This presentation does not contain any proprietary, confidential, or otherwise restricted information

HYDROGEN ENERGY SYSTEMS
AVALENCE™ LLC

High-Capacity, High Pressure Electrolysis System with Renewable Power Sources

Paul Dunn and Dave Mauterer, Avalence LLC
DOE Merit Review, 11 May 2011

Project # PD029

DOE Program Overview & Barriers Addressed

Timeline

Start Date: Jun 2008
End Date: Sep 2011
Percent Complete: 55%

Budget

Project Funds: $2.40M
DOE: $1.92M
Contractor: $0.48M
FY 08 Funds: $393K Spent
FY 09 Funds: $487K Spent
FY 10 Funds: $300K Allocated
$105K Spent
FY11 Funds: $375K Allocated
FY12 Funds: $365K Allocated

Barriers Addressed

Capital Cost
System Efficiency
Renewable Power Integration

Partners

Avalence:
Lead
Gas Equipment:
Sister-company
HyperComp:
Composite Wrapping

HYDROGEN ENERGY SYSTEMS
AVĀLENCE™ LLC

DEVELOPMENT PROGRAM MILESTONES

Project Milestones	
Description	**Status**
Determine a Manifolding and Sealing Arrangement for Nested Cell 1) H_2 and O_2 Gas Separation 2) Electrical Connection to Electrodes 3) Electrolyte Replenishment	Complete
Determine Containment Penetration Size and Design 1) Compatible with Composite Wrapped Vessel Constraints, 2) Support Cell Electrode Current Magnitudes (>1000 amp) 3) H_2 and O_2 Gas Off-Take 4) Electrolyte Replenishment	Complete
Design a Functional Shape of Outer Metal Jacket For Dual Purpose: ➢ Outer Electrode's Inner Surface ➢ Vessel Liner that is the Foundation for Composite Wrap	Complete
Demonstrate the Performance of the Nested Cell Core so that Accurate Projections of Energy Use can Be Integrated into the Cost Model	In Process
Demonstrate the Ability to Implement a Composite Fiber Outer Wrap Over the Nested Cell Core	In Process
Produce a Pilot Plant Design For Use as a Basis for a Sound Economic Analysis of Plant Fabrication and Operating Cost	In Process
Demonstrate the Operation and Efficiency of the Pilot Plant ➢ Laboratory Testing at Avālence ➢ Field Testing at NREL	Not Yet Started
Have a Site Ready to Accept the Completed Plant for Commercial Operation ➢ 100 kW of Renewable Power in Place ➢ Sale or Use of the Plant Products Defined	Not Yet Started

HYDROGEN ENERGY SYSTEMS
AVĀLENCE™ LLC

What's Different About Avālence?

- **Company formed as a spin-off of two established entities**
  - **Gas Equipment Engineering Corp.**
  - **Electric Heating Equipment Company**
- **Avālence *Hydrofillers* operate via Alkaline Electrolysis (KOH Electrolyte)**
- **Avālence *Hydrofillers* operate at a pressure of not less than 2,000 psig – and in some units at much higher pressure**
  - **Reduced or Zero Compression Power**
  - **Vastly Reduced Dryer Power / Loss**
- **Avālence *Hydrofiller* cells are designed for continuous operation – units in field with 40,000+ hours**

HYDROGEN ENERGY SYSTEMS
AVALENCE LLC™

Goals (subset), Design Approach, and Challenges

- Achieving at Least a 15 X Increase in the Production Rate of a Single Cell
- Demonstrate the High Pressure Cell Composite Wrap Which Enables Significant Weight Reduction
- Maintain Cylindrical Pressure Boundary Configuration
- Increase the Diameter By Using a Composite Outer Wrap
- Place Multiple Electrode and Membrane Pairings Inside a Single Cell Body
- Electrodes Act as Two Sided Unipolar Electrodes
- Large Diameter Membrane Formation
- Membrane to Manifold Sealing
- Fluid and Power Penetrations
- Composite Wrapping "Heavy" Cylinder
- Process Control of a Multiple, High-Capacity Cell Array
- Long-Term Operation at 6500 psi (O2 Side Purity)
- Low/No Leakage Electrical Isolation Hoses at 6500 psi

