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

A Preliminary Status Update

Presented to:

HTAC

Presented by:

Patrick Fullenkamp, GLWN

7 December 2016

Department of Energy
Award No. DE-EE-0006935

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Project Status

- Preliminary Report Only as of December 7, 2016
- Interviews Conducted: 7 OEM, 27 Tier 1's
- Visits Conducted: 3 OEM, 20 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

Patrick Fullenkamp, Principal Investigator

Patrick Fullenkamp joined GLWN (Global Wind Network) in October of 2009 as the Director of Technical Services to support manufacturing and renewable-energy related initiatives.

- 30 years prior experience in the automotive sector in international supply chain, engineering, manufacturing, quality, project management, and logistics. He started manufacturing facilities in the U.S., Portugal, India, and Mexico
- Principal Investigator for U.S. DOE Project "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: a Competitiveness Analysis"
- He leads the offshore supply chain development initiative and has worked with the offshore industry leaders in Europe and U.S., visited ports and manufacturing facilities in Germany, Denmark, and China.
- Principal Investigator for a U.S. DOE Project "U.S. Wind Energy Manufacturing and Supply Chain: A Competitive Analysis"
- BS in Mechanical Engineering from General Motors Institute and a Master of Science in Manufacturing Management from Kettering University.

GLWN

Cleveland-based **GLWN** is a non-profit international advisory group of Engineering and Manufacturing Executives that have been developing regional supply chains and **making a market for U.S. manufacturers** in the wind and emerging renewables clean energy industries since 2007. GLWN is a initiative of Westside Industrial Retention & Expansion Network (WIRE-Net)

- **DE-EE-0006102, "U.S. Wind Energy Manufacturing and Supply Chain: A Competitiveness Analysis"** project had a purpose of obtaining a greater understanding of the key factors determining wind energy component manufacturing cost and pricing on a global basis in order to enhance the competitiveness of U.S. manufactures and reduce installed system cost.
- This project **collected first-of-a-kind actual quoted manufacturing cost and verified process data via visits to 22 suppliers** across U.S., Europe, and Asia for towers, blades, foundations, and permanent magnet (PM) generators, for next generation wind turbines (3 MW and 5 MW) for both land-based and offshore applications.
- Our national and global clean energy supply chain work has also led to projects with NREL, Lawrence-Berkley labs, State and private energy groups with a focus on **assessing domestic manufacturers ability to compete** in emerging and next generation clean energy markets.

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 investment steps in capacity
- **China**
  - **GHG reduction policy with bus promotion** (8.5 m to 12 m mostly hybrid) enabling suppliers to gain experience
  - Suppliers seeking U.S. and European expertise for China Market growth.
- **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, D.C., LA Transit…)
  - **U.S. suppliers engaged globally**

U.S./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

New U.S. manufacturing opportunities exist today as automotive OEM's want 2 sources per component.

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

Readiness for Production at 1,000 vehicles/year								
	BPP		MEA		CEM		PV	
OEM	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 Productionof > 1,000 and up to 100,000 vehicles/year								
	BPP		MEA		CEM		PV	
OEM	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 1 K maybe 10K/yr vehicles and further substantial investment needed for 100K/yr

Readiness for Production at 1,000 vehicles/year										
	BPP		Membrane		GDL		Catalyst		PV	
SUP	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 Productionof > 1,000 and up to 100,000 vehicles/year										
	BPP		Membrane		GDL		Catalyst		PV	
SUP	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG	TECH	MFG
1	YES	NO								
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20	YES	NO								
11			NO	NO						
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

Broad Themes that Apply to FCEV Industry

- **Free and open markets with multiple (3–5) potential suppliers for each component are needed to create a competitive marketplace, drive down prices, and prevent being dependent on an individual supplier.**
  - At least two interchangeable suppliers is a prerequisite for any single OEM.
  - Most interviewees felt that this condition would be achieved when several OEMs achieved sales of around 100k-500k FCEVs per year.
  - It takes around 2 years to build relationships between suppliers and OEMs.
- **It is likely that the automotive FC industry will develop into the same kind of supply structure the modern auto ICE industry has developed into.**

Broad Themes that Apply to FCEV Industry

- **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

Broad Themes that Apply to FCEV Industry

- **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.

