U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis

US Department of Energy
Office of Energy Efficiency and Renewable Energy
Fuel Cell Technologies Office
DOE HTAC Hydrogen and Fuel Cell Technical Advisory Committee
April 22, 2015

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Core Team Members

Patrick Fullenkamp, GLWN, Principal Investigator
Brian James, Strategic Analysis Inc.
Douglas Wheeler, DJW Technologies
Charles Stone Ph.D., eon™ Consultants
David Hart Ph.D., E4tech
Dee Holody, GLWN
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.
- He leads the offshore supply chain development initiative and has worked with the offshore industry leaders in Europe, 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.
Cleveland-based GLWN is 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. 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 (3MW and 5MW) 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.
Presentation Content

- Objectives of the project.................................Slide 6
- Deliverables, Schedule, Responsibility...............Slide 7-9
- Project Approach including task description and party(ies) responsible for the task...............Slide 9-29
  - Wind Project Competitiveness Analysis...Slide 17-23
- Questions and Answers.................................Slide 30
Project Objectives

1. **Global Competitiveness Analysis of hydrogen and fuel cell systems and components** will be accomplished in the 1st Period of 18 months. The 5 high value components will be identified, generic drawings generated and a detailed cost analysis (CBA, DFMA®, VSM) will be conducted in 3 global regions for an apples-to-apples comparison. The outcome will identify global cost leaders, best global manufacturing processes, key factors determining competitiveness, and opportunities for cost reduction.

2. **Analysis to assess the status of global hydrogen and fuel cell markets** will be accomplished annually for 4 years. Periods 1, 2, 3, 4 (2014 to 2017) with a report out of H&FC units, size (MW), country, and application.
Deliverables, Schedule, and Parties Responsible for Deliverables

• **Milestone 1, Qtr 1** – Determine **5 key components**. Map industry structure. Conduct 30-40 Interviews – Doug Wheeler, Charles Stone

• **Milestone 2, Qtr 2** – Send out **15 RFQ’s** - 5 key components – 3 regions – Patrick Fullenkamp

• **Milestone 3, Qtr 3** – **Conduct plant visits** and report out on 10 of 15 suppliers – Patrick Fullenkamp

• **Milestone 4, Qtr 4** – Provide **5 sets of CBA and DFMA® data** to DOE – Patrick Fullenkamp, Brian James
Deliverables, Schedule, and Parties Responsible for Deliverables

- **Milestone 5, Qtr 5** – Report manufacturing opportunities, tipping points, VA segments, US strengths – Patrick Fullenkamp, Brian James

- **Milestone 6, Qtr 6** – Task 2 Report out the following to DOE: trade flows, supply and demand, global suppliers, government funding, capital available, countries tech dev., U.S. mfg. advantage – David Hart

- **Milestone 7, Qtr 7** – Submit draft Competitiveness Analysis manuscript to DOE & NREL– Patrick Fullenkamp, Brian James

- **Milestone 8, Qtr 8** – Submit final competitiveness Analysis Manuscript to DOE & NREL– Patrick Fullenkamp, Brian James
Deliverables, Schedule, and Parties Responsible for Deliverables

• **Milestone 9, Qtr 4 - Report 2014** to DOE, Units & MW/yr. fuel cells shipped by country and type – David Hart

• **Milestone 10, Qtr 8 - Report 2015** to DOE, Units & MW/yr. fuel cells shipped by country and type – David Hart

• **Milestone 11, Qtr 12- Report 2016** to DOE, Units & MW/yr. fuel cells shipped by country and type – David Hart

• **Milestone 12, Qtr 16 - Report 2017** to DOE, Units & MW/yr. fuel cells shipped by country and type – David Hart
Task 1.1 - Supply Chain Evolution – DJWT lead

- Where and what is the supply chain evolving to?
- When and why will major evolutionary steps occur?

