US DOE Webinar Series

Fuel Cell Technologies Office

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

EERE Fuel Cell Technologies Office

6 November 2014

2014 and 2015 Hydrogen Student Design Contests

Webinar Overview

1. **Introduction**
   Erika Sutherland, U.S. DOE Fuel Cell Technologies Office
2. **HEF and 2014 Contest Introduction**
   Development of a Drop-in Hydrogen Fueling Station
   Emanuel Wagner, Hydrogen Education Foundation
3. **Winning Design Presentation**
   Washington State University
4. **Honorable Mention Presentation**
   Humboldt State University
5. **2015 Contest**
   a. **Industry View**
      Connor Dolan – Fuel Cell Hydrogen Energy Association/H2USA
   b. **2015 Contest Theme and Timeline**
      Emanuel Wagner, Hydrogen Education Foundation
6. **Q&A**

Hydrogen Education Foundation

- Promotes clean hydrogen energy technologies through educational programs to encourage environmental stewardship, improve energy security, and create green jobs. More info: www.hydrogeneducationfoundation.org

- Programs include:
  - Hydrogen Student Design Contest (www.hydrogencontest.org)
  - H-Prize (www.hydrogenprize.org)
  - H_2andYou (www.h2andyou.org)
  - Washington Fuel Cell Summit (http://www.washingtonfuelcellsummit.com/)

H2refuel U.S. Department of Energy

- For timely updates:

Like us at: www.facebook.com/Hydrogen.Education.Foundation

Follow us at: @h2andyou

What is the Contest?

- The annual Hydrogen Student Design Contest challenges university students to design hydrogen energy applications for real-world use
- Supported by the U.S. Department of Energy's Fuel Cell Technologies Office and National Renewable Energy Laboratory
- Technical, multidisciplinary competition
  - Engineering
  - Architecture/planning
  - Industrial design
  - Economics
  - Business/marketing
  - Environmental science
  - Political science
  - Chemistry

History of Contest

- Started in 2004
- Past themes:
  - Hydrogen Fueling Infrastructure Planning
  - Residential Fueling
  - Designing a Hydrogen Community
  - Green Buildings with Hydrogen
  - Hydrogen Applications for Airports
  - Hydrogen Power Park
  - Hydrogen Fueling Station
- Several winning designs were built, e.g. the 2008 winning design is now an active hydrogen fueling station at Humboldt State University

HYDROGEN EDUCATION FOUNDATION

The Hydrogen Education Foundation's Hydrogen Student Design Contest
www.HydrogenContest.org

2014 Contest Sponsors and Supporters

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

CAT
Connecticut Center for Advanced Technology, Inc.

FUEL CELLS 2000
www.fuelcells.org

energy storage

2014 Contest Theme:

Development of a Drop-in Hydrogen Fueling Station

- Hydrogen infrastructure development is one of the most important challenges for the rapid commercialization of zero-emission fuel cell electric vehicles (FCEVs)
- Drivers of FCEVs need to know that they can rely on available fueling stations
- Hydrogen fuel suppliers need to be able to react to increasing fueling demand
- Low-cost drop-in fueling stations that require minimal set-up, operation and expense could meet the initial demand for fueling in areas that do not have a well-developed hydrogen fueling infrastructure
- A fueling station module that provides a positive fueling experience while being able to be mass produced could potentially have a game-changing effect on traditional hydrogen fueling station development plans

Theme Details

- Design a hydrogen fueling module that fulfills the requirements of
  - low-cost,
  - easy permitting,
  - low-maintenance,
  - mass-production, and
  - transportability

  in order to create a model for a reliable, convenient and reasonably priced refueling experience for all hydrogen fuel cell vehicle customers.
- Use only commercially available technology

2014 Contest Sections

- Design Data and Equipment Drawings
- Cost and Economics
- Safety Analysis
- Regulations, Codes and Standards
- Siting, Operation and Maintenance
- Environmental Analysis
- Interface Design / Customer Education

Who Participated?

- 12 teams from 7 countries submitted abstracts for the 2013-2014 Contest, involving 77 students in total
- Top Teams:

University	Award	Score
Washington State University	**Grand Prize**	**85%**
Humboldt University	**Honorable Mention**	**82%**
Zhejiang University	Top Five Finisher	72%
Ming Dao University	Top Five Finisher	70%
Kyushu University	Top Five Finisher	68%

Grand Prize Winner

Washington State University

- Presenters:
  - Ian Richardson
  - Jake Fisher

Report is available at:
http://www.hydrogencontest.org/pdf/2014/WSU_2014_HEF_CONTEST.pdf

Designing a Drop-in Hydrogen Fueling Station

U.S. Department of Energy Webinar

November 6, 2014

In this presentation…

1. Customer Considerations
2. Liquid H_2 Delivery
3. Station Design
4. User Interface
5. Safety Features
6. Site Logistics
7. Economic Analysis

Washington State University

Ian Richardson
ian.richardson@email.wsu.edu

Jake Fisher
jake.fisher@email.wsu.edu

The Hydrogen Education Foundation's Hydrogen Student Design Contest
2013-2014: Designing a Drop-in Hydrogen Fueling Station
www.HydrogenContest.org

Full report available at: http://hydrogencontest.org/2014.asp

Design with the Customer in Mind

Low Capital Cost

No Maintenance

Low Operating Cost

Minimal Footprint

Public Safety

Public Appeal

Why Liquid Hydrogen Delivery?

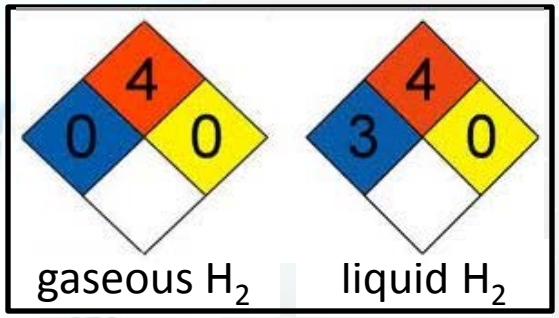
Image from www.worldindustrialreporter.com

- Lowest cost
- Low energy demand
- Minimizes equipment
- 4 times the density of delivered gas
- Existing infrastructure
  - Bottom line: 80-90% of all non-pipeline H_2 delivered by cryogenic liquid tankers.[1]

[1] Technology Transition Corporation (TTC), Hydrogen and Fuel Cells: The U.S. Market Report, (22 March 2010)

Liquid H_2 Changes the Design Paradigm

- Safety!



