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

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**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*



# DEVELOPMENT PROGRAM MILESTONES

Project Milestones	
Description	Status
Determine a Manifolding and Sealing Arrangement for Nested Cell <ol style="list-style-type: none"> <li>1) H<sub>2</sub> and O<sub>2</sub> Gas Separation</li> <li>2) Electrical Connection to Electrodes</li> <li>3) Electrolyte Replenishment</li> </ol>	Complete
Determine Containment Penetration Size and Design <ol style="list-style-type: none"> <li>1) Compatible with Composite Wrapped Vessel Constraints,</li> <li>2) Support Cell Electrode Current Magnitudes (&gt;1000 amp)</li> <li>3) H<sub>2</sub> and O<sub>2</sub> Gas Off-Take</li> <li>4) Electrolyte Replenishment</li> </ol>	Complete
Design a Functional Shape of Outer Metal Jacket For Dual Purpose: <ul style="list-style-type: none"> <li>➤ Outer Electrode's Inner Surface</li> <li>➤ Vessel Liner that is the Foundation for Composite Wrap</li> </ul>	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 <ul style="list-style-type: none"> <li>➤ Laboratory Testing at Avalence</li> <li>➤ Field Testing at NREL</li> </ul>	Not Yet Started
Have a Site Ready to Accept the Completed Plant for Commercial Operation <ul style="list-style-type: none"> <li>➤ 100 kW of Renewable Power in Place</li> <li>➤ Sale or Use of the Plant Products Defined</li> </ul>	Not Yet Started

## 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



## 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 (O<sub>2</sub> 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

## 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

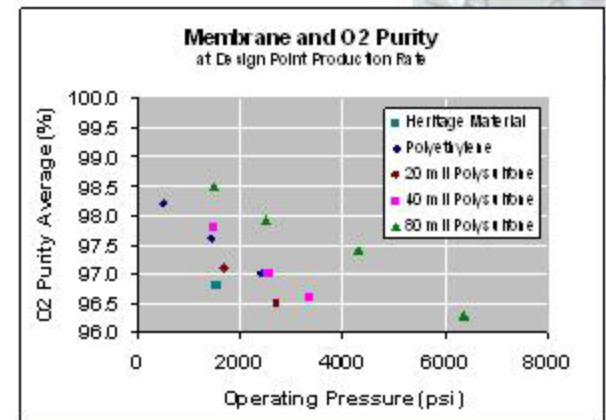
## Demonstrated Membrane Sealing

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



## Demonstrated 6500 psi Operation

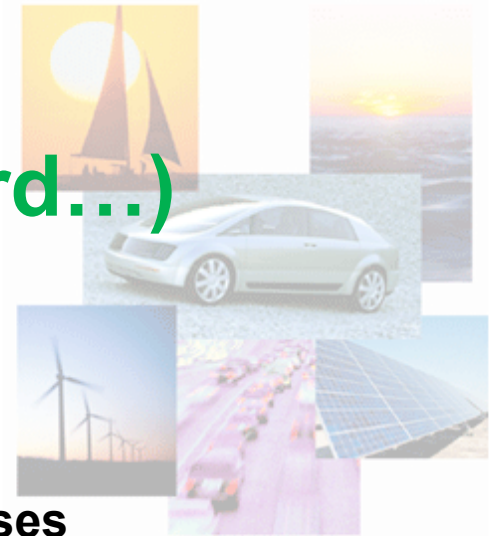
- Legacy cells used for testing
- Multiple membrane materials tested
- 80 mil thick membrane performed "OK" (lost efficiency)
- Electrolyte requires weekly "Decompression" to maintain purity
- "Not ideal" (NO SAFETY MARGIN)



Increasing Thickness      80 mil 67 kWh/kg  
 Decreased Efficiency      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 monsters**
    - **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...)