Supply Chain Drivers:
- **Cost**: Capital, Labor, Materials, Process, Training
- **Regulations**: Environment, Safety,
- **Customer Location**: North America, Asia, Europe
- **Maturity**: Technical, Manufacturing Process
- **Subsidies**: Low cost capital, low cost loans, taxes
- **Market Size**: Small (100s) –to- large (millions)
- **System rating**: Watts –to- MW
Supply Chain Evolution

Electrolyzer Synergism

Common
Components, Materials,
Manufacturing Processes,
System Designs

Component Availability

OTS – High Volume
OTS - Low Volume
Specialized – Low Volume

Domestic Supply Chain
• Advantages – How to benefit and expand
• Disadvantages – How eliminate / how to turn into an advantage
Component Focus
Initial top level analysis – down select to 5 key components by the end of Month 3

Fuel Cell System
- Fuel cell stack
  - Membrane
  - MEA – Membrane Electrode Assemblies
  - GDL – Gas Diffusion Layers
  - Bipolar Plates
  - Catalysts
- Balance-of-Plant
  - Compressor / Expander
  - Hydrogen Pump / Ejector
  - Thermal Management
  - Reactant Management
  - Sensors

Hydrogen Storage
- 700 bar pressure vessel
  - Carbon fiber
  - Vessel manufacturing
    - Winding process
  - Vessel liner
  - Safety specifications
- Balance-of-Plant
  - Regulators
  - Gauges
  - High pressure plumbing
Task 1.2 – High Level factors Influencing OEM Interaction Strategy – eon™ lead

- Recognize that **not all OEMs are equally advanced** in the development or understanding of PEMFC technology for automotive applications (FCVs).

- **OEM commitments levels** regarding commercialization of FCVs vary from entity to entity and within the entities themselves (technical versus business executives).
  - **Categorize OEMs based on technology understand and commitment to FCVs** commercialization and time interview schedule to approach the most knowledgeable and committed entities ahead of others.

- **Commitment levels of key Tier 1 suppliers** and their ability to fund the development phase of key component and subsystems ahead of volume production.
Task 1.2 – Questionnaire Development

- Use the key project objectives and tasks lists to define a set of measures and metrics that can be used in the development of specific questions
  - Not all questions will be appropriate for all OEMs – some customization will be required – but a set of core questions will be posed to all OEMs.

- Understanding of how OEMs operate and respecting their sensitivities to business and technical confidential information will be critical in the development of questions and during the interview process itself
  - Indirect but illustrative questions are likely to receive a fuller response (e.g., “How many FCVs will you manufacture in 2025? What will be the average cost per kW for the powertrain?” and “Which Tier 1 suppliers will produce the key components?” is unlikely to solicit a response other than what is already in the public domain)
  - Make sure the OEM commits to having the staff most capable of answering the questions be present or available by phone for the interview.
  - It is essential that at least one technical expert be present or on the phone for each interview – clarifying and follow-up questions can be most valuable.
Task 1.3 - CBA & VSM -Technical Approach – GLWN lead
(Cost Breakdown Analysis & Value Stream Mapping)

• Develop **standardized component specifications and drawings** with industry and labs for apples-to-apples comparison between global suppliers

• Visit and collect first-of-a-kind manufacturing cost and process data from **15 suppliers** across U.S., Europe, and Asia for the 5 components identified

• Utilize **Cost Breakdown Analysis (CBA)** and **Value Stream Mapping (VSM)**
Manufacturer Selection and Data Gathering Process

- **Identify and contact** current active or potential **suppliers in the U.S.A., Europe and Asia**
- **Send letter of introduction (DOE & GLWN)** to suppliers explaining scope of project and ask for interest
- **Send out an official Request for Quote** with detailed manufacturing drawings, Cost Breakdown Form and set a targeted plant visit date
- Schedule **Plant Visits** include meeting Management Teams, Project Presentation, Hosting Plant Presentation, Review of Process Flow, **Walking the Manufacturing Process** from beginning to end enabling the development of the **Value Stream Map**, Review of the cost data or plan to obtain it.

