Hydrogen Program

Develop infrastructure technology for a H₂ economy

**CTC**
- Program Management
- Hydrogen Delivery
  - CH₄/H₂ co-transport
  - H₂ separation
  - Delivery approaches
- Advanced Materials
  - Characterization
  - Testing/Analyses
  - Predictive Modeling
- Sensors

**Air Products and Chemicals, Inc. (APCI)**
Hydrogen Separation
Hydrogen Sensors

**EDO Fiber Science**
High Pressure/High Strength Composite Material Development and Prototyping

**Resource Dynamics Corporation (RDC)**
Tradeoff/Sensitivity Analyses of Hydrogen Delivery Approaches

**SRNL**
Pipeline Life Management Program

Aims to serve as “go-to” organization to catalyze PA Hydrogen and Fuel Cell Economy development
Funding and Duration

- **FY04 funding**
  - DOE: $2,943,232
  - Contractor: $738,965
- **Award notification**
  - September 1, 2004
- **Contract start date**
  - November 23, 2004
- **Contract end date**
  - March 31, 2006
Hydrogen Regional Infrastructure Program in Pennsylvania

• **Objectives**
  - Capture data pertinent to H₂ delivery in PA
  - Identify opportunities for safe/reliable delivery options

• **H₂ Delivery**
  - Co-transportation of H₂ and natural gas in existing pipelines
  - Separation of H₂ from H₂/natural gas blends at the point of use
  - Examine most attractive options for H₂ delivery approach(es) in PA
Hydrogen Regional Infrastructure Program in Pennsylvania

- **New Material Development**
  - Evaluate novel material approaches for pipelines and compressed gas storage tanks

- **Hydrogen Sensor Development**
  - Evaluate the ability of H₂-specific sensors to determine %H₂ in feed gas (including gas blends) and ppm-level H₂ for leaks
H₂ Delivery Approach

- Assess current gas pipeline materials and operational characteristics
  - Identify construction materials used in the US and PA according to:
    - Feed gas composition - PressureFlow Rate
    - Ambient conditions - Temperature
- Identify and quantify tradeoffs between alternative H₂ delivery approaches in PA
  - RDC
    - Examine economic, risk, and technology tradeoffs
      - Use data collection, economic analysis and sensitivity analysis
      - Recommend best approaches for delivering hydrogen from production facilities to end users
    - CTC
      - Provide inputs to assist with economic model
        - Natural gas demands
        - Co-transport deliver scenarios
H₂ Delivery Approach

- Investigate separation at point of use
  - Based on co-transport of natural gas and hydrogen
- Examine delivery scenarios and resulting effects on separation technology selection
  - Test and determine suitability of available technologies
- Assess current separation technologies
  - Organic membranes
  - Pressure Swing Absorption (PSA)
  - Vacuum Swing Absorption (VSA)
  - Palladium alloy membranes
  - Cryogenic distillation
  - External field-based approaches (thermal gradient, centrifuge)
  - Ceramic membranes
  - Zeolite membranes
Materials Approach

- Benchmark current or potential material issues
- Develop test protocols and perform materials testing
- Develop lifing and survivability model
  - Identify models and input parameters for lifing/survivability
  - Incorporate test data into lifing/survivability models
  - Investigate existing materials test data
- Simulate pipeline lifetime based on model data
- Investigate composite tanks
- Fabricate and test prototype off-board storage tank
Sensors Approach

- Define H₂ sensor performance requirements
- Access available sensor technologies
- Create test protocols for testing sensors against performance requirements
- Test priority sensor technologies in H₂ and gas blends
  - Identify effects of:
    - Contaminants
    - Humidity
    - Pressure
    - Temperature
  - Assess calibration and maintenance capability of sensors
Hydrogen Delivery Accomplishments

- Identified H₂ co-transport issues in existing natural gas system
  - Hydrogen production and injection location
  - Hydrogen/natural gas transport ratio as a function of demand
  - End user demands
  - Utility companies and PA Public Utility Commission
  - Gas-blend related issues and current pipeline failure modes
  - Potential effects of pressure drop losses in pipelines for various hydrogen/natural gas blends

