MANUFACTURING SUBCOMMITTEE

Update to HTAC

April 2, 2014

Charter and Formation

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

Name	Organization / Focus
Adrian Corless	Plug Power (Left Plug, no replacement for subcommittee planned)
Gary Flood	HTAC / Relion Inc.
Charles Freese	HTAC / General Motors
Robert Friedland	Proton OnSite
Nancy Garland	Department of Energy
Cassidy Houchins	Department of Energy
Maurice Kaya	HTAC / Energy, Renewable Consulting
Arianna Kalian	Clear Edge Power
Hal Koyama	HTAC / H2 PowerTech
Robert Shaw	HTAC / Energy Technology, Venture Capital
Robert Stokes	Versa Power Systems / SOFC
Levi Thompson	HTAC / H2 Energy Technology Research
Joe Triompo	HTAC / Clear Edge Power
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.

Initial Feedback (informal interviews, limited sample size)

Common themes:

- All have demonstrated H2 and Fuel Cell products which are commercially suitable, but address a narrow market, due to cost
- Very few commercial players trying to change the landscape, generate adoption, etc.
- Product cost and/or H2 availability/cost are the key barriers to accelerated growth
- All currently focus on batch and manual labor methods due to rate of technical change and low volumes

Take away points with regards to advanced manufacturing methods/technologies:

- A few components make a significant difference in cost and performance, e.g. stack and components for FC and compressors for H2 production.
- Higher and more consistent demand/volume of products is the most important factor to help suppliers of key components significantly reduce cost.
- Standardization across companies and applications is the second most important factor to help suppliers reduce their cost of key components.
- Supply chain fatigue and quality performance. Unwilling to project cost/volume, invest in the future due to multiple stops and starts with fuel cells.
- Performance (other than cost) in the key components does not seem to be a focus.
- There is skepticism about new manufacturing techniques being able to help commercialization in near term.
- Most final assembly is batch/hand due to it being more cost effective at current volumes than automated approaches. Methods introducing automation that can deal with a wide variety of product types/models could be useful at higher volumes.
- Specialized / new manufacturing techniques at the component supplier level could be beneficial, but requires investment in an uncertain and historically unreliable end market.
- Not my problem syndrome. Fuel cell equipment providers and hydrogen fuel providers pointing at each other as the problem for better economics and growth. Potentially unrealistic expectations of H2 fuel prices.
- The “next big thing” in technology, e.g. platinum free, is always brewing. Added investment uncertainty.

Underlined and blue highlighted indicates areas where advanced mfg could help

Industry Feedback / Questionnaire

- Questionnaire and process developed for structured and direct industry feedback*
- Three categories: Fuel Cell System producers (27), H2 Generation System producers (6), Suppliers (11)
- Government regulations limited sampling to 9 total: 3 FCS producers, 3 H2 producers, and 3 Suppliers chosen
- NREL (Mike Ulsh) conducting the questionnaire process for confidentiality
- Results will be aggregated, summarized and assessed by against earlier information for conclusions

* Letter and questionnaire provided for reference.

Additive Manufacturing

- Current state of H2 and fuel cell industry is low volume production with high rate of technical and commercial change
- Financial support and supply base are reluctant to invest in development and / or the cost is prohibitive
- In this environment, additive manufacturing techniques stand out as potential opportunity
- Specific areas where additive manufacturing could assist fuel cell and H2 in accelerating commercialization and/or commercial penetration include
  - Rapid prototyping at lower cost and risk
  - Low cost tooling to provide lower cost, at lower volume components
  - Expanded component design options to simultaneously address cost, reliability and durability
- DOE held webinar on additive manufacturing highlighted its potential

Additive Manufacturing*

Metallic Substrates

- Supplier Techniques
- Direct Metal Laser Sintering (DMLS)
  - Laser fused powdered metal
  - Geometry capability beyond any traditional manufacturing method
  - Common alloys available (Stainless Steel, Titanium, Aluminum, Inconel®, etc.)
  - Extremely quick turnaround
  - Competitive pricing compared to billet
  - Requires additional machining (tolerances up to +/-0.005”)
- Rapid Casting
  - Lost wax investment casting utilizing an SLS fabricated disposable pattern
  - Quick lead time compared to traditional casting
  - Turnaround time on par with billet
  - Requires additional machining

