Project ID: MN014
U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis
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2015 Annual Merit Review and Peer Evaluation
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Core Team Members

Patrick Fullenkamp, GLWN, Principal Investigator
Brian James, Strategic Analysis Inc.
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Charles Stone Ph.D., eon™ Consultants
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Dee Holody, GLWN
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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.
Presentation Content

• Objectives of new project.................................Slide 5

• Deliverables, Schedule, Responsibility...............Slide 6 - 8

• Project Approach including task description and party(ies) responsible for the task.........Slide 9 - 23
Project Objectives

1. **Global Competitiveness Analysis of hydrogen and fuel cell systems and components** will be accomplished in the 1\textsuperscript{st} 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).
Task 1.3 - CBA & VSM - Technical Approach

• 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>Proft</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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Regional Materials Costs

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<tr>
<th>Region</th>
<th>Weld wire</th>
<th>Bolts, Washers, Nuts</th>
<th>Paint</th>
<th>Range</th>
<th>Door Frame</th>
<th>Steel Plates</th>
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Regional Labor Costs

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<th>Milling</th>
<th>Electrical Welding</th>
<th>Cathodic Protection</th>
<th>Cathodic Test Coating</th>
<th>Sandblasting</th>
<th>Paint/Primer</th>
<th>Frame, Machine &amp; Глави</th>
<th>Cutting</th>
<th>Grinding</th>
<th>Milling, Front End &amp; Final</th>
<th>Final Test</th>
<th>Weld</th>
<th>Repair</th>
<th>Sand / Abrasive</th>
<th>Paint / Primer</th>
<th>Bending / Trestle</th>
<th>Handling, Grid Bolts, Layout</th>
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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
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
Task 1.3 – DFMA® – SA Inc lead
(Design for Manufacturing and Assembly)

- DFMA-style 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

Process Schematic Denoting Physical Processing Steps
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 sider 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

Above: Non-exhaustive, illustrative breakdown
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.

Source: E4tech Fuel Cell Industry Review 2014