- Performed research and demographic studies for PA H₂ demand scenarios
  - Performed sample calculations
  - Estimated required refueling station quantities and capacities

- Completed report on existing natural gas pipeline materials and associated operational characteristics
Hydrogen Delivery Accomplishments

- Identified transmission and distribution pipeline characteristics for the US and PA
  - Materials
  - Failures (leaks)
    - Significant corrosion issues in PA vs. US
  - Year of Construction
  - Operation parameters

- Identified operation concerns
  - State regulations and tariffs (BTU content)
  - Wobbe Index
  - Hydrogen loss cost to the end user
  - Odorants
  - Thermodynamic properties
  - Piping system layout
## Comparison of US and PA Transmission Pipeline

<table>
<thead>
<tr>
<th>Category</th>
<th>US</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>Percent of Total Miles</td>
<td>Percent of Total Miles</td>
</tr>
<tr>
<td>Steel</td>
<td>99.73</td>
<td>98.5</td>
</tr>
<tr>
<td>Other</td>
<td>0.27</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100 (291,704 mi)</td>
<td>100 (9,501 mi)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decade of Installation</th>
<th>US</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>2.9</td>
<td>0</td>
</tr>
<tr>
<td>Installed Pre-1940</td>
<td>5.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Installed 1940-1949</td>
<td>8.7</td>
<td>9.3</td>
</tr>
<tr>
<td>Installed 1950-1959</td>
<td>24.5</td>
<td>28.7</td>
</tr>
<tr>
<td>Installed 1960-1969</td>
<td>24.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Installed 1970-1979</td>
<td>10.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Installed 1980-1989</td>
<td>9.3</td>
<td>16.6</td>
</tr>
<tr>
<td>Installed 1990-1999</td>
<td>10.6</td>
<td>10.2</td>
</tr>
<tr>
<td>Installed 2000-Present</td>
<td>3.5</td>
<td>3.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leaks</th>
<th>% Leak Repairs</th>
<th>% Leak Repairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion Leaks</td>
<td>44.7</td>
<td>71.8</td>
</tr>
<tr>
<td>Mat'l/Welds Leaks</td>
<td>19.4</td>
<td>18.8</td>
</tr>
<tr>
<td>Other/Forces Leaks</td>
<td>35.9</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Based on 2003 Data
Comparison of US and PA Distribution Pipeline

<table>
<thead>
<tr>
<th>Category</th>
<th>US</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td><strong>Percent of Total Miles</strong></td>
<td><strong>Percent of Total Miles</strong></td>
</tr>
<tr>
<td>Steel</td>
<td>50.4</td>
<td>55</td>
</tr>
<tr>
<td>Plastic</td>
<td>45.7</td>
<td>35</td>
</tr>
<tr>
<td>Other</td>
<td>3.9</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100 (1,097,994 mi)</strong></td>
<td><strong>100 (40,584 mi)</strong></td>
</tr>
<tr>
<td><strong>Leaks</strong></td>
<td><strong>% Leak Repairs</strong></td>
<td><strong>% Leak Repairs</strong></td>
</tr>
<tr>
<td>Corrosion</td>
<td>35</td>
<td>62.8</td>
</tr>
<tr>
<td>Outside Force</td>
<td>8.6</td>
<td>16.8</td>
</tr>
<tr>
<td>Third Party</td>
<td>17.9</td>
<td>4.1</td>
</tr>
<tr>
<td>Material Defect</td>
<td>6.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Construction Defect</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>Other Causes</td>
<td>29.2</td>
<td>13.4</td>
</tr>
</tbody>
</table>

Based on 2003 Data
Hydrogen Delivery Accomplishments: H₂ Delivery Options

- Estimated potential feedstocks required and availability
  - PA Electricity, natural gas, biomass, coal, petcoke, gasoline, methanol
- Developed production scenarios
- Developed data on existing infrastructure
  - Roads, pipelines, power plants, refineries, coal mines, biomass sources
- Developed spreadsheets to perform cost analysis
- Discussed H₂A model with NREL
- Testing H₂A component model
- Refining spreadsheets to perform cost analysis
Hydrogen Delivery Accomplishments: PA H₂ Demand Scenarios