Last Year…

- We got it to work (6,500 psig), but it didn't meet company (or CE / TUV) safety standards
- And, we had efficiency loss

Demonstrated Membrane Sealing

- Poly-Sulfone Material Wrapped Around Perforated Tubular Form
- Proprietary Adhesive Used to

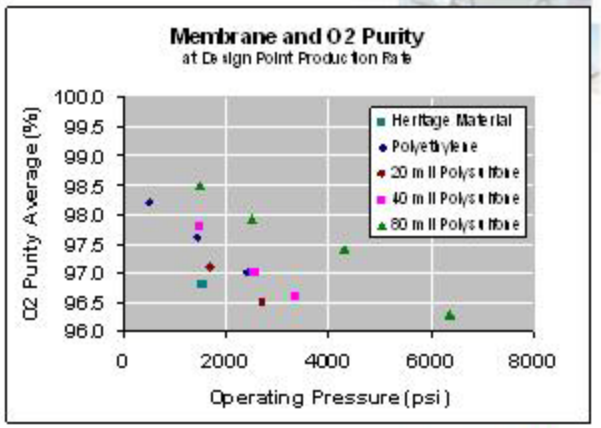
Significant Project Accomplishments

1) Identified and Tested Formable Sheet Membrane Material
2) Successfully Demonstrated Membrane Tube Forming and Seam Joining
3) Identified Vendor and Ordered 6500 psi Capable Electrical Isolation Hoses
4) Completed Design of Single Cell Test Article and Test Apparatus
5) Demonstrated 6500 psi Production on Small Capacity Cells

-8-

Demonstrated 6500 psi Operation

- Legacy cells used for testing
- Multiple membrane materials tested
- 80 mil thick membrane performed "OK" (lost efficiency)
- Electrolyte requires weekly "Decompression" to maintain purity
- "Not ideal" (NO SAFETY MARGIN)



Increasing Thickness Decreased Efficiency
80 mil 67 kWh/kg
40 mil 62 kWh/kg

6,500 psig!! (Why It's Hard…)

- **Electrochemistry still works, but…**
  - **Bubbles are very small (almost invisible)**
  - **Velocity of bubbles is low (masking)**
  - **Since velocity is lower, dwell time in cells increases**
    - **This by itself can impact purity…**
      - **More time to react with any electrolyte contaminants**
      - **Greater time for any side electrolysis reactions (hoses) to accumulate impurity**
      - **Since diffusion is either steady or increasing with pressure, the additional dwell time amplifies any impurity as a result of diffusion**
  - **And all other leak paths, which seemed to be trivial before, become <u>monsters</u>**
    - **NPT threads (we had to remove them from the cell design)**
    - **Dielectric Hoses (we had multiple attempts before success)**
    - **Internal cell seals (we have redesigned head on legacy cells, and used those design concepts on large cell)**

6,500 psig (Why It's Worth It…)

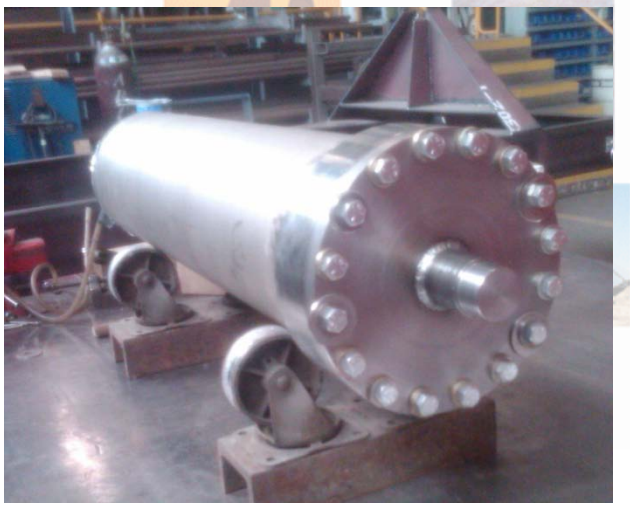
- 5,000 psig is a standard pressure for industrial vehicles
  - Buses
  - Forklifts
  - Other logistics support vehicles

