Advanced Manufacturing Status and Opportunities to Accelerate Growth in Fuel Cell and Hydrogen Products

Manufacturing Subcommittee (MSC) report to Hydrogen and Fuel Cell Technical Advisory Committee (HTAC)

December 12, 2014

Date: December 12, 2014

Executive Summary

The HTAC Manufacturing Subcommittee (MSC) was formed at the request of the DOE program office with the objective of assessing the extent to which advanced manufacturing is being used by the US hydrogen and fuel cell industry and how it could be used to enhance the industry's growth and manufacturing competitiveness. The MSC was composed of industry experts from the HTAC and outside the HTAC, as detailed below. The MSC also drew on extensive previous studies, literature and interactions with industry participants, including a structured questionnaire which went to nine key companies in the field of hydrogen and fuel cells. Several themes and suggested areas of further investigation or recommendations have emerged from this effort.

It is apparent from this assessment and that of previous efforts that the hydrogen and fuel cell industry has made remarkable strides with the support of the Department of Energy. Products have stabilized and are viewed as commercial and acceptable in their applications, e.g. telecom backup power, material handling, and initial commercial volumes have been established. In short, early adoption has been achieved in several categories. However, it also appears that the industry is at a sort of "tipping point," where product cost reductions could either drive it towards accelerated adoption rates and self-sustaining growth, or without cost reductions, hold the industry at subcritical mass. While advanced manufacturing (principally automation) has been implemented in a few instances, it is underutilized to realize its benefits. Additionally, investment in advanced manufacturing methods and other cost reduction opportunities are being withheld by OEMs and suppliers due to uncertainty about future market volume. On the surface, the situation appears comparable to the "chicken and egg" dilemma, but with a key difference. In this case, there may be very practical and discrete actions which would break through the stalemate. In particular, there are three areas, which should be considered simultaneously and which are described below in further detail, and outlined in the November 19, 2014 presentation to the HTAC, Appendix C of this report.

Recommendation 1: Increase stimulation programs for targeted demands, including deployments in and outside the United States

This report does not focus on determining the effectiveness or ways to increase product demand through stimulation or deployment programs. However, increased demand and increased consistency of demand were frequently cited as key factors holding back further investment in advanced manufacturing and product improvements. Hence, finding a means of establishing such an increase in conjunction with cost efforts is seen to be a very important factor of successfully generating self-sustaining growth, investment, and competitive manufacturing.

Programs could be similar to previous ones, focused on commercially proven products and relatively short term deployments. These programs should concentrate on key buying factors (e.g. installed cost for backup fuel cells, hydrogen infrastructure for material handling) to achieve deeper adoption by new and existing customers, with an emphasis on making the products mainstream to their business. For example, such programs might consider requirements that at least some customer participants be new end users, in addition to repeat users, that customer participants show progress in making the fuel cell and hydrogen products a mainstream part of their routine purchase decisions (versus only a special project), and that these customers provide feedback on the economics and other factors needed to significantly increase the use of the products. Also, it has been noted that a significant amount, perhaps the majority, of fuel cell and hydrogen product purchases and installations may be outside the United States. This represents an opportunity to capture more market demand by exporting these products. Hence, it is additionally recommended that there be an assessment of specific export opportunities and how OEMs in the United States might increase their competitiveness to access these markets.

Recommendation 2: Focus on Selected key component cost reduction and standardization

Consistent with previous studies, there are specific, key components and/or subsystems which if cost reduced could have a disproportionately positive impact on product cost. These components include membrane electrode assembly (MEAs) and their sub-components, fuel cell bipolar plates, selected pumps, compressors, fuel reformers. The list is relatively short. The important new development is that because the hydrogen and fuel cell products are in the commercial market, designs are or can be relatively stable. Also, the initial commercial sales volumes, while small for any single OEM, when taken together are now reasonably large. This suggests a near term opportunity to standardize on a selected set of key components and/or consolidate the supply chain to focus the available commercial volumes. Doing this could reduce material costs and encourage supply chain investment in new manufacturing methods more geared toward higher volume and lower cost.

It is suggested that a deep dive effort be organized to focus on a select set of such components and their suppliers, and OEMs who have established commercial sales volumes to determine feasibility of and potentially develop action plans to accomplish such standardization and consolidation. Additionally, it is recommended that a particular emphasis be placed on how to leverage potential synergies between stationary and automotive component cost and volumes, especially with regards to fuel cell stacks and components.