Kg/day of H₂

0-5,000
5,001-15,000
15,001-20,000
30,001-100,000
100,001-200,000
200,001-500,000
500,001+

1% (Fleet Only)
Hydrogen Delivery Accomplishments: PA H₂ Demand Scenarios

10% (Fleet Only)

Kg/day of H₂

- 0-5,000
- 5,001-15,000
- 15,001-20,000
- 30,001-100,000
- 100,001-200,000
- 200,001-500,000
- 500,001+
Hydrogen Delivery Accomplishments: Separation

- Made assumptions to evaluate technologies
  - Composition: 80% NG / 20% H₂
    - Typical NG composition
    - H₂ feedstock at 50, 100, or 200 psig
  - Hydrogen refueling station conditions
    - Pressure - 6000 psig
    - Demand - 100 kg/day H₂
    - Tolerances -
      - 1 ppm CO
      - 500 ppm inert species
      - <10 ppb H₂S
  - Loss via incomplete recovery in a separation device or to natural gas consumers
Hydrogen Delivery Accomplishments: Separation

- Identified and reviewed candidate separation technologies
  - PSA
  - VSA
  - Organic membranes
  - Combinations: Organic membranes + temperature swing absorption (TSA), Organic membranes + PSA or VSA
  - Palladium alloy membranes
  - Selectively reacting H₂ with hydride + TSA to regenerate
  - Cryogenic distillation
  - External field-based approaches (thermal gradient, centrifuge)
  - Ceramic and Zeolite membranes
- Modeling PSA recovery
  - Performed modeling for PSA using SIMPAC software
    - Results show good recovery of 85+% at 99.95+% purity
    - Suggests that organic membrane addition will not greatly improve recovery/purity
  - Considering modeling palladium membrane (ASPEN?)
    - Interested due to its selectivity to H₂
Hydrogen Delivery
Accomplishments: Separation - PSA

99.95+% Hydrogen Product

Molecular Sieve
Activated Carbon
Silica Gel

Hydrogen Feed
20% H₂
Materials Accomplishments

- Performed baseline assessments related to hydrogen delivery materials
  - Evaluated material issues based on
    - Failures
    - Pressures
    - Blends
    - Prevalence in infrastructure
- Assessed currently available high pressure composite tanks
  - Investigating where manufacturing costs can be reduced
    - Builds on 15+ years experience with Navy materials work
### Materials Accomplishments

<table>
<thead>
<tr>
<th>Materials</th>
<th>Metals</th>
<th>Composites</th>
<th>Plastics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Strength Low Alloy</td>
<td>Metal Liner</td>
<td>PE</td>
</tr>
<tr>
<td></td>
<td>Low Carbon Steels</td>
<td>Plastic Liner</td>
<td>PVC/Other</td>
</tr>
<tr>
<td>Prevalence in Infrastructure</td>
<td>Future high pressure</td>
<td>Future Applications (pipe, tank,</td>
<td>Existing NG Pipeline Distribution 45.7%</td>
</tr>
<tr>
<td></td>
<td>applications</td>
<td>miscellaneous hardware)</td>
<td>Transmission &lt;1%</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>0 - 10,000</td>
<td>6,600**</td>
<td>&lt;100*</td>
</tr>
<tr>
<td></td>
<td>0-1,200</td>
<td>10,000**</td>
<td>&lt;100*</td>
</tr>
<tr>
<td>Possibility of Distortion</td>
<td>N/A</td>
<td>Possible</td>
<td>Possible for higher pressures than currently</td>
</tr>
<tr>
<td>under cyclic conditions</td>
<td></td>
<td></td>
<td>used</td>
</tr>
<tr>
<td>Potential or Existing</td>
<td>H₂ embrittlement, fatigue,</td>
<td>H₂ embrittlement, embrittlement, and fatigue</td>
<td></td>
</tr>
<tr>
<td>Failures</td>
<td>and corrosion</td>
<td>H₂ permeation, embrittlement, and fatigue</td>
<td>H₂ permeation, embrittlement, and fatigue</td>
</tr>
<tr>
<td>Issues related to use</td>
<td>Joining/welding</td>
<td>Joints and thermal expansion/fatigue at interface in hybrid structures</td>
<td>Joints</td>
</tr>
</tbody>
</table>

