

U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis (PEM Automotive FC)

A Preliminary Status Update

Presented to:

2016 Ohio Fuel Cell Symposium DOE

Presented by:

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- Preliminary Report Only as of September 27, 2016
- Interviews Conducted: 7 OEM, 23 Tier 1's
- Visits Conducted: 3 OEM, 19 Tier 1's
- DFMA Cost Analysis: OEM's and Tier 1 supplier cost direction
- RFQs In Process: Tier 1's quoting to generic drawings By SA and GLWN of key components
- Team Members:
 - GLWN: Patrick Fullenkamp (PI), Dee Holody
 - Strategic Analysis Inc. (SA): Brian James, Cassidy Houchins
 - DJW Technologies: Doug Wheeler
 - E4tech: David Hart, Franz Lehner

Key Points by Region

- **Japan**
 - **National support for markets, level of certainty, enabling suppliers to develop manufacturing knowledge and capability lead by Toyota and Honda**
 - Suppliers are making incremental steps
- **China**
 - **GHG reduction policy with bus promotion** (8.5m to 12m mostly hybrid) enabling suppliers to gain experience.
 - Suppliers seeking U.S. and European expertise.
- **Europe**
 - **Fuel Cell development funded by both EU and Germany to address technology and cost barriers.**
 - German suppliers leveraging current products and processes
- **United States**
 - **U.S. DOE Hydrogen Fuel Cell Office technology and cost targets recognized globally.**
 - Fuel Cell bus and small fueling demonstrations (Stark County Transit Canton OH, Brentwood Post Office near Washington DC, LA Transit...)
 - **U.S. suppliers engaged globally.**

US/NA Manufacturers supplying to Asia and Europe

“Gore Technology Enables Toyota Mirai Fuel Cell Electric Vehicle | Gore.” Press Release. W.L. Gore, March 3, 2016. <http://www.gore.com/news-events/press-release/fuel-cell-components-news-gore-technology-enables-toyota-mirai-fuel-cell>.

Ballard Inks Fuel Cell Module Deal, Expanding into China’s Guangxi Province Press Release
September 7, 2016 <http://ballard.com/about-ballard/newsroom/news-releases/news09071601.aspx>

Key Components - Readiness at 1,000 and 100,000 vehicle volumes

Readiness for Production at 1,000 vehicles/year								
OEM	BPP		MEA		CEM		PV	
	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG
1	YES	YES	YES	YES	YES	YES	YES	YES
2	YES	YES	YES	YES	n/a	n/a	YES	YES
3	YES	YES	YES	YES	YES	YES	YES	YES
4	YES	YES	YES	YES	YES	YES	YES	YES
5	Maybe	YES	YES	YES	n/a	n/a	YES	YES
6	YES	YES	YES	YES	n/a	n/a	YES	YES
7	YES	YES	YES	YES	YES	YES	n/a	n/a

Readiness for Production of > 1,000 and up to 100,000 vehicles/year								
OEM	BPP		MEA		CEM		PV	
	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG
1	NO	NO	NO	NO	NO	NO	NO	NO
2	NO	NO	NO	NO	n/a	n/a	NO	NO
3	NO	NO	NO	NO	YES	NO	NO	NO
4	NO	NO	NO	NO	YES	NO	NO	NO
5	NO	NO	NO	NO	n/a	n/a	NO	NO
6	NO	NO	NO	NO	n/a	n/a	NO	NO
7	NO	NO	NO	NO	NO	NO	n/a	n/a

Legend	
YES	Ready
Maybe	Advancements needed to be ready
NO	Not Ready

Overall, current capability up to 1K maybe 10K/yr. vehicles and further substantial investment needed for 100K/yr.