Recommendation 3: Improve Access to Additive Manufacturing (and other advanced manufacturing techniques)

As noted in the questionnaire responses, the cost of modifying products (OEMs) and the cost of tooling and or modifying parts (suppliers) is a barrier for advancing cost reduction efforts. Additive manufacturing has the potential to reduce the cost of product prototyping for OEMs and part prototyping for suppliers. It has also been suggested that tooling costs for lower production volumes could benefit from additive manufacturing. Hence, making additive manufacturing technology more readily available to both OEMs and suppliers to the hydrogen and fuel cell industry could help lower product costs by encouraging innovation and reducing tooling costs, even at relatively low volumes.

Anecdotal evidence shared at the Clean Energy Manufacturing Initiative Western Regional Summit in San Francisco, 4/17/14, questionnaire respondents, and industry participants on the MSC indicates that there is little access to additive manufacturing or other advanced manufacturing technologies for most hydrogen and fuel cell companies and suppliers. It is recommended that a focused assessment of the potential to use additive manufacturing as described above be conducted with industry OEMs and suppliers, and that if found sufficiently beneficial, a means to afford greater access be developed. Additionally, it is noted that the MSC has initiated follow up inquiries with the questionnaire respondents on the topic of how better access to a broad range of advanced manufacturing technologies might be made possible.

Structure of Effort

Charter: Investigate potential opportunities for advanced manufacturing to benefit hydrogen and fuel cell product manufacturing and commercialization.

MSC members: The MSC committee members were selected based on their specific expertise in the areas of hydrogen production and fuel cell products, and their manufacturing and technical experience in these areas. The committee also reached out to include experts who were not members of the HTAC.

Name	**Organization and background**
Adrian Corless	Plug Power (participant for first half, expertise in material handling fuel cells and operations)
Gary Flood	HTAC/CEO ReliOn, Inc. Backup power fuel cell company.
Charles Freese	HTAC/General Motors fuel cell vehicle development.
Robert Friedland	President and CEO, Proton OnSite. Commercial hydrogen generators.
Nancy Garland	Department of Energy
Cassidy Houchins	Department of Energy
Maurice Kaya	HTAC/Energy, Renewable Consulting
Arianna Kalian	ClearEdge Power. (participant for first half) VP operations, stationary fuel cell products
Hal Koyama	HTAC/CEO H2 PowerTech. Hydrogen reforming, backup power fuel cell products
Robert Shaw	HTAC/Energy technology, Venture Capital
Robert Stokes	VERSA Power Systems. Solid oxide fuel cells.
Levi Thompson	HTAC/energy Technology Research
Joe Triompo	HTAC ClearEdge Power (participant for first half)
Michael Ulsh	National Renewable Energy Laboratory

Methodology

Focus: The initial scope of the effort was very broad, potentially spanning a wide range of fuel cell and hydrogen generation technologies, stages of commercialization, applications / product types, and supply chains. In order to make the effort more tractable, the MSC determined to focus on relatively small scale commercially available hydrogen and fuel cell products in automotive, mobile and stationary applications.

Process and Key Activities: The MSC met via conference calls roughly bi-weekly to exchange experience and feedback on emerging information and hypotheses. The following were key activities conducted by the MSC in generating this report:

1. Identified and researched relevant published reports (see Appendix A: References)
2. Participated in Clean Energy Manufacturing Initiative Toledo, Ohio regional summit, 6/21/13
3. Participated in Clean Energy Manufacturing Initiative Western Regional Summit, San Francisco, California, 4/17/14
4. Conducted initial informal hydrogen and fuel cell industry interviews with industry participants
5. Generated and, in conjunction with NREL, implemented an industry questionnaire to target specific areas of feedback (see below and Appendix B)

Industry questionnaire: It was decided that more detailed and structured feedback was needed across a broad base of the hydrogen and fuel cell industry and supply base. To accomplish this, the MSC developed a questionnaire, Appendix B, and identified nine key companies to participate. Due to government regulations, the questionnaire was limited to nine participants. This industry has typically required some level of confidentiality in order to participate in such information gathering. Michael Ulsh of NREL (and a member of the MSC) was engaged to conduct the questionnaire process in order to provide confidentiality to the respondents. In addition to written responses, several respondents were interviewed for clarification or additional detail on the responses. To ensure confidentiality, the responses are grouped by topic area and aggregated below in "Questionnaire Key Points" sections.