* Typical pressures, although up to 125 psi have been documented. **Pressures related to composite tanks currently available.
## Materials Accomplishments: Composites

<table>
<thead>
<tr>
<th>Company Manufacturer</th>
<th>Operational Pressure</th>
<th>Structural Material</th>
<th>Liner Material</th>
<th>Service Life</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dynetek Industries Ltd.</strong></td>
<td>3,000-6,500psi/6,600-14,300psi</td>
<td>wound layer of carbon fiber reinforced composite material</td>
<td>seamless aluminum liner</td>
<td>15 years</td>
</tr>
<tr>
<td><strong>Quantum Technologies</strong></td>
<td>5,000-10,000psi/15,000-23,500psi</td>
<td>multiple layers of carbon fiber/epoxy laminate and a proprietary external protective layer for impact resistance</td>
<td>seamless, one piece, permeation resistant, cross-linked ultra-high molecular weight polymer liner</td>
<td>15 years</td>
</tr>
<tr>
<td><strong>Lincoln Composites</strong></td>
<td>7,000-10,000psi/11,750-23,000psi</td>
<td>high strength carbon fiber blended with tough glass filaments placed on the liner. Then an energy absorbing material followed by a fiberglass outer layer</td>
<td>plastic high density polyethylene (HDPE) liner that is permeation and embrittlement resistant</td>
<td>20 years</td>
</tr>
</tbody>
</table>
Materials Accomplishments: Lifing and Survivability Model

- Identified material models and supporting material database needs
  - Hydrogen permeation evaluation
  - Identification material properties degradation

- Identified hydrogen embrittlement model voids
  - Finite element programs available
    - Focus on a pre-existing crack and its progression
    - Provide in-depth understanding of the failure process
  - Hydrogen embrittlement analysis packages not available

- Enumerated modeling needs
  - Engineering model to analyze hydrogen embrittlement
  - Numerical scheme to implement the engineering model and evaluate the material
Materials Accomplishments: Lifing and Survivability Model

- Pursuing statistical analysis of hydrogen embrittlement
  - Identified a purely empirical approach (Yokobori)
  - Reviewed prior experiments and analysis (Davies)
  - Identified statistical analysis needs
    - Weibull distribution for tensile failure, fatigue failure, distribution for different materials
- Taking damage mechanics approach for material evaluation
  - Bypassing details in microscopic scale
    - Focusing on overall material performance or material merits
  - Introducing damage parameters to quantify material degradation
  - Used to study the failure of materials with complex structures
    - Includes composite materials and large engineering structures
  - Not previously adopted in the modeling of hydrogen embrittlement
Materials Accomplishments: Lifing and Survivability

- Diffusion Measurement
- Material Degradation Measurement
- Quantification of Damage Model
  - Pipeline Component Service Conditions
  - Commercial Finite Element Software
  - Evaluation of Component Performance

