Advanced thermal insulation & composite material compatibility for cold/cryogenic compressed gas fuel storage for onboard vehicles applications

DATE: October 19, 2015

SUBJECT: Request for Information (RFI): DE-FOA-0001420

DESCRIPTION: This is a request for information from the U.S. Department of Energy's (DOE) Fuel Cell Technologies Office (FCTO) in the Office of Energy Efficiency and Renewable Energy (EERE) concerning advanced thermal insulation for sub-ambient temperature alternative fuel storage systems. DOE requests information on how to maintain vacuum stability of systems, use of advanced composites within the systems, and accelerated test methods to determine performance and applicability of materials and systems for long-term cold and cryogenic based alternative fuel storage systems for onboard vehicle applications. Alternative fuels could include hydrogen or natural gas stored onboard the vehicle at sub-ambient temperatures as a compressed gas, liquefied gas or adsorbed onto a porous material.

BACKGROUND: Automakers have made significant advances and are beginning to roll out early commercial Fuel Cell Electric Vehicles (FCEV). In early 2014, Hyundai launched the first FCEV available for lease in Southern California, called the Tucson FCEV. In November 2014, Toyota made headlines with the official announcement of Toyota's Mirai - its first FCEV to be commercially available in the United States. The unveiling of the Honda FCEV concept car, also in 2014, quickly followed. Other automakers such as Daimler, General Motors, BMW, Nissan, and Ford plan to follow suit - all having committed to putting FCEVs on the road. All of the current light-duty FCEVs being released are designed for 700 bar ambient compressed hydrogen storage onboard the vehicle. While 700 bar compressed hydrogen storage provides a near-term commercialization pathway, the performance of this storage technology falls short of the DOE onboard FCEV hydrogen storage targets, particularly for volumetric hydrogen energy density and system cost.

One potential pathway to increase the volumetric hydrogen energy density and reduce system cost is to lower the system operating temperature through cold/cryo-compressed or cryo-adsorbent hydrogen storage systems. These storage methods also provide potential opportunities with synergies in advanced natural gas storage, such as liquid natural gas (LNG) storage, and these methods may be applicable for hydrogen delivery and early market applications (e.g., fleets, buses, etc.) as well, and not solely for light-duty vehicles.

This is a Request for Information (RFI) only. EERE will not pay for information provided under this RFI and no project will be supported as a result of this RFI. This RFI is not accepting applications for financial assistance or financial incentives. EERE may or may not issue a Funding Opportunity Announcement (FOA) based on consideration of the input received from this RFI.

All of these next generation technologies operating at sub-ambient temperature, some at extremely low temperatures (<<200K), hinge on the performance of thermal insulation. For automotive applications, the insulation must be stable over the life of the vehicle and under conditions (vibration, acceleration, shock, environmental exposure (salt, water, dirt, dust), etc.) experienced by the vehicles. An advanced thermal insulation, such as a vacuum space separating the inner pressure vessel and outer jacket walls that includes multi-layer-insulation, must be demonstrated with long-term vacuum stability to prevent an increased heat transfer causing pressure build up and loss of fuel through venting.

Vacuum stability is particularly challenging since many of these high-pressure storage systems rely on carbon fiber reinforced composites that tend to off-gas under vacuum and hydrogen permeation through the vessel liner is often observed. In addition, vacuum stability and sealing needs to be maintained over a vehicle's lifetime as servicing the vehicles frequently to restore the vacuum is neither desirable nor can it be insured. If the pressure in the vacuum chamber increases then the thermal heat transfer rate increases, leading to a higher temperature which increases the pressure of the gas contained in the inner pressure vessel. When the pressure limit of the inner pressure vessel is reached, hydrogen (or LNG) would be released which reduces the benefit of these technologies. In addition to the customer's loss of fuel due to the increased heat transfer, a cold or cryogenic fuel system will have an inconsistent and lower fueling capacity without the proper performance of the thermal insulation over time.

