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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.

Douglas Wheeler, DJW Technologies

Charles Stone Ph.D., eon™ Consultants

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Dee Holody, GLWN

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, 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 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

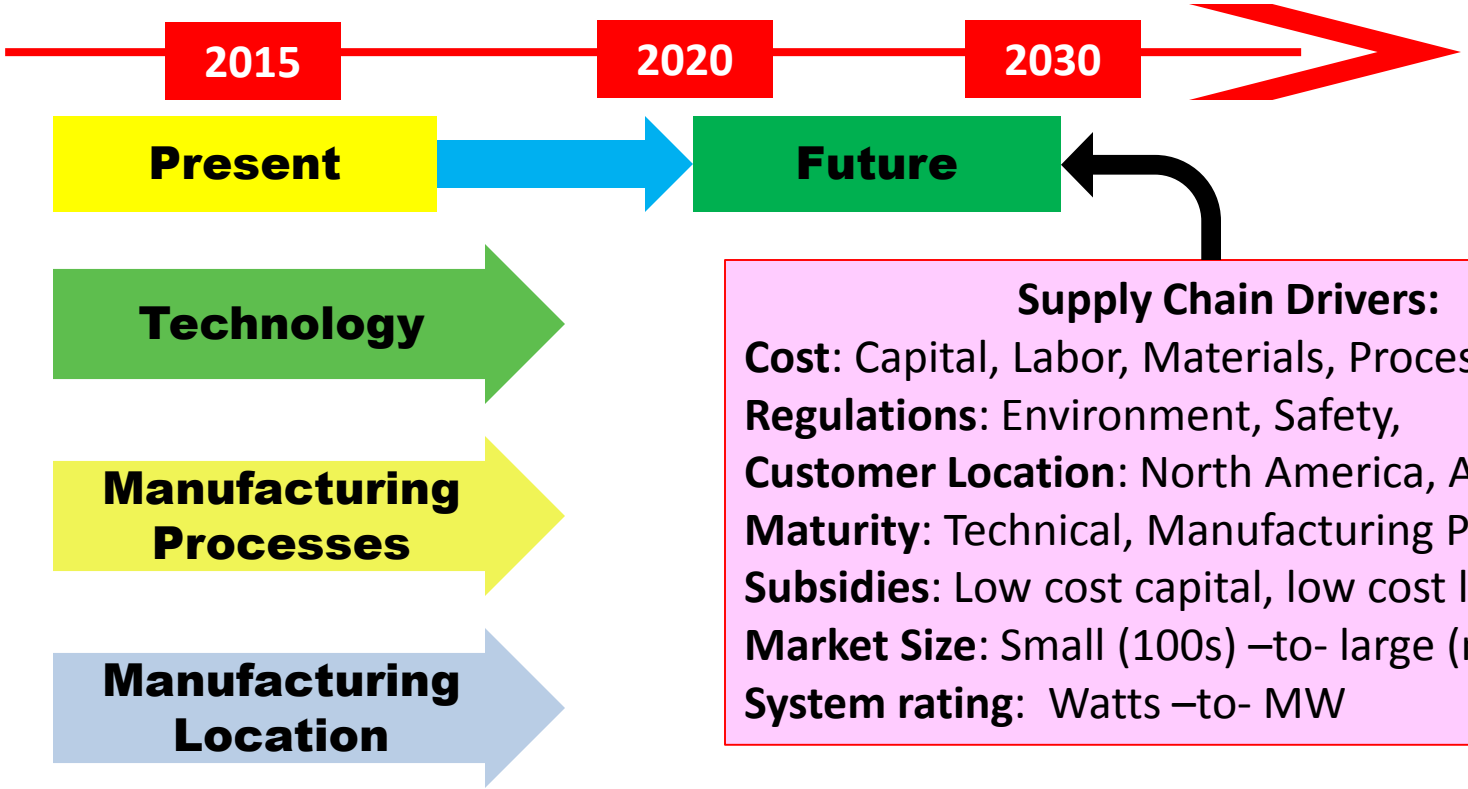
- **Milestone 5, Qtr 5** – Report **manufacturing opportunities, tipping points, VA segments, US strengths** – Patrick Fullenkamp, Brian James
- **Milestone 6, Qtr 6** – Task 2 **Report out** the following to DOE: **trade flows, supply and demand, global suppliers, government funding, capital available, 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

