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DOE Fuel Cell Technologies Program Workshop: Manufacturing Progress and Barriers

Low Temperature Fuel Cell and Electrolyser Balance-of-Plant Manufacturing Needs

Agenda

1. Market and development overview
2. DOE manufacturing overview
3. Current mfg status (automation, volume, etc.)
4. Barriers to achieving high volume production
5. Manufacturing R&D needs

Near Term Market Trends

- I will focus on the green highlighted areas below as they are the near term applications:

- Electrolyser
  - Industrial Applications
  - Fuel Cell Refuelling Applications
  - Energy Storage Applications

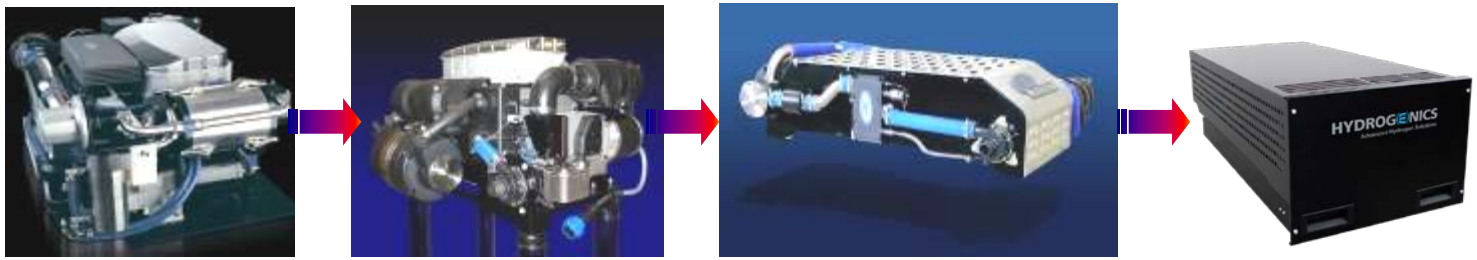
- Fuel Cells
  - Automotive
  - Stationary Long Life
  - Stationary Intermittent / Short Life / Back-Up Power
  - Material Handling
  - APUs (cars/trucks/planes/boats/etc.)
  - Portable Applications

Summary of Hydrogenics' Fuel Cell Development Trends

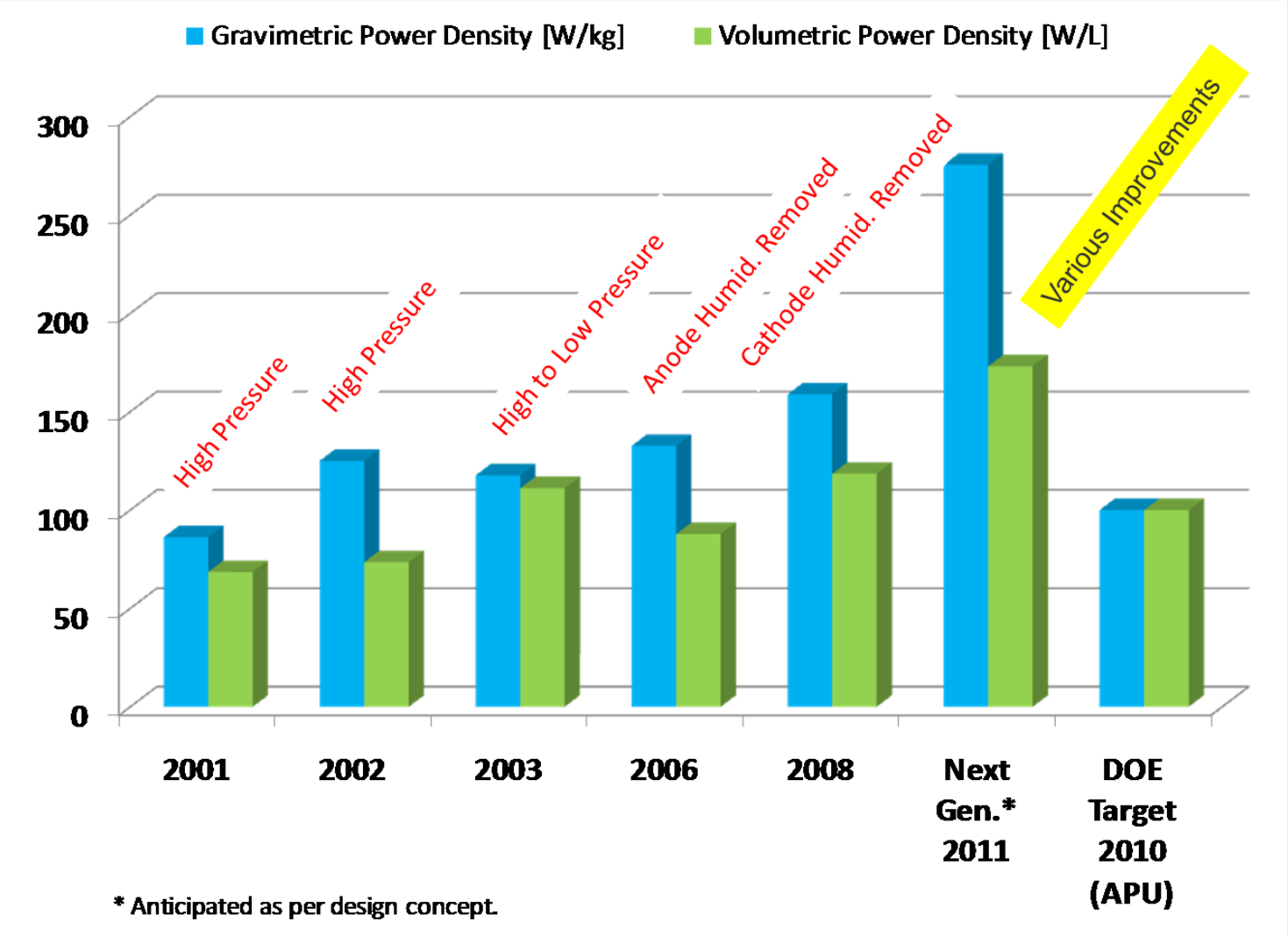
- Transition from high to low system pressure design
  - Reduction in size and weight
  - Reduction in number of components
  - Reduction in noise level
  - Increase in overall system efficiency