Questionnaire participants:

Company	**Industry Segment**
General Motors	Fuel cell vehicle automotive OEM
Proton OnSite	Hydrogen generator OEM
Hydrogenics	Stationary fuel cell OEM
Plug Power	Material handling fuel cell OEM
Altergy	Stationary backup power fuel cell OEM
Ballard Power Systems	Stationary and bus fuel cell OEM
Eaton	Fuel cell balance of plant component supplier
3M	Fuel cell MEA supplier
American Trim	Fuel cell component supplier

Discussion by topic area

The information and findings for this effort are organized by topic area with an overall Summary, combining an assessment of researched information, MSC member expertise and questionnaire feedback, and a Key Points section summarizing specific feedback from the questionnaire.

Topic Area A: Volume and Capacity

Summary: Responses to production volumes and manufacturing capacity varied across the group polled. A significant difference when comparing responses is seen between the automotive industry and all others. The automotive application is not yet serial commercial. "Low" volumes in automotive terms are relatively high volumes when compared to any of the stationary or smaller mobile, e.g. MHE, applications with system sizes on the order of a few to 15 kW. This is particularly important when thinking about capacity for fuel cell stack components such as MEAs, for which the number and size (active area) in a stack vary greatly between automotive and smaller applications. Hence, unless there is commonality between components used in fuel cell vehicles and small stationary/mobile fuel cells, the volume and capacity implications should be thought of separately.

With regards to the smaller hydrogen and fuel cell producers and suppliers, current volumes are in the range of 1000's to 10,000's of kWe, or 1000's of units. Comparing this information to analogous data from previous studies of manufacturing readiness for fuel cell systems and stacks in backup power and material handling applications Wheeler, Ulsh; 2008, 2010, suggests up to a 10 fold increase in unit production over the last 3-5 years. However, there remains significant unused system assembly capacity for these smaller applications, on the order of 3 to 10 times current. This suggests a need for a second step in demand for products to address utilization of existing capacity in small fuel cell and hydrogen production applications.

Considering potential synergy between automotive and small stationary/mobile fuel cells, while the DOE considers that a niche market requires a production volume of 500,000 vehicles/year, even an early, low volume deployment of commercial FCVs could have a tremendous impact on key fuel cell component supply such as MEAs. For example, 10,000 vehicles, each with an 80kWe stack, creates a 10 to 100 times supply capacity relative to the small stationary and mobile fuel cell applications. This could be transformative in terms of cost and further market penetration for small stationary and mobile fuel cells, *if these components were made common*. Conversely, another 10 fold or more increase in small stationary and mobile market growth could double the volume of an early automotive deployment, thereby further assisting in cost reduction for that application. In fact, if the cost curve for stationary fuel cells is similar to that of automotive fuel cells, then the study "Transportation Fuel Cell Cost Analysis", presented by Strategic Analysis, Inc., June 19, 2014 seems to indicate that a relatively modest increase in stationary fuel cell volume from "10,000's" of kWe, to around 50,000 kWe could achieve costs in the range of $280/kWe. This would be a reduction of about 70% from current small stationary fuel cell costs and would have a substantial positive impact on sales volume increases. This suggests that the timing may be attractive for growth stimulus of both of these applications and joint planning for overlapping sourcing and manufacturing capacity.

There was significant variation in the responses on volume variability over the last few years: from no variability, to cyclic variation, to growth of 30-100%.

Questionnaire Key Points (#2,3,4)

- Supply chain capacity values varied widely, reflecting the uncertain nature of current fuel cell markets, the variation in quantity of sub-components in a system (e.g. a blower vs. MEAs/cells) as well as the inclusion of capacity developed for other, more mature markets.
- All system makers (with products currently in production) cited volumes in the 1000s to low 10's of thousands of kW per year.
- All system makers that differentiated between capacity and volume in their response cited additional capacity beyond current volumes, by a factor of at least three and up to 10.