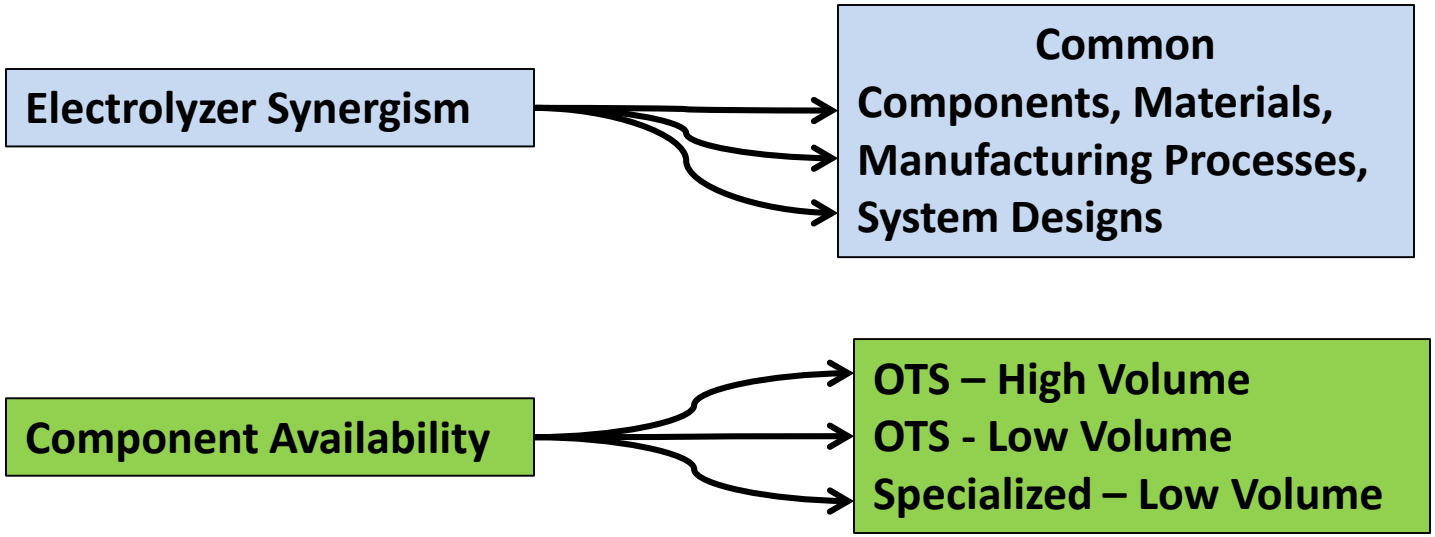
- Where and what is the supply chain evolving to?
- When and why will major evolutionary steps occur?



