Proposed Agreement between California Energy Commission and Porifera Inc.

Title: Carbon Nanotube Membranes for Energy Efficient CO2 Separation
Amount: $115,397.00
Term: 24 months
Contact: Cheryl Closson
Committee Meeting: 7/21/2010

Funding

FY	Program	Area	Initiative	Budget	This Project	Remaining Balance	
09	Electric	ETSI	ARRA	$7,170,389	$115,397	$285,129	4%

Recommendation

Approve this agreement with Porifera, Inc. for an 24 month, $115,397.00 cost share grant to supplement the contractor's American Recovery and Reinvestment Act of 2009 (ARRA) award. Under the Advanced Research Projects Agency - Energy (ARPA-E) DE-FOA-0000065, Porifera, Inc. was awarded $1,153,975 in U.S. Department of Energy (DOE) ARRA funds and is providing $173,097 in additional match funding to conduct research and development of carbon nanotube (CNT) membranes for carbon dioxide (CO2) separation. The total budget for the project is $1,442,469.

Issue

Growing concerns about greenhouse gas emissions and global warming drive an increasing need for power plants and other industrial facilities to significantly reduce CO2 emissions to the atmosphere. At present, the majority of technologies used to remove CO2 from power plant and industrial flue gas emissions are based on a reversible chemical solvent absorption process. As part of this process, flue gas is piped into an absorber chamber and exposed to a solvent spray (such as alkylamine, methanol, or glycol ether), allowing the solvent to selectively absorb the CO2 contained in the flue gas. The CO2-rich solvent is then sent to a stripper where the solvent is heated to release the CO2 gas. This CO2 gas is captured for later storage or use and the solvent is recycled back to the absorber. While effective, the need for powerful compressors and solvent regeneration makes the process expensive and energy intensive, using about 27% of a 500 megawatt (MW) power plant's gross energy production capacity.

Membrane-based separation of CO2 could potentially deliver more efficient and less expensive separation with lower energy consumption. However, commercially-viable membrane-based CO2 separation technologies require membranes that are both highly CO2 selective (capable of transmitting CO2 gas more readily over other gases) and highly permeable/high flux (allowing a greater volume of gas through a unit area per unit of time). Current polymer-based membranes can be made to be highly selective; however, the chemical modifications necessary to increase selectivity reduce permeability to the point of making the membrane separations economically unviable.

Development of CNT gas separation membranes offers a potential solution to this problem by providing a membrane framework that is already highly permeable. CNT membranes are comprised of extremely small (approximately 10,000 times smaller than a human hair) and strong hollow tubes made of graphite carbon atoms. Gas flows through these seamless and ultra-smooth tube "pores" one hundred times faster

than other pores of the same size. The unique strength and properties of CNTs are a function of two main factors: the relatively larger surface area of nanostructures that makes them more chemically reative; and the physics or behavior of materials at the nanoscale. Even if selectivity modifications reduce the permeability of CNT membranes by a few orders of magnitude, the resulting performance will still be economically viable and provide a superior alternative to the solvent-based CO2 separation processes currently in use. High CNT performance stability is also possible because the pore structure of the CNT membrane is not affected by compaction or swelling, and a matrix can be chosen to provide high mechanical strength and durability independently of the targeted selectivity and permeability.

The enhanced performance of CNT membranes could reduce both facility energy consumption and CO2 capture costs. CNT membranes with higher permeability and selectivity allow for use of smaller, less expensive compressors, thereby reducing facility energy and capital costs. Much smaller compression ratios are also required for efficient separation, and the richer CO2 permeate stream generated reduces compression and management requirements for future injection and storage.

Background

Federal Funding

Under the provisions of the American Recovery and Reinvestment Act of 2009 (ARRA) and the Advanced Research Projects Agency - Energy (ARPA-E) DE-FOA-0000065, Porifera, Inc. was awarded $1,153,975 to conduct research and development of CNT membranes for CO2 separation. The total budget for the project is $1,442,469. This total includes $288,494 that Porifera, Inc. must provide to meet the 20 percent cost share requirement set by the United States Department of Energy (DOE). The DOE award to Porifera, Inc. was established as a cooperative agreement with a performance period from March 1, 2010 through February 29, 2012. Porifera, Inc. developed the project's scope of work and two-year timeline based on the ARPA-E stated preference for project performance periods of no more than 24 months.

Energy Commission Cost Share Cost Share

Porifera, Inc. submitted an application to PIER for cost share funding under PON-08-011, Addendum 7, for their ARRA DE-FOA-0000065 project and was awarded $115,397 in accordance with the terms of PON-08-011.