- Elimination of anode and cathode humidification devices
  - Reduction in size and weight
  - Reduction in number of components
  - Increase in overall reliability
  - Reduction in cost

- Future development trends
  - Further system simplification (mechanical and electrical components)
  - High volume manufacturing of these components (mold/cast/stamp/etc.)



Next Generation HyPM® Power Module



Evolution of Electrolyser Technology at Hydrogenics

Electrolyser

The Electrolyser Corporation founded

Atmospheric alkaline mono-polar (Gen II)

stuart energy
the power of hydrogen

Stuart Energy Systems IPO in October 2000

Atmospheric alkaline mono-polar (CST)

HYG starts PEMWE program

VANDENBORRE HYDROGEN SYSTEMS

Acquires Hydrogen Systems January 2003

HYG demonstrates Large Active Area PEM electrolyser

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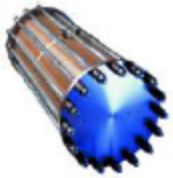
Hydrogenics acquires Stuart Energy January 2005

Adopt pressurized alkaline bi-polar (IMET) S-1000



Large pressurized (IMET) S-4000

1948 2000 2001 2002 2003 2004 2005 2006 2007

Electrolyser Development Progress and Focus

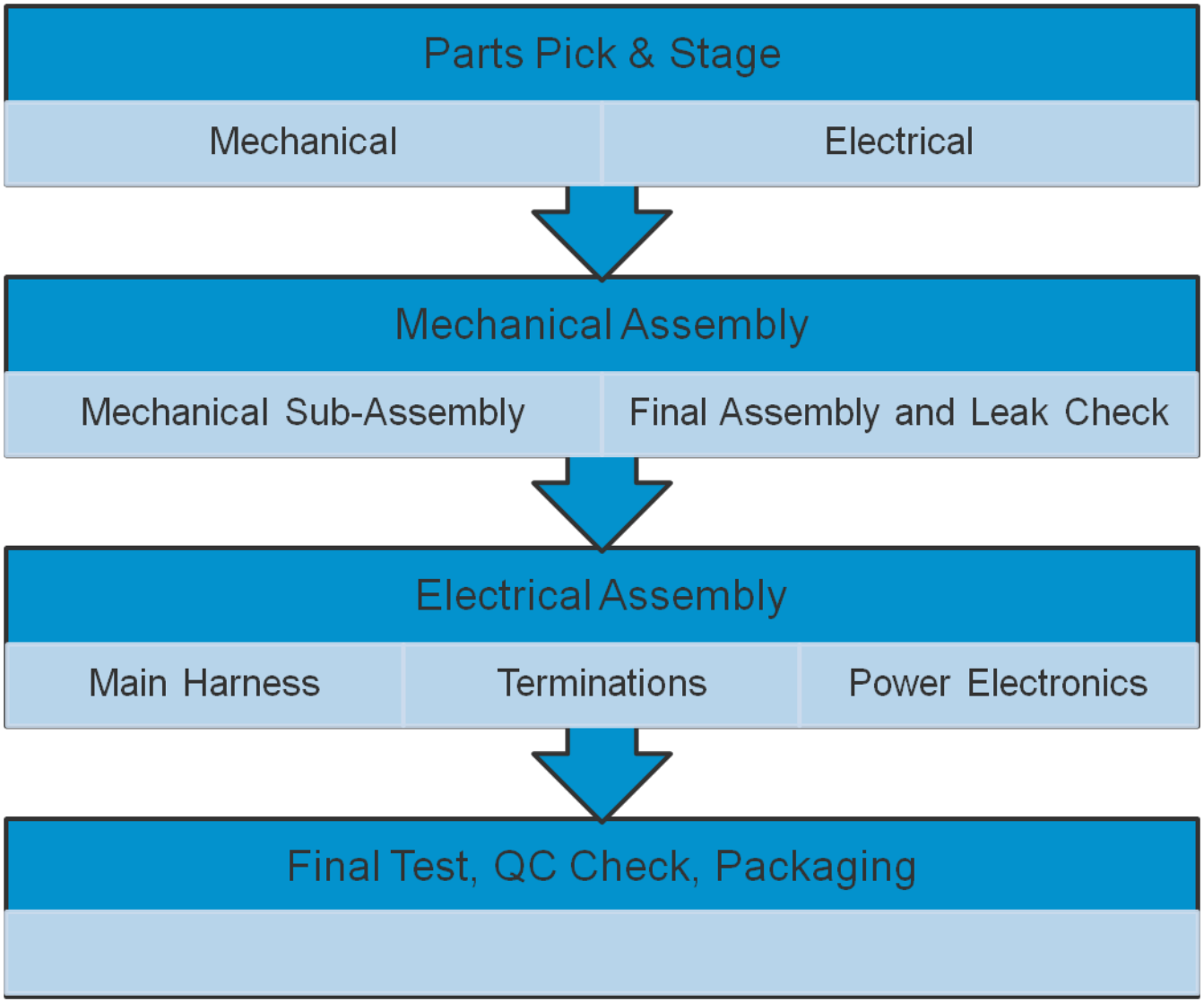
1. Operating Cost Reduction
   - MEA development: thinner/reinforced high-efficiency membrane
   - More efficient BOP
   - Better hydrogen recovery after purification
2. Capital Cost Reduction
   - Simplified BOP(fewer components)
   - Larger scale stacks (fewer stacks per kg/H_2 produced)
   - Higher pressure stacks (reduce or eliminate compression)
3. Mass Production Preparation
   - Stack bipolar plate design optimization
   - MEA / GDM optimization
   - High volume BOP component tooling and manufacturing (molding / casting / stamping / etc.)

Hydrogenics High Volume Manufacturing Status

General Requirement for Fuel Cell and Electrolyser BOP Manufacturing

- Clean environment (No dust, VOCs, controlled humidity and temperature, etc.)
- Safe process – high pressure gases, flammable gases, high voltages
- Optimized Design
  - QFD
  - VAVE
- Optimized Process
  - DFMA
  - Process FMEA
  - Lean / Six Sigma
- High quality – 100% inspection of key parameters
- High yield – high cost product necessitates high yield
- Streamlined global sourcing
- Product traceability for quality and safety