For the customer, it is important that no measurable fuel is lost while the vehicle is parked, even for extended periods, and that fueling is consistent and delivers the expected capacity. In order to achieve these customer goals, the thermal insulation needs to maintain its dormancy and performance over several years with minimal additional weight, volume and cost to the storage system. For example, a cryogenic hydrogen storage system with 100L capacity could require an estimated 5-7 Watt maximum heat leakage performance at the beginning of system life with limited degradation over the vehicle's lifetime to be viable.

PURPOSE: The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on issues related to advanced thermal insulation, primarily cold/cryo-compressed and cryo-adsorbent hydrogen storage systems, liquefied natural gas storage systems and related sub-ambient alternative fuels storage for onboard vehicle applications. EERE is specifically interested in feedback from stakeholders on the following questions:

1) Thermal / Vacuum Stability Approaches: DOE could potentially pursue many pathways to achieve thermal (vacuum) stability. These include but are not limited to developing low-volatile resins within the composite that do not off-gas, improved getters to remove volatile components and hydrogen from within the vacuum space, coatings to reduce/eliminate hydrogen permeation through liners or loss of volatile components from composites, improved sealing designs, alternative insulation approaches, and

alternative insulation designs/architecture which would minimize the potential for volatiles to reach the vacuum layer.

   a. Of these options, are there pathways that DOE should consider more than others?
   b. Are there other viable pathways that DOE should consider if it were to fund research in this topic area?
   c. To achieve the necessary challenging heat leakage values required for cold/cryogenic operating conditions while being able to withstand the extreme operating conditions onboard vehicles, are there alternative technologies to multi-layer vacuum super insulation (MLVSI) which DOE should pursue?

2) <u>Targets</u>:
   a. What sort of dormancy/heat leakage targets should DOE aim for?
   b. For instance, what is an acceptable heat leakage degradation percentage over a 15 year timespan?
   c. How does this differ over varying operating temperatures/pressures?
   d. Is 15 years a reasonable goal to maintain the thermal stability for onboard vehicle fuel storage applications?
   e. Are there other targets DOE should consider that would affect the vehicle performance as related to cold/cryogenic insulation?

3) <u>Testing / Screening Procedures</u>:
   Small Scale Material Testing:
   a. What are the best approaches to rapidly test and screen thermally stable materials?
   b. How does one perform accelerated lifecycle system testing?
   c. Are there preferred material-level screening methods or test sequences based on thermal insulation failure mechanisms that could be used to accelerate the lifetime assessment under extreme automotive conditions based on a representative vehicle lifetime?

   Larger Scale System Testing:
   d. How does one adequately perform accelerating lifecycle system testing?
   e. Are there preferred system level screening methods or test sequences based on thermal insulation failure mechanisms developed to accelerate the lifetime assessment under extreme automotive conditions based on a representative vehicle lifetime?
   f. Do these test methods require full-scale systems or can sub-scale system tests suffice?

4) <u>Manufacturing</u>:
   a. Which companies are currently manufacturing these materials or related materials for this or similar cold / cryogenic compressed gas storage applications?
   b. Is advanced thermal insulation technology to a point where DOE should consider pursuing manufacturing related R&D for low-cost reliable manufacture of MLVSI techniques?

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5) Other:
   a. Are there other considerations/feedback you would like to provide DOE as it considers funding research and development for advanced thermal insulation for hydrogen and other alternative fuel storage applications to ensure best use of tax payer funds and stakeholder visions?

Please note that DOE is planning a workshop related to this RFI to gather additional feedback from composites experts in automotive, aerospace, and other industries. The workshop will be held on October 29, 2015 in Dallas, Texas and co-located with the Composites and Advanced Materials Expo (CAMX) [see the "Co-Located Meetings" tab at: http://www.thecamx.org/other-meetings-events/].