Topic Area B: Automation

Summary: There is a wide range of implementation of automation in the production processes among the respondents. While MEA manufacturers have widely implemented automation in the form of continuous roll-to-roll processes, system manufacturers report a mix of batch and automated processes, and overall, a low level (<20%) of automation in current production systems. Most respondents acknowledge the potential benefits of automation. However, nearly all indicate that volume (demand) is not sufficient yet to realize those benefits for all production needs (if they have already invested in automation), or to take steps to invest in automation (if they are still using batch and manual processes). Respondents indicated a per-company demand threshold of around 10,000 to 20,000 kW/year for making automation investments. To date, the industry is short of that threshold, even though a number of companies have made such investments several years ago. In addition to being below a minimum volume for making such investments, there is a general uncertainty about the consistency of demand. Taken together, this indicates that the market may be at an inflection point, where modest increased and consistent demand could spur automation utilization and new investment in automation, both of which could contribute positively to lowering product cost, increasing margins and driving further business growth.

Questionnaire Key Points (#5,6,10,11,12)

- Most companies reported a mixture of production styles, between batch and continuous processes, and a low level of automation (<20%) in current production systems.
- A few companies reported high levels of automation (including continuous processes and robotics), but that usage currently can depend on the product line or the quantity of the order.

- Most companies reported that they have investigated automation in detail, and most that have not already implemented significant automation indicated that they would implement higher levels of automation if market volumes justified the capital expense.
- Companies responded to the threshold for capital expenditure on automation in a variety of ways, however, several system makers listed a threshold volume of 10,000-20,000 kW/year.
- All companies that are not sub-tier supply chain indicated that they have discussed implementation of automation with their suppliers. Most expected the supplier to make the capital expenditure for automation, and several indicated that their volumes had not yet met the supplier's threshold for internal investment.

Topic Area C: Standardization

Summary: The term standardization is applied to how parts or components of the fuel cell or hydrogen products are procured. Early in the commercialization of fuel cell and hydrogen technologies, parts and components were highly modified or specialized. However, respondents now indicate a significant move towards using more parts which are already being produced for other commercial applications, from between 50 and 95% of parts for fuel cell and hydrogen OEMs, thereby lowering the cost of the product. At a lower level, respondents indicated that most BOP and MEA components (membrane and GDLs) were sourced, while cell and stack assemblies were typically fabricated in-house. Alternately, some parts and components still may require some modification (beyond a standard design used in other commercial applications) in order to be used in the fuel cell or hydrogen product. If such after-market modifications can be minimized or eliminated, it should further improve the cost and quality position. Additionally, even if parts are "standard" commercial parts, they still may be relatively high cost due to low volume production, e.g. sensors used in lab applications versus sensors used in home appliances. Another aspect of standardization would be for fuel cell and hydrogen companies to be using the same components. Respondents mentioned this as a particularly important opportunity in MEA and fuel cell stack architecture. Although a great deal of progress has occurred, there appears to be significant opportunity remaining in standardization by moving to more mass produced and low cost off the shelf components, and by adopting standard components, form factors, and specifications across fuel cell and hydrogen OEMs, especially for high cost items such as MEAs and selected BOP components.

Questionnaire Key Points (#7,8,9)

- Most system makers indicated a mix of components made in-house vs. sourced. Almost all indicated that cell and stack assemblies were fabricated and/or assembled in-house. Most BOP components were sourced, other than a few instances where the company had specialized in-house technologies. All indicated that MEA components (membranes and GDLs) are sourced.
- Most companies indicated a level of standardization of parts of at least 50%, with some up to 95%. BOP components were much more likely to be standard than stack components.
- All companies saw value in continued efforts toward standardization. Several mentioned standardization of MEA and stack architecture as a specific area of opportunity.

Topic Area D: Quality Systems

Summary: All respondents agreed with the necessity of standardized quality systems in the production of fuel cell and hydrogen systems, and indicated that they have adopted such systems. In many cases, companies have implemented industry standard quality systems such as ISO9001 or 14001 or their foreign counterparts. Those who have not adopted standard systems indicated adoption of similar internally developed systems often modeled after the industry standard systems. The cost of implementing industry standard systems was mentioned as an impediment, especially with currently low market volumes.

Questionnaire Key Points (#13)

- All companies indicated the use of well-defined and standardized quality systems. Several specified a quality certification such as ISO 9001 or 14001.