gaseous H_2 liquid H_2

- Transportability

- Liquid H_2 Storage

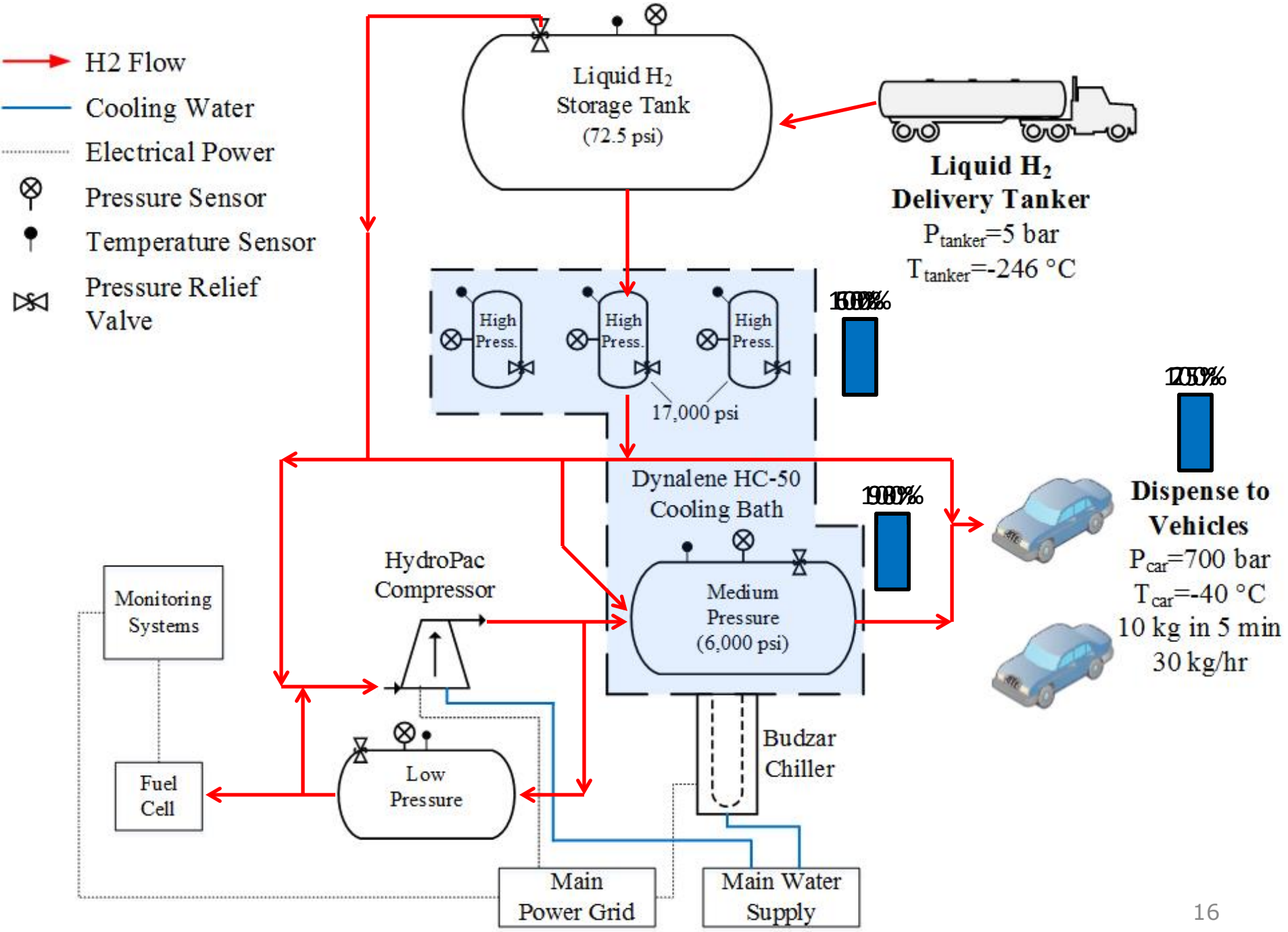
Image from www.chartindustries.com

- Thermal Compression

Image from www.hypercompeng.com

- Hydrogen Boil-off

Image from www.horizonfuelcell.com


H2 Flow
Cooling Water
Electrical Power
Pressure Sensor
Temperature Sensor
Pressure Relief Valve
Liquid H2 Storage Tank (72.5 psi)
Liquid H2 Delivery Tanker
Ptanker=5 bar
Ttanker=-246 °C
High Press.
High Press.
High Press.
17,000 psi
Dynalene HC-50 Cooling Bath
Medium Pressure (6,000 psi)
HydroPac Compressor
Monitoring Systems
Fuel Cell
Low Pressure
Budzar Chiller
Main Power Grid
Main Water Supply
Dispense to Vehicles
Pcar=700 bar
Tcar=-40 °C
10 kg in 5 min
30 kg/hr

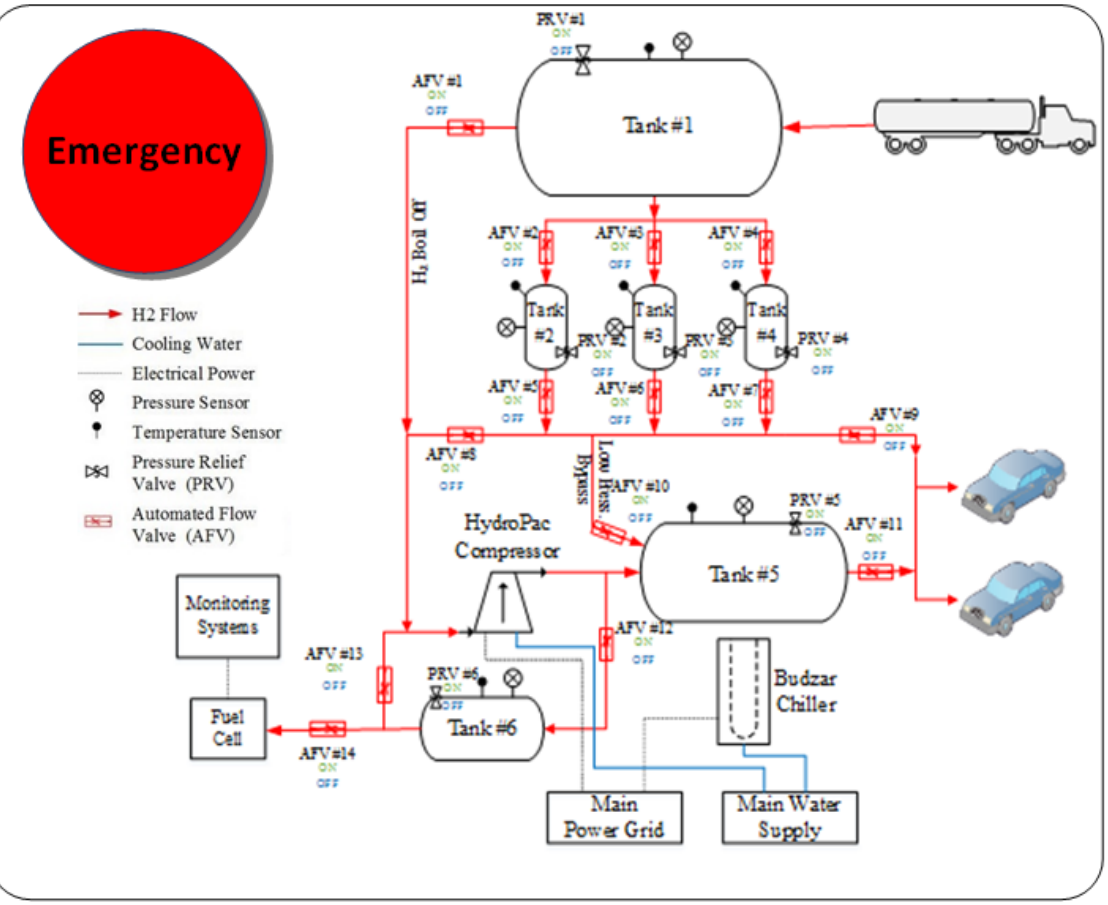
Remote Operator Interface

ON

OFF

Administrator: S. Guo Remote Access: ON OFF 4:20PM 03/21/14 Friday

Control Panel:



Status Monitor:

Pressure:

Tank #1:	5 bar	Tank #2:	1100 bar
Tank #3:	1100 bar	Tank #4:	5 bar
Tank #5:	400 bar	Tank #6:	100 bar

Temperature:

Tank #1:	-261 °C	Tank #2:	-40 °C
Tank #3:	-40 °C	Tank #4:	40 °C (WARNING)
Tank #5:	-40 °C	Tank #6:	10 °C

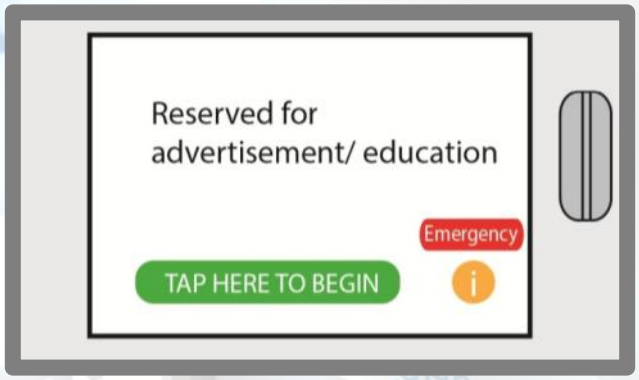
Valve Status:

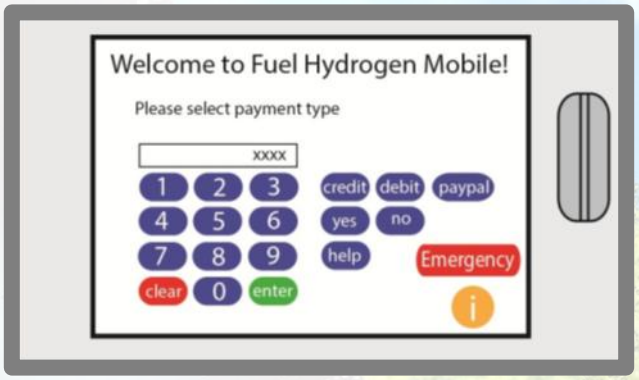
#1	ON	OFF	#2	ON	OFF
#3	ON	OFF	#4	ON	OFF
#5	ON	OFF	#6	ON	OFF
#7	ON	OFF	#8	ON	OFF
#9	ON	OFF	#10	ON	OFF
#11	ON	OFF	#12	ON	OFF