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



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

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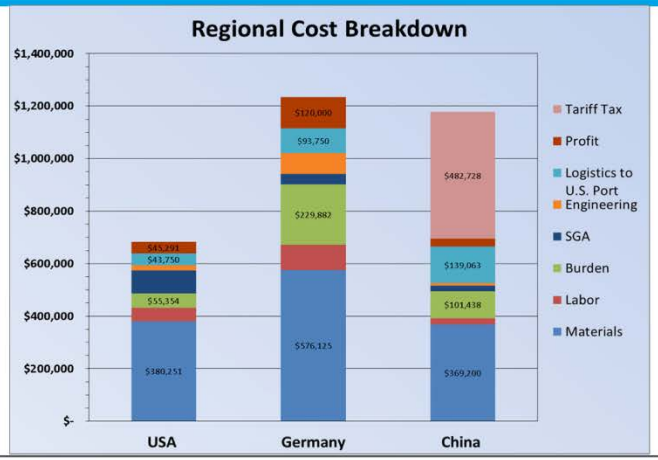
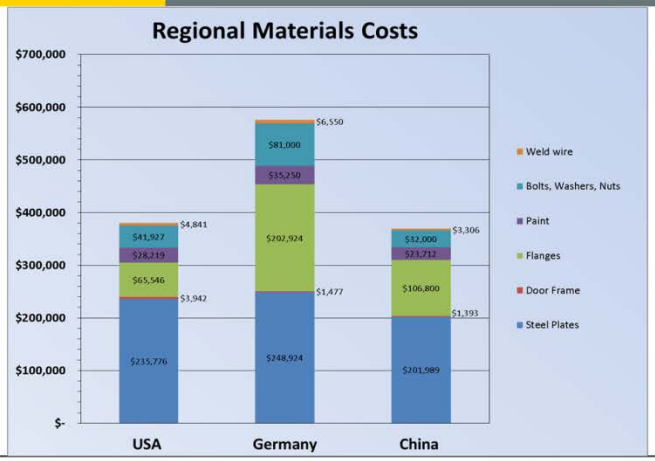
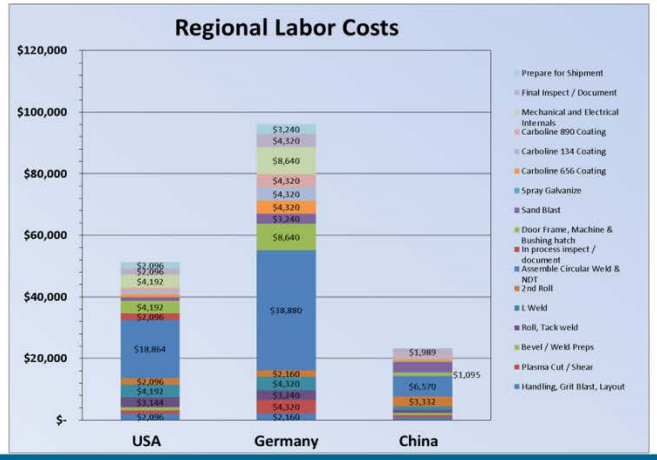




Towers are on avg. 27% of Wind Turbine Cost

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

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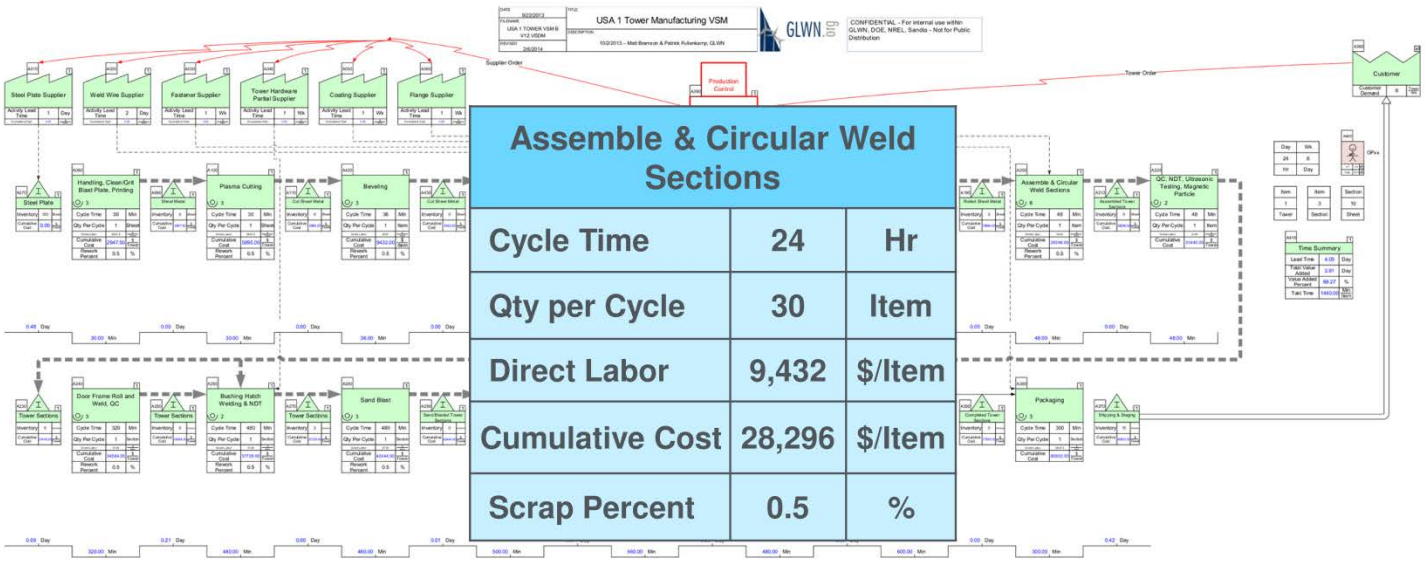
USA 1 Tower – 17 Process Steps