Topic Area E: Opportunities for Advanced Manufacturing

Summary: Awareness of advanced manufacturing techniques was high, especially for additive manufacturing. However, use of advance manufacturing methods was essentially limited to implementation of some initial automation and as previously noted, is currently underutilized. Also, consistent throughout the responses, was a reluctance of the OEMs and suppliers to invest in automation or other advanced manufacturing due to the current levels of demand and uncertainty in demand increases. However, with regards to additive manufacturing, respondents expressed a potential opportunity in using this technique with prototyping and early / lower volume production. In this case, additive manufacturing could play an important role in reducing reluctance to innovate, speeding up cycle time and finding lower cost component designs. Additionally, there was strong agreement among the respondents that use of advanced manufacturing techniques other than additive manufacturing on stack and MEA components could be of high value and were of high priority to them. Given that for fuel cell products, the MEA and other stack components are by far the most significant cost challenge and opportunity, this seems to be a natural area for further focus.

Questionnaire Key Points (#14,15)

- All companies indicated at least an awareness of additive manufacturing. Most indicated that they had considered it or have used it for prototyping or qualifying new designs. Almost all responses indicated an opinion that the technique's usefulness for them is or would be limited to prototyping and very low level production, as opposed to production at significant volumes.
- All responses indicated opportunities for improvement in production and/or quality by implementation of advanced manufacturing techniques. Several indicated that stack and/or MEA components offered the most opportunity or were their highest priority for implementation of advanced manufacturing techniques.

Topic Area F: Status and Opportunities for Tooling

Summary: Consistent with related responses, participants expressed reluctance to invest in new tooling. This reluctance is driven primarily by the relatively low current volume, but also the unpredictability of increased volume. Responses were also mixed as to the greatest area of need for tooling, some citing needs related to BOP, others for stack hardware and bi-polar plates. Additionally, in most cases, it is noted that the technology continues to advance at a rapid rate, which has the potential of making new tooling obsolete. Proper tooling is important in order to achieve cost reductions and consistent quality, both critical to the development of the emerging market demand. Hence, this reluctance to invest in new tooling can become a significant negatively reinforcing factor. One potential solution to this dilemma is the use of additive manufacturing for iterating and producing tooling with lower investment. This is an area which should be further investigated.

Questionnaire Key Points (#16)

- Responses were mixed on tooling. Some indicated that BOP would benefit most, others that stack hardware and bipolar plates would benefit most. Several responses pointed out the dynamic between volume and design stability in the decision to 'pull the trigger' on tooling.

Topic Area G: Market Concerns

Summary: Respondents were asked to comment on their greatest concern over the next five years relative to making investments in manufacturing processes, tooling or automation. Uncertainty in volume, high initial investments, and unavailability of needed technologies were provided as examples. The overwhelming response was a concern that volumes will not justify the expenditures. This response was consistent between OEMs and supply chain companies. A few of the respondents commented on the lack of process or quality technologies. While there has been significant progress over the last several years validating fuel cell products and establishing initial commercial demand, volume appears to be constrained by the relatively high cost of the fuel cell products. While it is remarkable that a significant amount of adoption of fuel cell products was able to occur through the "great recession," it is also likely that it has caused the current stalemate between investing in the cost reduction and achieving the next level of industry growth. Hence, the opportunity is to find methods for creating new demand and investing in innovative methods for reducing product costs. Achieving this could produce a new cycle of demand and self-sustaining market growth and industry investment.

Questionnaire Key Points (#17)

- The overwhelming response was the concern that ultimate market volumes will not justify capital expenditures.

Topic Area H: Funding

Summary: Although responses were split between the desire for funding to support commercial product deployments and funding to support further capital, manufacturing, scale up, etc., these could be seen as two aspects of the same challenge. As noted above, the industry has been very successful at developing and validating true commercial fuel cell products and early adopter customers have established initial commercial demand. However, a consistent theme has been the need to move the product cost lower in order to access the more typical applications and significantly large market demand. One way to do that is to stimulate demand through subsidized programs. The intent of such stimulus would be to “jump start” investment and supply chain cost reduction, which would lead to further, and ultimately self-sustaining, product demand. Another approach would be to invest in new designs, production techniques, tooling, etc. to lower the product cost, which in turn would stimulate demand and self-sustaining growth. Specific responses of this type were focused on stack/MEA cost reduction and quality techniques for MEAs. Both perspectives were voiced in the responses, yet it is not clear that either approach, alone would be sufficient to achieve the needed self-sustaining product demand. It is likely that some combination of targeted demand/deployment stimulus and cost focused investments and initiatives are needed.

