Cost Reduction and Performance Improvements of Composite Overwrapped Pressure Vessel Systems for Compressed Hydrogen for Onboard Vehicle Applications

DATE: June 7, 2016

SUBJECT: Request for Information (RFI): DE-FOA-0001596 - Strategies to reduce cost and improve performance of 700 bar onboard hydrogen storage systems.

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 strategies and potential pathways for cost reduction and performance improvements of composite overwrapped pressure vessel (COPVs) systems for compressed hydrogen storage for onboard vehicles applications.[1]

Currently, carbon fiber (CF) reinforced polymer (CFRP) composites are used to make COPVs. Type III COPVs have a metallic liner and Type IV COPVs have non-metallic liners. COPVs designed to store hydrogen gas at pressures up to 700 bar are being deployed in fuel cell electric vehicles (FCEVs) currently available on the market. However, their high cost is a barrier for widespread commercial deployment of light-duty FCEVs. DOE requests information on technology strategies and pathways to reduce the cost of components of Type III and Type IV COPVs, including but not limited to the composite materials such as CF precursors, lower cost conversion processes for CF production, alternative fibers to CF, lower cost polymer resins, resin additives, etc., and other components such as liner and boss materials. In addition to strategies to reduce cost, DOE also requests information on technology strategies to improve system performance to reduce the amount of high cost composites required, designs for enhanced conformability and improved packaging, and design improvements with potential to lower cost of operation and improve performance of the refueling infrastructure (e.g., eliminate need for hydrogen pre-cooling). The purpose of this RFI is to identify future strategic research and development pathways for the DOE to pursue with potential to meet future system cost targets.

[1] Note, this RFI is focused on COPVs which require high-strength fiber reinforced composites and is therefore differentiated by activities carried out through the EERE Vehicle Technology and Advanced Manufacturing Offices for vehicle lightweighting, which are focused on lower strength fiber reinforce composites.

Background

Automobile manufactures have made significant advances in hydrogen and fuel cell technologies for automotive applications and, as a result, are beginning to roll out early commercial light-duty FCEVs. In early 2014, Hyundai launched the Tucson FCEV, the first FCEV available for commercial lease in Southern California. In November 2015, Toyota delivered the first Toyota Mirai FCEV to a commercial customer in the US. Honda has announced plans to release a commercial version of their Clarity FCEV in California in 2016, and is already selling these vehicles in Japan. 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.

Although improvements in compressed hydrogen storage volumetric density are limited by real gas compression physics, there may be paths forward for significant system cost reductions to address DOE FCTO's technical targets. DOE FCTO published a cost and performance analysis of 700 bar compressed hydrogen systems in 2015 indicating a projected high-volume cost of approximately \$15/kWh (\$500/kg) of stored hydrogen.[2] Figure 1 shows a breakdown of the projected system costs. This cost represents approximately a 12% reduction from the baseline costs projected in 2013.[3] However, additional advances must be made to achieve the DOE 2020 hydrogen storage system target of \$10/kWh and the Ultimate target of \$8/kWh.

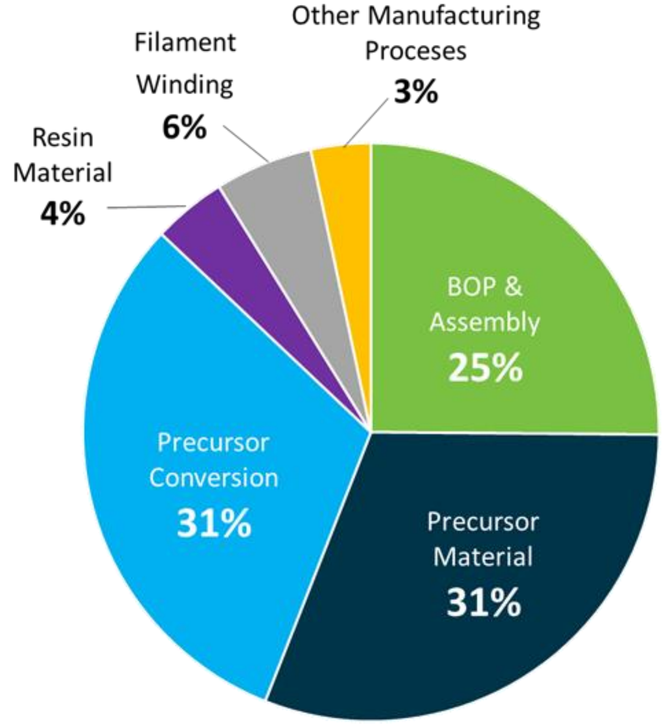

Figure 1: 700-Bar Compressed Hydrogen Storage System Cost Breakout (single tank system) from 2015 DOE FCTO Record #15013.

