345 W. 52nd Ave., Wheat Ridge, CO 80033

Hydrogen fuel cell electric vehicles (FCEV) technology is attractive due to lack of exhaust produced (only heat and water) and the possibility of reducing our dependence on hydrocarbon fuel sources. One impediment to widespread adoption of hydrogen FCEVs has been high production costs, driven in part by the need to over-engineer carbon-fiber-overwrap pressure vessels (COPVs) that carry the compressed hydrogen fuel. Improved, non-destructive technologies for evaluating carbon-fiber health are necessary and will be the basis of improvements in carbon fiber manufacture and novel structural health monitoring systems for the COPVs used in hydrogen FCEVs. TDA Research, Inc. (TDA) proposes a novel technology for monitoring the structural health of carbon fibers in COPVs. This method can be used on the production floor and as the basis of a COPV structural health monitoring system. In Phase I, TDA will show that the magnetic signature of carbon fiber, and of the associated aluminum lining for Type III vessels, can be assessed with our method to identify damage not apparent by visible inspection. In Phase II, TDA will use data from Phase I to build an array of our small, compact sensors, which can be used to indicate damage to the carbon-fiber or aluminum liner and report to an onboard vehicle computer. Demonstration pieces in Phase I will be performed on COPV pieces and vessels provided by our commercial partner who manufactures COPVs. The magnetic signature of healthy, virgin carbon-fiber materials will be characterized and compared to samples with known types of damage, including impact damage, delamination within the carbon fiber, separation of the liner from the carbon overwrap, and damage acquired after drop test and pressurization cycles. Using data from Phase I, we will design an array suitable for integration with onboard COPVs in hydrogen FCEVs. The fuel cell market is expected to reach $12 billion by 2022 and 11 car manufacturers are expected to have hydrogen FCEV offerings by 2021. Widespread adoption of hydrogen FCEVs relies on a reduction in unit costs, some of which can be achieved by improved structural health monitoring of carbon fibers.

Thin-Ply Conductive Interleaving for Health Monitoring of Composite Overwrapped Pressure Vessels

Composite Technology Development, Inc.
2600 Campus Drive, Suite D, Lafayette, CO 80026

Fuel cell electric vehicles utilizing hydrogen stored in composite overwrapped pressure vessels (COPVs) have unique safety risks. Hydrogen is an extremely volatile/explosive gas. Modern hydrogen distribution and vehicle systems are targeting 700-bar storage pressure (>10,000 psi). At these high pressures, automotive-sized COPVs have a very high energy density, presenting a significant hazard. Tank failure can be catastrophic to the driver, passengers, and public and must be prevented through effective design followed by consistent health monitoring in operation. Composite Technology Development, Inc. (CTD) will develop a pressure vessel/tank health monitoring technology consisting of fully embedded, in situ electrode layers in tank overwrap composite. These electrodes will enable resistance-based monitoring of the tank health. As demonstrated repeatedly by many researchers, resistance measurements of composites have shown correlation to matrix microcracking, delamination, and various forms of composite laminate failure. In the proposed effort, CTD seeks to develop the materials and processes for interleaving multiple thin conductive plies through the thickness of filament-wound tank walls. These layers form electrodes within the tank wall and enable resistance measurements of the overwrap composite to be readily acquired to monitor tank health over time. The overarching goal of the Phase I effort will be to evaluate the feasibility of the proposed approach for structural health monitoring of composite tanks. The three key stages of the proposed work plan include: (1) material development/ evaluation, (2) coupon-level testing (strength and stiffness), and (3) tank-level testing. CTD will develop a complete prototype monitoring system (hardware/software) and methodology (processing and algorithms) as part of Phase I and will demonstrate its effectiveness on a small-scale carbon fiber composite filament-wound pressure vessel. The entry point for this technology will likely be in the automotive hydrogen fuel cell market where hydrogen vehicles are taking to the road. Beyond the automotive industry, the proposed health monitoring technology has the potential to be an early warning system for any fiber-reinforced composite tank wall or composite laminate for that matter. Composite structures such as aircraft skins or spacecraft composite panels may be monitored with this same system. Furthermore, the technology has the potential to reduce the cost of vehicles by reducing or eliminating the tendency for engineering over-design of COPVs.

