Air Products’ Experiences with Indoor Refueling

National Hydrogen Association
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Market Leader in Refinery Hydrogen

Diverse markets and geographies

$10B in sales

Global #1 HyCO Position

Onstream 2007

APD (1940MMscfd)

Comp X

Comp Y

Comp Z

4,600 Million SCFD

Increasing Sales

H₂ Plant Operating Years

APD . . .

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Leadership in Hydrogen Fuel Infrastructure

- Worlds largest producer of merchant hydrogen
- Our capacity ~1.75 million TPY Could support 7-8 million vehicles
- Active since 1993
  - Built over 95 hydrogen station projects
  - About 100,000 fuelings
  - in 14 countries
- Strong and broad IP position.
Background

- Hydrogen is identified as a fuel from the 60s
- Energy costs & environmental issues increased interest in hydrogen
- Over the road vehicle programs from 1993
- Material Handling was identified as an early adopter of fuel cells
  - Manufacturing facilities, Warehouses, distribution depots
  - Evolution of Indoor Dispensing
Hydrogen & Industrial Market

- Pipeline & tube trailers supply up to 2400 psig applications
- Liquid supplied systems to 130 psig
  - 2400 psig liquid pumping developed in 1980’s
  - 6000 psig and 7000 psig systems since 2000
- 1000’s of gaseous supply systems
- Over 1000 LHY supply systems
- Small percentage to date are fuel stations
Development of Fueling Stations

- 1990’s ushered in fuel station
- Existing technology served as platform
- Pressures increasing to 350 and 700 bar
- Dispensing technology and protocols developed
- Fuel dispenser was step out
- More than 100 stations installed
Indoor Hydrogen Use in Industry

- Indoor Hydrogen Use is not new
- Most comparable sized industrial hydrogen systems serve indoor applications
  - Heat treating
  - Food hydrogenation
  - Electronics
  - Power Generation
  - Laboratories
  - Etc.
- Outdoor storage and supply systems
- Indoor piping distribution systems to end uses
- Flows
  - Frequently large
  - Batch use also
Indoor Hydrogen Usage

- Extensive experience piping hydrogen into buildings
- Appropriate safeguards installed
  - Outdoor shutoff for emergency stop
  - CGA 5.4 “Hydrogen Piping”
  - ASME B31.3
  - Gas/fire detection not required for these applications
    - Gas detection sometimes installed at point of use
    - Fire detection rarely installed
- Material Handling is a new application
  - Follow and improve upon existing practice
  - Develop additional codes and standards
- Natural Gas is another analogy
  - Very common, even large mains
  - LFL’s comparable (5% vs 4%)
  - Limited means of shutoff, detection, etc.
Indoor Hydrogen Fueling

- Brings together:
  - Industrial Hydrogen Experience
  - Fuel Station Experience
  - Indoor Hydrogen Experience

- Why Indoor Fueling?
  - Required to serve material handling fleet

- Codes and Standards
  - Same as for other applications
  - Also develop new, specific Standards

- “Source Valve” concept for separate code coverage
  - NFPA 52 vs NFPA 55
Overall Approach

- Outdoor Supply, Compression and Storage
  - Leverage from existing industrial gas equipment
    - Refined for this market
  - Follow existing Codes and Standards

- NFPA 55 is for Industrial Gas Supply Systems
  - Chapter 10 for Gaseous Hydrogen
  - Chapter 11 for Liquid Hydrogen

- NFPA 52 will not cover hydrogen supply systems to avoid overlap
Air Products Indoor Hydrogen Fueling Experience

- Over 12 dispensers deployed
  - 8 more in process

- Usage is growing exponentially
  - To date: Almost 50,000 fills for material handling alone
  - February 2009: Almost 1000/week
  - April 2009: 1500/week estimated
  - September 2009: 3000/week estimated

- Excellent Operating History to date
  - Multiple Facilities On-line
  - Supports day to day operations
    - No longer just “demonstration”
Development of Fueling Stations