Commercial Finite Element Software
<table>
<thead>
<tr>
<th>Material</th>
<th>Test Type</th>
<th>Prior Exposure</th>
<th>Test Environment</th>
<th>Testing Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A42</td>
<td>Tensile</td>
<td>None, H2 - 7 MPa, 1 hr</td>
<td>Air, 1 atm, RT; H₂, 7 MPa, RT</td>
<td>SRNL</td>
</tr>
<tr>
<td>A42 &amp; weld, HAZ</td>
<td>Tensile</td>
<td>None</td>
<td>Air, 1 atm, RT</td>
<td>SRNL</td>
</tr>
<tr>
<td>A42</td>
<td>Creep Rupture</td>
<td>None, H2 - 7 MPa, 1 hr</td>
<td>Air, 1 atm, RT; H₂, 7 MPa, RT</td>
<td>TBD</td>
</tr>
<tr>
<td>Weld, HAZ</td>
<td>Creep Rupture</td>
<td>None, H2 - 7 MPa, 1 hr</td>
<td>Air, 1 atm, RT; H₂, 7 MPa, RT</td>
<td>TBD</td>
</tr>
<tr>
<td>A42</td>
<td>Fatigue, R=0.7, 0</td>
<td>None, H2 - 7 MPa, 1 hr</td>
<td>Air, 1 atm, RT; H₂, 7 MPa, RT</td>
<td>TBD</td>
</tr>
<tr>
<td>Weld, HAZ</td>
<td>Fatigue, R=0.7, 0</td>
<td>None, H2 - 7 MPa, 1 hr</td>
<td>Air, 1 atm, RT; H₂, 7 MPa, RT</td>
<td>TBD</td>
</tr>
<tr>
<td>A42 - Tube</td>
<td>Cyclic, 0 to 1000 psig</td>
<td>None</td>
<td>H₂, RT</td>
<td>TBD</td>
</tr>
<tr>
<td>A42 - Tube</td>
<td>Burst</td>
<td>None</td>
<td>H₂, RT</td>
<td>TBD</td>
</tr>
</tbody>
</table>
Sensor Accomplishments