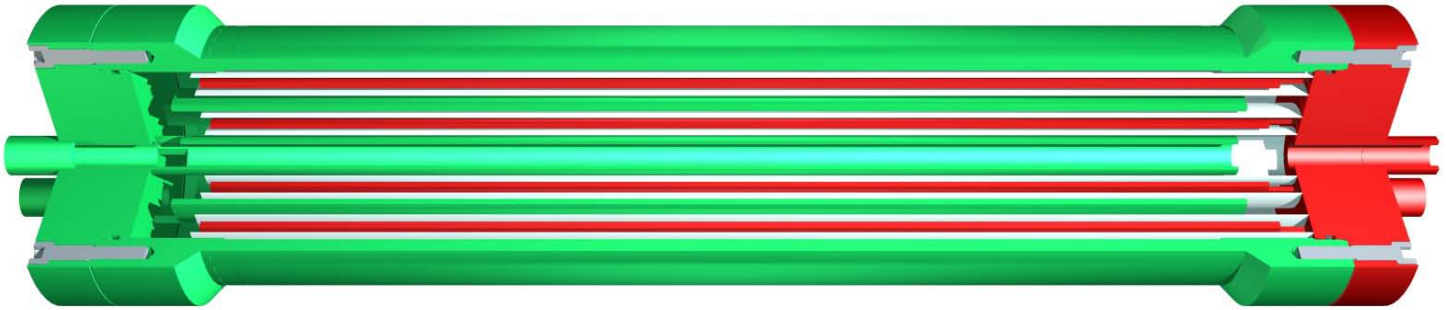
- Compressor power can be eliminated (replaced by water pumping power)
  - The compressor (multistage especially) is a major source of complexity, unreliability, and maintenance
  - For those few applications with extreme pressures (10,000-20,000 psig), the compressor will be one stage only (diaphragm)

- Since H2 is saturated in water at electrolysis pressure, higher electrolysis pressure means vastly reduced dryer power
  - In some cases, no additional drying is required

This Year…

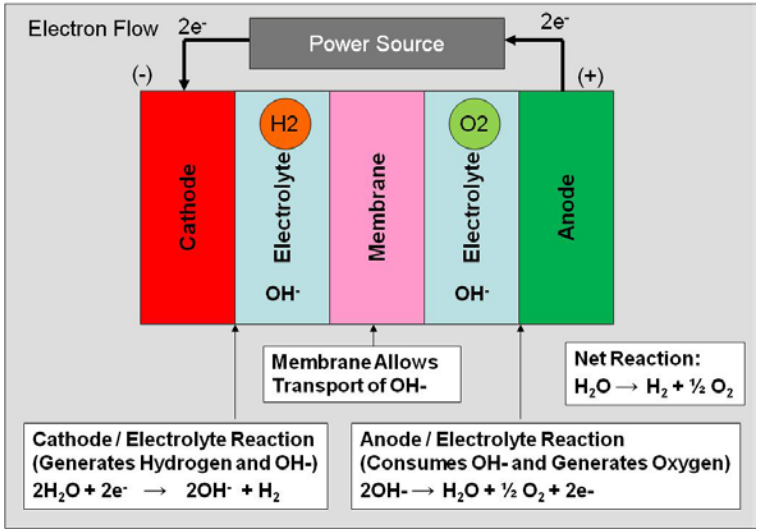
- Tested nested components of large cell with recirculation (but not all together)
  - Done
- Build two large cells (in process)
  - Stainless version (~1,000 psig)
  - Composite overwrap version (2,800 to 6,500 psig)
    - 6,500 psig with external axial support
- Test large cells (in process)
- Build pilot plant using array of large cells (planned)
  - With axial support structure