Cost Breakdown Analysis (CBA)

- A Specific Cost Breakdown Form to be developed which includes a complete **Bill of Materials** with weights, general process steps for **Labor** and **Burden**, categories of **SGA (Sales General Administrative)**, **Engineering**, **Logistics Cost to U.S. Port**, and **Profit**
- **Quoted Data** is consolidated into spreadsheets for analysis. Data provided to NREL for analysis

Value Stream Map (VSM)

- **VSMs** are generated using data gathered during plant visits.
### Task 1.3 - Cost Breakdown Analysis Example

### Accomplishments and Progress

**TOWERS – Cost Breakdown**

#### Regional Cost Breakdown

<table>
<thead>
<tr>
<th>Region</th>
<th>Tariff Tax</th>
<th>Profit</th>
<th>Logistics to U.S. Port</th>
<th>Engineering</th>
<th>SGA</th>
<th>Burden</th>
<th>Labor</th>
<th>Materials</th>
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<tr>
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<td>$572,938</td>
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<td>$676,154</td>
<td>$572,938</td>
<td>$485,130</td>
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<td></td>
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<tr>
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<td>$890,000</td>
<td>$572,938</td>
<td>$485,130</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

#### Regional Materials Costs

<table>
<thead>
<tr>
<th>Region</th>
<th>Weld Wire</th>
<th>Batts, Washers, Nuts</th>
<th>Paint</th>
<th>Ranges</th>
<th>Door Frame</th>
<th>Steel Plates</th>
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<td>$18,250</td>
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<td>$53,204</td>
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#### Regional Labor Costs

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<th>Region</th>
<th>Prepare for Un负载</th>
<th>Fab/Assem / Mach / Weld</th>
<th>Structural / Electrical</th>
<th>Mechanical / Electrical</th>
<th>Catwalk Grating / Stairway / Balconies</th>
<th>Structural / Electrical</th>
<th>Catwalk Grating / Stairway / Balconies</th>
<th>Structural / Electrical</th>
<th>Catwalk Grating / Stairway / Balconies</th>
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<tr>
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**Towers are on avg. 27% of Wind Turbine Cost**

**R&D Projects** from findings (partial list):

- **Material** is over 50% of the cost of the Tower of which Steel Plate accounts for 62% in the U.S. Mfg’s to work with steel mills to optimize material and size of plate to reduce mill cost and mfg process weld time. **Welding in flat state is more efficient.** Circular weld highest labor hours

- **Weld wire size and delivery system** – 1 to 5 wires – magnetic field and weld pattern impact

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Task 1.3 - Value Stream Map Example

Technical Approach
Value Stream Map – Towers

USA 1 Tower – 17 Process Steps

Assemble & Circular Weld Sections
- Cycle Time: 24 Hr
- Qty per Cycle: 30 Item
- Direct Labor: 9,432 $/Item
- Cumulative Cost: 28,296 $/Item
- Scrap Percent: 0.5 %

- Identifies areas of waste and improvement opportunities for domestic suppliers
- Better characterize flow of materials, labor, tasks, and information
Wind Blades Example

Blades are on avg. 20% of the Wind Turbine Cost R&D Projects from findings (partial list):
- Material is ~45% of the cost of the Blade of which Resin, Carbon, Glass, & Foam account for 90% of the U.S. material cost. Material Improvements that provide material cost and process time reductions would be of most benefit
- Blade design and analysis looking at: power output, least material usage, shape with 1 or 2 piece for cost and transportability
- Smart Automation
Global Wind Project Scope

Wind Manufacturing Competitiveness:
US vs. Europe vs. Asia – 22 Manufacturers Total

Limited Snap Shot Study - 2013

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A WES-Net Initiative
Capable U.S. Wind Manufacturers
German Offshore Wind Value Add Model

Germany Offshore Wind
Total Value Add - 5.9B € as of 2011

Manufacturing 3.61

In Billion Euro’s

Source: wab, windenergie agentur

“Go USA Manufacturing!”