Composite Overwrapped Pressure Vessel Monitoring by Electrical Resistance

Intellisense Systems, Inc.
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Composite overwrapped pressure vessels are commonly employed in various industries, including in the automotive industry, to store and transport gases. With increased sales of hydrogen fuel cell cars that rely on composite overwrapped pressure vessels for hydrogen storage, tank safety has become a major concern due to their high energy capacity. Recent rocket explosions are a prominent example of how composite overwrapped pressure vessels may catastrophically fail. Continuous structural health monitoring solutions are sought to assure the safety of composite overwrapped pressure vessel operation. To sense and record abnormalities in mechanical strain and to mitigate the risks associated with structural failures of these pressure vessels, a new conductive synthetic fiber-based strain monitoring technology based on proven technology will be developed for this application. Synthetic smart fibers will be embedded in the composite overwrap to act as in situ pressure and strain sensors inside the host structure. The strain sensing smart fiber is a co-extruded, bi-component polymer filament with a dielectric sheath layer and an electrically conductive core layer. Pressure and strain sensing is achieved by monitoring the changes to the filament's resistive and reactive properties due to mechanical deformation under applied strain. This integrated pressure monitoring system will provide continuous on-line monitoring of structural conditions for the vessel, improving its safe operational lifespan. The Phase I development will focus on demonstrating the feasibility of the system, including strain sensing fibers, their connectorization, an electronic reader, and an analysis algorithm. We will embed the smart fibers into different layers of the composite overwrap and test the sensors' responses to different modes of failure (tensile and impact testing). An electronic reader will also be developed for real-time recording of the change in resistance of the embedded strain sensing fibers. The data will be analyzed for abnormalities through the use of learning algorithms, and the results will be used for triggering a vessel failure warning. The combination of smart fibers, capable of being integrated into carbon overwraps, and low-power reader electronics will provide in situ structural health monitoring for automotive hydrogen fuel cells, increasing their safety of operation and potentially reducing cost and weight due to improved safety margins. Competitive advantages include the reduced cost of the smart fibers compared with existing structural health monitoring technology, as well as the ability to seamlessly integrate into the composite structure.

Innovative Catalyst Design for Direct Hydrogenation of CO_2 to Methanol

NexTech Materials, Ltd.
404 Enterprise Drive, Lewis Center, DE 43035

In this SBIR Phase I effort, NexTech is collaborating with the University of Cincinnati to design innovative catalysts for the direct CO_2 hydrogenation to methanol as a way to efficiently utilize captured CO_2. This power-to-liquid fuels approach will utilize the excess and idle capacity of renewable (solar and wind) electricity to power a solid fuels electrolysis cell, which will provide renewable hydrogen for the power-to-liquid approach. This is because methanol synthesis is an attractive approach for storing hydrogen for future uses, direct fuel, or a feedstock for chemical synthesis. Commercially, methanol is produced from natural gas via the CO hydrogenation (syngas)—a product of steam methane reforming—route, utilizing $CuO/ZnO/Al_2O_3$ catalysts. In this process, CO_2 is added in amounts up to 30% of the total carbon in syngas, which significantly improves the methanol yield by improving the energetics of the reaction. Therefore, in order to facilitate methanol synthesis, some CO in syngas is first converted to CO_2 through a water gas shift reaction. The direct hydrogenation of CO_2 for methanol synthesis therefore represents an attractive option for the utilization of stranded renewable energy sources with the key benefit being that the reaction is already energetically favorable compared to the traditional methanol synthesis through syngas, and it is a direct way of utilizing otherwise anthropogenic CO_2. NexTech and the University of Cincinnati propose to: (1) couple catalysts with proven remarkable activity in the conversion of coal-derived syngas to low molecular weight oxygenates developed at the University of Cincinnati, and (2) design a new set of mixed metal oxide catalysts from promising candidates with NexTech's own patent-pending set of high thermal conductivity catalyst support materials. Integrating these highly active catalysts with high thermal conductivity support materials will enable improved management of the system's thermal energy. In this Phase I effort, NexTech will conduct a feasibility study involving the viability of the solid oxide electrolysis cell to methanol synthesis approach, develop catalysts for direct CO_2 hydrogenation on NexTech's high thermal conductivity supports, and study their catalytic activities. These activities are geared toward creating a better understanding of the proposed system and as a route for scale up in a potential Phase II effort.

Nanostructured Proton Exchange Membrane

eSpin Technologies, Inc.
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The polymer electrolyte membrane (PEM) remains one of the most significant cost components of the fuel cell stack. Development of a low-cost PEM suitable for rapid commercialization of fuel cells, with a wide range of desired characteristics meeting the DOE performance targets, is the subject of this project. This SBIR Phase I project aims to design, develop, and produce a new low-cost proton-conducting PEM employing nanofiber electrospinning technology. The PEM will be produced using low-cost non-fluorinated polymers. This ultra-thin membrane will be composed of a robust ionomer having inorganic backbone embedded in a reinforcing network of sub-micron-diameter fibers co-electrospun from a thermally and chemically stable polymer. During Phase I, the ionically conducting hydrocarbon polymer will be synthesized and a process for membrane production will be fully developed; the resultant membranes will be characterized in terms of microstructural features, mechanical, thermal and chemical stability, proton transport characteristics, and fuel cell performance. The prospective Phase II work shall address long-term fuel cell durability and development of manufacturing processes to meet the cost targets. The proposed electrospinning project will lead to a potential commercial product that may not only accelerate deployment of automotive fuel cells but can also have a significant environmental impact. From a technical point of view, the subject membrane will have the major physicochemical characteristics (specific resistance, mechanical strength and lateral swelling) similar to or better than those of the currently available perfluorosulfonic acid fuel cell membranes but with the advantage of significantly increased thermal stability, lower hydrogen and oxygen crossover rates, and lower production cost. Additionally, the use of the proposed membrane will lead to simplification of the fuel cell hydration subsystem and will eliminate the threat of dangerous releases of fluorine compounds inherent to the operation of fuel cells with perfluorosulfonic acid-based PEMs. If successfully completed, the project might help reverse the erosion of manufacturing in the United States.