Questionnaire Key Points (18,19,20,21)

- There was generally a bi-modal response to the questions on funding, incentives, and mechanisms to support the industry. Some indicated a desire for grants or funding focused on defraying development and/or capital costs for manufacturing capabilities, scale-up, and product qualification. Others indicated more of a preference for financial support of large-scale demonstrations or deployments that would seed demand in certain markets and potentially lead to follow-on industry-paid sales.
- Several indicated that the focus of funding opportunities should continue to focus on stack/MEA cost reduction.
- A few responses indicated that additional support for hydrogen infrastructure would help the industry.
- A few responses specifically mentioned the need for further development of quality systems for MEAs.

Topic Area I: Other Comments

Summary: As shown in the [Reference DOE report], joint efforts of the DOE and industry participants have resulted in significant technical and commercial progress for fuel cell products during an extremely challenging economic period. Products have been developed, commercially validated and the adoption cycle initiated. Comments in this section seem to mainly reflect the identified need to bring those products to a self-sustaining growth point through more targeted funding of development and deployment programs.

Questionnaire Key Points (#22)

- A few responses focused on the inadequacy of current funding mechanisms, such as SBIR and federal low interest loans, and called for better mechanisms for small companies. Others called for continued DOE support for Manufacturing R&D and early market deployment funding (market transformation).

Appendix A: References

Manufacturing Fuel Cell Manhattan Project, ACI Technologies, Inc., November 2011

2011 NREL/DOE Hydrogen and Fuel Cell Manufacturing R&D Workshop Report

New Approaches to Manufacturing Innovation in DOE, EERE August 16, 2013

Additive Manufacturing in Research & Development presentation and webinar by Brad Wright, Eaton Corp., February 11, 2014

An Assessment of the Current Level of Automation in Manufacture of Fuel Cell Systems for Combined Heat and Power Applications, Michael Ulsh, Doug Wheeler, NREL, August 2011

2013 DOE Hydrogen and Fuel Cells Program Review, Roots Air Management System with Integrated Expander, Dale Stretch EATON Corp., May 14, 2013

Fuel Cell Transportation Cost Analysis, Strategic Analysis, Inc., June 19, 2014

"Manufacturing Readiness Assessment for Fuel Cell Stacks and Systems for the Back-up Power and Material Handling Equipment Emerging Markets," D. Wheeler, M. Ulsh; NREL Technical Report number TP-5600-45406; May 2009.

"2010 Manufacturing Readiness Assessment Update to the 2008 Report for Fuel Cell Stacks and Systems for the Backup Power and Material Handling Equipment Markets," D. Wheeler, M. Ulsh; NREL Technical Report number TP-5600-53046; October 2011.

Appendix B: Questionnaire and Letter

February 27, 2014

Dear Hydrogen and Fuel Cell Industry member:

The National Renewable Energy Laboratory (NREL) is the U.S. Department of Energy's (DOE) primary national laboratory for renewable energy and energy efficiency research and development. NREL, in conjunction with the Hydrogen and Fuel Cell Technical Advisory Committee (HTAC), is conducting an assessment of the state of manufacturing techniques that are or could be used to benefit commercialization in the fuel cell and hydrogen generation industries. As you may be aware, the HTAC was established under Section 807 of the Energy Policy Act of 2005 to provide technical and programmatic advice to the Secretary of Energy on DOE's hydrogen research, development, and demonstration efforts. For more information on the HTAC, please visit: http://www.hydrogen.energy.gov/advisory_htac.html).

Your company is being asked to participate in an assessment of the status of manufacturing techniques because of its significant position in the industry. We are requesting that companies fill out the attached questionnaire to the best of their ability, and have a follow up call with a representative from NREL. Inputs into this process will be used to generate a report by NREL for HTAC that will make recommendations to the Secretary of Energy regarding how advanced manufacturing might enhance commercialization of fuel cell and hydrogen products.

Individual company responses to the questionnaire will be aggregated and no individual response will be attributed to any company. NREL will use the well-known data processing techniques of the National Fuel Cell Technology Evaluation Center (NFCTEC) to ensure data integrity and security. No HTAC members will have access to the individual company data collected as a result of this questionnaire. The HTAC/NREL will provide a copy of the aggregated assessment to each participant, thus we hope that participation will provide you with added value. For more information on the NFCTEC, please visit: http://www.nrel.gov/hydrogen/facilities_nfctec.html

The hard copy questionnaire is attached below. Please email your responses to these questions to Michael Ulsh at michael.ulsh@nrel.gov. After receipt of your response, Mike will contact your company representative to schedule a follow-up phone conversation on your responses, if desired.