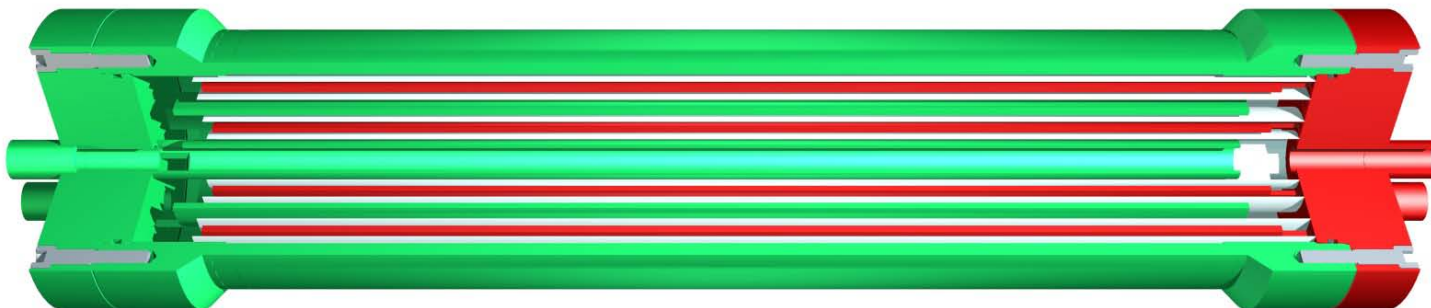
- **5,000 psig is a standard pressure for industrial vehicles**
  - Buses
  - Forklifts
  - Other logistics support vehicles
- **Compressor power can be eliminated (replaced by water pumping power)**
  - The compressor (multistage especially) is a major source of complexity, unreliability, and maintenance
  - For those few applications with extreme pressures (10,000-20,000 psig), the compressor will be one stage only (diaphragm)
- **Since H<sub>2</sub> is saturated in water at electrolysis pressure, higher electrolysis pressure means vastly reduced dryer power**
  - In some cases, no additional drying is required