Improved Ionomers and Membranes for Fuel Cells

Tetramer Technologies, LLC
657 S. Mechanic St., Pendleton, SC 29670

Polymer electrolyte membrane fuel cells are one of the most promising energy conversion technologies for renewable clean energy applications. The development of alternatives to current commercial perfluorosulfonic acid-based membranes, that lower cost and increase performance, would increase penetration of fuel cell technology into the mass market. This work will focus on the synthesis and development of new, improved ionomers and membranes to increase the efficiency and reduce costs of high-power-density fuel cells. Specific requirements to be addressed include reduced hydrogen permeation (to improve efficiency and limit potentially hazardous mixing of hydrogen and oxygen), increased performance over a range of humidity and temperature conditions, reduced costs, and improved durability compared with current commercially available materials. Our Phase I approach will be to initially obtain baseline data and assess the performance of our ionomer technology developed for an alternative application. The backbone molecular architecture and chemical functionality of these conductive polymers will then be systematically modified to highlight the most promising pathways to meet current and future fuel cell performance requirements. New membranes will be evaluated for conductivity, gas permeability, chemical and physical durability, and in situ fuel cell performance and durability, both in house and at the state-of-the-art facilities of our internationally recognized collaborator. Success of this work would be a significant step toward clean energy production in two of the largest energy markets, transportation and stationary power (including back-up power). The development of more efficient fuel cells would result in a reduced dependence on fossil fuels and the associated economic, political, and environmental issues related to their extraction, refinement, supply, and final use.

Segmented and Blocky Hydrocarbon Ion Pair Membranes for Fuel Cells

NanoSonic, Inc.
158 Wheatland Drive, Pembroke, VA 24136

The U.S. Department of Energy has identified a need for thin and durable proton-conducting membranes that offer enhanced energy efficiency to power zero-emission vehicles. Specifically, a cost-effective hydrocarbon-based alternative to expensive commercial perfluorosulfonic acid ionomers is sought. Current hydrocarbon membranes do not meet the performance or durability needed in the conditions for transportation fuel cells, operating at 120°C. The objective of the proposed Small Business Technology Transfer project is to develop and demonstrate thermally stable hydrocarbon-based membranes that meet the chemical and mechanical stabilities necessary for the demanding environments and durability for high startup cycles. The approach involves the synthesis of novel segmented hydrocarbon polymers for new ion pair complexed membranes. In Phase I, quaternary ammonium-functionalized segmented polymers with controlled molecular weight(s) shall be synthesized to develop membranes with tailorable morphology. The quaternary ammonium groups will be used to form ion pairs with imbibed phosphoric acid. The ion pair formation via a controlled imbibing process yields proton conduction membranes with good acid retention. The phase separated morphology may enhance the proton conductivity while directly influencing phosphoric acid location (i.e., phosphoric acid will preferentially concentrate in the hydrophilic phase with the quaternary ammonium groups). Proton conductivity shall be evaluated as a function of percent quaternary ammonium functionalization and morphology under a wide range of fuel cell vehicle operating conditions, including humidity and temperature. The proton diffusion and transport properties shall be investigated in the ion pair membranes. The membrane prototypes will be evaluated for film formation and quality, thermo-oxidative and chemical stabilities, and mechanical durability. Preliminary fuel cell tests shall set a technology readiness level of 6–7. Short-term fuel cell durability testing at an independent national laboratory shall be performed on down-selected membranes. Durable, thermally stable proton-conducting hydrocarbon ion pair-based membranes shall be commercialized primarily as fuel cell membranes. These membranes are directly applicable in stationary power applications as well as water purification/desalinization applications.