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	%

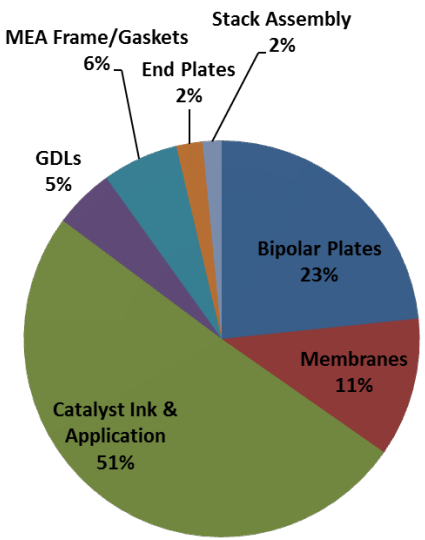
- Identifies areas of waste and improvement opportunities for domestic suppliers
- Better characterize flow of materials, labor, tasks, and information

GLWN.org SA STRATEGIC ANALYSIS DJWT eon E4tech Strategic thinking in sustainable energy

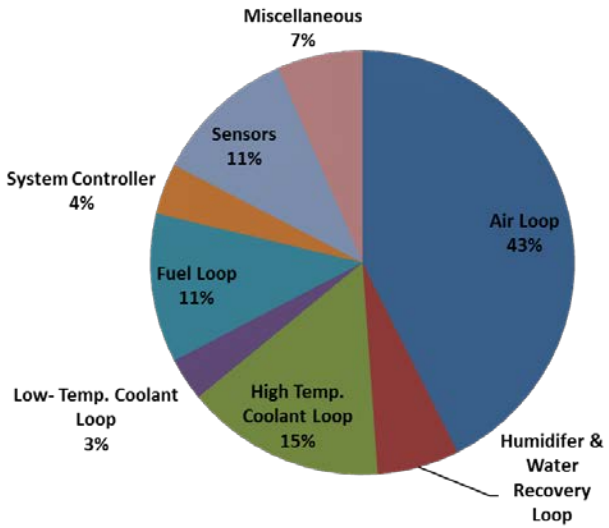
Task 1.3 – DFMA® – SA Inc lead
(Design for Manufacturing and Assembly)

- **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)