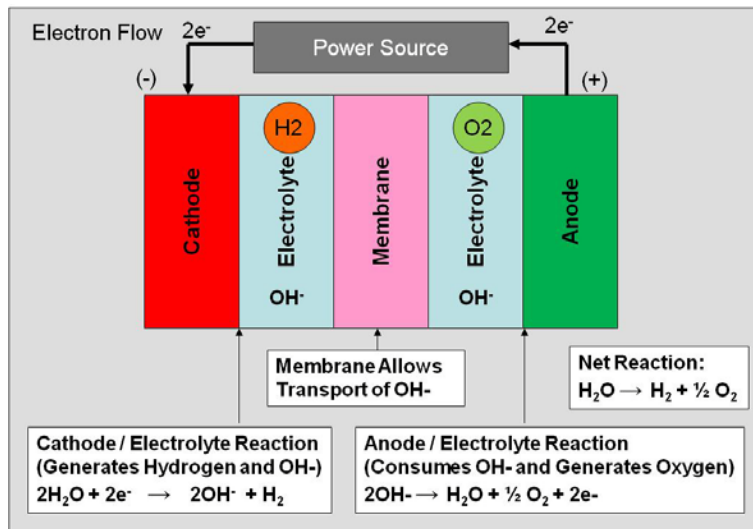


## This Year...

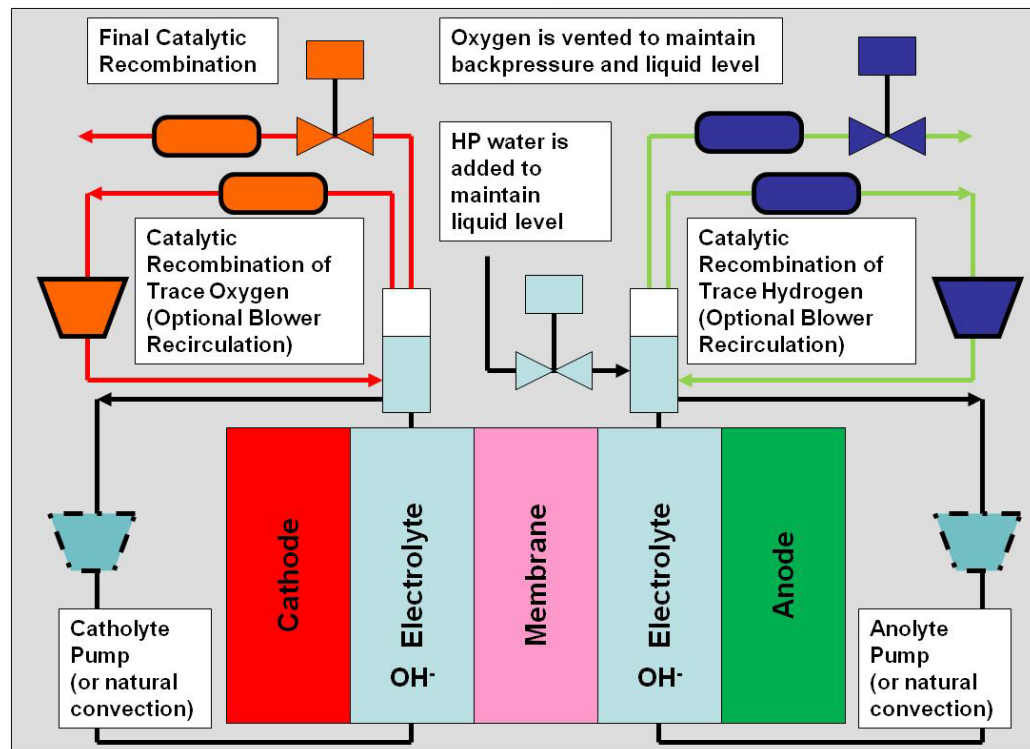
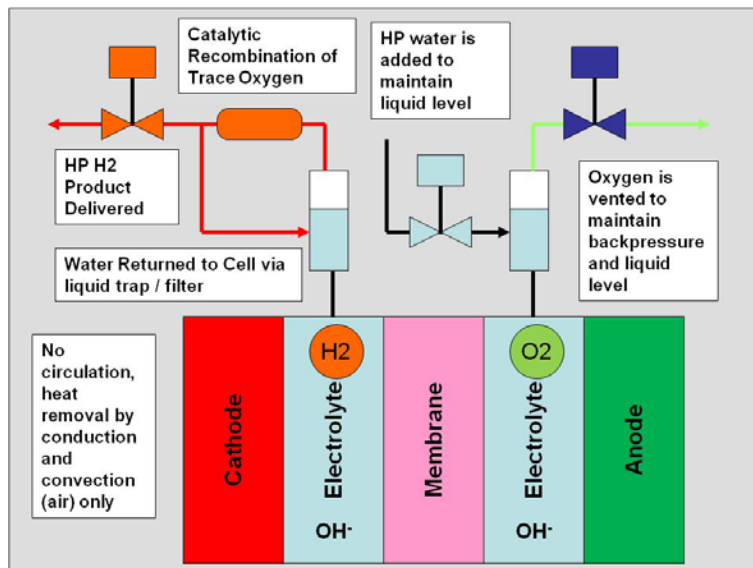
- **Tested nested components of large cell with recirculation (but not all together)**
  - Done
- **Build two large cells (in process)**
  - Stainless version (~1,000 psig)
  - Composite overwrap version (2,800 to 6,500 psig)
    - 6,500 psig with external axial support
- **Test large cells (in process)**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