Your feedback is highly valued and it is hoped that your company can participate in this process. If you have any questions or concerns, please do not hesitate to contact Michael Ulsh at 303-275-3842, or by email at michael.ulsh@nrel.gov.

Sincerely,
Michael Ulsh
Project Lead, Fuel Cell Manufacturing R&D, NREL

CC: Dr. Sunita Satyapal, Director, Fuel Cell Technologies Office
Nancy Garland, Ph.D., Technology Manager, Manufacturing R&D
Hal Koyama, Chair, HTAC Manufacturing Subcommittee

Fuel Cell and Hydrogen Generation Manufacturing Questionnaire

1. Briefly describe the product or component your company provides to the fuel cell or hydrogen generation industry.

2. What is your approximate current annual production volume vs. production capacity in kW and units?

3. By what percentage does the volume vary from year to year (say over the last three years)?

4. How many different products do you manufacture?

5. How would you characterize your production method - Batch, continuous, mixed?

6. How would you characterize the level of automation intensity in your factory? High = >80% of the product is made using automated manufacturing. Low = <20% of product is made using automated manufacturing. Moderate, between 20% and 80%. *Note: percentages are intended to represent percent of system cost, but may be subjective.*

7. What are the main components of your system or product, fabricated in house, versus sourced?

8. Standardization intensity: What is the estimated percentage of "standard" components in your product(s) by percent value coming from high volume, mature production processes, versus scientific, custom, unique, low volume components?

9. Do you believe there would be significant value (cost reduction) in using more "standard" components in your product?

10. Have you investigated automation or a significant change in manufacturing approach in your factory? If so, what kinds of alternate manufacturing techniques have you considered?

11. What is the minimum unit volume, or other conditions, needed to consider investment in in-house automation, or other new manufacturing techniques? What would be the primary motivation for such an investment – cost reduction, quality improvement, or performance enhancement?

12. Have you had discussions with key suppliers about them making investments in automation, or other cost saving manufacturing techniques, e.g. new mold? If so, what is the minimum unit volume, or other conditions they require in order to make such an investment?

13. Does your production process have a documented quality control system? What kind?

14. Are you familiar with the term "additive manufacturing," or 3D printed manufacturing? Do you or your supplier base use this technology? Are there specific areas in your product manufacturing which you think could benefit from it?

15. What are the components in your system / product which could realize the greatest cost benefit from advanced manufacturing, or changes in manufacturing techniques from current? Are these purchased and assembled or internally fabricated? Which could realize the greatest benefit in quality improvement from advanced or alternative manufacturing techniques?

16. It has been suggested that tooling, either in-house or at suppliers, could be a significant benefit to the fuel cell or hydrogen generation industry if it were possible to make changes more cost effectively for lower volumes, thereby facilitating more supplier willingness to invest (less risk) and lower component costs. Would this be a benefit to your product? What component(s) would benefit most?

17. What concerns you the most in the next five years regarding making investments in manufacturing processes, tooling or automation, e.g. volume will not justify it, initial investment too high, techniques needed are not available, etc.?

18. What incentives for investing in new manufacturing techniques would be appealing to you?

19. What priority needs do you have to enable a strong U.S. manufacturing industry in hydrogen and fuel cell technologies?

20. What research/funding can be leveraged, and from where, to achieve #19?

21. Where do you see the most need for DOE/Federal investment to help address your key issues?

22. Are there other questions/comments that would be valuable for answering #19 and 20, or any other feedback for DOE?

Appendix C: Presentation MSC Draft Report Summary to HTAC, November 19, 2014

MANUFACTURING SUBCOMMITTEE (MSC)

Draft Report Summary to HTAC

November 19, 2014

Charter and Formation

Investigate potential opportunities for advanced manufacturing to benefit H2 and Fuel Cell production and commercialization

Name	Organization and background
Adrian Coreless	Plug Power (participant for first half, expertise in material handling fuel cells and operations)
Gary Flood	HTAC/CEO Relion, Inc. Backup power fuel cell company.
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Robert Friedland	President and CEO, Proton Onsite. Commercial hydrogen generators.
Nancy Garland	Department of Energy
Cassidy Houchins	Department of Energy
Maurice Kaya	HTAC/Energy, Renewable Consulting
Arianna Kalian	Clear Edge Power. (participant for first half) VP operations, stationary fuel cell products
Hal Koyama	HTAC/CEO H2 PowerTech. Hydrogen reforming, backup power fuel cell products
Robert Shaw	HTAC/Energy technology, Venture Capital
Robert Stokes	VERSA Power Systems. Solid oxide fuel cells.
Levi Thompson	HTAC/energy Technology Research
Joe Triompo	HTAC Clear Edge Power (participant for first half)
Michael Ulsh	National Renewable Energy Laboratory