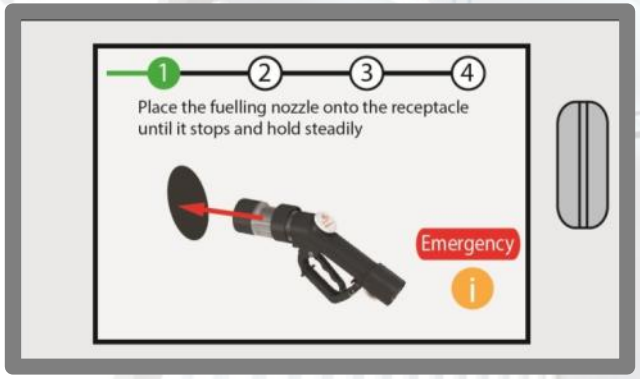
Backup Power System: ON OFF

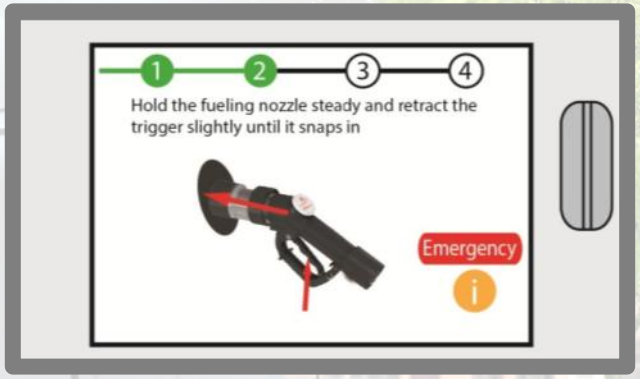
Standby Off-Line

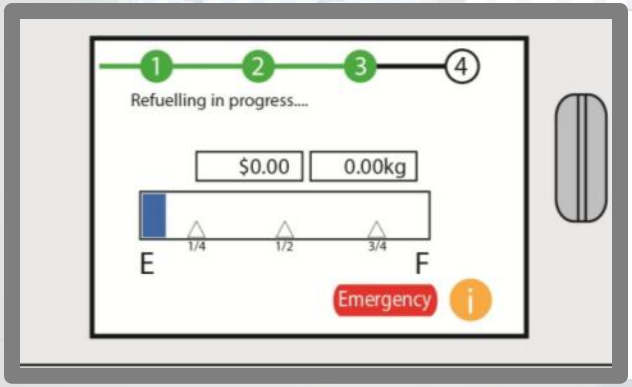
Customer Interface

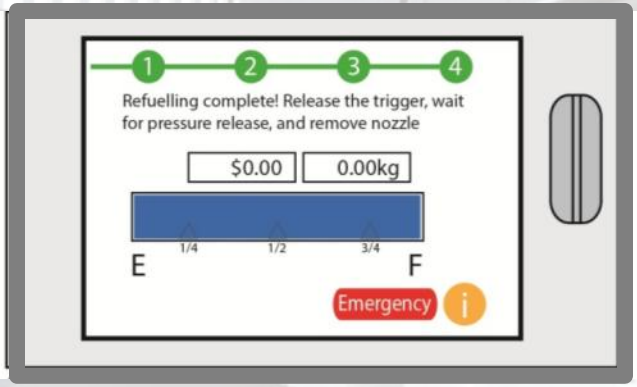


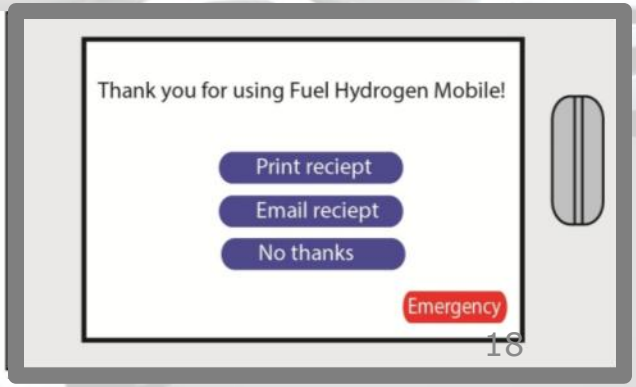












Intrinsically Safe Design

Pressure Relief

Image from www.swagelok.com

Ventilation

Image from www.industrialfansdirect.com

Continuous Monitoring

Image from www.xicomputer.com

Image from www.horizonfuelcell.com

Explosion Relief

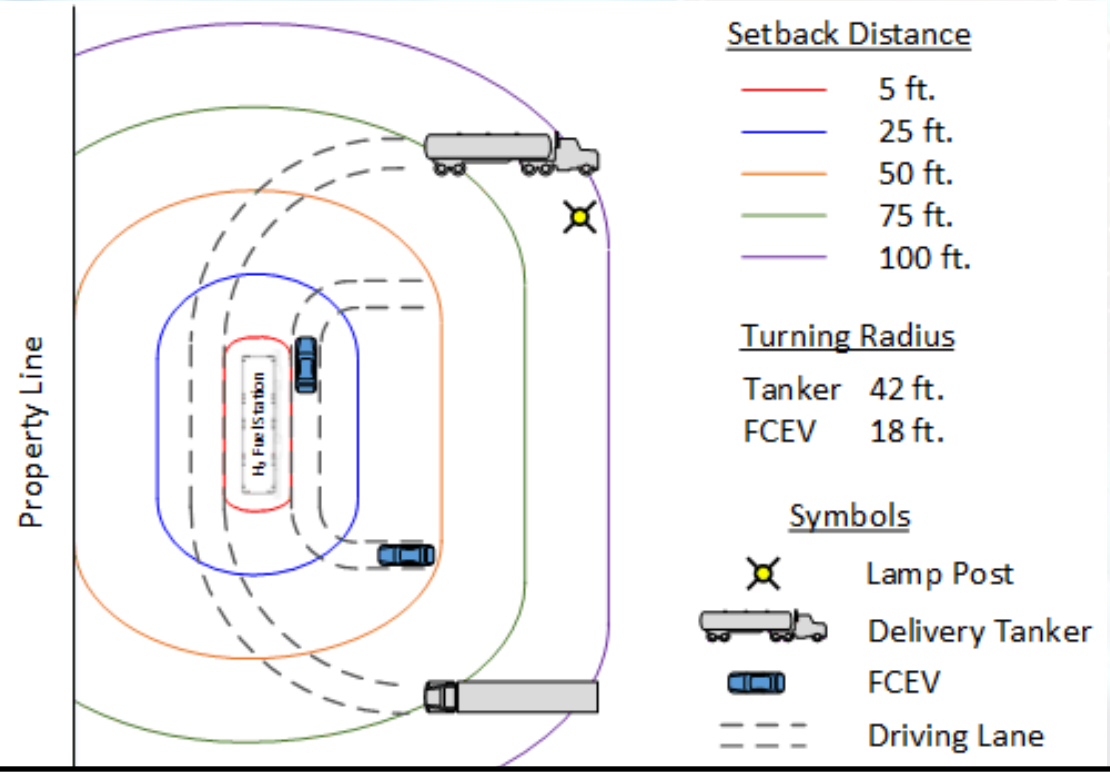
Image from www.hazsafe.com

Fire/Emergency Systems

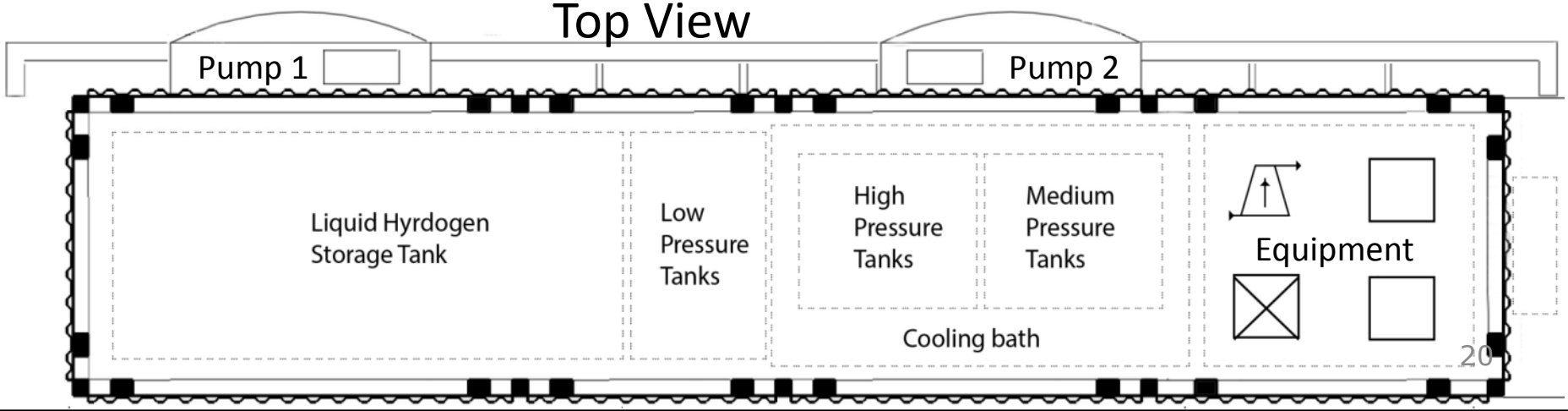
Image from www.ceasefire.com

Images from www.firelite.com

Station Meets Site Regulations

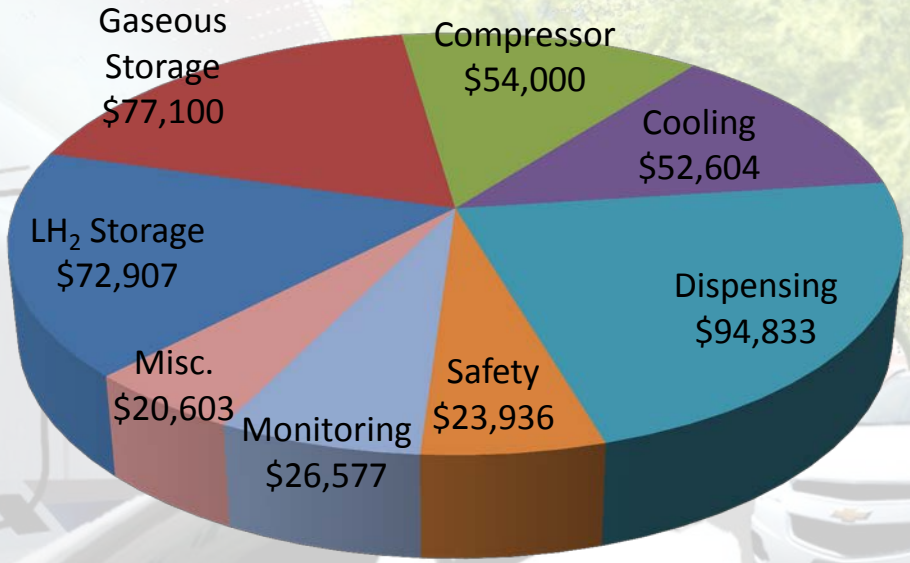


- Located on WSU campus
- Existing gasoline station on-site
- Easy access for vehicles and refuelers
- Meets NFPA codes
- Fire resistant walls reduce setback distances



Economic Analysis

- Explicit and implicit costs considered:
  - Fixed cost = **$423,000** (all equipment)
  - Monthly costs = $735 (power, water, maintenance – demand dependent)
  - Discount rate of 6.25%
  - $7/kg delivery cost
  - 10 year life span
- Price (P) model [$/kg]
  - Monthly Demand (D)
  - Rate of Return (R_R)