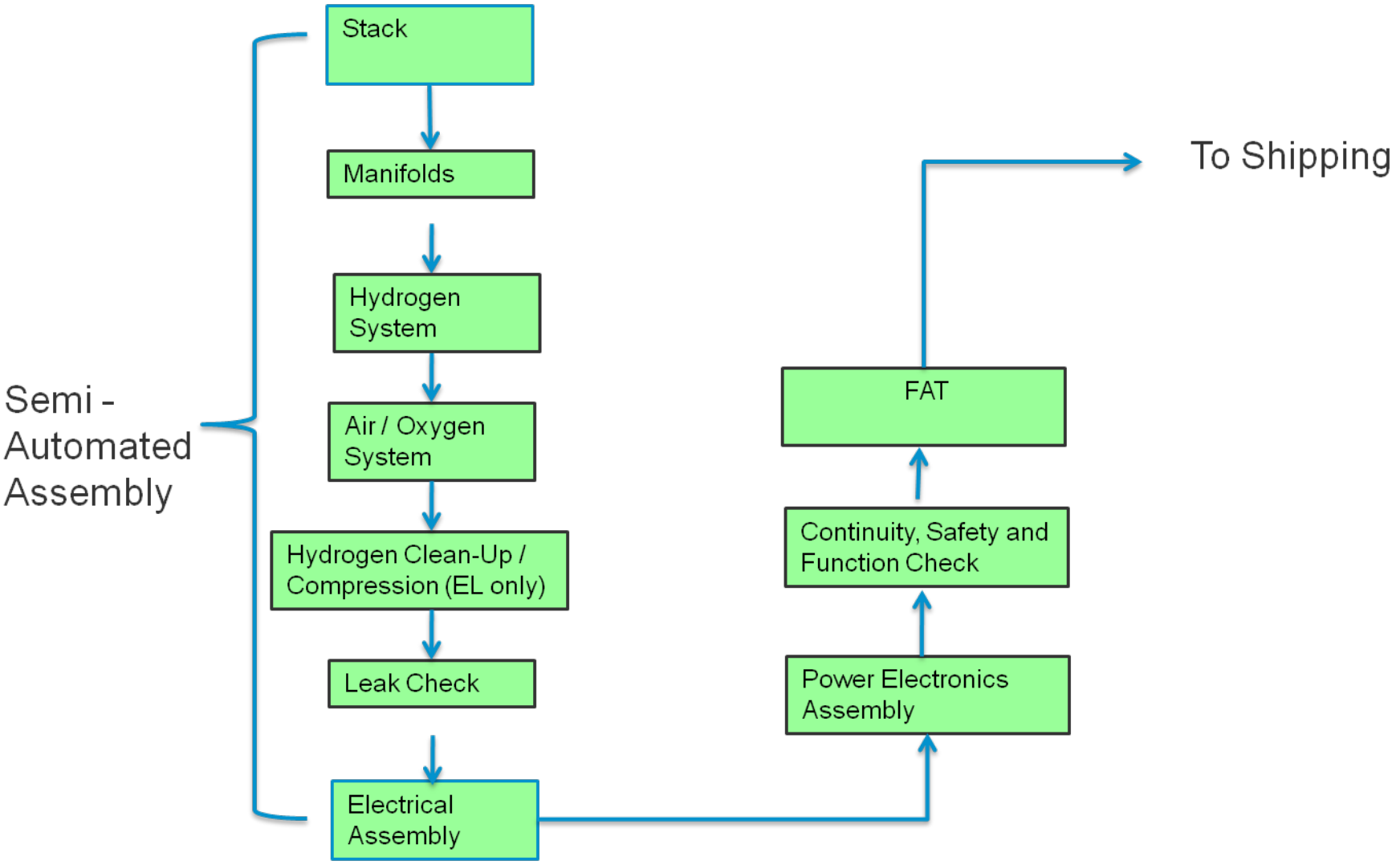
EL and FC Power Module Build Process (Current 1-2k/yr)



Improvements Required For High Volume Production:

- Automated Stack Production
- Rapid Stack Break-in and FAT
- Semi-Automatic Cellular FCPM and EL System Production
- Automated Leak and Electrical Checks
- Clean Room Production
- Rapid FCPM and EL System FAT

Future FCPM and EL Production Process (10-20k/yr)



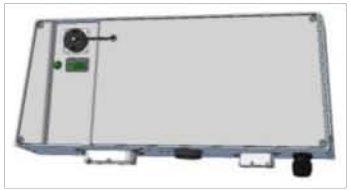
What are the major BOP component hurdles for High Volume Manufacturing?

HyPM® Fuel Cell Power Module BOP

Blower / meter / filter

Fuel delivery, hydrogen recirculation

Coolant pump, radiator



Electronics / controls / sensors / power electronics

FC Stack Subsystem

FC Power Module Subsystems

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Fuel Cell Power Module BOP

- Air Delivery System
  - Blower / Compressor
  - Humidifier (possibly)
  - Air flow sensor (possibly)
  - Intercooler (possibly)
- Hydrogen System
  - Feed and purge solenoids
  - Manifolds / tubing / fittings
  - Recirculation pump (fairly standard)
  - Humidification (possibly)
  - Storage (discussed elsewhere)
- Cooling System
  - Radiator (standard)
  - Coolant Pump (standard)
  - Sensors (standard)
- Control / Diagnostics / Monitoring system
  - PCB (very standard)
- Power Electronics / Energy Storage
  - DC-DC (fairly standard)
  - DC-AC (fairly standard)
  - Batteries or UCs (fairly standard)