# Evolution from Legacy Approach

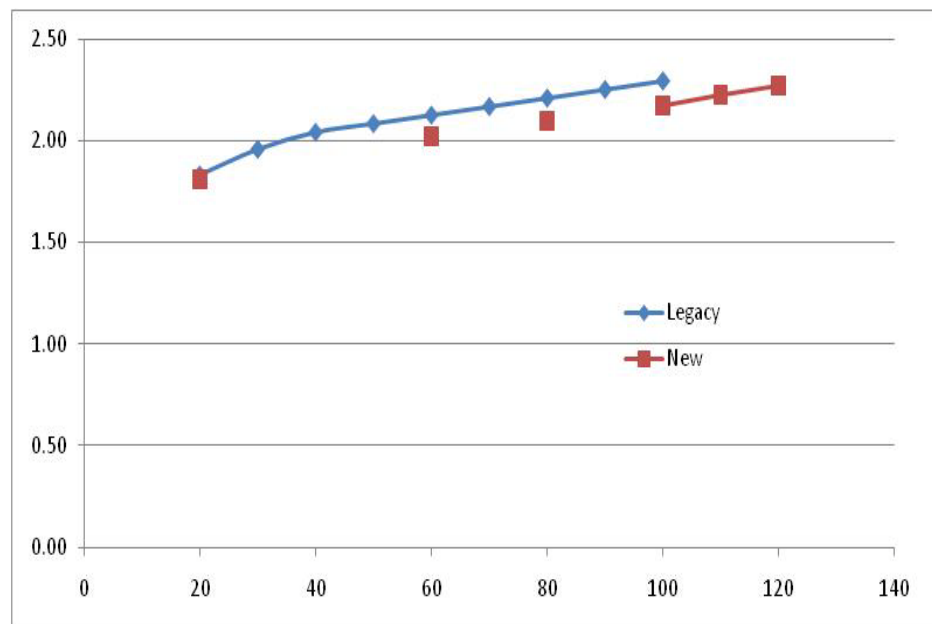
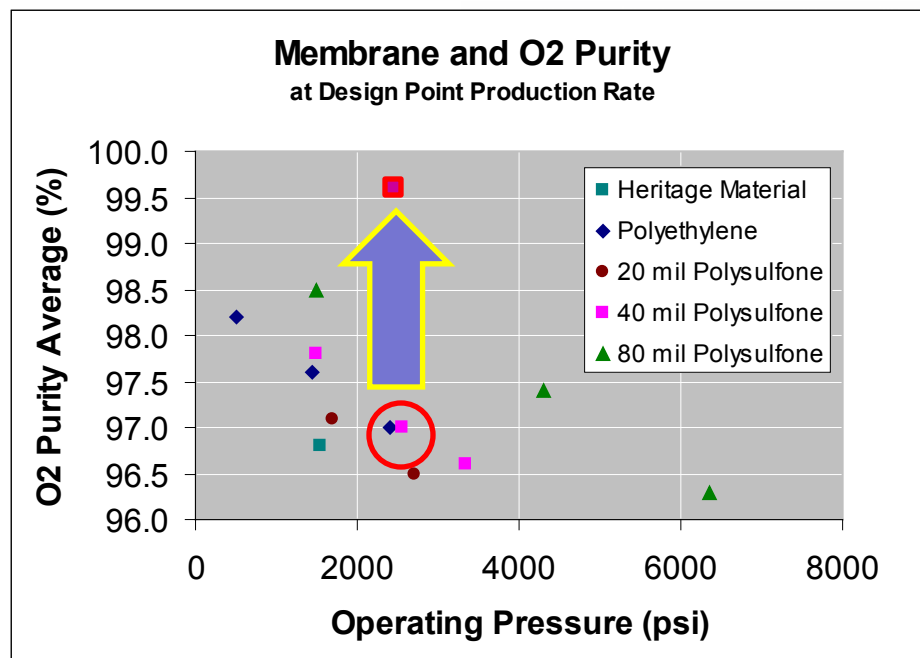


- Legacy approach demonstrated to 6,500 psig, no recirculation – unsafe
- New approach demonstrated to 2,500 psig, safety margin achieved