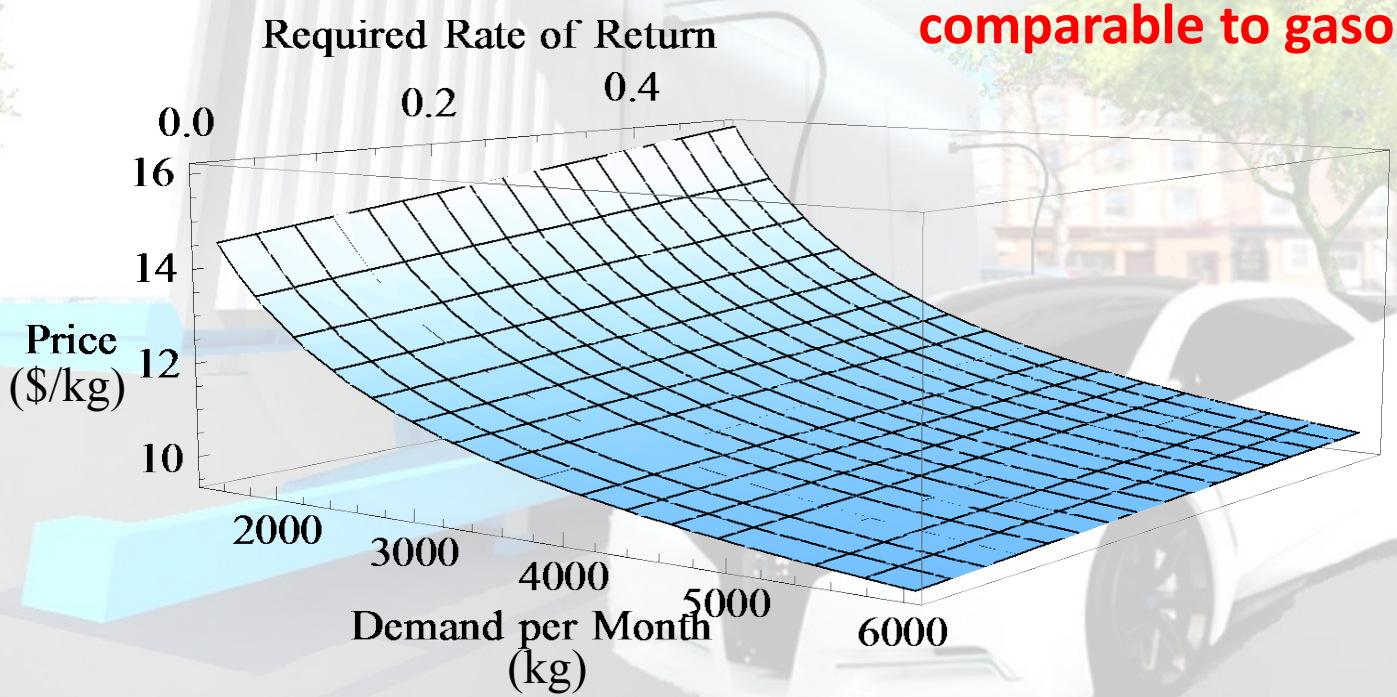


$$P = \frac{10125.9 + 7.77778D + 4695.23R_R}{D}$$

Hydrogen can be Affordable

Required Return	Monthly Demand (kg)	Price ($/kg)	Price per 5 kg or 300 miles ($)
10%	3000	11.31	56.55
30%	3000	11.62	58.10
10%	**6000**	9.62	48.10
30%	**6000**	9.78	48.90

comparable to gasoline



Development Efforts

- Partnership with GP Strategies on a DOE proposal for Cryogenic Thermal Compressor (CTC) (in review)
  - Provisional patent on CTC
- Designing single dispenser prototype station
  - Could refuel shuttle bus on WSU campus
- In negotiations with other companies to develop prototype station

Conclusion

- Total equipment cost = $423,000
- Utilizes established liquid hydrogen infrastructure
- Utilizes thermal compression
- System designed to be inherently safe
- **This design could be built today!**

Thank You

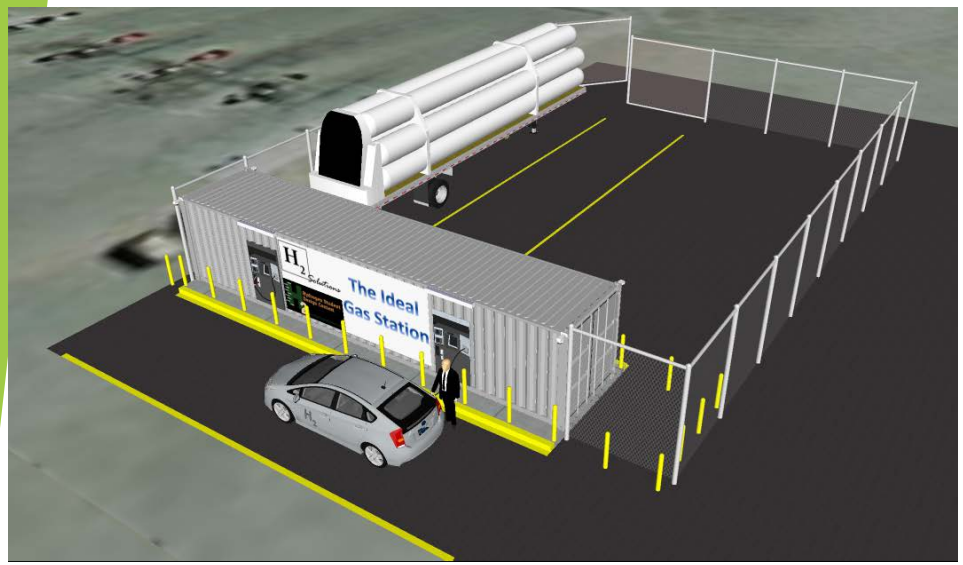
H2 Mobile Platforms are designed with safety in mind by utilizing liquid H2 storage that has decades of proven safety and reliability by NASA's Space Shuttle program. The fuel provided by these stations is generated locally and powers cars that produce no emissions leading the way to a sustainable future. Dual stage compression makes H2 Mobile Platforms the most efficient hydrogen stations on the market reducing fuel cost. Lower cost, no emissions; savings we can all appreciate!

Honorable Mention Design

Humboldt State University

- Presenters:
  - Solomon Clark
  - Anthony Eggink
  - Mathew Nyberg
  - Julian Quick

Report is available at:
http://www.hydrogencontest.org/pdf/2014/Humboldt-HEF%20Contest%20Entry.pdf



The Hydrogen Education Foundation's
Hydrogen Student Design Contest
www.HydrogenContest.org

Modular Hydrogen Fueling Station Design

U.S. DOE Webinar • November 6, 2014

Presented By: Solomon Clark, Anthony Eggink, Mathew Nyberg, Julian Quick

Humboldt Hydrogen Solutions
hydrofueldesignteam@humboldt.edu

DESIGN GOALS

Objective – Design A Modular Drop-in Fueling Station For Immediate Deployment

- Modular & Easily Transportable
- Fast Fill SAE TIR J2601 Compliant
- Minimal Site Preparation
- Comprehensive Safety Features
- Off-the-shelf Components
- Industry & Consumer Cost
- California Hydrogen Highway Connection