High-Pressure, Low-Temperature Composite Nozzles for Long-Term Hydrogen Dispensing

NanoSonic, Inc.
158 Wheatland Drive, Pembroke, VA 24136

The U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy has identified a need for high-performance materials and innovative manufacturing solutions to produce rugged hydrogen dispensing nozzles. Specifically, high-pressure and low-temperature durable materials and nozzle designs that minimize leaks and maintenance are needed. The goals for this program are to develop materials suitable for hydrogen nozzles and produce prototype dispensing nozzles for field testing. The objective of this program is to develop and demonstrate innovative materials and methods to produce leak-free hydrogen dispensing nozzles. The approach involves the compounding and extrusion of new montmorillonite pelletized composites for injection molding or 3-D printing of nozzle structures. In Phase I, new montmorillonite intercalated composites shall be compounded with current low hydrogen permeable polymers and pelletized through an extruder for use in traditional and new manufacturing techniques. Representative nozzles shall be formed via injection molding and 3-D printing for test conditions that mimic repeated filling of light-duty vehicles at hydrogen stations. Digital image correlation, X-ray analysis, and pressurized leak testing shall be carried out at Pacific Northwest National Laboratory to achieve technology readiness level 5. A plan to reach technology readiness level 7 shall be established through field testing at hydrogen stations with our partners. Lower-cost and more reliable hydrogen dispensing nozzles shall significantly reduce unscheduled maintenance and reduce the overall capital costs associated with hydrogen fueling. These locally produced nozzles shall benefit our nation by enhancing the lifetime, safety, and reliability of hydrogen nozzles and thereby ensure domestic leadership in the hydrogen infrastructure.

Thermoplastic Forming of Bulk Metallic Glass Nozzles for High-Pressure, Low-Temperature Hydrogen Fueling

Supercool Metals
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Strong environmental concerns related to an extensive use of fossil fuels lead to a more active development of vehicles that use an alternative fuel. Hydrogen is one such fuel that has the potential to be a cheaper, more efficient, and cleaner alternative to gasoline. With the predicted growth of fuel cell vehicles and hydrogen fueling stations, a reliable and cost-effective hardware for the hydrogen infrastructure is becoming very important. Specifically, the reliability and cost of nozzles for dispensing of hydrogen into fuel cell vehicles has been identified as one of the critical barriers. In this project, we are proposing to develop highly reliable nozzles for high-pressure, low-temperature hydrogen gas filling using bulk metallic glass technology. This presents a unique and transformative technological approach that will increase the competitive advantage of the United States in this field and accelerate a wider adoption of hydrogen fuel cell vehicles. Bulk metallic glasses are complex metal alloys that have superior mechanical properties and processability compared to that of conventional metals. Preliminary research suggests that bulk metallic glasses also have a higher resistance to hydrogen embrittlement due to lack of grain boundaries. In addition, bulk metallic glasses can be shaped effectively with processes similar to plastics to produce seamless nozzle-like shapes that will minimize leakage and improve reliability. Supercool Metals has been focused on development and commercialization of these unique forming processes for bulk metallic glasses and plans to use them in this project. Phase I of this project is focused on the overall assessment of bulk metallic glasses for the use in hydrogen environments under pressures and temperatures associated with hydrogen refueling. It also aims to demonstrate the feasibility of using thermoplastic forming methods specifically for shaping nozzles with required performance and safety, and to conduct a techno-economic analysis of bulk metallic glass nozzles. Phase II of the project will be focused on fabrication of nozzle prototypes for hydrogen refueling stations and their testing. We will work with commercial partners, such as U.S.-based producers of steel nozzles, developers of refueling stations, and fuel cell vehicle manufacturers. Phase III of this project will include further testing and qualifications of the products, development and building equipment for larger-volume production, and improving economics.

Thin Film Hydrogen Sensor Development, Testing, and Integration into Low-Cost Wireless Sensing Systems

Element One, Inc.
7253 Siena Way, Boulder, CO 80301

There is a growing impetus to increase the use of hydrogen in both advanced power generation and transportation systems. A major technical challenge to solve is improving the safety and effectiveness of systems using hydrogen and to reduce costly down time due to system shutdowns when hydrogen leaks are detected. There are many tragic examples in industry of undetected hazardous gas discharges leading to loss of life and property, and hydrogen is of particular importance. Because of their high installed cost, current electronic sensors are deployed in limited quantities and do not reliably detect leaks because uncontained hydrogen gas rises and dissipates more rapidly than any other gas. When they do detect a leak, they cannot identify its magnitude or exact location, and safety precautions often dictate that a facility be shut down while leaks are located and repaired. Several automakers have introduced hydrogen fuel cell vehicles, and the use of hydrogen as a consumer fuel has heightened concerns about safety. These concerns could become a barrier to consumer acceptance, product liability, insurability, permitting requirements, and the establishment of reasonable codes and standards. This problem can be addressed by deploying very low cost hydrogen sensors prolifically in close proximity to potential leak sites, such as valves, fittings, and connectors. Integrating Element One's thin film sensor technology with current radio-frequency identification wireless technology could reduce the cost of each sensing point from $1,000+ to under $10. Successful completion of the Phase I effort will include the testing of different wireless sensor design configurations and testing their performance for several applications. Key performance parameters include range, durability, selectivity, and sensitivity. The Phase I effort will include the development of algorithms for onboard calculation of detected hydrogen concentrations and will demonstrate the successful operation of an array of such wireless sensors in a laboratory test environment. Element One will partner with Esensor, Inc., who will develop the hardware for a wireless sensor module. The value that Element One delivers is the technology to dramatically reduce cost while improving the ability to detect leaks wherever such gases are used as a feedstock, reagent, or fuel. The prolific use of low-cost wireless gas sensors will significantly reduce the potential for undetected releases of hazardous gases in industrial facilities and hydrogen fuel cell vehicles.