- Created performance requirements for sensors to be evaluated
- Conducted technology assessment of sensors
- Identified and purchased two COTS and one pre-commercial sensor(s)
  - COTS
    - H2 Scan portable hydrogen leak detector
    - Nanomix Sensation Technology wireless hydrogen sensor
- Created test protocols for testing sensors
# Sensor Performance Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component specificity</td>
<td>( \text{H}_2 )</td>
<td>-</td>
</tr>
<tr>
<td>Oxygen requirement</td>
<td>not required</td>
<td>-</td>
</tr>
<tr>
<td>Operating range</td>
<td>0.01 – 5</td>
<td>%</td>
</tr>
<tr>
<td>Chemical interference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>( \text{ppm v} )</td>
<td></td>
</tr>
<tr>
<td>( \text{H}_2\text{S} )</td>
<td>( \text{ppm v} )</td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td>5% - dewpoint</td>
<td>-</td>
</tr>
<tr>
<td>VOC (diesel exhaust)</td>
<td>( \text{ppm v} )</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>( \pm 5 )</td>
<td>%</td>
</tr>
<tr>
<td>Calibration drift (short)</td>
<td>&lt; 2.5 (24 hrs)</td>
<td>%</td>
</tr>
<tr>
<td>Calibration drift (long)</td>
<td>&lt;10 (3 months)</td>
<td>%</td>
</tr>
<tr>
<td>Electrical noise</td>
<td>&lt; 100</td>
<td>ppmv</td>
</tr>
<tr>
<td>Response time (10 % change)</td>
<td>&lt; 2</td>
<td>sec</td>
</tr>
<tr>
<td>Full range (0.1-5 %) time-constant</td>
<td>&lt; 5</td>
<td>sec</td>
</tr>
<tr>
<td>Ambient temperature range</td>
<td>-200</td>
<td>° F</td>
</tr>
<tr>
<td>Ambient pressure range</td>
<td>0.8 – 1.2</td>
<td>atm</td>
</tr>
<tr>
<td>Calibration/validation requirement</td>
<td>One point NIST-Ref</td>
<td>-</td>
</tr>
<tr>
<td>Sensor size (w/electronics)</td>
<td>2x2x1</td>
<td>inches</td>
</tr>
<tr>
<td>Alarm levels (if process required)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>10,000</td>
<td>ppmv</td>
</tr>
<tr>
<td>Level 2</td>
<td>20,000</td>
<td>ppmv</td>
</tr>
<tr>
<td>Level 3</td>
<td>30,000</td>
<td>ppmv</td>
</tr>
<tr>
<td>Level 4</td>
<td>40,000</td>
<td>ppmv</td>
</tr>
<tr>
<td>Level 5</td>
<td>50,000</td>
<td>ppmv</td>
</tr>
<tr>
<td>Sensor-to-electronics distance</td>
<td>&lt; 6</td>
<td>feet</td>
</tr>
<tr>
<td>What</td>
<td>How</td>
<td>Details</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>A Qualification:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 O2 effect</td>
<td>Cycled between N2 and air (1% H2)</td>
<td>Flowing challenges</td>
</tr>
<tr>
<td>2 Linearity from 0.01 to 4% H2</td>
<td>H2 challenges in air at 10 points from 0.01% to 4% H2</td>
<td>Flowing challenge; Random sequence</td>
</tr>
<tr>
<td>3 Hysteresis</td>
<td>H2 challenges in air at points from 0.01% to 4% H2</td>
<td>Sequenced from low to high; soak at high for 1 hr and reverse sequence; 30 minute challenges</td>
</tr>
<tr>
<td>4 Statistical repeatability</td>
<td>Repeat linearity testing (#4) every other day over 6 days</td>
<td>Statistical regression analysis</td>
</tr>
<tr>
<td>5 Inter-sensor variability of responses between sensors</td>
<td>Repeat linearity testing (#4) on 4 sensors</td>
<td>Statistical regression analysis</td>
</tr>
<tr>
<td>6 Effect of ambient temperature variation on the sensor response</td>
<td>Repeat linearity testing (#4) while module is at constant temperature and changed from -30 °C to 60°C</td>
<td>Sensor can be in a sealed box immersed in a constant temperature liquid or in a heated/cooled oven</td>
</tr>
<tr>
<td>7 Effects of natural gas constituents as interferences to H2 sensing</td>
<td>H2 challenges in natural gas at 5 points from 0.01% to 4% H2</td>
<td>Followed by retesting with stds in air.</td>
</tr>
<tr>
<td>8 Effects of controlled ambient air contaminants as interferences to H2 sensing</td>
<td>4% H2 in air diluted 50% with 20% CO in N2, 100% CO2,</td>
<td>Each contaminant is followed by retesting with stds in air.</td>
</tr>
<tr>
<td><strong>B Functional Behavior</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Effects of controlled ambient air contaminants as interferences to H2 sensing</td>
<td>4% H2 in air diluted 50% with N2 passed through 100% motor car exhaust, N2 passed through motor oil (devoid of aerosol), N2 passed through anti-freeze, N2 passed through food products</td>
<td>Each contaminant is followed by retesting with stds in air.</td>
</tr>
<tr>
<td>2 Effects of uncontrolled ambient air contaminants as interferences to H2 sensing</td>
<td>Operation of unit exposed to ambient air near a farm or factory for 6 days</td>
<td>Followed by retesting with stds in air.</td>
</tr>
</tbody>
</table>
Purchased Sensors
(Applied Sensors)

Early version

Current testing system
Purchased Sensors
(H₂ Scan & NanoMix)

H₂ Scan Hand held w/extended tip

Nanotube w/wireless
Test Platform/Equipment

- Computer Interface
- 8-channel Datalogger
- Automatic Sequencer
Testing Setup

- **Air**
- **H2**
- **N2**
- **DCH**
- **DCL**
- **Sensor**
- **Bag**

- Hand Activated 2-way valve
- Pneumatically controlled 2-way valve
Plans

- Evaluate production needs given different demand scenarios
- Evaluate transportation/delivery options
- Complete evaluation of separation technologies
- Determine effects of H₂ on infrastructure materials
- Identify key test data gaps
- Perform lifetime simulation on common pipeline material
  - Input test data into a Lifing and Survivability model
  - Input existing test data into Lifing and Survivability model
- Construct and test prototype tank
- Evaluate COTS H₂ sensors for implementation in transportation and delivery applications
- Complete laboratory test evaluation of 3 sensors
  - Per established test plan/protocol
- Perform limited field testing
Questions