DISCLAIMER AND IMPORTANT NOTES: This RFI is not a FOA; therefore, EERE is not accepting applications at this time. EERE may issue a FOA in the future based on or related to the content and responses to this RFI; however, EERE may also elect not to issue a FOA. There is no guarantee that a FOA will be issued as a result of this RFI. Responding to this RFI does not provide any advantage or disadvantage to potential applicants if EERE chooses to issue a FOA regarding the subject matter. Final details, including the anticipated award size, quantity, and timing of EERE funded awards, will be subject to Congressional appropriations and direction.

Any information obtained as a result of this RFI is intended to be used by the Government on a non-attribution basis for planning and strategy development; this RFI does not constitute a formal solicitation for proposals or abstracts. Your response to this notice will be treated as information only. EERE will review and consider all responses in its formulation of program strategies for the identified materials of interest that are the subject of this request. EERE will not provide reimbursement for costs incurred in responding to this RFI. Respondents are advised that EERE is under no obligation to acknowledge receipt of the information received or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this RFI do not bind EERE to any further actions related to this topic.

PROPRIETARY INFORMATION: Because information received in response to this RFI may be used to structure future programs and FOAs and/or otherwise be made available to the public, **respondents are strongly advised to NOT include any information in their responses that might be considered business sensitive, proprietary, or otherwise confidential.** If, however, a respondent chooses to submit business sensitive, proprietary, or otherwise confidential information, it must be clearly and conspicuously marked as such in the response.

Responses containing confidential, proprietary, or privileged information must be conspicuously marked as described below. Failure to comply with these marking requirements may result in the disclosure of the unmarked information under the Freedom of Information Act or otherwise. The U.S. Federal Government is not liable for the disclosure or use of unmarked information, and may use or disclose such information for any purpose.

If your response contains confidential, proprietary, or privileged information, you must include a cover sheet marked as follows identifying the specific pages containing confidential, proprietary, or privileged information:

> **Notice of Restriction on Disclosure and Use of Data:**
> Pages [list applicable pages] of this response may contain confidential, proprietary, or privileged information that is exempt from public disclosure. Such information shall be used or disclosed only for the purposes described in this RFI DE-FOA-0001420. The Government may use or disclose any information that is not appropriately marked or otherwise restricted, regardless of source.

In addition, (1) the header and footer of every page that contains confidential, proprietary, or privileged information must be marked as follows: "Contains Confidential, Proprietary, or Privileged Information Exempt from Public Disclosure" and (2) every line and paragraph containing proprietary, privileged, or trade secret information must be clearly marked with double brackets or highlighting.

EVALUATION AND ADMINISTRATION BY FEDERAL AND NON-FEDERAL PERSONNEL: Federal employees are subject to the non-disclosure requirements of a criminal statute, the Trade Secrets Act, 18 USC 1905. The Government may seek the advice of qualified non-Federal personnel. The Government may also use non-Federal personnel to conduct routine, nondiscretionary administrative activities. The respondents, by submitting their response, consent to EERE providing their response to non-Federal parties. Non-Federal parties given access to responses must be subject to an appropriate obligation of confidentiality prior to being given the access. Submissions may be reviewed by support contractors and private consultants.

REQUEST FOR INFORMATION RESPONSE GUIDELINES: Responses to this RFI must be submitted electronically to H2Storage@ee.doe.gov no later than <u>5:00pm (ET) on Friday, November 6th</u>. Responses must be provided as a Microsoft Word (.docx) attachment to the email, of <u>no more than 3 pages in length</u>, 12 point font, 1 inch margins. Only electronic responses will be accepted.

Please identify your answers by responding to a specific question number if possible. Respondents may answer as many or as few questions as they wish.

EERE will not respond to individual submissions or publish publicly a compendium of responses. A response to this RFI will not be viewed as a binding commitment to develop or pursue the project or ideas discussed.

Respondents are requested to provide the following information at the start of their response to this RFI:

- Company / institution name;

- Company / institution contact;
- Contact's address, phone number, and e-mail address.

On behalf of the entire Hydrogen Storage Team, thank you in advance for providing your input on this important topic and contributing to DOE's success in achieving its programmatic objectives.

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