Robust and Reliable Hydrogen Leak Detection and Warning Systems

SPEC Sensors, LLC
8430 Central Ave., Suite D, Newark, CA 94560

The U.S. Department of Energy seeks research and development to enable viable hydrogen leak detection technologies, including the integration with communications technologies that notify a system operator when a leak occurs in large or small facilities. This work will improve the safety of proposed hydrogen refueling stations and has a general public benefit for improving the safety of many public or private spaces where the risk of gas leaks poses a threat. This project will develop a wireless mesh network, consisting of individually networked hydrogen sensor nodes that will provide redundancy and reliability for quickly identifying and locating leaks and other types of facility failures. The overall objective of the Phase I SBIR is to install a meshed sensor network in a test facility for characterization of its reliability and to provide the instrumentation necessary to guide the regulation and requirements of a monitoring system for commercial refilling facilities. Briefly, this will include collaboration with two federal research facilities to (1) determine the ideal physical placement of nodes in regard to detecting hydrogen plumes and diffusion, and (2) develop a simple algorithm to identify the location of potential sources of release. The partners will also provide all relevant data and reports from their field trials to assist in hydrogen fueling safety system development. With this knowledge, the ideal physical placement of a large network of nodes will direct engineering efforts focused on development of the wireless network. It will be designed to ensure the maximum reliability of communication between each node and to ensure system integrity. This network will be equipped with both local (PC-based) and remote (Cloud-based) interfaces capable of displaying real-time relevant information. Redundancy will be provided with both local wireless and remote cellular connections while on facility power or operating on battery backup. Federal research partners will facilitate the installation and evaluation of the prototype network at a federally operated hydrogen fueling station. The partners will also provide research-grade, thin film hydrogen sensor samples to be integrated into test nodes and their performance will be compared to other commercial methods of hydrogen detection. Phase II will primarily focus on safety and sensor improvements for the network nodes. The commercialization of this technology could expand to other industries and applications. For instance, it can be adapted to create a large network of nodes for neighborhood air quality monitors, as nodes wirelessly strung together to create mining safety alarms, or as a networked carbon monoxide/gas alarm for schools.

Advanced Materials for Detection and Removal of Impurities in Hydrogen Adsorbents

NuMat Technologies
8025 Lamon Avenue, Skokie, IL 60077

Under this Phase I grant, NuMat Technologies (NuMat) will determine if metal-organic frameworks (MOFs) can be used to remove impurities from hydrogen gas streams at the point of use. The impurities of interest include carbon monoxide, ammonia, sulfur-containing compounds, hydrocarbons, and water. Under the first objective of Phase I, a comprehensive evaluation of MOFs will be carried out to identify the most efficient materials to remove each impurity of relevance. This objective will be achieved by employing a computational screening of the adsorption properties of a library of more than 1,000 MOFs, followed by synthesis and validation of the highest performing MOFs experimentally. Secondly, methods for incorporating the leading candidates into formed bodies suitable for the application will be evaluated including incorporation into adsorbent filters and membranes. Ways to detect excursions in the purity of the hydrogen stream also will be evaluated. Two sensing routes will be assessed: the use of the MOF itself and the incorporation of other sensor systems to determine gas purity. Finally, the economics of scaling the most promising MOFs will be evaluated, allowing NuMat to understand the cost of commercialization at different scales. Phase I work will allow for prototype systems to be developed under Phase II. The primary focus of the team at NuMat is the development of commercial technologies based on MOFs. To achieve this goal a multidisciplinary team of more than 30 people has been assembled that includes chemists, engineers, and business experts. This team has successfully developed the first commercial MOF-based product, ION-X. It is a product used in the electronics industry to safely store and deliver highly toxic gases, including arsine and phosphine, sub-atmospherically. Beyond ION-X, NuMat has a robust product pipeline with other MOF-based products focused on separation and purification of multicomponent gas streams. In developing these technologies, NuMat has established expertise, instruments, and protocols to rapidly identify MOFs for commercial applications and evaluate if they can be incorporated into successful products. This SBIR opportunity presents an ideal route for growth at NuMat, aligning with the goals of the company to expand MOFs into new commercial opportunities. NuMat's initial commercial success has been a result of identifying small-volume, high-value applications where MOFs could be leveraged to overcome commercial challenges. The inline purification of hydrogen is an application that could proliferate over the coming years as hydrogen markets expand. Furthermore, the MOF-based technologies developed here may be broadly applicable to the bulk purification of hydrogen.