Focus and Process

- Sample industry to identify the range of manufacturing technologies and processes which could be considered.
- Focus on a subset of commercial or near commercial fuel cell and hydrogen production products / technologies to determine where there might be an opportunity to applying advanced manufacturing techniques.
- Develop hypotheses on opportunities with advanced manufacturing.
- Test, validate and refine hypotheses and update status of advanced manufacturing in the industry using questionnaire.
- Target output is a report on the status of use of manufacturing techniques, identification of additional opportunities for advanced manufacturing and identification of facilitation opportunities to enable further exploration and use.

Key Activities

- Identified and researched relevant published reports
- Participated in Clean Energy Manufacturing Initiative Toledo, Ohio regional summit, 6/21/13
- Participated in Clean Energy Manufacturing Initiative Western Regional Summit, San Francisco, California, 4/17/14
- Conducted initial informal hydrogen and fuel cell industry interviews with industry participants
- Generated and, in conjunction with NREL, implemented an industry questionnaire to target specific areas of feedback

Industry Questionnaire

Range of industry represented. Total number of participants limited to 9. Questionnaire administered by Mike Ulsh of NREL to ensure confidentiality of individual responses.

Company	Industry Segment
General Motors	Fuel cell vehicle automotive OEM
Proton Onsite	Hydrogen generator OEM
Hydrogenics	Stationary fuel cell OEM
Plug Power	Material handling fuel cell OEM
Altergy	Stationary backup power fuel cell OEM
Ballard Power	Stationary and bus fuel cell OEM
Eaton	Fuel cell balance of plant component supplier
3M	Fuel cell MEA supplier
American Trim	Fuel cell component supplier

Questionnaire Feedback Areas

- Topic Area A: Volume and Capacity
- Topic Area B: Automation
- Topic Area C: Standardization
- Topic Area D: Quality Systems
- Topic Area E: Opportunities for Advanced Manufacturing
- Topic Area F: Status and Opportunities for Tooling
- Topic Area G: Market Concerns
- Topic Area H: Funding
- Topic Area I: Other Comments

* Letter and questionnaire provided for reference.

Executive Summary

- Significant progress has been made in commercialization of fuel cells and hydrogen generation – products accepted in industry
- Adoption is at a “tipping point” requiring further cost reductions to achieve self-sustaining growth.
- Suppliers and OEMs are reluctant to invest in areas which could achieve these cost reductions, due to uncertain demand and timing of demand.
- Initiatives in a few key areas could have significant positive impact on moving the industry into the next phase of growth.
- Recommending three areas for further work.

Recommendation 1: Targeted demand stimulation programs, including deployments in and outside the United States

- Focus on proven commercial products
- Include existing customers, but attract new ones
- Emphasis on accessing export opportunities / non-USA markets
- Participants should demonstrate integration of products into their normal purchasing and decision processes
- Participants should provide purchasing criteria feedback for next level of volume adoption

Recommendation 2: Selected key component cost reduction and standardization

- A few components could have significant impact on total product cost.
- There may be significant opportunity at this time to leverage synergy between automotive and stationary volumes and supply chains.
- Recommend deep dive, quantitative assessment of standardizing and/or consolidating specific components and materials, and the potential intersection between stationary and automotive

Recommendation 3: Greater access to additive manufacturing and other advanced manufacturing techniques

- Additive manufacturing may be valuable at this stage for lowering the cost barrier to innovating on parts and tooling which could lead to product cost reductions, even without volume increases.
- Access to additive manufacturing and other advanced manufacturing methods, seems to be limited by fragmentation and/or cost, creating a barrier to fuel cell companies to take advantage of these resources.
- Recommend focused (specific parts/components) assessment of additive manufacturing potential impact on cost for fuel cell OEMs and suppliers.
- Recommend assessment of how to better coordinate and make available advanced manufacturing tools to fuel cell and hydrogen OEMs and suppliers, e.g. network, central facility, etc.

Next Steps

- Receive input from HTAC over the next 2 weeks
- Refine and submit final report (draft included in HTAC material binder)