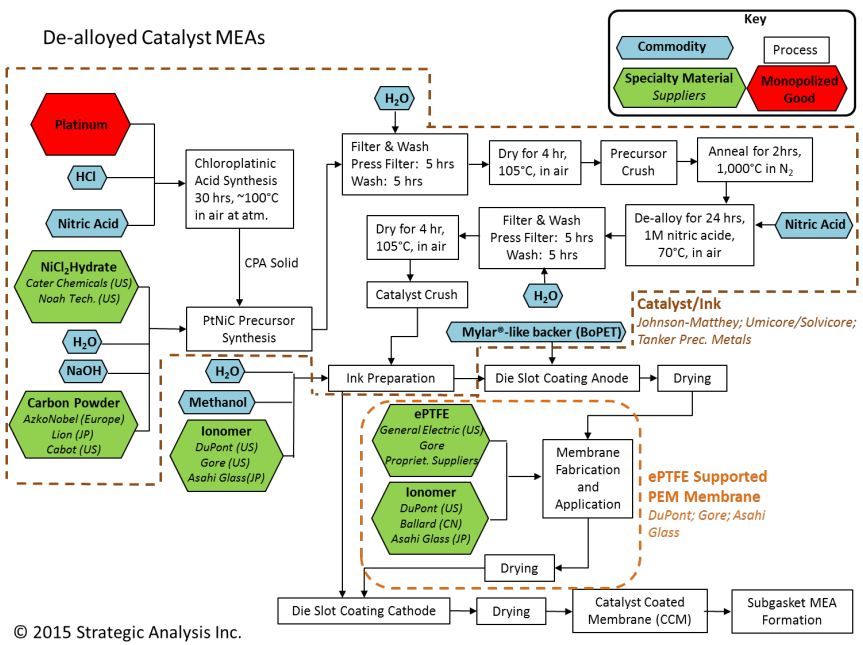
BOP Cost Breakdown (500,000 Units/year)



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



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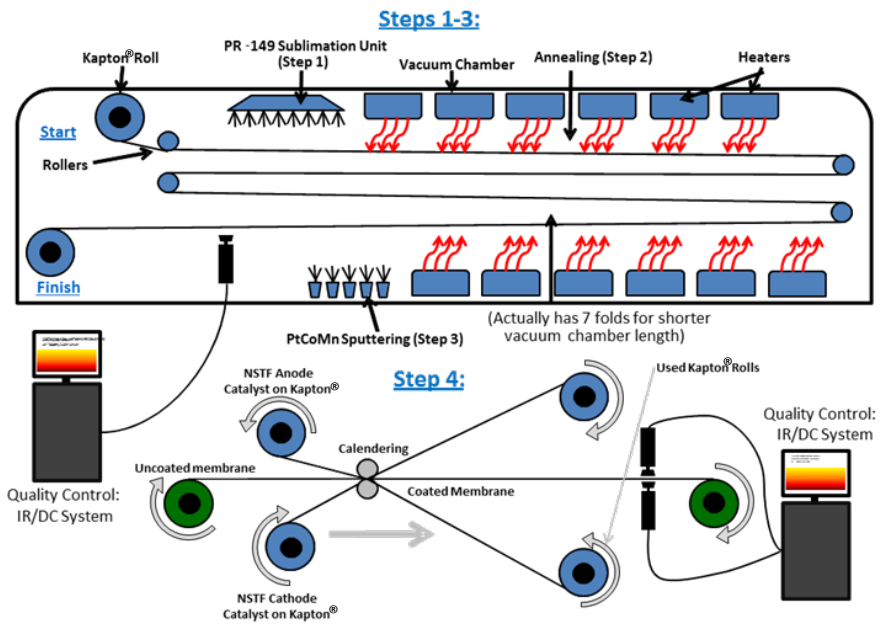
Process Schematic Denoting Physical Processing Steps



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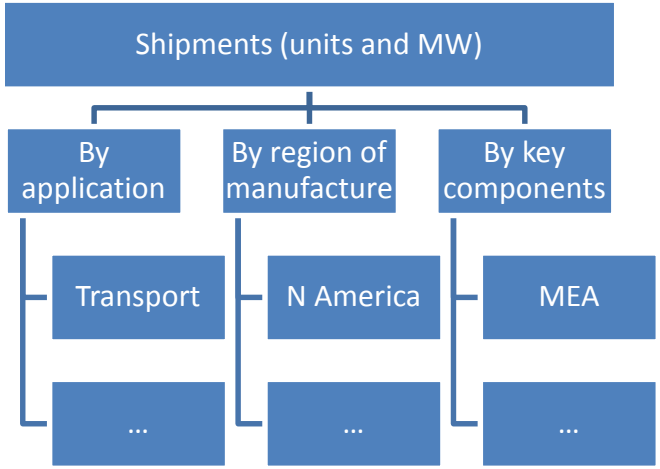
Task 2 -Trade flows and suppliers – E4tech