Postulated Supply Chain

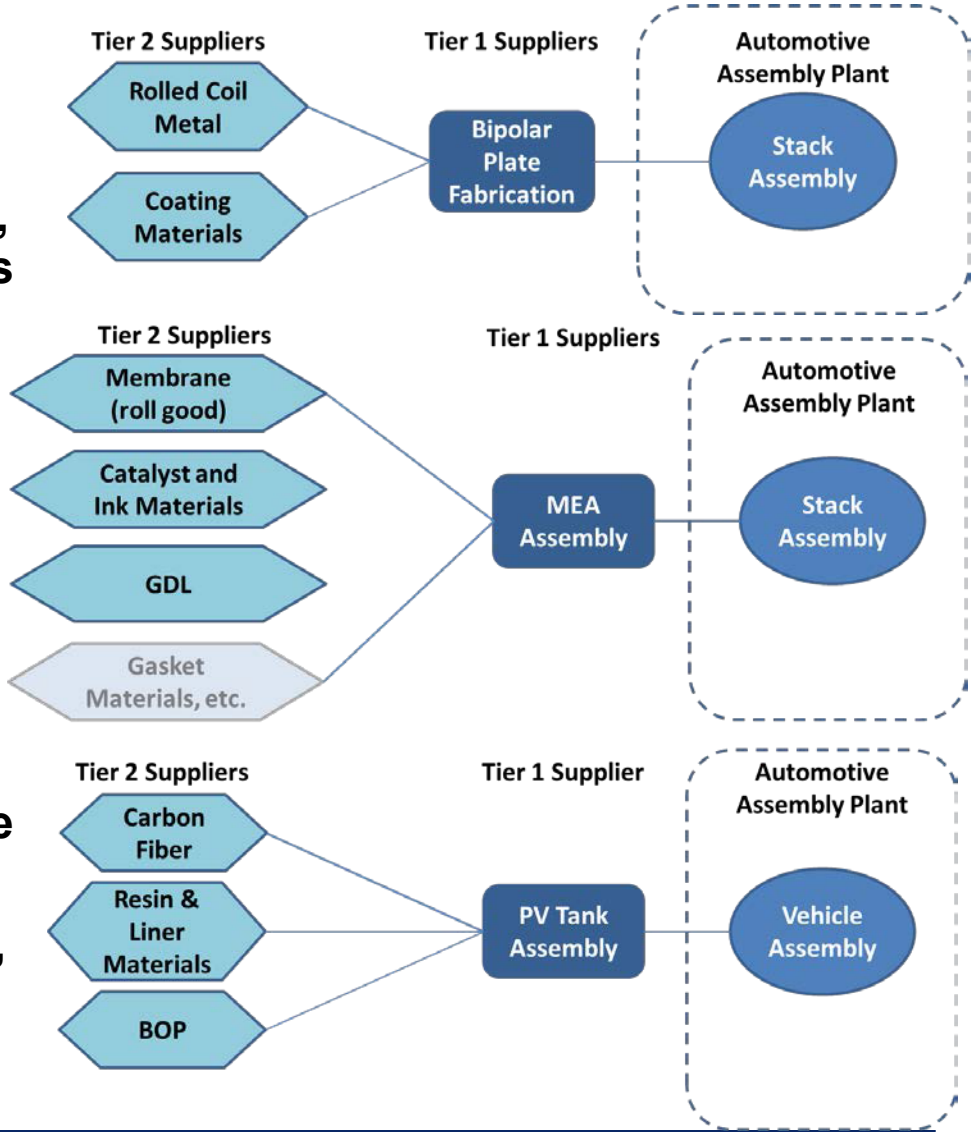
- General agreement that the postulated supply chain scenarios were feasible.
- But other scenarios are possible/likely.
- **Key to low cost is a fully utilized, flexible manufacturing facility – similar products for multiple markets, possibly with common base materials and customized assembly.**
- For low rate production:

  - Centralized prod., single facilities supplying multiple customers

  - Greater OEM & supplier vertical integration (out of necessity)

  - For high rate production, the fuel cell supply chain will probably mimic the current ICE automotive supply chain:

- **North American FC production for the North American FC market,**
- **Asia production for the Asian market,**
- **European production for the European market.**