Readiness for Production at 1,000 vehicles/year										
SUP	BPP		Membrane		GDL		Catalyst		PV	
	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG
1	YES	YES								
2	YES	YES								
7	YES	YES								
13	YES	YES								
14	YES	YES								
15	YES	YES								
16	YES	YES								
20	YES	YES								
11			YES	YES						
5			YES	NO						
18			YES	YES						
8			YES	YES						
19			YES	YES						
9					YES	YES				
10					YES	YES				
12					YES	YES				
6							NO	NO		
17							YES	YES		
3									YES	YES
4									YES	YES

Readiness for Production of > 1,000 and up to 100,000 vehicles/year										
SUP	BPP		Membrane		GDL		Catalyst		PV	
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5			YES	NO						
18			YES	NO						
8			YES	NO						
19			NO	NO						
9					NO	NO				
10					YES	YES				
12					YES	Maybe				
6							NO	NO		
17							YES	NO		
3									YES	YES
4									NO	YES

Summary Observations -General

- **Regional FC production/assembly is expected**
 - Similar to automotive industry today
 - NA production for NA consumptions, Europe=>Europe, Asia => Asia
- **IP/know-how** generally more important than low labor/utility cost
- **Shipping costs** are negligible. Many products in roll-form.
- We are in a **paradigm of enticing suppliers** with core skills and resources but no business equation for them to participate
- **Key to low cost is a fully utilized flexible manufacturing facility** – similar products multiple markets
- **Balance manufacturing** to common takt times for all components, and ideally in one manufacturing complex

Summary Observations -General

- **Need plan to get volumes** to the 100,000 vehicle level and engaging a larger supply base.
- **Manufacturing R&D** needed to increase processing speeds and decrease number of parallel lines needed.
- **Additional quality control development needed** for high rate production for virtually all components
- Relatively **small number of component suppliers** capable of meeting automotive standards

Summary Observations - Bipolar Plates

- **Material** Stainless steel is the predominate BPP base material. **Custom based design of materials is missing.**
- **Handling/Assembly of individual BPPs is a significant challenge**
 - Sealing approaches differ between OEMs
 - Welding and adhesives are the dominant approaches
 - Handling and registering thin bipolar plates in automated assembly will be challenging; one solution may be to assemble cells from stamped coil
- **Laser welding**
 - **Welding is the bottleneck** of the steel plates: cycle times need to be improved
 - Engineering solutions can achieve fast(er) cycle times (<2 sec) (via multiple beams, progressive welding stations, etc.)
- **Coating and Sealing**
 - Vacuum deposited coating is viewed with some skepticism
 - OEMs looking for better sealing systems
- **R&D areas** – Power density flow field, sealing material and process, coating material and process, laser welding process, roll-to-roll continuous production, custom design of materials

Summary Observations - Membrane

- **PFSA Ionomer:** will likely be manufactured as one component in a portfolio of products from a fluoropolymer manufacturer at an existing chemical plant
- **Place on value chain:** companies considering membr., CCM, catalyst prod.+CCM
- OEMs like to **collaborate to share cost/risk and pool demand**, with one membrane supplier for a group of companies.
- Not all membrane suppliers are at the same **technology level**, therefore the price remains high until multiple comparable competitors
- During the process there will be **rapid change in membrane, medium in GDL, and low in catalyst**. Balance is needed among these different manufacturing facilities.
- Suppliers are conservative with investment with high change potential at this pre-maturity stage
- **Future generally envisioned as thin (7 to 10 micron) ePTFE supported membranes** to achieve balance point of strength and performance
- **R&D areas** – reduce thickness of membrane, reduce platinum amount and catalyst cost, power density, durability, higher speed manufacturing, QC to correlate size and type of defect, fully flexible manufacturing facility with similar products multiple markets

Summary Observations - Catalyst

- Precious metal (**Pt**) **catalyst** are expected for **foreseeable future**
- Cost is dominated by platinum cost
- Focus on **durability, performance, and Pt reduction**
 - Pt Target: 7 – 9 gram Pt/system
- High barriers to entry into catalyst business
 - **Only few companies in world** viewed as suitably reliable suppliers for OEM long-term partnership
 - **Long development cycles, high overhead, much IP and trade secrets**
 - **Physical security of Platinum** through all stages is a concern
- Pt recycle is complex and a substantial cost
- **R&D areas** – different ink formulation for cathode, different elements, reduced Pt loading,

Summary Observations

Gas Diffusion Layer (GDL)