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A WINKELMANN Initiative
Major Observations - Wind Project

- U.S. has a good foundation – more to improve
- Lessons learned from auto, 30-50% process savings potential observed
- If you don’t make it, you can’t innovate it (Castings & Forgings – 23%) Policy & Investment support
- Educate Manufacturers and Regional, State, National Leaders on risk of manufacturing sector loss

Full Report at [www.glwn.org](http://www.glwn.org)
Task 1.3 – DFMA® – SA Inc lead (Design for Manufacturing and Assembly)

- DFMA Cost Analysis used:
  - As framework to identify system architecture, components, and functions
  - To identify key cost component of current/future systems
  - To map manufacturing processes
  - To define component dimensions and design
  - Assists in exploring supply chain impact of changing manufacturing rates

Stack Cost Breakdown (500,000 Units/year)

BOP Cost Breakdown (500,000 Units/year)
Will Use Existing DFMA® models to define specific manufacturing steps and Supply Chain Participants

- Detailed cost analysis is not goal of project
- DFMA® to be used as tool to explore Supply Chain issues

Process Schematic
with Supplier Specifications

De- alloyed Catalyst MEAs

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Task 2 - Trade flows and suppliers – E4tech

• **Scope**
  – This analysis will focus on the **most relevant players** in PEM FC and hydrogen storage technology, and from there will identify relevant countries to include on a global map.

• **Approach**
  – Take **technology list** from Task 1.
  – Use E4tech’s current PEM-FC company list, **filter this using criteria of ‘relevance’** to be agreed with DoE, e.g.
    • threshold of **annual shipments** per player (in terms of units and/or MW)
    • threshold **minimal system size** for products shipped
  – Build **company list of players in hydrogen storage technology**. Develop and apply filters as above to identify the relevant players
  – Identify and map supplier **relationships** using
    • **Interviews** with selected players and other industry experts
    • **In-house knowledge** and databases at E4tech and within the wider team
    • Careful review of **publicly available sources** such as company statements and reports
  – Gather data on governmental funding, capital available & technology focus
    • Focus on **countries of major relevance**, including the US, Canada, Japan, South Korea, and Germany
    • Review of publicly available information with focus on **policies and incentives**
    • Identify and assess potential competitive **manufacturing advantages of U.S.**
Task 3 - Shipment data for PEM technology

- **Gather and aggregate shipment data** for PEM fuel cells with defined scope and level of detail
  - Annual basis (calendar year)
  - Global reach
  - Break down global data into subsets
    - **Systems by application** (transport, stationary, portable, and any key sub-groups of these)
    - **Systems by Region** of manufacture, further split by key countries
    - **U.S. system production split** by world regions shipped to
    - **Key components** (MEA, GDL, Bipolar plates, BOP)

- **Approach**
  - Start with **original data previously gathered by E4tech** (in an aggregated form only)
  - Collect **additional data directly from fuel cell manufacturers** where they are willing to share it (use DOE introduction letter)
  - **Fill gaps** in original data with
    - **interviews** with industry experts
    - careful review of **publicly available sources** such as
      - company statements,
      - press releases,
      - reports of public companies and
      - demonstration and roll-out programmes
Supporting slide: Data break downs

1. Systems & MW
   - shipped
     - Stationary
     - Transport
     - Portable

6. & 7. Systems
   - System shipped
     - Stationary
     - Transport
     - Portable

2. Systems
   - shipped
     - Stationary
       - Manufactured in
         - N A
         - Asia
         - Europe
     - Transport
       - Manufactured in
         - N A
         - Asia
         - Europe
     - Portable
       - Manufactured in
         - N A
         - Asia
         - Europe

8. MW and 1,000 units
   - Manufactured in
     - US
     - Japan
     - South Korea
     - Others

9. Key components
   - Totals shipped
     - MEA
     - GDL
     - Bipolar Plates
     - BOP components

3. Systems & MW
   - shipped
     - by location of manufacture
     - US
     - Japan
     - South Korea
     - Others

4. Systems and MW
   - shipped
     - Stationary
       - Manufactured in
         - US
         - Canada
         - Japan
         - S Korea
         - Germany
         - Others
     - Transport
       - Manufactured in
         - US
         - Canada
         - Japan
         - S Korea
         - Germany
         - Others
     - Portable
       - Manufactured in
         - US
         - Canada
         - Japan
         - S Korea
         - Germany
         - Others

5. MW and systems
   - Manufactured in
     - China
     - Germany
     - Japan
     - Canada
     - Denmark

28
FC Industry Review is an example of directly relevant work

- The review is conducted at a system level, so non-trivial work is required to assess levels below this.
Questions?