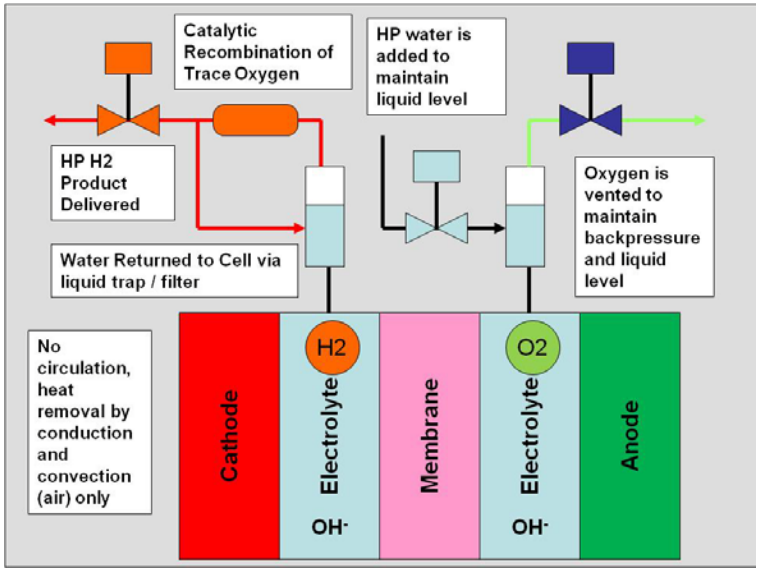


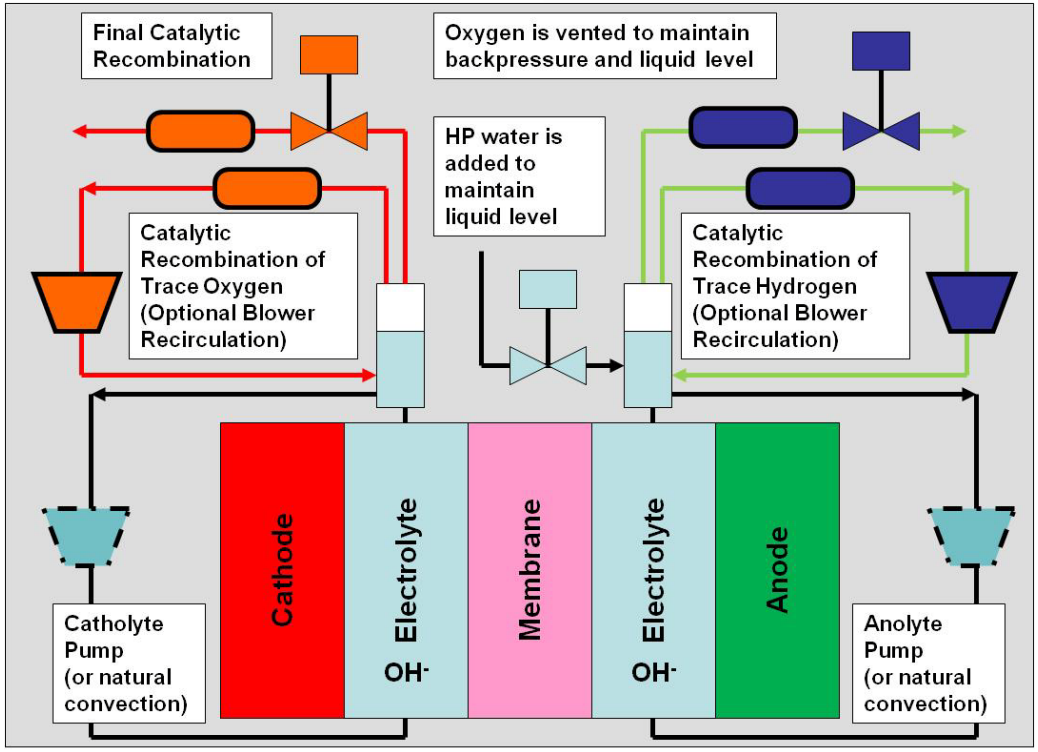
HYDROGEN ENERGY SYSTEMS
AVALENCE LLC

Evolution from Legacy Approach



- **Legacy approach demonstrated to 6,500 psig, no recirculation – unsafe**
- **New approach demonstrated to 2,500 psig, safety margin achieved**