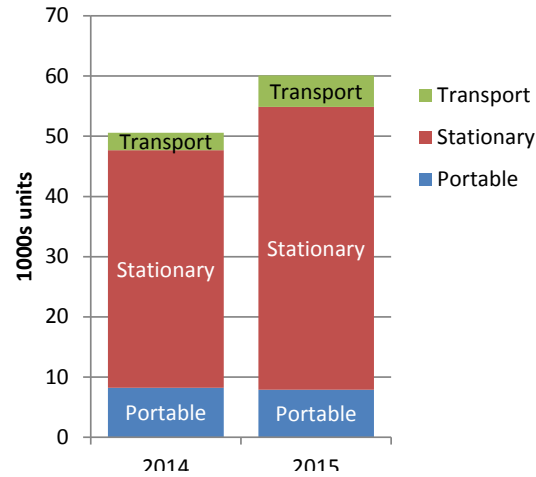
- **GDL is currently produced:**
 - From PAN carbon fibers
 - Using paper-making process equipment
 - Using a high temperature carbonization/sintering process
 - Using coating/MPL layer application(s)
- **GDL is relatively expensive** and OEMs are in search of ways to reduce/eliminate use of carbon fiber (while retaining the MPL)
- Price is currently quite variable presumably due to **production rate and scrap differences:** high plant utilization, wide (~1m) and custom widths preferred
- **Complex processing knowledge** is held as **trade secrets** thereby creating a barrier to competitor's market entry.
- **Characteristics needed for GDL** – electr. conduct., heat transfer, gas permeable
- **Thinning** has its limits since GDL acts like a spring
- **GDL cost drivers** -carbon fiber cost do not drive GDL cost but total materials are about 50%, slow carbonization and sintering processes
- **R&D areas** – alternatives to carbon paper, reducing thickness

Summary Observations - Pressure Vessel

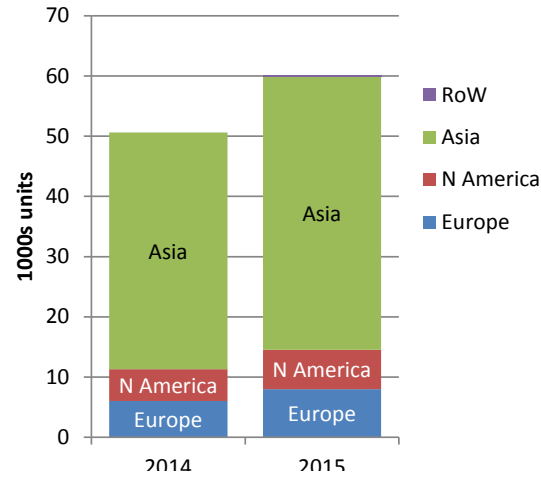
- **Carbon Fiber (CF)**
 - Pressure vessel cost is dominated by CF price
 - Toray is the led supplier, although 5 – 6 alternates exist with lower tensile strength
 - Entry into the market is difficult and capital intensive
- **Current winding process has long history** – NASA, ICBM, High Pressure CNG storage vessels. Applying same technology to hydrogen vessels
- **Shipping** will likely play a moderate role in siting pressure vessel suppliers near auto assembly plants, since it is more efficient to ship spools of carbon fiber
- **BOP** will need to be warrantied/tested: this may open an opportunity for a Tier 1 storage system integrator separate from the vessel manufacturer
- **R&D areas-** different type of vessel, alternative to multiple winding lines, lower grades of CF, library of tanks, match the resin and carbon fiber, coupon testing of alternate material combinations