SBIR PHASE II (OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY)

Emergency Hydrogen Refueler for Individual Consumer Fuel Cell Vehicles

Skyhaven Systems, LLC
2 Park Drive, Unit 4, Westford, MA 01886

Skyhaven Systems, LLC is developing an emergency hydrogen refueler that can be stored in the vehicle trunk and used by the consumer to refill the vehicle if they run out of hydrogen fuel away from a hydrogen fueling station. A chemical hydride and water conduit system was developed and demonstrated in a Phase I program to safely react producing hydrogen gas with the requisite purity for a fuel cell vehicle. Material and refueler optimization focused on reacting 100% of the chemical hydride to hydrogen in a refueling period on the order of 15 minutes. Operational prototype hydrogen refuelers will be developed in the Phase II project that can produce 750 g of hydrogen gas to refill a fuel cell vehicle for a 50-mile driving range. The Phase II project will focus on material optimization, refueler design, codes and standards, hazardous materials and reliability assessment, manufacturing of the refueler, and prototype testing.

Cross-Polarized Near-Ultraviolet/Visible Detector for In-Line Quality Control of Polymer Electrolyte Membrane Materials

Mainstream Engineering Corporation
200 Yellow Place, Rockledge, FL 32955-5327

Modern fuel cells have been in development since the 1960s and stand on the cusp of commercialization, but they are held back by high manufacturing costs and expensive catalysts. Membrane costs alone can account for as much as 45% of the total cost of a commercial fuel cell system. Furthermore, manufacturing defects in the membrane can cascade into complete stack failure, which is expensive and time consuming to resolve. These defects are often not discovered until costly catalyst has been irreversibly applied and the membrane electrode assembly is fully assembled, leading to additional wasted materials and a slow correction of the coating process. To achieve large-scale commercialization, fuel cell manufacturing needs a high-efficiency, real-time quality control system that can provide 100% inspection of the membrane at coating speeds up to 60 feet per minute. Mainstream's approach uses a near-ultraviolet/visible light to infer membrane film thickness, composition, and defects with a single detector, light source, and pair of cross-polarizers. Mainstream's Cross-Polarized Near-Ultraviolet/Visible (CPNUVV) system simultaneously measures membrane thickness and determines and quantifies membrane defects in real time at roll-to-roll coating speeds. This information can be relayed to a printer to mark defective membranes, allowing exclusion from catalyst coating as well as rapid feedback to correct the membrane coating process.

During Phase II, Mainstream successfully developed the CPNUVV low-cost optical detector for continuous analysis of membranes for polymer electrolyte membrane fuel cells. The inspection technique samples the entire web in real time so defects in membrane electrode assembly materials can be removed prior to assembly into fuel cell stacks and automotive systems. In the sequential Phase IIB program, Mainstream will finalize a suite of instruments that provide a full turnkey inspection package for membrane production to commercialize the CPNUVV technology developed in Phase II. In 2019, Mainstream created a website to communicate all publications and new technologies: https://www.mainstream-engr.com/products/mantis-eye-optical-scanner/. Mainstream also:

1. Installed reflectance test equipment that can be used for analyzing 12-inch by 12-inch samples and to develop software that operates at the target 100 feet per minute roll speed.
2. Developed and deployed software on an industrial computer that can acquire and process reflectance images at up to 20 feet per minute.
3. Implemented a plan for determining the minimum defect that impacts membrane electrode assembly performance. Mainstream tested a gas-diffusion electrode and a catalyst-coated membrane with a 100-µm pinhole in a 50-µm-thick membrane; data indicated that fabricating membrane electrode assemblies with catalyst-coated membranes reduces the impacts of defects. However, neither case led to initial failure.
4. Measured optical catalyst loading on a gas-diffusion electrode to within ± 0.1 mg Pt/cm^2 for spot sizes of 0.03 cm^2, but error may be related to actual variation on the surface. Correlation between thickness and loading is underway.
5. Established a quantitative relationship between optical imaging and catalyst loading on a catalyst-coated membrane. Defects were seen and identified down to sub-25 µm. X-ray fluorescence indicated that spot variation seen in optical images is real and correctly identified.