www.powertechlabs.com

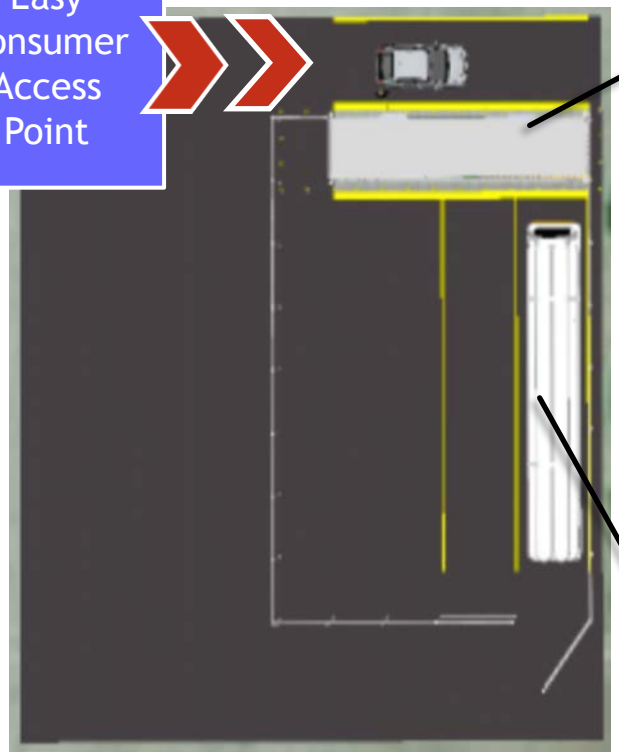
www.autoevolution.com

http://www.fastcoexist.com

STATION LAYOUT

40’ Container Housing –Trailer Storage – Easy Access – Fuel Source Options

Easy Consumer Access Point



40’ Shipping Container Housing

Tube Trailer Storage or other Fuel Source

Http://Www.Ahasvc.Org/Page123.Html

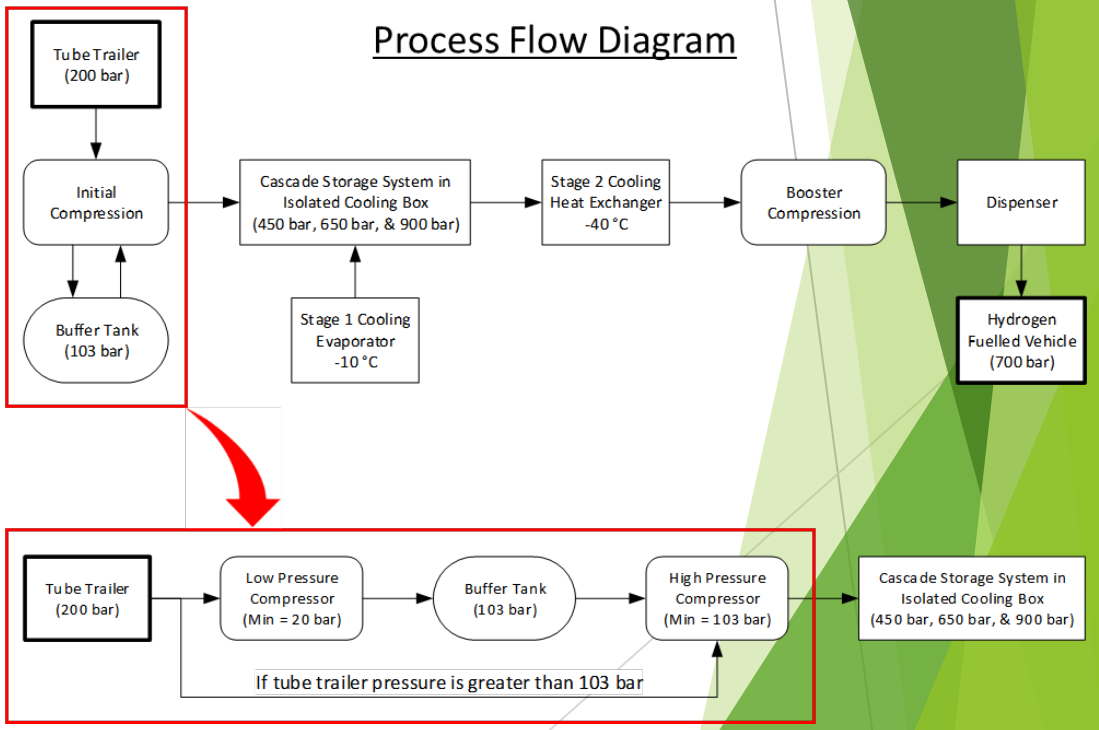
Optional Fuel Source - Hydrogen Generation Could be Housed in 40’ Shipping Container

SYSTEM OVERVIEW

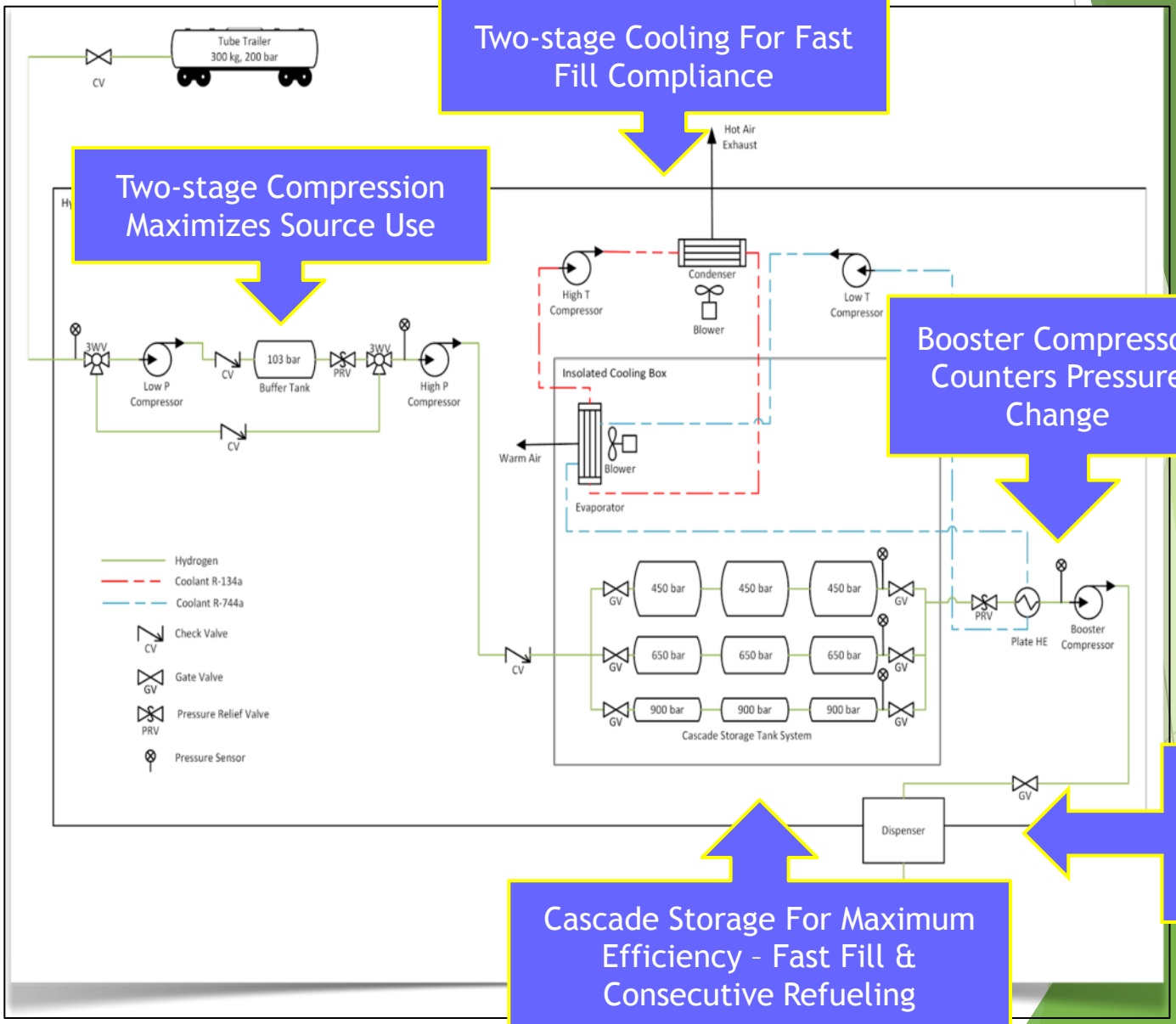
Pathway For Hydrogen Fuel From Source To Consumer

- Two-stage Compression
- Two-stage Cooling
- Flexible Storage For Remote Or High Traffic Areas
- Fast-fill SAE TIR J2601 Compliant

The key components of the design are illustrated in the Process Flow Diagram:



SYSTEM SCHEMATIC

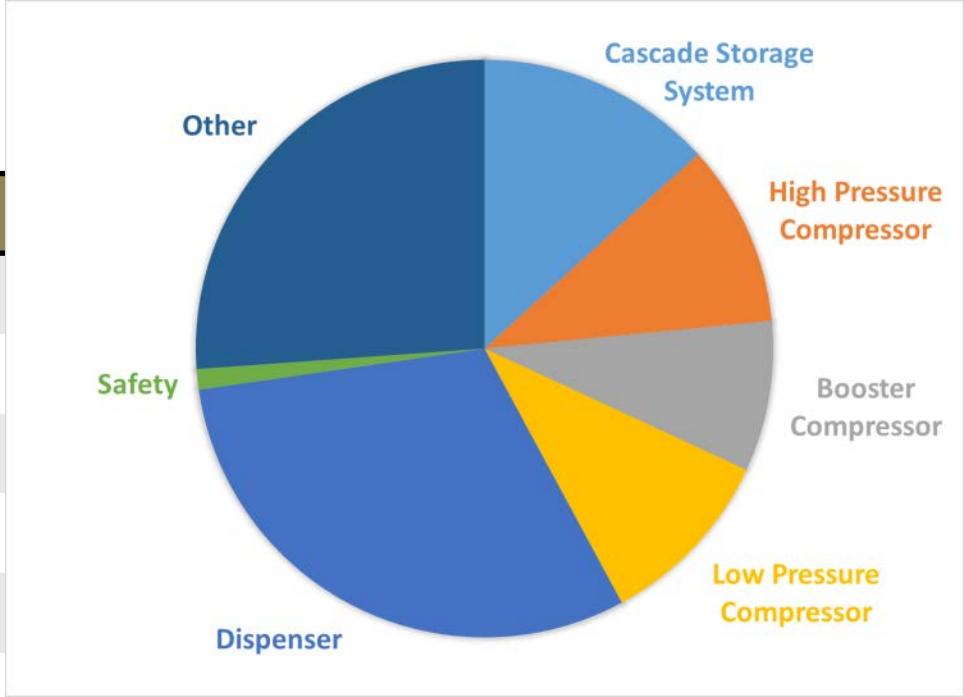


STATION COST

Goal – Low Cost Station Using Off-the-Shelf Components

Key Objective – Station Cost Below $1m

COMPONENT	COST
Cascade Storage System	$130,000
High Pressure Compressor	$100,000
Booster Compressor	$82,700
Low Pressure Compressor	$100,000
Dispenser	$300,000
Safety Compliance	$11,196
Other/Installation	$256,104
Total	$980,000

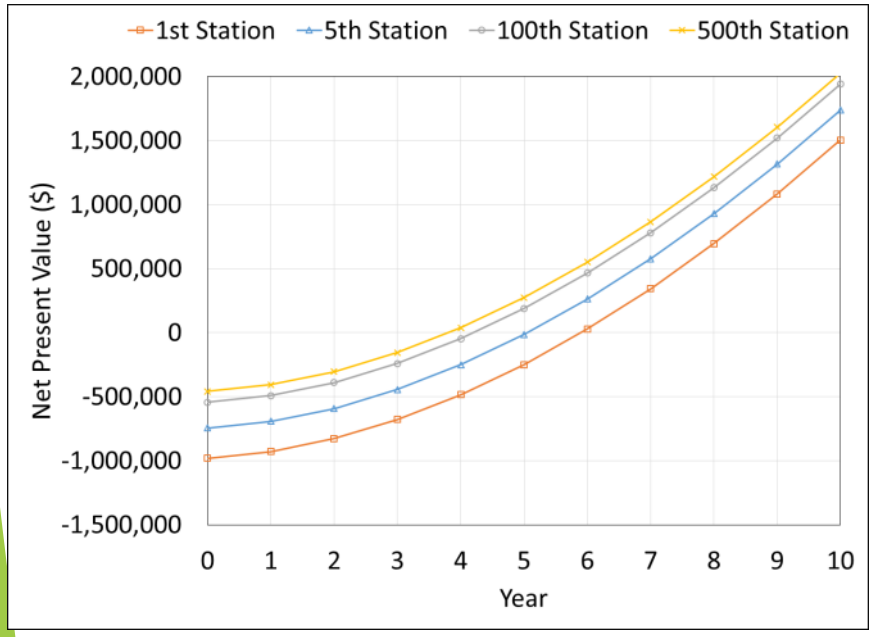


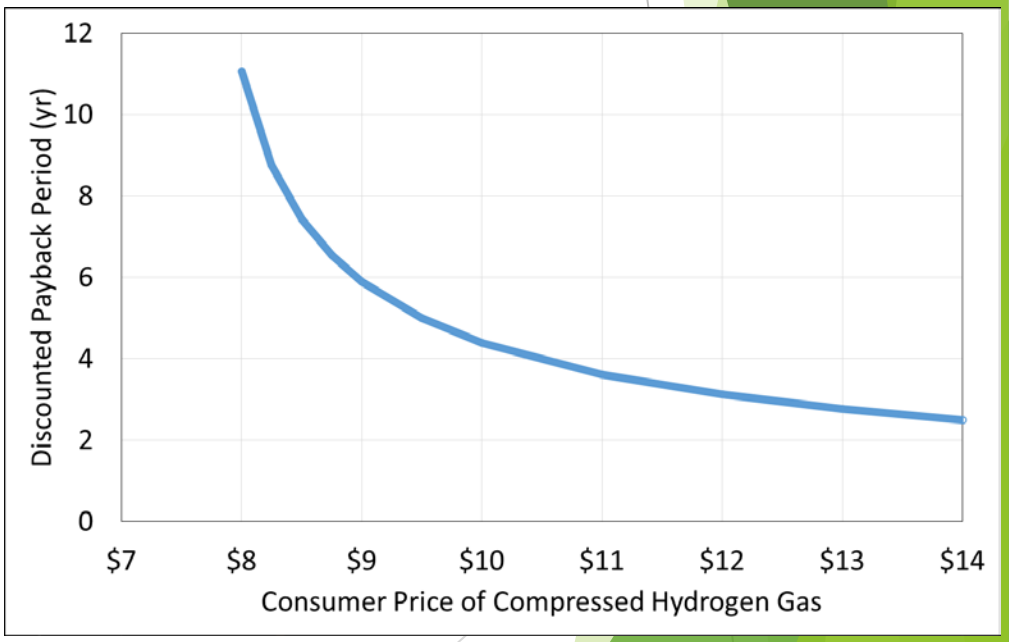
STATION ECONOMICS

Goal – Low Cost Station with Short Payback Period

Key Objective – Balanced Retail Fuel Cost and Station Profitability

STATIONS PRODUCED	CAPITAL COST PER STATION
1ST	$978,000
5TH	$745,000
100TH	$542,000
500TH	$457,000





SAFETY COMPLIANCE

Goal – Safe Fueling Interface for Consumers

Key Objective – Meet or Exceed Safety Compliance Directives

Controls Station Operation and Safety - Contacts Support Technician Fuel Delivery

http://www.conrad.com

Waterless Fire Suppression Independent of Power Supply

http://www.etapii.com/ceasefire.html

Hydrogen "Sniffer" Enacts Station Shutdown

http://www.sbsbattery.com

Pressure Sensor For Leak Detection and Cascade Storage Operation

DESIGN SOLUTIONS

Goal - Modular Hydrogen Fueling Station for Immediate Deployment

Market Solutions

- Specialization and Expansion of Existing Hydrogen Industry
- Gaseous Delivery Allows for Low Cost to Industry
- Existing Infrastructure is Utilized

Technical Solutions

- Robust Modular Design Allows for Customization, Expansion
- "Off-the-shelf" Components Allow the Station to be Built Today
- SAE TIRJ2601 Fast Fill Compliant

THANK YOU

Hydrogen Education Foundation

U.S. Department of Energy

California Hydrogen Business Council

Technology Transition Corporation

Schatz Energy Research Laboratory

Douglas Saucedo, Advisor

Renewable Energy Student Union, HSU

Emanuel Wagner, Program Manager, TTC

Award Ceremony at ACT Expo 2014 in Long Beach, CA

HYDROGEN EDUCATION FOUNDATION

The Hydrogen Education Foundation's
Hydrogen Student Design Contest
2015: Development of Innovative Hydrogen Fueling Station Business and Financing Models
www.HydrogenContest.org

2015 Contest Introduction

The theme of the 2015 Hydrogen Student Design Contest is **"Development Of Innovative Hydrogen Fueling Station Business And Financing Models".**

Student teams are challenged to conceive business and financing models for hydrogen fueling stations and pitch them to investors.

