CHANGING WHAT'S POSSIBLE

Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL)

Projects in the Renewable Energy to Fuels Through Utilization of Energy-Dense Liquids (REFUEL) program seek to develop scalable technologies for converting water and molecules from the air into energy-dense, carbon-neutral liquid fuels (CNLFs) using electrical energy from renewable sources. REFUEL projects will convert low-cost renewable energy into a transportable chemical fuel and use these fuels for transportation applications, while reducing production costs and environmental impact.

Because of its attractiveness as a hydrogen and energy carrier, most selected REFUEL projects target the production of ammonia or its conversion to hydrogen or electricity. State-of-the-art industrial ammonia production using the Haber-Bosch process requires a hydrogen source (usually natural gas), remains highly capital and energy intensive, and is only economical at a large scale. Many projects seek to overcome these limitations to enable economically competitive, distributed production of this prototypical CNLF.

Ultimately, REFUEL projects will accelerate the shift to domestically produced transportation fuels, improving American economic and energy security and reducing energy emissions.

PROJECT DESCRIPTIONS

Bettergy Corporation – Peekskill, NY

Low Temperature Ammonia Cracking Membrane Reactor for Hydrogen Generation (Category 2) – $1,524,607

The Bettergy Corporation team will develop a system to "crack," or break apart, ammonia, releasing pure hydrogen, using a non-precious metal catalyst at temperatures below 450 °C. Bettergy's innovation creates a one-step cracking process during which ammonia is separated and the hydrogen passes through a selective membrane, leaving only harmless nitrogen as a byproduct. If successful, this breakthrough technology would transform the process of hydrogen production, providing low-cost, on-demand generating options for hydrogen refueling stations.

FuelCell Energy, Inc. – Danbury, CT

Protonic Ceramics for Energy Storage and Electricity Generation with Ammonia (Category 1& 2) – $3,100,000

The FuelCell Energy, Inc. team will build a reversible electrochemical cell to produce ammonia from nitrogen and water or consume ammonia to generate electricity. The FuelCell team's innovation relies on an electrode incorporating a ruthenium catalyst—a material that reduces the energy requirement of the reaction—that has shown to be more active for ammonia production than traditional methods. If successful, the FuelCell team will increase ammonia production rates to 100 times current electrochemical methods—comparable with commercial processes while avoiding the need for separate hydrogen production thanks to its use of water, thus decreasing feedstock costs.

Gas Technology Institute – Des Plaines, IL

A Novel Catalytic Membrane Reactor for DME Synthesis from Renewable Resources (Category 1) – $2,300,000

The Gas Technology Institute team will develop a reactor to synthesize dimethyl ether (DME), which functions as a substitute for diesel fuel, from carbon dioxide, hydrogen, and electricity. The team will integrate an advanced membrane reactor design with a novel dual-function catalyst and high-performance product purification to create a scalable, low-cost DME synthesis platform.

Giner, Inc. – Newton, MA

High-Efficiency Ammonia Production from Water and Nitrogen (Category 1) – $1,500,000

The Giner, Inc. team will develop a variety of novel catalyst materials to improve nitrogen reduction reactions, which are key to the efficient production of ammonia, an easily portable and storable hydrogen and energy carrier. Giner will also use high-performance hydroxide exchange membranes to further boost ammonia production rates, integrating this and the catalysts into its water electrolysis platform to maximize cell performance. If successful, the team will reduce ammonia production capital and operating costs by 30-40 percent compared to the conventional Haber-Bosch process.

Materials and Systems Research, Inc. – Salt Lake City, UT

Cost-Effective, Intermediate-Temperature Fuel Cell for Carbon-Free Power Generation (Category 2) – $1,100,000

The Materials and Systems Research, Inc. (MSRI) team will develop a new solid oxide fuel cell design that generates power directly from ammonia at temperatures under 650 °C. The team also seeks to develop a manufacturing process for the cell. If successful, the MSRI team will greatly reduce the cost of solid oxide fuel cells while providing a high-efficiency, long-life power generating option with a reduced carbon footprint.

Molecule Works, Inc. – Richland, WA

Novel Electrochemical Membrane Reactor for Synthesis of Ammonia from Air and Water at Low Temperature and Low Pressure (Category 1) – $2,300,000

The Molecule Works, Inc. team will develop a modular reactor for producing ammonia using air and water at low temperatures. The team will build an anion exchange membrane (AEM) using a thin porous ceramic/metal sheet, allowing the cell to operate between 50 and 180 °C. The porous metal sheet cathode will provide a large catalytic reaction area per unit volume and greatly increase the diffusion rate of nitrogen gas within the cell compared to conventional approaches.

Opus 12, Inc. – Berkeley, CA

Renewable Electricity-Powered Carbon Dioxide Conversion to Ethanol for Storage and Transportation (Category 1) – $1,903,268

The Opus 12, Inc. project team will develop a device to facilitate the direct conversion of carbon dioxide to ethanol using a proton exchange membrane (PEM) electrolyzer system. PEM systems are commonly used for hydrogen generation, and Opus 12's innovation changes the environment of the PEM electrolyzer to have high selectivity for carbon dioxide utilization. The one-step synthesis process contributes to system efficiency, keeps capital costs low, and if successful, the project would integrate seamlessly into existing ethanol purification infrastructure.