- **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 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

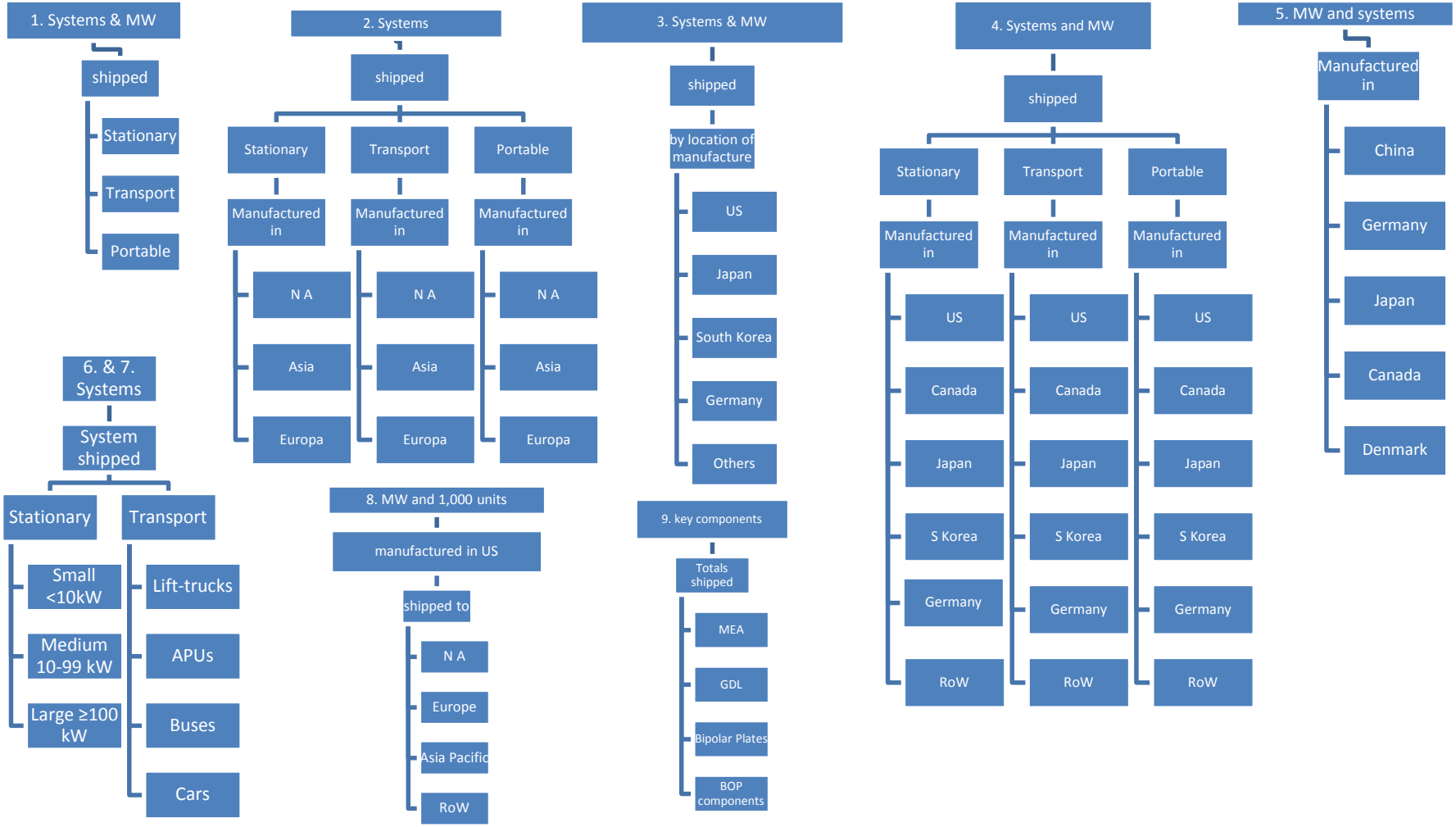
- **Gather and aggregate shipment data** for PEM fuel cells with defined scope and level of detail
  - Annual basis (calendar year)
  - Global reach
  - Break down global data into subsets
    - **Systems by application** (transport, stationary, portable, and any key sub-groups of these)
    - **Systems 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)