Technology and Manufacturing Readiness of the Industry

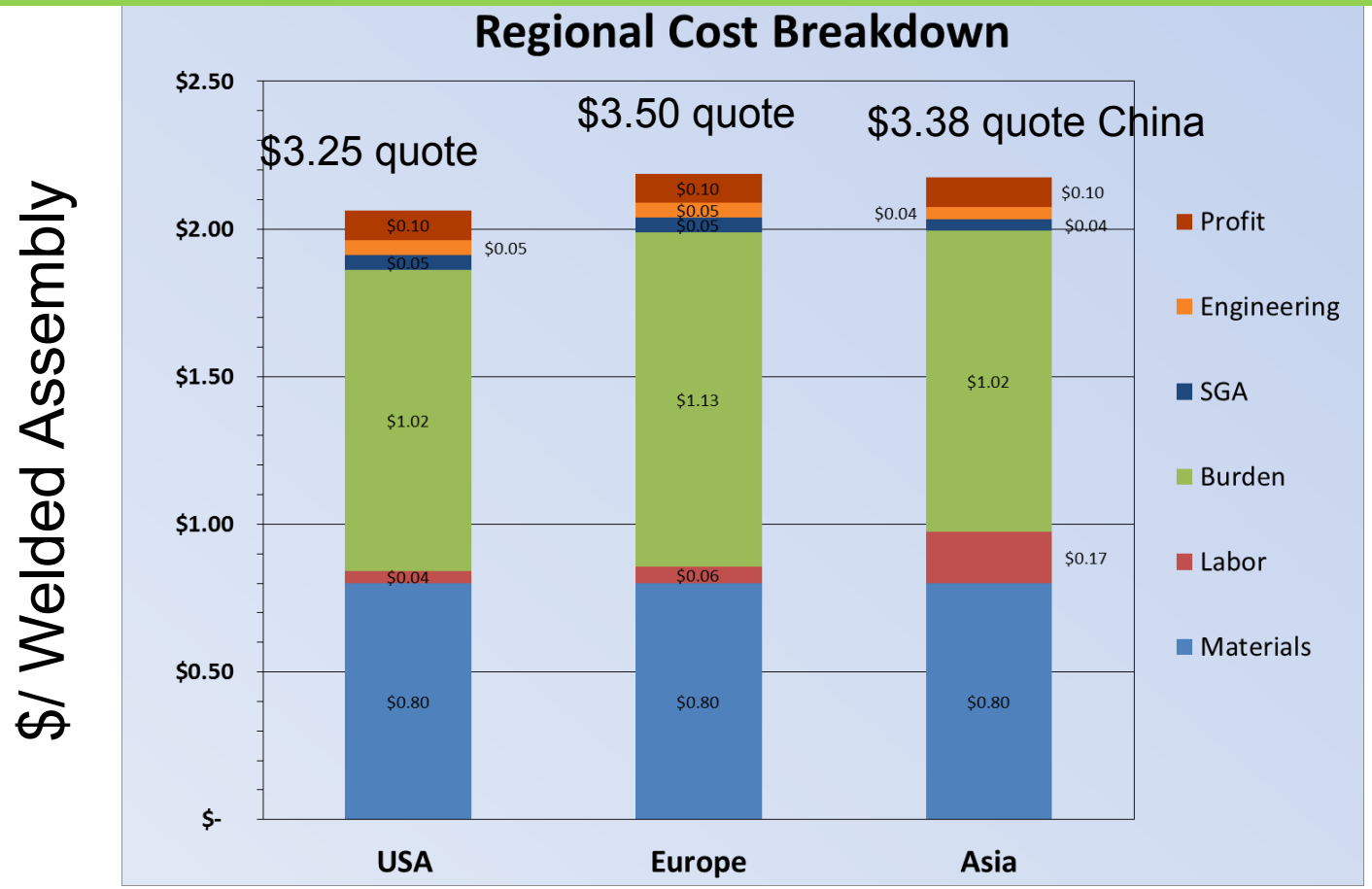
- **Current manufacturing techniques are capable of supplying 10k-30k FCEVs per year** on a single fully utilized production line for key components (BPP, membrane/CCM/MEA, GDL, pressure vessels)
- Using many parallel production lines to increase capacity is **not** easily feasible due to QC concerns. This suggests that new manufacturing technology is needed (for BPP, PV winding, laser welding, coating).
- **Technology readiness**: most components are **suitable for 1k/year and 10k/year production**, but need some level of basic technology improvement to achieve the cost goals of 100k/year production.
- **Manufacturing readiness**: most components are **suitable for 1k/year and 10k/year production,** but need substantial investment for facility scale-up to 100k/year and in most cases substantial manufacturing research to develop the high-speed, reliable, manufacturing methods with the required quality control. However manufacturing shortfalls were generally not viewed as “show-stoppers”.