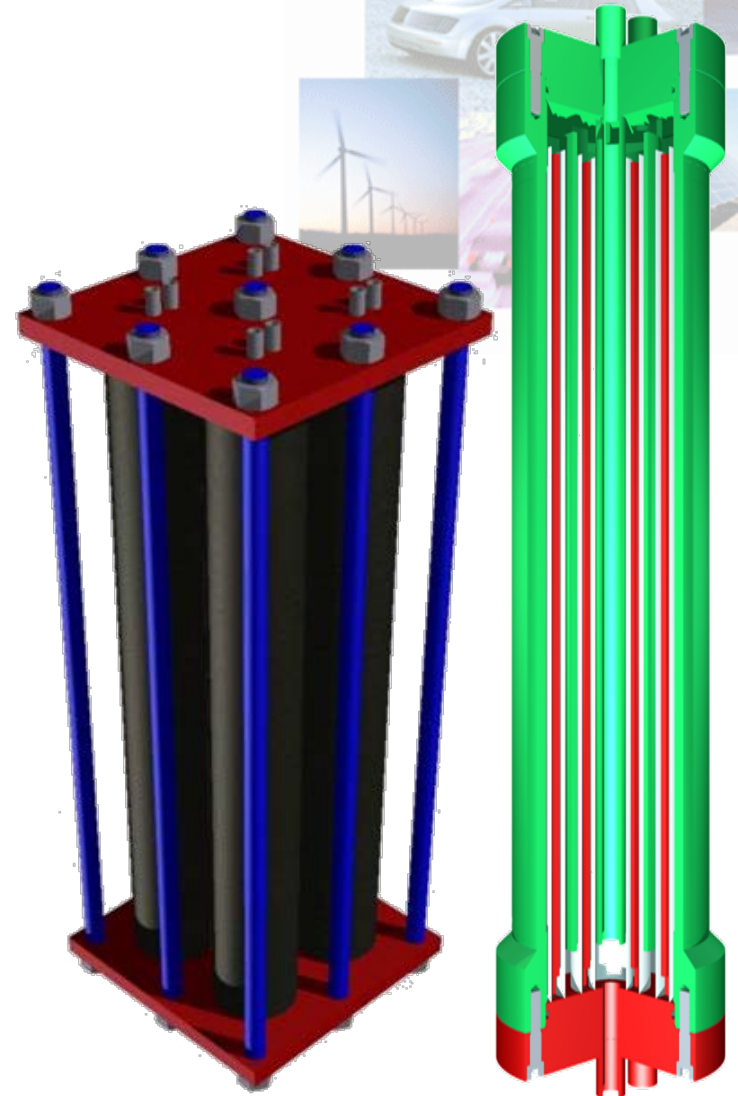
# New Cell Results

- **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)
  - Metallic 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



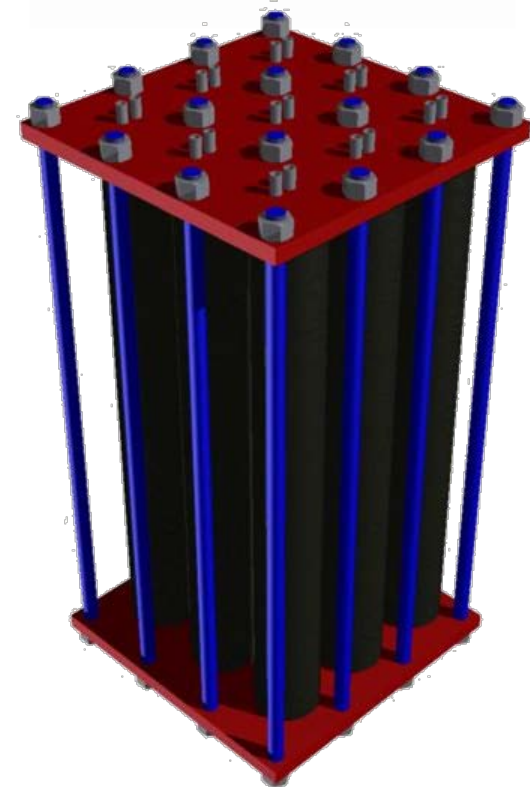
## Avālence *Hydrofiller* ISO Series

- **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 H<sub>2</sub>/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 H<sub>2</sub>
  - This units will also produce 240-960 kg/day of high purity O<sub>2</sub>
    - Production of O<sub>2</sub> is cost effective in larger sizes



## 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 H<sub>2</sub> / O<sub>2</sub> 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

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Alpha Unit with >40,000 hours Operation