Ionomer Dispersion Impact on Advanced Fuel Cell and Electrolyzer Performance and Durability

Giner, Inc.
89 Rumford Avenue, Newton, MA 02466-1311

The non-aqueous ionomer dispersion technology has demonstrated great potential to significantly improve the lifetime of proton exchange membrane fuel cells and electrolyzers. However, further improvements and scale-ups are needed to make this technology commercially viable. The overall objective of this project is to further develop and commercialize non-aqueous ionomer dispersion technology. The ionomer dispersions have been screened via a large library of solvents. It will be integrated with a dimension-stabilized membrane platform to create more durable membrane electrode assemblies for proton exchange membrane fuel cells and electrolyzers. In our Phase II project, we have successfully demonstrated improved durability of fuel cells and electrolyzers using non-aqueous ionomers via accelerated stress test and real cell tests. This ionomer dispersion technology has been successfully combined with dimension-stabilized membrane technology to create more durable membrane electrode assemblies. In the Phase IIB project, we will further develop this technology in more processable, scalable, and profitable ways. We will use a roll-to-roll process to make full-sized membrane electrode assemblies that combine non-aqueous ionomer dispersion and dimension-stabilized membranes. We will evaluate these membrane electrode assemblies in more extensive and practical conditions and explore their potential markets.

Cryogenically Flexible, Low Permeability Thoreau's Rubber Hydrogen Dispenser Hose

NanoSonic, Inc.
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One of the U.S. Department of Energy Office of Efficiency and Renewable Energy Fuel Cell Technology Office's hydrogen delivery goals is to realize hydrogen as a safe, reliable, and cost competitive replacement for gasoline. A single hydrogen dispenser hose exists on the market, though it does not meet the service requirement of 25,550 fills/year for a combined working pressure of 875 bar and temperature range of -50°C to +90°C. The current hose price also does not allow for a cost of $2–$4 per gasoline gallon equivalent. A new class D hydrogen dispensing hose, for use on station side applications, is being systematically and chemically engineered to survive 51,240 fills (70 fills per day for 2 years). This metal-free state-of-the-art hose is based on a unique fiber reinforced, high performance, cryogenically flexible polymer to resist hydrogen embrittlement, survive the Joule-Thompson effect thermal cycles, perform consistently at pressures greater than 875 bar (H70 service, 700 bar and safety overpressure), and endure mechanical wear and fatigue at the pump. During Phase I and II, a superior class of non-electrically conductive, low-glass-transition-temperature polymer hose cores was developed that exhibits ultra-low hydrogen presence after severe 180° bending in a -50°C chamber and offers an innovative path to dissipate static electricity. A novel creamer coupling agent was developed to minimize the coefficient of thermal expansion between the fitting and hose and resulted in significantly enhanced hose burst strengths. Fiber-reinforced hydrogen hoses were modeled and produced using an automated filament winding manufacturing process (sixteen 3-meter hoses per day for reduced cost) with burst strengths >31,000 psi. Failure was due to fitting slippage.

During the Phase IIB program, the down-selected hydrogen hose shall be commercialized with a new fitting to increase the current technology readiness level of 7 to 9. Fittings and hose assembly partners have been formalized to proceed with the certification and commercialization plan. The new hose and fitting system shall be presented to hydrogen dispensing stations and fittings/breakaway/fueling nozzle manufacturers with a detailed integration design plan and cost analysis. The fully integrated hydrogen dispensing hose system, rated for H70 service, shall be demonstrated as compliant with SAE TIR J2601 and NIST Handbook 44 as a durable and competitive alternative to gasoline. This hydrogen hose shall serve as a new standard for metal-free, hydrogen embrittlement mitigating, high-pressure hoses with the additional benefits of enhanced flexibility, consumer maneuverability, fire resistance, and low temperature durability. A state-of-the-art metal-free hydrogen dispensing hose is being developed with the potential to revolutionize hydrogen as a safe, green alternative energy source to gasoline and diesel fuels.

Low Cost Alloys for Magnetocaloric Refrigeration

General Engineering & Research, LLC
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Replacement of petroleum-based vehicles with fuel cell electric vehicles operating on hydrogen produced from domestically available resources would dramatically decrease emissions of greenhouse gases and other pollutants as well as reduce dependence on oil from politically volatile regions of the world. One major inhibitor to a hydrogen society is the lack of infrastructure, which requires hydrogen liquefaction refrigeration systems to provide safe and economical storage and transportation of this fuel. One of the more promising technologies of interest for hydrogen liquefaction is magnetic refrigeration due to its high efficiency particularly at cryogenic temperatures. Magnetic refrigeration utilizes the magnetocaloric effect, which is the temperature variation of a magnetic material after exposure to a magnetic field. There are several major issues that need to be solved to move this technology forward. One issue inhibiting magnetic refrigeration progress is the lack of commercially available low cost magnetocaloric effect materials that will actually function, for a long period of time, in a magnetic refrigeration environment. During the Phase I and II efforts, novel low cost compositions with 2nd order, hysteresis-free response to cover the entire 9–300 K temperature range were successfully discovered. These materials are now commercially available in small quantities on the www.geandr.com webstore, and they are the highest performance materials on the market. Another major issue inhibiting magnetic refrigeration from moving forward is that very little work has been done designing and engineering actual systems that utilize the magnetocaloric effect mechanism. The Phase IIB effort will bridge the gap between material science and engineering applications. We will use our magnetocaloric effect materials and build a high efficiency (>50% of Carnot) magnetic refrigeration system to demonstrate small-scale liquefaction. A variety of commercial opportunities for high-efficiency small-scale liquefaction systems exist; however, one major opportunity, which would also be an enabling technology for fuel cell electric vehicles, is the reduction or elimination of boil-off losses at hydrogen fueling stations. The boil-off losses create logistical challenges that inhibit scale-up. Economical and efficient systems to re-liquefy hydrogen would solve these problems. If successfully implemented, this could have a major impact on the automobile industry. Further, successful demonstration of a high-efficiency cost-competitive system for a relevant commercial application would validate this technology and stimulate industrial innovation with the potential to advance the state of the art in all refrigeration technologies.