[2] https://www.hydrogen.energy.gov/pdfs/15013_onboard_storage_performance_cost.pdf
[3] https://www.hydrogen.energy.gov/pdfs/13010_onboard_storage_performance_cost.pdf

As illustrated in Figure 1, the primary cost driver for the 700 bar compressed hydrogen storage system is the composite materials and processing – primarily driven by the precursor material and the precursor conversion to CF. While DOE recognizes the impact of balance of plant (BOP) on the overall system cost, this RFI is focused primarily on the COPV as it is believed that industry will be the primary driver in designing their own specific hydrogen storage system BOP. Improved designs, such as conformable designs, have potential to reduce costs by reducing the need for multi-tank systems. However, in order to achieve a significant cost reduction of onboard compressed hydrogen storage systems, the primary focus needs to be on the composite materials used in these systems.

Figure 2 shows a waterfall plot of the projected 700 bar hydrogen storage system costs from the 2013 baseline to the 2015 updated projections along with yet to be identified pathways to meet the 2020 and ultimate DOE targets. The 2015 analysis shows how systematic research in composite materials and processing, as well as, BOP and assembly were successful in reducing the total high volume projected system cost from the 2013 baseline of $16.8/kWh to $14.8/kWh.

The primary cost driver of the composite materials and processing is the synthesis and conversion of precursor polymer into CF. Polyacrylonitrile (PAN) is the current state of the art precursor material that is converted to high-strength CF. Pitch-based CF is a lower cost alternative to PAN based CF; however, pitch-based CF has not been demonstrated to meet the strength and durability quality needed to meet 700 bar compressed hydrogen storage system performance. The current synthesis and production of high-quality, high PAN content precursor fiber is expensive, representing approximately 50% of the cost of the CF. The conversion process of PAN precursor to CF is energy intensive. Furthermore, the CF mass yield is approximately 50% relative to the PAN input mass. Therefore alternative precursor materials that can lead to lower cost CF through lower cost materials, lower cost and less energy intensive processing, and/or higher CF output yields are of interest.

Another cost driver is the polymer resin. COPVs are typically made using epoxy type resins. The resin is critical for the distribution of shear stresses during hydrogen gas pressure loading to the CFs, which are the main structural elements of the tanks. Epoxy resins can be expensive and have high density, which is detrimental to system cost and gravimetric density.

Compressed hydrogen storage systems can also be improved by design considerations that address packaging onboard the vehicle and reducing the cost and complexity of the refueling infrastructure. For example, compressed hydrogen systems could be designed with improved heat dissipation capability to reduce hydrogen station delivery precooling requirements. This would translate to a reduced fuel cost and better capability to reach a full state of hydrogen fill at more cost effective temperatures than the current state-of-the-art.

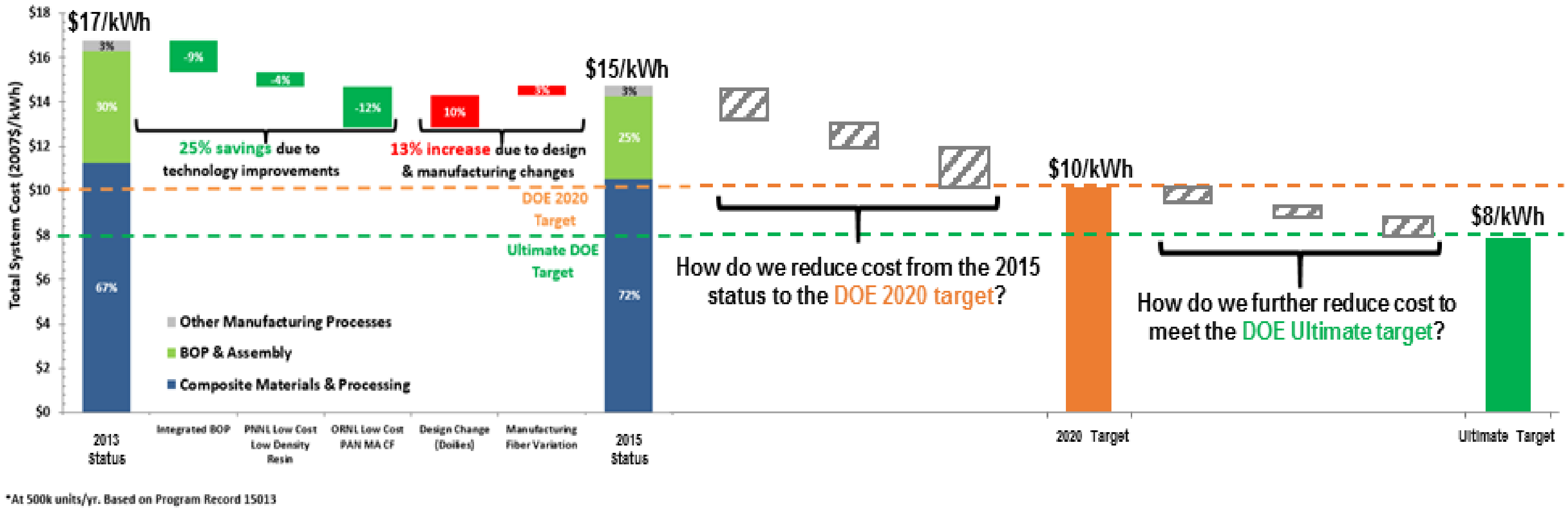

Figure 2: Waterfall plot of the 2013 700 bar compressed hydrogen storage system cost baseline and 2015 cost status update. The cost reductions identified from the 2013 baseline to the 2015 update are shown. Schematics of the 2020 target and Ultimate target are shown to illustrate DOE FCTO's request for input on how best to reach the targets.