- Extensively reviewed internally by Air Products
  - HAZOP – Hazard and Operability Reviews
    - Every Project
    - Participate with customer
  - Failure Mode and Effects Analysis (FMEA)
  - Job Safety Activity (JSA) performed
  - Functional Review Process within Air Products
    - Reviewed by Corporate
  - Quantitative Risk Analysis
  - Dispersion Modelling

- Reliability Improvement team
  - Feedback for reliability and safety from dedicated Operations team to Engineering
Development of Fueling Stations

- Extensively reviewed externally by others
  - Professional Engineer
    - Completed report for DDSP installation
  - Authorities Having Jurisdiction (AHJ’s)
  - Third party inspection agencies
  - Customer review process

- Future
  - Component Listings
Outdoor System Safety Features

- Pumps and compressors
  - Multiple safety shutdowns
  - Isolation valves
  - Redundancy

- Piping systems
  - SS 316 construction
  - ASME B31.3

- Storage
  - ASME compliant

- System meets NEC and NFPA 55 for liquid/gaseous hydrogen

- Importance of siting and location
  - All venting is outdoors to safe location (elevated stack)
  - Dispersion and radiation analysis
  - Separation distances to exposures
Outdoor/Indoor Interface

- Storage located outdoors before entering building
  - Two valves outside
  - Additional valve inside
- No mechanical fittings inside building except in cabinet
  - All welded construction
- E-Stop both outside and inside, hard wired
- Release limited to piping inside building on idle system
- (0.05 kg/100 ft (20scf) of piping)
  - No storage inside building
  - Very limited inventory in piping... less than ½ of a standard cylinder
Dispenser Safety Features

● Special attention on dispenser
  – End use application
  – Limited access to trained personnel via PIN or card access
  – On screen instructions on dispenser
  – Deviations will abort fill

● Multiple “Layers of Safety” to build redundancy
  – Pressure Protection
    • Transmitter, Regulator, Switch, Relief Valve
  – Shutoff Valves
    • Triple redundancy
Dispenser Safety Features

- Vehicle and station electrically bonded through nozzle
- Vehicle grounded through parking surface
  - Verified at startup
- Non-interchangeable nozzles for pressure rating
- Special design nozzles per SAE J2600
  - Extensive testing, third party approvals
  - Double block and bleed, unlike industrial connections
  - Cannot be opened unless connected
- Self-sealing break away joints
  - For vehicle pull-away/accident
Dispenser Safeguards

- Secondary containment (sleeve) over fill hose & mechanical joints
  - No exposed joints
- Sleeve routed to dispenser cabinet
- Gas Detection in cabinet
- Gas Detection in fueling area (NFPA 52 requirement)
- Flame Detection in fueling area (NFPA 52 requirement)
- All vents outdoors, nothing inside
- All safeguards will stop fill
Dispenser Safeguards – Leak Protection in AP Dispenser

- Indoor piping pressure monitored continuously when system idle
- At start of fill, leak check of entire dispenser
- Instrumentation check
- Leak check after connection, prior to fill
- Hose break detection during fill
- Electronic Excess Flow protection
Dispersion Study, Cabinet Leak

Study Folder: newstudy
Audit No: 245
Model: Vessel/Pipe Source
Material: 98 mol% H2 in air
Averaging Time:
Flammable(18.75 s)
C/L Offset: 0 ft
Concentration: 0.04082 fraction
Weathers

- Blue line: D Stability 5 m/s @ 0.91f
- Green line: D Stability 9 m/s @ 0.52f
- Yellow line: F Stability 0.6 m/s @ 2.8

Diagram showing dispersion study results with distance downwind (ft) on the x-axis and cloud height (ft) on the y-axis.
Recent Indoor Dispenser
Indoor Dispensing Features

- Communication fills
  - Greater degree of control
  - Ability to instantaneously compare flow to pressure rise. Deviation stops fill
  - Ability to know if “OK to fill” is interrupted

- Dispenser compliant with NFPA 52 and NFPA 70 (NEC)
  - Dispenser cabinet Class I, Div 1, Group B
  - Controls Class I, Div 2, Group
Training and Access