Aluminum DMLS Part

Aluminum DMLS Surface Finish

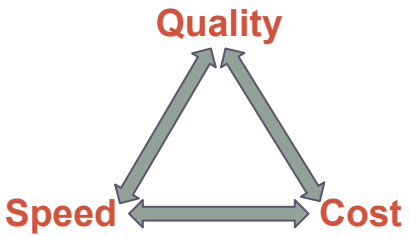
Aluminum DMLS Part Post Machining

* From Additive Manufacturing for Fuel Cells webinar, Feb. 11, 2014
http://www1.eere.energy.gov/hydrogenandfuelcells/webinar_archives_2014.html#date021114

Additive Manufacturing*

Value Proposition

- Considerations
  - Application / Material Properties
  - Part Quality
  - Lead Time
- Production Volume / Quantity
- Part Cost
- Tooling Cost



FDM	DMLS	Rapid Cast	Billet	Production Cast
Lead Time - 8 hours Cost - $50	Lead Time - 3 Days Cost - $2500	Lead Time - 4 weeks Cost - $2000	Lead Time - 4 weeks Cost - $1500	Lead Time - 2 Months Cost - $5

Lead Time →

Cost ←

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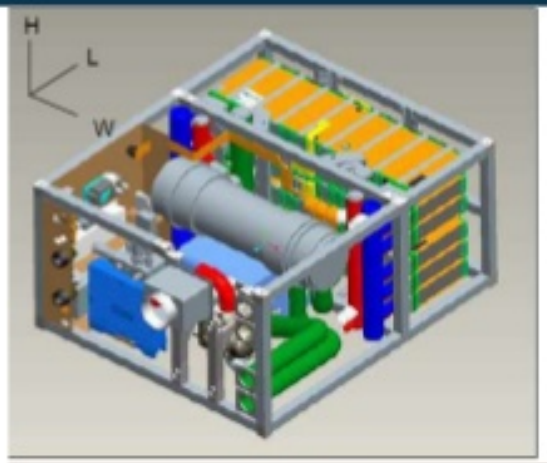
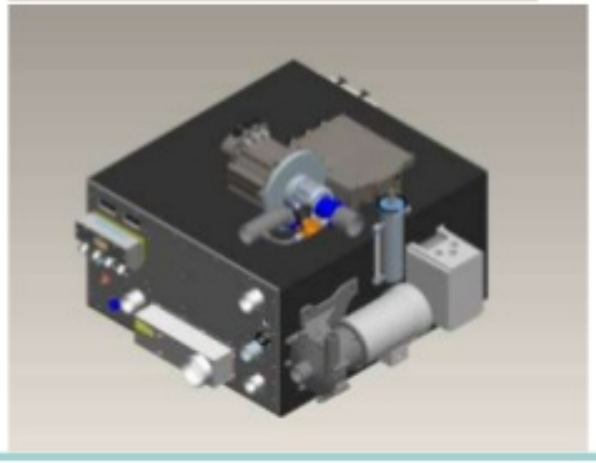
Fuel Cell Air System

FCvelocity-HD7 Module

- Latest generation fuel cell stacks
- Reduced parts count
- Higher FC stack durability
- Lower price
- Air compressor and coolant pump included in scope of supply
- Lower Parasitic loads
- Scalable from 50 to 200 kW
- Available by Q2 / 2014





Courtesy of Larry Stapleton, VP Sales, Ballard, from Ballard Fuel Cell Bus Presentation, November 2013

Next Steps

- Collect questionnaire feedback, change recipients if needed
- Process feedback with subcommittee and iterate any open points
- Produce findings and suggestions
- Suggest inviting additive manufacturing specialist speaker to next HTAC meeting

Resources

- **2011 NREL/DOE HYDROGEN AND FUEL CELL MANUFACTURING R&D WORKSHOP REPORT**
- **Manufacturing Fuel Cell Manhattan Project,** Copyright 2011, ACI Technologies, Inc. All Rights Reserved, including rights of the U.S. Government under Contract No. N00014-08-D-0758
- **New Approaches to Manufacturing Innovation in DOE,** presentation by Kelly Visconti, August 2013, EERE
- **An Assessment of the Current Level of Automation in the Manufacture of Fuel Cell Systems for Combined Heat and Power Applications,** Technical Report NREL/TP-5600-52125, August 2011
- **2013 DOE Hydrogen and Fuel Cells Program Review** Project ID: FC103. Roots Air Management System with Integrated Expander, Eaton Corporation May 14, 2013