RTI International – Research Triangle Park, NC

Innovative Renewable Energy-Based Catalytic Ammonia Production (Category 1) – $3,111,910

The RTI International team will build an improved Haber-Bosch ammonia synthesis system with an innovative process design to respond to changes in available power, making it ideal for intermittent renewable energy resources. By using a breakthrough catalyst to synthesize ammonia, the team seeks to enable operation at temperatures at least 20 percent lower, and with reduced pressures compared to traditional Haber-Bosch catalysts. If successful, the project will result in a small-scale ammonia synthesis system that is economically viable and can start and stop in synchronization with intermittent renewable power sources.

SAFCell, Inc. – Pasadena, CA

Distributed Electrochemical Production and Conversion of Carbon-Neutral Ammonia (Category 2) – $3,000,000

The SAFCell project team will build a high-pressure stack designed to generate hydrogen from ammonia, purify it, and pressurize it in a single device, greatly simplifying the infrastructure required to get hydrogen fuel to refueling stations and store it there. Solid acid stacks operate at intermediate temperatures of around 250 °C and are highly tolerant of compounds that normally damage anode catalysts like carbon monoxide, ammonia, and hydrogen sulfide. If successful, the SAFCell team expects low cost, long-life, on-demand compressed hydrogen production from a distributed system with a quick start-up time.

Storagenergy Technologies, Inc. – Salt Lake City, UT

High Rate Ammonia Synthesis by Intermediate Temperature Solid-State Alkaline Electrolyzer (Category 1) – $2,523,958

The Storagenergy Technologies, Inc. team will build a system to produce ammonia from water and nitrogen. Storagenergy's innovation relies on a cell containing an electrolyte made from a solid composite and nanostructured catalysts for nitrogen reduction reactions. If successful, the Storagenergy team will create a cell capable of producing ammonia at temperatures between 100 and 300 °C without the need for separate hydrogen production, thus decreasing feedstock costs.

Sustainable Innovations, Inc. – East Hartford, CT

Electricity from an Energy-Dense, Carbon-Neutral Energy Carrier (Category 1) – $1,200,000

The Sustainable Innovations, Inc. team will use electricity, carbon dioxide, and hydrogen to create a sustainable and economic source of dimethyl ether (DME), a fuel similar to diesel. The Sustainable Innovations team seeks to take waste carbon dioxide from industrial or chemical processes and—using an electrochemical cell and water—convert it to methanol, with subsequent conversion to DME producing only oxygen and water as byproducts. If successful, the project could create a large new market for carbon dioxide and offer compelling applications for fuel cell vehicles, stationary power, grid energy storage, and as a diesel fuel substitute.

University of Delaware – Newark, DE

Direct Ammonia Fuel Cells for Transport Applications (Category 2) – $2,500,000

The University of Delaware team will build a fuel cell with a hydroxide-ion conducting membrane electrolyte that consumes ammonia directly to generate electricity. Use of such a fuel cell for transport will be facilitated by a lower-cost polymer electrolyte and catalysts capable of oxidizing ammonia effectively around 100 °C. The team goal is an ammonia-fed fuel cell generating 500 mW per cm^2 of cell active area, with rapid startup enabled by the low operating temperature.

University of Minnesota Twin Cities – Minneapolis, MN

Small Scale Ammonia Synthesis Using Stranded Wind Energy (Category 1) – $2,900,000

The University of Minnesota Twin Cities team will insert an inorganic absorbent material in the ammonia synthesis loop of a traditional Haber-Bosch process to remove ammonia from the gas stream. Doing so will allow increased single-pass conversion and increase production rates. Once the material is loaded with ammonia, it will be regenerated and release ammonia. This approach will allow for ammonia production at 10 times lower pressure than the Haber-Bosch process, thus making it better suited for small-scale systems using renewable power.

University of South Carolina – Columbia, SC

A Novel Hollow Fiber Membrane Reactor for High Purity Hydrogen Generation from Thermal Catalytic Ammonia Decomposition (Category 2) – $1,600,000

The University of South Carolina team will build a membrane reactor to generate hydrogen fuel from ammonia decomposition, which may then be used by a hydrogen fuel cell vehicle or stationary generator. The team will use an innovative hollow fiber membrane reactor design with a highly active ruthenium-based catalyst to increase ammonia conversion at lower temperatures while reducing catalyst cost. If successful, the project would serve as a low-cost ammonia decomposition system and could contribute greatly to solving the issues surrounding hydrogen transportation and storage.

West Virginia University Research Corporation – Morgantown, WV

Renewable Energy to Fuels Through Plasma Catalytic Synthesis of Ammonia (Category 1) – $1,250,000

The West Virginia University Research Corporation (WVURC) team will develop a method to produce ammonia from hydrogen and nitrogen using a microwave plasma. Using low temperatures and pressure, the project team expects to produce ammonia at five times the conversion rate of the Haber-Bosch process. Temperature and pressure requirements are also amenable to intermittent renewable energy sources, as warm-up times can be substantially shorter. If successful, the WVURC will produce a test reactor capable of producing 1 kg of ammonia per day.

Wichita State University – Wichita, KS

Alkaline Membrane-Based Ammonia Electrosynthesis with High Efficiency for Renewable and Scalable Liquid Fuel Production (Category 1) – $855,000

The Wichita State University team will demonstrate a method for creating ammonia from air using a hydroxide-exchange membrane (HEM) powered by renewable electricity. Current methods of generating ammonia are energy-intensive and suffer from inefficiencies that drive up costs. If successful, the team's HEM approach could increase the selectivity for ammonia product—making it more efficient—while the device's tolerance for high electrical current would help lower costs relative to other electrochemical approaches to synthesize ammonia.