Summary Observations - Bipolar Plates

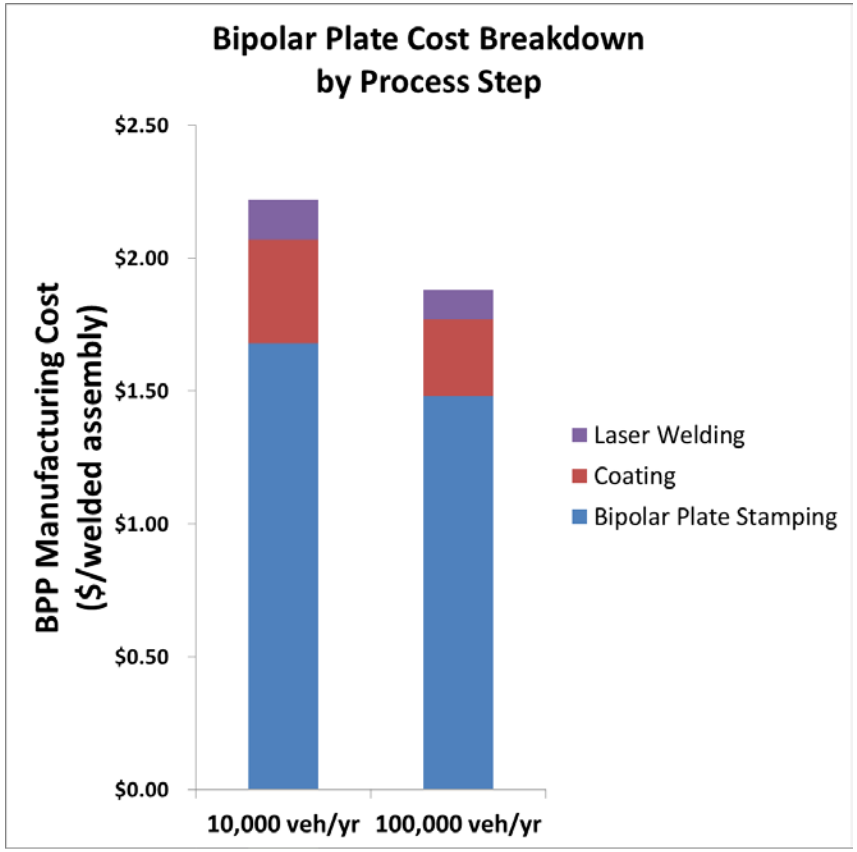
- **Bipolar Plates will likely be supplied as welded stainless steel and coasted assemblies. Custom based design of materials is missing.**
- **Handling/Assembly of individual BPPs is a significant challenge**
  - Sealing approaches differ between OEMs
  - Welding and adhesives are the dominant approaches
  - 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 improved
  - Engineering solutions can achieve fast(er) cycle times (<2 sec) (via multiple beams, progressive welding stations, etc.)
- **Coating and Sealing -** OEMs looking for better sealing systems
- **4–5 suppliers worldwide** are currently capable of producing BPP's with the quality and reliability required by OEMs
- **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