Detection of Micron-Scale Flaws through Nonlinear Wave Mixing

Luna Innovations, Inc.
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Storage of hydrogen is challenging due to high storage pressures and potential for hydrogen embrittlement. Pressure vessels are currently retired from service under conservative guidelines due to the inability to identify damage until damage is imminent. There exists a need for a system that can resolve micrometer-scale features and relate these to the damage state of pressure vessels for accurate life estimates resulting in reduced operating costs. Luna proposes to develop an inspection system that leverages nonlinear interactions between two mixed acoustic waves to identify the presence of micrometer flaws in steel. The development effort will focus on electromagnetic acoustic transducer technology to allow non-contact inspections and rapid surface scanning. The sensing system will produce maps of damage features that enable remaining useful life estimates to be formulated. Following a successful Phase I feasibility study, the Phase II program will focus on expanding upon the wave mixing techniques established in Phase I in order to tailor them for use on hydrogen tank inspections. Sets of test articles having relevant geometries, damage features, and compositions to the hydrogen industry will be developed and used to optimize the test protocols. Partnerships with hydrogen-material interaction experts at Sandia National Laboratories will be leveraged to develop a better understanding of the unique damage progression of pressure vessel walls exposed to hydrogen gas for development of remaining useful life models. A prototype system will be designed, manufactured, and demonstrated on full-scale test articles obtained from commercial hydrogen pressure vessel vendors (e.g., Fiba Technologies). The market for this inspection technology includes the energy, automotive, and aerospace sectors. In all of these markets, the ability to reliably identify damage early in a component's life enables improved maintenance planning and reduced the numbers of inspections required. In an effort to move toward a condition-based rather than time-based maintenance protocol, there is increased adoption of non-destructive evaluation technology, which will aid in the commercial success of the wave-mixing system.

Highly Efficient Smart Tanks for Hydrogen Storage

TDA Research, Inc.
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The commercial success of fuel cell electric vehicles will require significant reductions in the cost of hydrogen fueling. Current fueling stations require precooling equipment that chills the hydrogen to -40°C; this is needed to offset the temperature rise caused by compression during fueling and to keep the polymer liner of the vehicle's tank below its maximum operating temperature of 85°C. If the precooling requirement could be reduced or eliminated, the cost of delivered hydrogen could be significantly reduced. TDA Research is developing a smart hydrogen storage tank that incorporates novel cooling schemes to quickly dissipate/absorb the heat of compression and keep the hydrogen gas temperature well below the tank design temperature of 85°C. TDA's design maximizes the heat transfer area and the heat transfer coefficients to quickly dissipate the heat throughout the refueling process. This system has minimal impact on the cost, weight, volume, and fill time, and it increases the well-to-power plant efficiency.

In Phase I of the project, TDA (1) designed and carried out computational fluid dynamics modeling to demonstrate refueling from ambient temperature conditions, eliminating the precooling requirements at the station, and (2) completed a preliminary design of the smart hydrogen storage tank for fuel cell electric vehicles and compared it against the DOE baseline 700-bar system. TDA's system is only 14.6% larger in weight and 6.9% in volume, but it has a higher gravimetric and volumetric capacity (1.1 kg/kWh and 0.68 L/kWh, respectively, compared to 1.04 kg/kWh and 0.60 L/kWh for the baseline system) when using hydrogen at 0°C and 25°C for refueling (instead of at -40°C). It completely eliminates the precooling needs of the fueling station providing a greater than 15% improvement in well-to-power plant efficiency, lowering cost of hydrogen delivered by $0.6/kg. In Phase II TDA will optimize key parameters, complete a detailed design of the smart tank, and then fabricate full-scale prototype units. The full-scale prototype units will be tested at the National Renewable Energy Laboratory's hydrogen refueling test facility at design pressures of 700 bar to show the merits of the technology. Based upon the results, TDA will generate a production plan that includes both manufacturing and quality assurance plans. The smart hydrogen tank designs developed here for fuel cell electric vehicles will also be applicable to compressed natural gas tanks. In both applications, it will lower the cost of dispensing and open significant market opportunities for vehicles running on hydrogen and natural gas, offering environmental benefits and long-term U.S. energy independence.