HYDROGEN ENERGY SYSTEMS
AVALENCE LLC

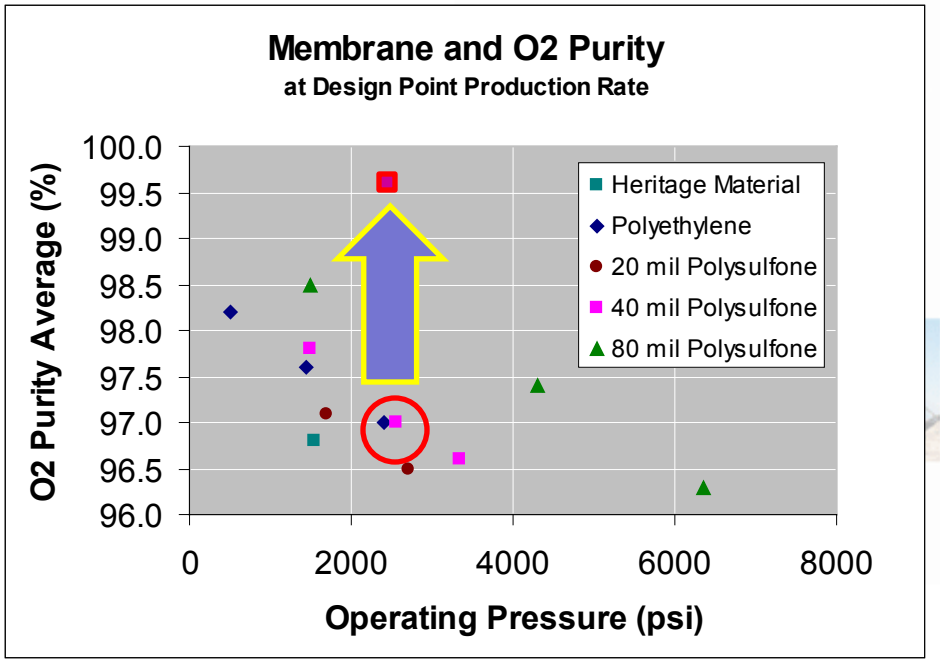
New Cell Results

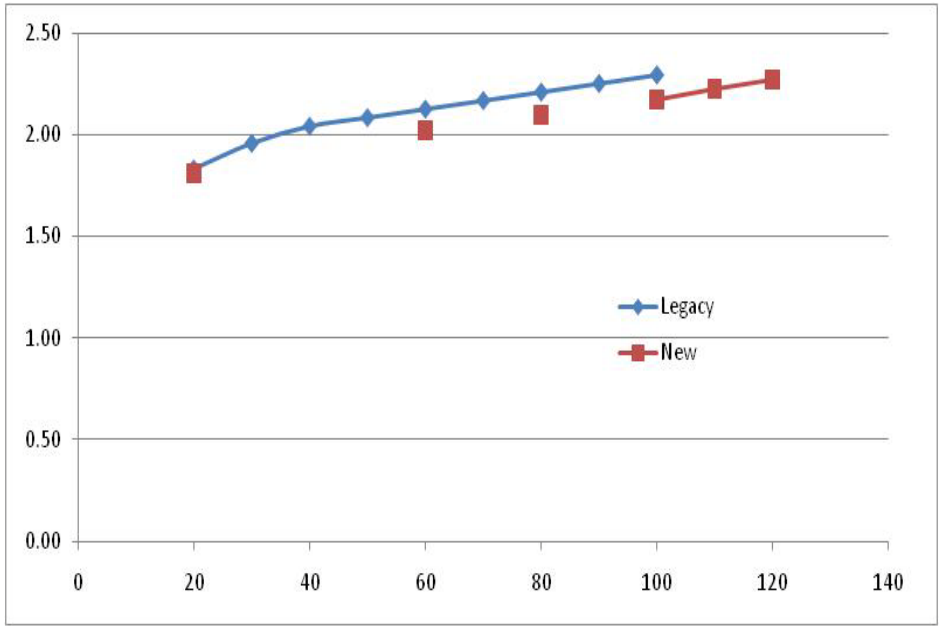
- 10 cell test string run with:
  - Partial Nested Electrode set
  - Anolyte and Catholyte circulation
  - More efficient membrane
  - New head design (better sealing)