Purpose

The purpose of this RFI is to solicit feedback from industry, academia, research laboratories, government agencies, and other stakeholders on potential technology strategies to further reduce the cost and improve the performance of 700 bar hydrogen storage COPVs for onboard automotive applications DOE seeks to identify future strategic research and development pathways to pursue with potential to meet future system cost targets. Specifically DOE is looking for input on the following questions:

1. Please rank the following potential strategies for reducing the cost and increasing the performance of COPVs for hydrogen storage that should be pursued by DOE's Hydrogen Storage Program. Please keep in mind potential return on investment from a technology perspective when determining your preference (1=Most important for DOE to pursue; 8=Least important for DOE to pursue):

   ______ Precursor Material
   ______ Precursor Conversion
   ______ Alternative Fibers
   ______ Resins
   ______ COPV Design
   ______ COPV Manufacturing
   ______ Codes and Standards
   ______ Other_______________ (please specify; add more lines if necessary and ranking

2. <u>Precursor Material:</u> What are other potential lower-cost alternatives to conventional PAN precursor for high-strength CF production?

3. <u>Precursor Conversion:</u> Are there other CF processing methods or precursor conversion approaches that DOE should consider?

4. <u>Alternative Fibers:</u>
   a. Are there other types of non-traditional, lower cost or higher strength CF that DOE should pursue?
   b. What are other potential lower-cost, high-strength fiber alternatives to CF (e.g., high strength glass fibers, high strength aramid fibers, fiber hybridization schemes) that would not adversely impact the weight and volumes of COPVs?

5. Resins:
    a. Are there alternative lower cost / lower density resins that DOE should pursue? Please provide details.
    b. Are there resins with superior load transferring properties (i.e., improved fiber translation efficiency) or resins additives that may act as toughening agents (i.e., nanomaterials) that DOE should pursue? Please provide details.

6. COPV Designs:
    a. Are there alternative COPV designs such as alternative winding patterns or other design approaches that should be pursued to reduce cost and/or improve performance?
    b. Are there novel compressed hydrogen storage system designs for improved onboard packaging (conformability) and reduced cost / complexity?
    c. Are there novel compressed hydrogen storage system designs for improved translational efficiency?
    d. What are potential strategies to improve the heat dissipation / reduce the hydrogen precooling requirement for fast refueling to 700 bar?
    e. Are there other strategies for reducing the cost and complexity of the refueling infrastructure through onboard system design that DOE should consider?

7. COPV Manufacturing:
    a. Should DOE continue to pursue alternative COPV manufacturing processes to reduce the cost and/or the amount of CF currently used in 700 bar COPVs?
    b. What manufacturing volumes do you consider necessary to result in a significant reduction in cost?
    c. Are there opportunities for standardization and/or bundling demand across multiple customers/applications to increase volume? If so, please provide examples.

8. Safety, Codes and Standards:
    a. Are there sensors or other design aspects that can be incorporated into the COPVs to reduce system cost while still maintaining performance and safety requirements?
    b. Are there existing industry codes, standards, or regulations that should be reexamined as part of the goal to reduce cost and increase performance while still maintaining the strict safety requirements?

9. Other Novel Approaches: Are there other novel, outside-the-box strategies for reducing the cost and improving performance of 700 bar onboard hydrogen storage COPVs that were not covered in the background section above, that DOE should consider pursuing?

10. Workshops: Are there any specific topics related to 700 bar onboard hydrogen storage COPVs that would benefit from an in-depth technical workshop organized by DOE and open to the public?

11. Other: Please provide any other input you consider valuable aligned with the intent of this RFI.

Disclaimer and Important Notes

This RFI is not a Funding Opportunity Announcement (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 [Enter RFI Number]. 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 5:00pm (ET) on June 30, 2016. Responses must be provided as attachments to an email. It is recommended that attachments with file sizes exceeding 25MB be compressed (i.e., zipped) to ensure message delivery. Responses must be provided as a Microsoft Word (.docx) attachment to the email, and no more than 5 pages in length, 12 point font, 1 inch margins. Only electronic responses will be accepted.

Please identify your answers by responding to a specific question or category if applicable. 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 DOE FCTO Hydrogen Storage Program, thank you in advance for providing your input on this important topic and contributing to DOE FCTO's success in achieving its programmatic objectives.