Relationship to West Coast Regional Carbon Sequestration Partnership (WESTCARB)

This research effort is not formally part of WESTCARB. However, success in this area could make CO2 separations from natural gas power plants more cost effective. WESTCARB Phase II is researching this topic.

Proposed Work

DOE set performance targets for CO2 separation membranes at permeability greater than 3 x 10-7 mol•m-2•sec-1•Pa-1 and selectivity greater than 100 CO2/nitrogen (N2). Porifera, Inc. proposes to develop and demonstrate a comprehensive set of chemical and physical modifications to CNT membranes that will allow the CNT membranes to meet or exceed the above DOE performance targets.

The project will pursue two basic approaches: 1) develop a membrane with aligned CNTs whose end tips are modified with chemical amines to enhance CO2 selectivity; and 2) develop a self-assembled, nano-structured composite membrane that combines an ultra-permeable nanotube framework with ultra-thin CO2 selective layers. The project work will start with fabricating membrane frameworks and identifying the most promising membrane matrix material and technique. The Contractor will concurrently work on membrane functionalization to provide for CO2 selectivity greater than 100 CO2/N2. This functionalization process will include adding specific chemical groups at the CNT entrance or in thin layers to provide sites for CO2 adsorption and facilitate CO2 separation from N2 and oxygen (O2) gas. The Contractor will then characterize and test membrane performance and assess potential performance problems, including membrane fouling considerations; the effects of water vapor on membrane permeability and use of membranes before and after wet scrubbers; and potential impacts of leaks and membrane defects on selectivity. Laboratory-scale demonstrations of membrane performance will be performed on a proposed 4-inch, wafer-scale end-product CNT membrane. The 4-inch size is convenient to handle and large enough to pinpoint potential issues that may be encountered with future large-scale manufacturing of the membrane.

The research team includes scientists and engineers from Porifera, Inc. (a private sector start-up company), Lawrence Livermore National Laboratory (LLNL), and the University of California (UC) at Berkeley. Results from the project will be communicated to interested parties and organizations (such as the North American Membrane Society) through technical papers and presentations at conferences and in society publications. While LLNL has an established foundational intellectual property (IP) patent on CNT membranes (which is licensed exclusively to Porifera, Inc.), no other research projects of this kind are known to have been performed previously in California. Porifera, Inc. and its team partners will seek intellectual property patents for the specialized CO2 CNT membranes developed by the project. Once appropriate IP protections are in place, Porifera, Inc. will work with their existing customers, power plant operators, and industrial facilities to develop appropriate CNT membrane market solutions and transition to large scale commercial manufacture and deployment of the membranes.

The total budget for this project is $1,442,469. In general, the budget can be broken down as follows:

- 40% - Contracts with LLNL and UC Berkeley for collaborative development activities
- 34% - Direct Labor and Fringe Benefits
- 18% - General & Administrative (G&A)
- 7% - Equipment and Materials
- 1% - Travel and Miscellaneous costs

The ARRA funding provides 80% of the total with the remaining 20% match of $288,494 coming from Porifera, Inc. ($173,097) and the proposed PIER cost share contribution ($115,397). The proposed PIER funding to Porifera, Inc. would be used to offset G&A project costs.

Justification and Goals

This project "[will] advance energy science or technologies of value to California citizens..." (Public Resources Code 25620.(c)), and is part of a "full range of research, development, and demonstration activities that . . . are not adequately provided for by competitive and regulated markets (Public Resources Code 25620.1.(a)).

As noted above, the purpose of this project is to develop highly permeable and highly CO2 selective CNT membranes for efficient separation of CO2 from industrial emissions. The project work represents early-stage technology development that is not currently supported by the competitive and regulated markets. If this early stage research is successful, Porifera, Inc. plans to work toward commercial development and marketing of the technology. In addition to development of an innovative technology, the project, and any future development and marketing of the CNT membranes, will also create jobs in California because Porifera, Inc. is a California-based, private company. California power plants and industrial facilities, as well as national and international facilities, would ultimately benefit from the project through the expected energy savings and improved performance of the CNT CO2 separation membranes, once they are fully developed and commercialized.

This project also supports the goals of Senate Bill 1368 (Perata, Chapter 598, Statutes of 2006), the Greenhouse Gases Emission Performance Standard for Baseload Electrical Generating Resources, through the research, development , demonstration and possible commercialization of an energy efficient CO2 separation technology that could help power plants better meet emissions standards for CO2. The potential for reduced energy consumption and greater ease of CO2 separation from the CNT membranes supports both California and national goals for the reduction of green house gas emissions and for carbon capture and storage.

This will be accomplished by:

- demonstration of a 4-inch wafer CNT membrane that meets the DOE performance targets for CO2 separation membranes.