- Improved polarization
  (even when cold)
  (even on a current density basis)
  - Massively reduced masking

- Purity at 2,500 psig 99.7%!!!
  (before catalyst / cleanup)
  - Vs. 97.0% with Legacy Design
  - We now have safety margin ++

- Endurance testing still underway, probably 1,000 hours at this point
  - We believe level control and thermal management will be issues (in nested cell), but are resolvable

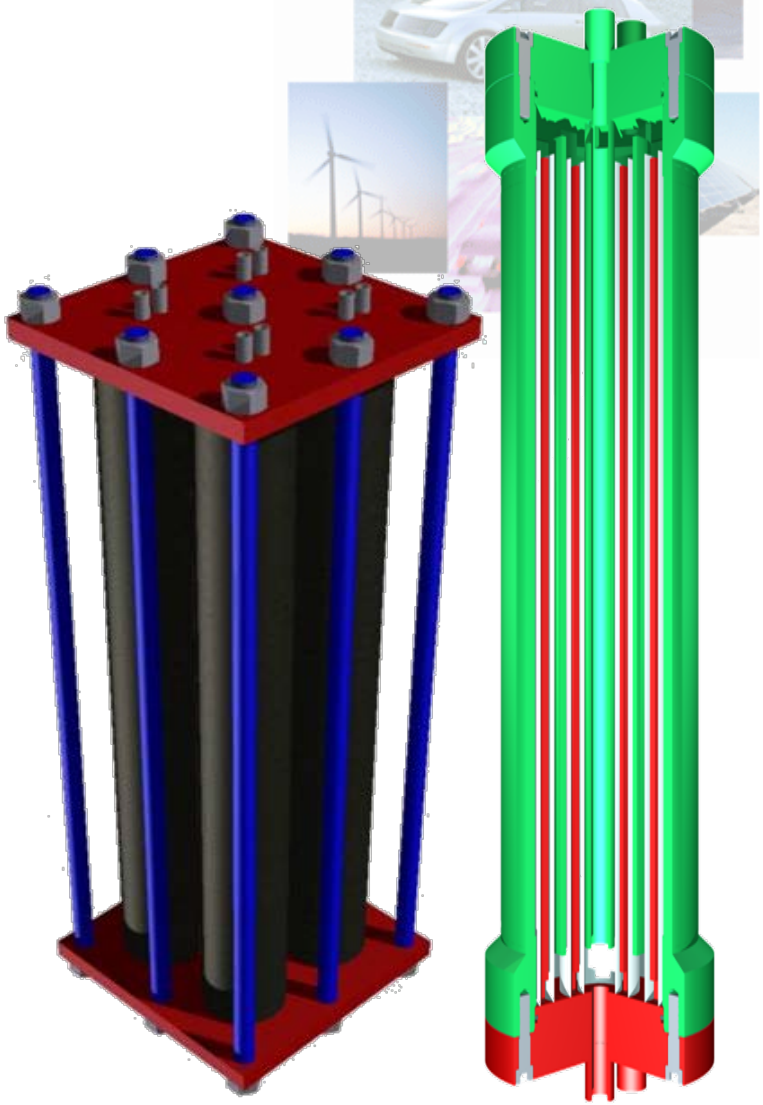




Nested System – Next Steps

- **Fully loaded nested test cell (with 1 meter membranes) will be tested at up to 1,000 psig, then composite wrapped and tested at 2,000 psig, then full pressure (with modified closure)**
  - **Metalic components will take 1,400 psig (hoop stress) or 2,800 psig (axial stress)**
  - **Composites and tie rods get us to 6,500+ psig**