Fuel Cell Power Module BOP

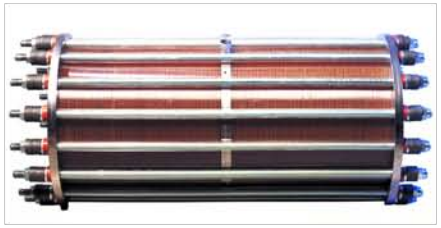
- Air Delivery System
  - Blower / Compressor
    - Currently use off the shelf blowers from a variety of commercial application suppliers. Compressors tend to be more custom.
    - Blowers currently have the following issues:
      - Too loud
      - Too big
      - Inefficient (consume about 90% of the parasitic power for a fuel cell engine (fuel cell power module) (not including cooling pumps and fans)
      - Too costly
    - However, they are ready for high volume production in some respects:
      - Manufacturing capacity
      - Product maturity (current technology)
      - Lifetime (brushless motors…10-20k life expected)

Fuel Cell Power Module BOP

- Hydrogen System
  - Tubing / manifolds / fittings:
    - Tubing and fittings tend to be compression fittings and 316SS tubing(Swagelock, etc.)
      - Overengineered for the application
        - » Temp/pressure ratings are very high relative to market needs
      - Expensive
      - Not easily installed:
        - » Tube bending must be precise
        - » Compression fittings require a number of steps to seal properly
          - Defect free tubes – no scratches
          - Deburred cut ends
          - Special compression tool or 1-1/4” manual turn (not practical in tight engine integration
    - Plastic materials for hydrogen carrying components need to be UL approved (testing required for each material set):
      - » New supply of composite tubes for hydrogen with quick connect fittings would be helpful.
      - » UL compliant ‘off the shelf’ composites for moulding manifolds and other hydrogen interacting components would help.
      - » Optimized low cost plastics for hydrogen use in all areas (pressures) of the BOP would be ideal

Hydrogenics Electrolyser Module BOP

HySTAT-P
PEM Stack



HySTAT-A
Alkaline Stack

Stack Subsystem

Water Conditioning & Delivery

Power Conditioning

Gas/liquid Separation &
Heat Management

Gas Purification

Electrolyzer Subsystems

Electrolyser BOP

- Feed Water Preperation
  - Feed pump (standard)
  - RO / DI system (standard)
- Thermal Management System
  - Radiator (COTS)
  - Pump(s) (COTS)
  - Temperature sensors (COTS)
- Hydrogen clean-up system
  - Pressure regulator (COTS)
  - Sensors for pressure, temperature (COTS)
  - Water removal
  - Oxygen removal
- Hydrogen Compression
  - Solenoids
  - Regulators
  - Compressors
- Overall Control System
  - PCB (COTS)
  - Sensors (COTS)

Electrolyser BOP

- Hydrogen clean-up system
  - Water and Oxygen removal
    - Currently dessicant driers are used to remove water from these system
    - Catalytic burners are use to remove Oxygen from the systems
    - Issues with these technologies
      - Dryer systems can
        - » Waste a lot of hydrogen
        - » Be large (2 or 3 X the size of the stack)
        - » Have a number of solenoids that will eventually fail
      - Oxygen clean up systems can be
        - » Large (1 X the size of the stack)
        - » Costly to purchase (tend to be precious metals)
        - » Ineffecient to run (tend to be kept warm to improve kinetics and prevent water drop out which renders them ineffective)

Electrolyser BOP

- Hydrogen Compression
  - Solenoids
  - Regulators
  - Compressors

Compression Systems have a number of issues such as:

- Very limited supplier base
- Very high cost components
- Unreliable components
  - » Solenoids fail
  - » Piston rings fail
  - » Regulator needles fail
- The systems are large. They can be double the size of the electrolyser stack and BOP (not included power electronics and controls.) The system volume breakdown is roughly 1/3 Stack / BOP, 1/3 Compression Sub-System, 1/3 Power Electronics.
- They are noisy
- Excessive maintenance (partly due to the relibility issues noted above)

Manufacturing R&D needs for BOP and Systems?

FC BOP and System Manufacturing R&D Needs

- Advanced blowers / compressors that are easy to integrate into our system
- Hydrogen gas lines and manifolds that are robust, low cost and easy to source, certify, install and connect to our system
- Integrated BOP outsourced to third party suppliers for easier assembly Fuel Cell manufacturers
- Automation of Stack and BOP assembly (whatever portion is feasible)

EL BOP and System Manufacturing R&D Needs

- Integrated BOP outsourced to third party suppliers for easier assembly Electrolyser manufacturers
- Advanced Hydrogen clean-up systems that are easy to integrate into our system, reliable, low cost, efficient and compact.
- Advanced Hydrogen compression systems that are robust, low cost and easy to install and connect to our system
- Automation of Stack and BOP assembly (whatever portion is feasible)