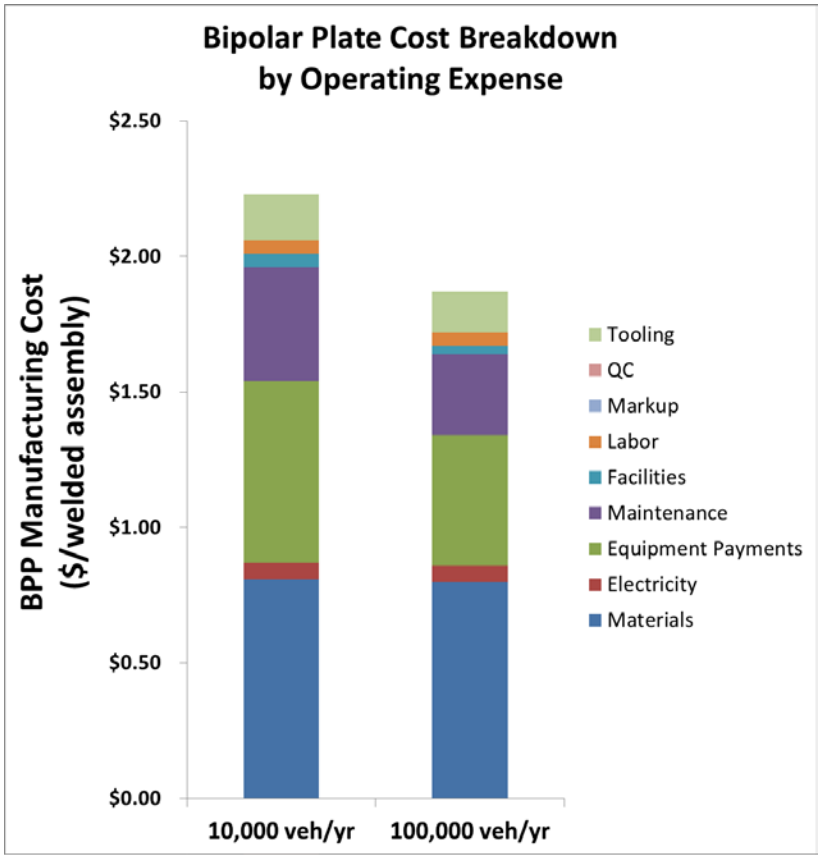
BPP CBA at 100k/year Vehicles

Global commodity pricing reflected for stamped welded assembly. Differences between CBA & quotes is suspected for consequence of supplier low volume selection of process for coating and welding.