Above: Non-exhaustive, illustrative breakdown

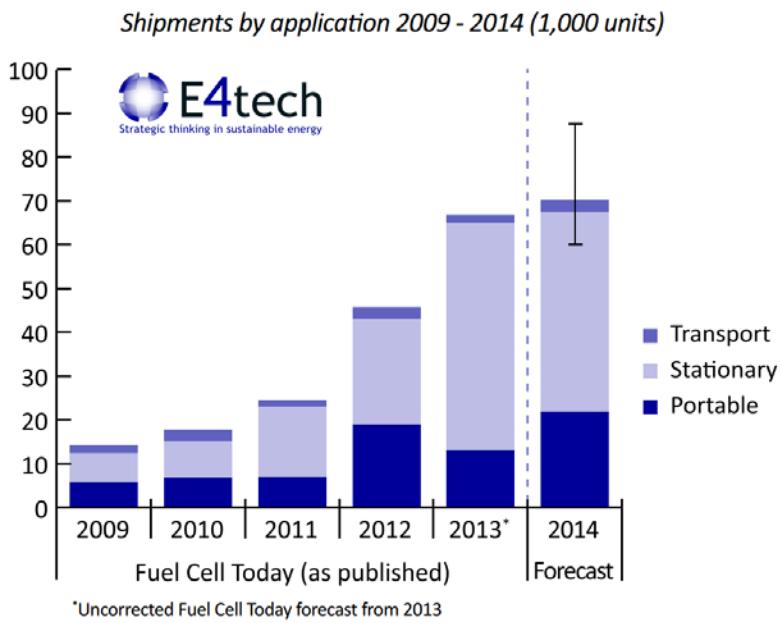
- **Approach**
  - Start with **original data previously gathered by E4tech** (in an aggregated form only)
  - Collect **additional data directly from fuel cell manufacturers** where they are willing to share it (use DOE introduction letter)
  - **Fill gaps** in original data with
    - **interviews** 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

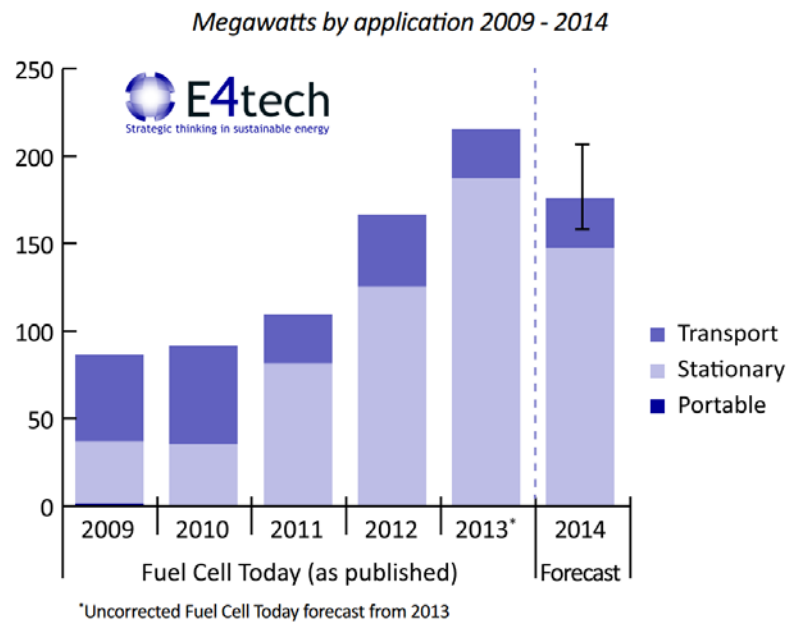
Supporting slide: Data break downs



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