2014 – 2015 Fuel Cell Market Data – E4tech

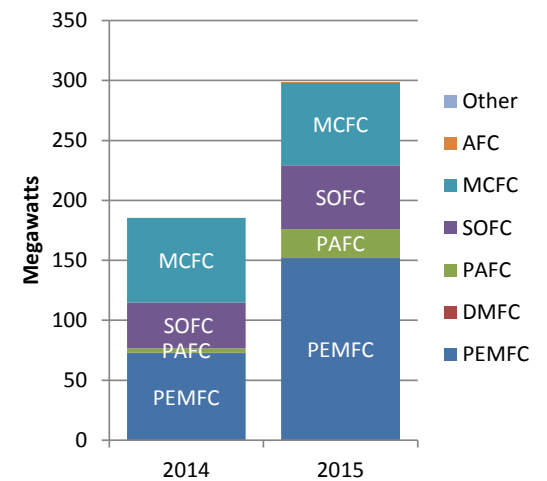
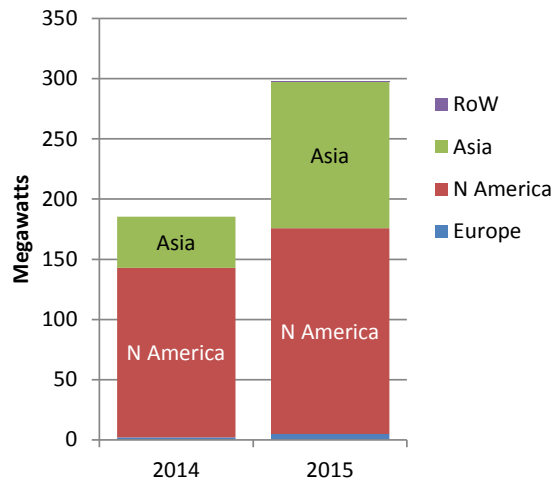
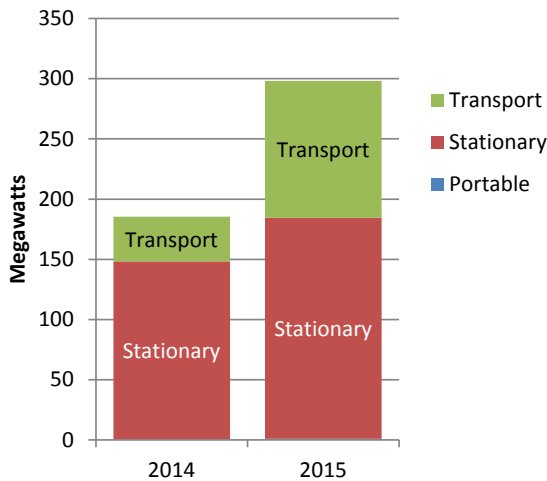
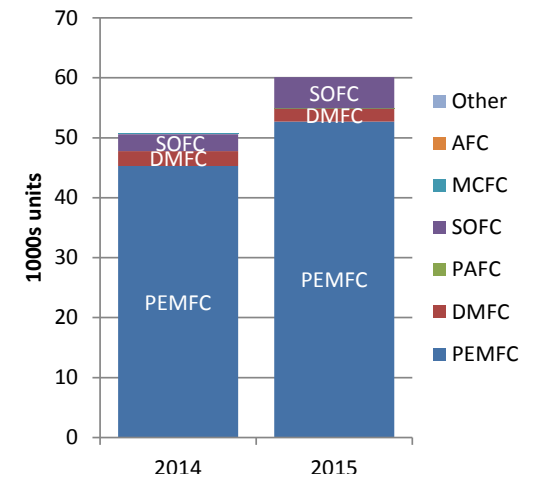
By application



By region of manufacture



By fuel cell technology



E4tech 2015 Market Data Collection Process

- **Gathered and delivered FC system shipment data for 2014 and 2015. Main highlights in 2015 figures are:**
 - Strong increase in megawatts shipped from Asian manufacturers, mainly because of the launch of Toyota's Mirai and growing numbers of Hyundai's Tucson fuel cell cars
 - Some increase in units and megawatts shipped from Asian manufacturers from growing numbers of micro CHP fuel cells installed under Japan's Enefarm program
 - Several US based manufacturers show year on year growth as well, in particular Doosan Fuel Cell America
 - Fewer fuel cell systems were manufactured in Europe, despite a large number of local companies
 - In stationary applications micro CHP dominates the unit numbers, large CHP dominates the megawatts
 - In transport, for the first time, FCEVs are the main contributor to the megawatt figure, followed by material handling applications such as fork lifts, previously dominant in this segment
 - In portable applications, chargers for consumer products still dominate the unit numbers, but shipments are lower than projected or are getting delayed. Portable off-grid power remains successful in this segment.
 - PEMFCs continue to dominate across applications and regions, because of the versatility of the technology
 - Other fuel cell technologies continue to contribute to the mix. PAFC has seen growth year on year, and AFC is being deployed in small amounts
- **Gathering of shipment data for key components ongoing (MEA, GDL, Bipolar plates, BOP).**

Questions?

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