Bipolar Plate Costs: DFMA Results

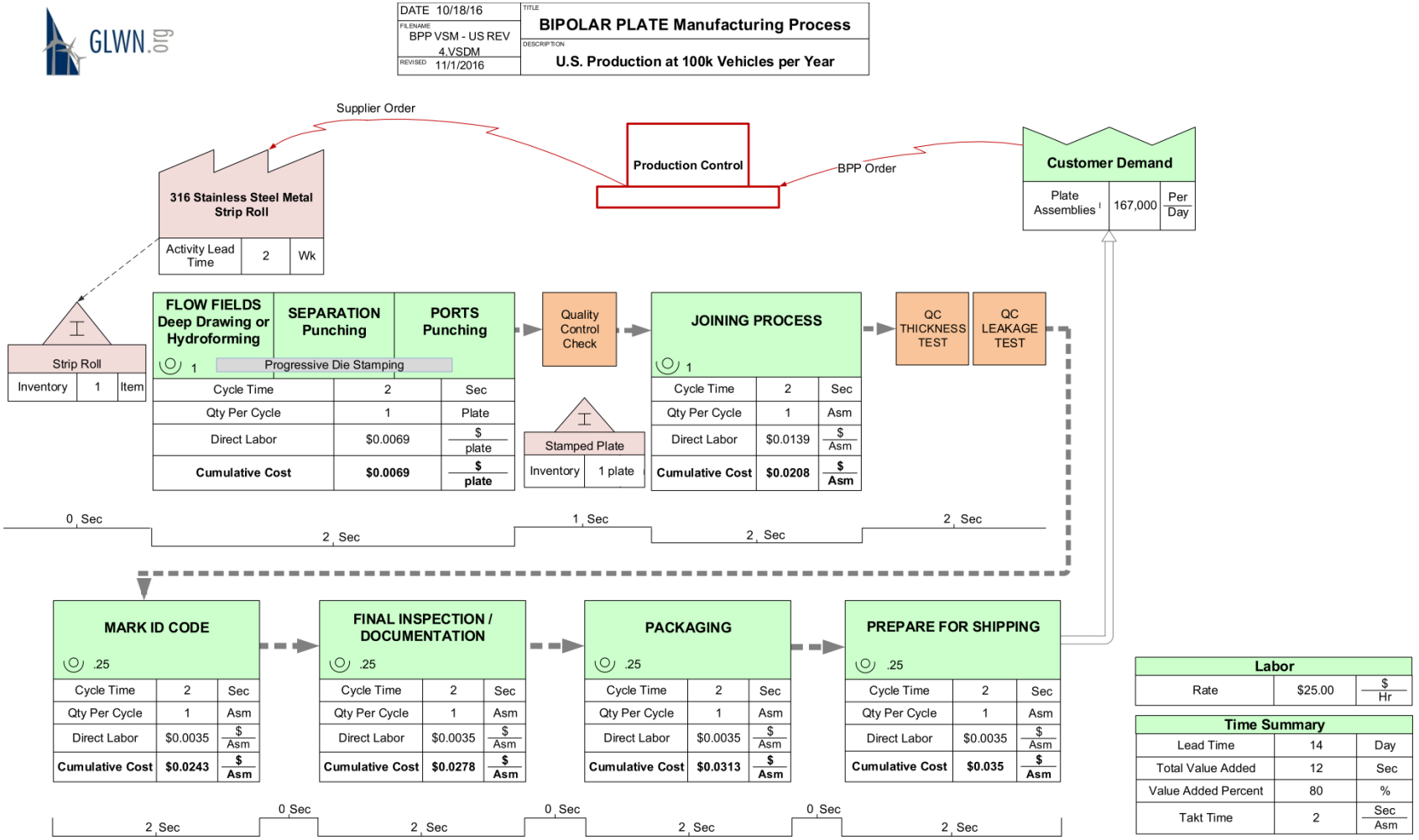




- DFMA results for stamped, welded, and coated bipolar plates
- Facilities cost are not typically included in DFMA analysis, but were estimated to provide input to the CBA and DCF analyses

NOTE: DFMA results are cost, not price, and reflect U.S. assumptions for materials, discount rate, labor, and electricity.

BPP VSM – U.S.



- Value stream map is a hybrid of process flow used in DFMA and inputs from suppliers and OEMs
- VSM outputs are used for cost breakdown analysis and as a cost reduction tool

Summary Observations - Membrane

- **PFSA Ionomer:** will likely be manufactured as one component in a portfolio of products from a flouropolymer 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.
- **Too few (4–5) membrane supplier to reduce cost**. 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 3–4 global catalyst suppliers** 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)

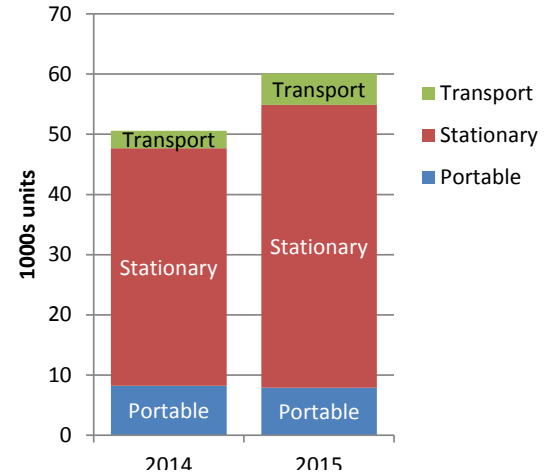
- **GDL is currently produced:**
  - From PAN carbon fibers
  - Using paper-making process equipment
  - Using a high temperature carbonization/sintering process
  - Using coating/MPL layer application(s)
- **GDL is relatively expensive** and OEMs are in search of ways to reduce/eliminate use of carbon fiber (while retaining the MPL)
- Price is currently quite variable presumably due to **production rate and scrap differences:** high plant utilization, wide (~1 m) and custom widths preferred
- **~3 Suppliers worldwide currently capable of supplying GDL. 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** -materials are about 50%, slow carbonization-sintering processes
- **R&D areas** – alternatives to carbon paper, reducing thickness