- Provide general hydrogen training
- Train operators on dispensing
  - MSDS & Safetygrams
- Additional training at customers request
- Emergency response
  - Weave system into customers system
Example System - DDSP

- 40 Class 1 Lifts
  - 20 Plug Power
  - 20 East Penn/Nuvera
- 9,000 gallon liquid hydrogen storage
- Dual CHC 6000/7000 pumps and vaporization
- Series 150 gas compressor
- Gaseous hydrogen storage – 120 kg
- Two indoor gaseous hydrogen dispensers
- Operating at about 300 fills/week since February
- Reviewed and approved by third party Professional Engineer
DDSP Fueling Station
Code Issues

- Codes under development
- Actively participating
  - NFPA 55, NFPA 52, NFPA 2
    - Separation distances
    - CGA, SAE, ASME, CSA
    - ICC, HIPOC
- Strive to meet current codes
  - Where questionable safety or conflicting requirements….we will work to correct through code process
9.3.3.13 Indoor Fast-Fill Fueling, Outdoor Storage, and Compression.

Fast-fill fueling indoors shall be permitted where storage, gas processing, and compression equipment is located outdoors complying with 9.3.2.1 through 9.3.2.5.

9.3.3.13.1 Where attended fast-fill fueling is performed indoors, the following shall be installed:

(1) An emergency manual shutdown device shall be installed as required by Section 9.11.

(2) A gas detection system equipped to sound a latched alarm and visually indicate when a maximum of one-quarter of the lower flammable limit is reached shall be installed.

9.3.3.13.2 The actuation of the gas detection system shall shut down the compressor and stop the flow of gas into the structure.
NFPA 52 Code Changes in Progress

- NFPA 52
- NFPA52.pdf

52-94 Log #226
(9.3.3.13)

Final Action: Accept

Submitter: Larry L. Fuer, Fuer, Inc.
Recommendation: Add new text as follows:

9.4 9.3.3.13 Indoor Fast-Fill Fueling, Outdoor Storage, and Compression. Fast-fill fueling indoors shall be permitted where storage, gas processing, and compression equipment is located outdoors complying with 9.3.2.5.
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9.3.3.13.2 The actuation of the gas detection system shall shut down the compressor and stop the flow of gas into the structure.

9.4.1 Qualified operator. Dispensing operations shall be performed by an operator who has been qualified by training to perform the functions necessary in the filling operation as described by the manufacturer’s operating instructions.

9.4.2 Construction of indoor areas. Walls, ceilings and floors within 15 feet (4.6 meters) of the dispenser shall be constructed as fire barriers having a fire resistance rating not less than 2 hours.

9.4.2.1 Openings. Opening protectives shall be provided for wall openings in accordance with the requirements of NFPA 5000 Building Construction and Safety Code.
NFPA 52 – 2009 Highlights

- Numerous additional requirements for training, construction, and shutdowns
- Fire detection system is required
  - Must provide local indication
  - Must stop flow of gas and dispensing
- Emergency Stop
- Manual Fire Alarm Pullbox in vicinity
- Automatic and Manual Shutoff Valves
- Gas detection system is required inside dispenser
NFPA 52 – 2009 Highlights

● Ventilation
  – Requires traditional ventilation for indoor storage with exception
  – Exception for large room volumes
    • Volumes so large as effectively “outdoors”

● Table 9.4.3.1.1 details ventilation exception
  – Limits maximum dispensed quantity per room volume.
    • For example, no more than .8 kg for 1000 m³ room volume.
    • Increased proportionally with room volume
Requirements for Ventilation

Exception

- Automatic Fuel Shutoff at dispensed quantity
- Ceiling must be greater than 25’ height
- Maximum Flow rate of 2 kg/minute
- Potential leak points must be monitored continuously
- Room size adjusted for number of dispensers
- Electrical classification
  - Class 1, Group B, Div 2 within 15’ of dispenser
Thank you

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