- **Pilot Plant will demonstrate module(s) of nested cell**
  - **2x2 is the likely configuration (best for 6,500 psig)**
  - **Larger modules, 3x3, 5x5 possible, but result in VERY high currents**



Avālence *Hydrofiller* ISO Series

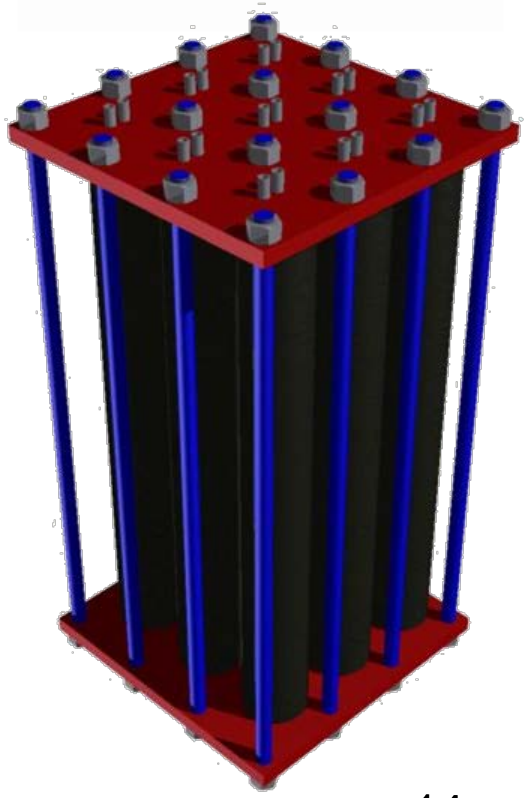
- **Avālence will continue to produce variants of the *Hydrofillers* (the core of the nested cell)**
  - **HF-15 to HF-175**
  - **0.75 to 10.0 kg H2/day per electrolyzer**
  - **Small footprint, suitable for laboratory or outdoor environment**

- **Avālence will offer larger, lower cost (per kg), higher performance *Hydrofillers* in ISO Container sizes (variants of the nested cell)**
  - **8'x 8.5 / 9.5' x 20', 30', 40', or 53' Standard Hi Cube ISO Van sizes**
  - **Depending on pressure, we expect these units to cover the range of 30-120 kg/day H2**
  - **This units will also produce 240-960 kg/day of high purity O2**
    - **Production of O2 is cost effective in larger sizes**

HYDROGEN ENERGY SYSTEMS
AVĀLENCE LLC™

Summary

- Efforts are continuing on DOE Large Cell Grant
- Hugely difficult to get to 6,500 psig, with high purity, but we now think we have it done
  - We will also produce both H2 / O2 products
- The nested cell remains to be fully proven, but we believe the major risks have been reduced and will move forward with full scale testing and pilot plant
- Avālence will offer larger cells and higher capacity plants, at lower costs with new architecture
- We would like to acknowledge the patience and guidance of DOE



Contact Information

CEO:
Anthony Della Volpe
Operations and Funding
ajd@avalence.com

CTO:
Paul Dunn
Technology Development
pmd@avalence.com

Project Lead:
Dave Mauterer
dwm@gasequip.com

Alpha Unit with >40,000 hours Operation

1240 Oronoque Road • Milford, Connecticut 06460 • Tel: 203-701-0052 • Fax: 203-878-4123
www.avalence.com