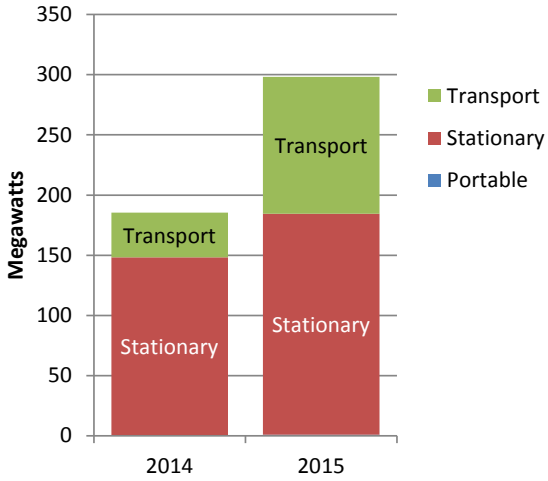
Summary Observations - Pressure Vessel

- **Cost driven by Carbon Fiber** (CF)
  - Toray is the lead 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

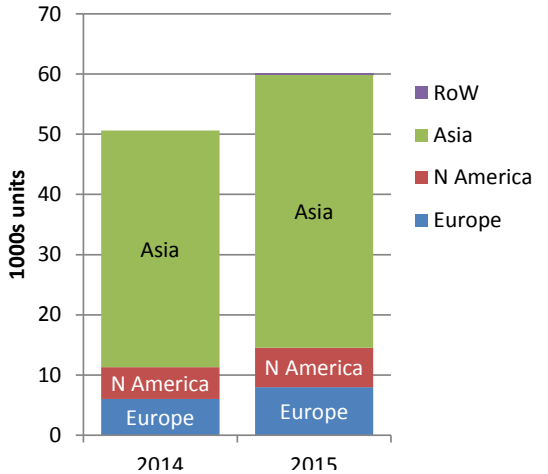
2014 – 2015 Fuel Cell Market Data – E4tech

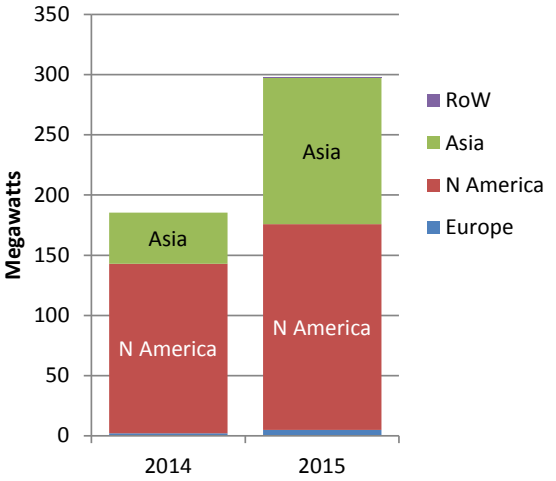
By application



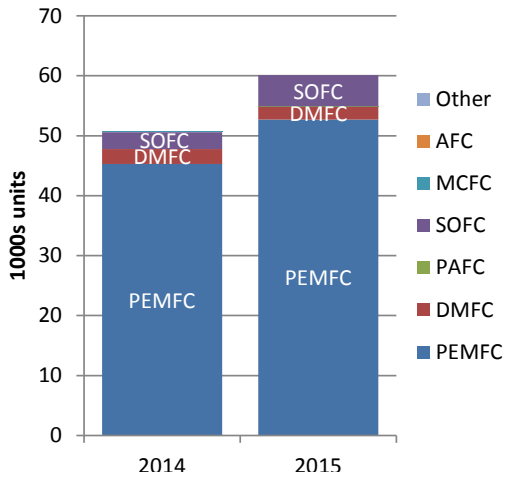


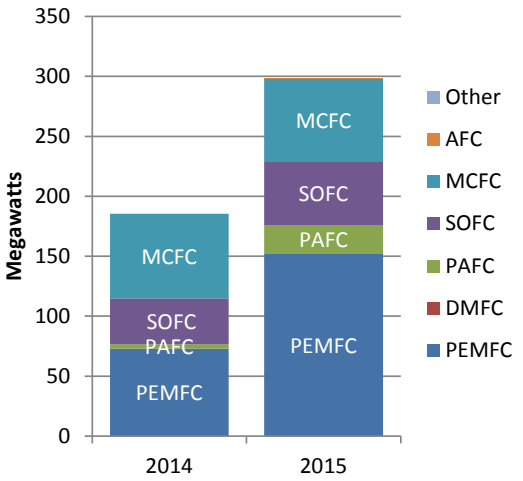
By region of manufacture





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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