TOYOTA | Let's Go Places

NREL NATIONAL RENEWABLE ENERGY LABORATORY

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Theme Overview & Motivation

- Connor Dolan, External Affairs Manager, Fuel Cell & Hydrogen Energy Association/H2USA

Fuel Cell & Hydrogen Energy Association

Signatories on the Letter of Understanding

U.S. Department of Energy

State of California

Northeast States for Coordinated Air Use Management

Air Liquide

American Gas Association

American Honda Motor Company

ARC: Hydrogen

Argonne National Laboratory

Association of Global Automakers

California Fuel Cell Partnership

Chrysler Group LLC

Electric Drive Transportation Association

Fuel Cell & Hydrogen Energy Association

General Motors Holding LLC

Hawaii Natural Energy Institute

Hydrogenics

Hyundai Motor America

Intelligent Energy Ltd.

ITM Power

Kobelco Compressors America, Inc.

Linde North America

Massachusetts Hydrogen Coalition

Mercedes-Benz USA, LLC

National Association of Convenience Stores

National Renewable Energy Laboratory

Nissan North America R&D

Nuvera

PDC Machines

Plug Power Inc.

Pacific Northwest National Laboratory

Volkswagen Group of America

Proton Onsite

Sandia National Laboratories

Savannah River National Laboratory

SCRA

Toyota Motor North America

H2USA

2015 Contest

- **Contest Sections**
  - Technical Station Design
  - SWOT Analysis
  - Economic Analysis
    - Develop Innovative Revenue Models
    - Manage uncertainty and risk
    - Define other applications for hydrogen
  - Marketing Plan

- **Venture Forum**
  - Representatives of the top teams will be invited to participate in a venture forum to pitch their idea to a group of investors. In that pitch, the teams need to:
    - Describe market size for product
    - Articulate clear pitch to investors
    - Describe the innovative idea based on reliable numbers, "why should this work vs. what's done now"
    - Outline their product development effort

- ***Materials to be provided***
  - The HEF will provide specific information that enables a comparison of different revenue models by providing identical base assumptions. The information will include:
    - Numbers on vehicles: Showcase scenarios including a potential variance
    - Station Cost: Construction, O&M, Site Work Fuel cost: Credible price for delivered hydrogen

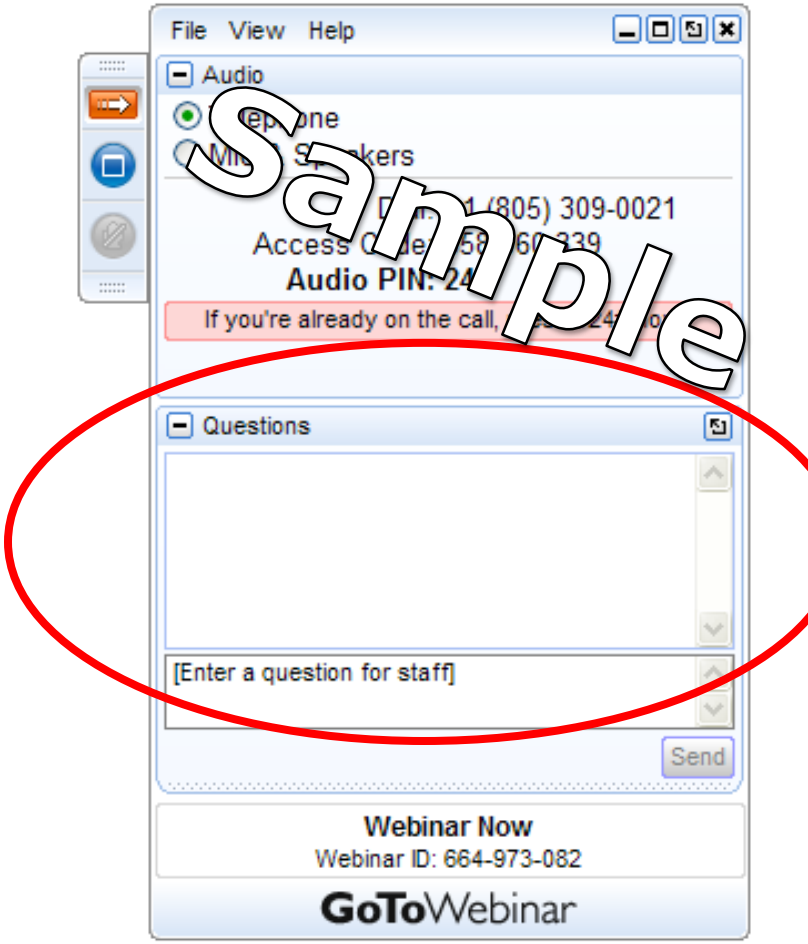
More Info & Timeline

- Stay tuned for details on the Contest - available at: www.hydrogencontest.org

- Proposed Timeline (dates are subject to change)
  - December 8, 2014 – Early Registration & Abstract Deadline
  - January 16, 2015 – Final Abstract Deadline
  - March 2, 2015 – Phase 1 submission
  - March 16, 2015 – Phase 1 feedback
  - May 4, 2015 – Phase 2 (Final Entry) submission
  - May 18, 2015 – Select finalists
  - June 1, 2015 – Presentations to judges/investors
  - June/July – Award ceremony/Announcement of Winner

Question and Answer

- **Please type your question into the question box!**
- Check out the Contest website for FAQs, Rules& Guidelines, Past Entries: www.hydrogencontest.org
- Check out the H2 Refuel H-Prize competition: www.hydrogenprize.org
- Stay up to date on industry news and competition info with the Hydrogen Education Foundation's Facebook page
- Please take the survey upon conclusion of this webinar!



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EERE Fuel Cell Technologies Office

6 November 2014

Thank You for Your Participation

$$C' = C^0 \left(\frac{Q'}{Q^0}\right)^{\alpha} \left(\frac{V'}{V^0}\right)^{\beta}$$

Where:

C' = station capital cost ($/station)
C^0 = base station capital cost ($/station); assumed $2.80M
Q' = station capacity (kg/day)
Q^0 = base station capacity (kg/day); assumed 450 kg/day
V' = cumulative capacity (kg/day)
V^0 = cumulative capacity at cost status of base station (kg/day); assumed 20,000 kg/day
α = scaling factor; assumed 0.707
β = learning factor; assumed -0.106

Melaina, M.W. and Penev, M. (2013). “Hydrogen Station Cost Estimates”. National Renewable Energy Laboratory. (Sep. 2013).