Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Overview

Chris Ainscough[2], Joe Pratt[1], Terry Johnson[1], Danny Terlip[2], Jennifer Kurtz[2]

HTAC Meeting

October 28, 2015

1. Sandia National Laboratories (SNL)
2. National Renewable Energy Laboratory (NREL)

The Hydrogen Fueling Infrastructure Research and Station Technology Project

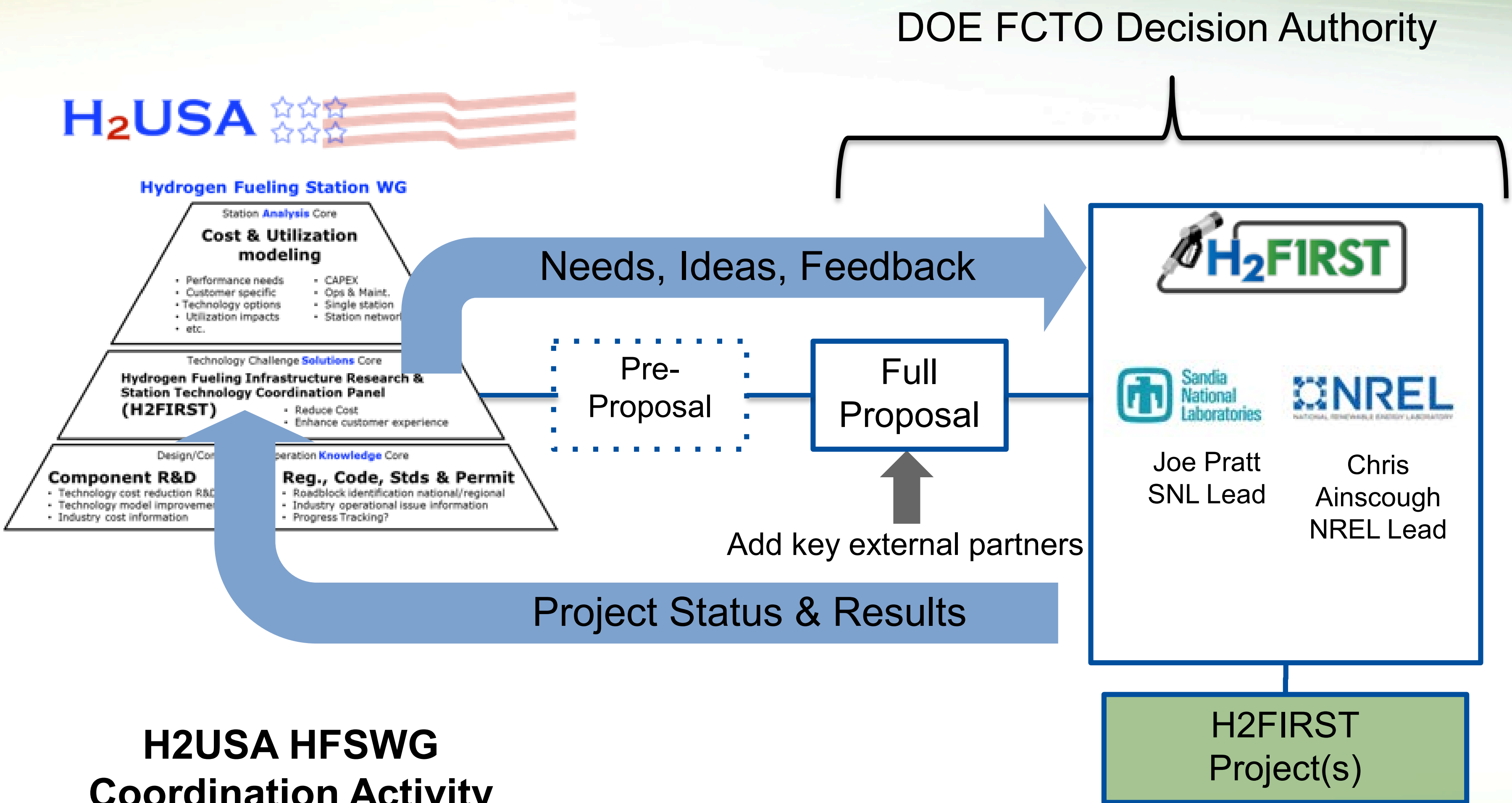
H2FIRST

Objective: Ensure that FCEV customers have a positive fueling experience relative to conventional gasoline/diesel stations as vehicles are introduced (2015-2017), and transition to advanced refueling technology beyond 2017.

- *Co-led by NREL and SNL*
- *Leverages lab core capabilities*
- *Supports goals and objectives of H2USA*

Sandia National Laboratories

H2FIRST Project Coordination (Review)



H2USA HFSWG Coordination Activity

H2FIRST Project Partners Activity

1. Logo credit H2USA.

HFSWG – Hydrogen Fueling Station Working Group; FCTO – Fuel Cell Technologies Office

The Big Picture

Denver skyline[1], Oct. 15, 2015

Non-attainment areas[2]

1. Credit: Chris Ainscough (2015)
2. 2. EPA, *Summary Nonattainment Area Population Exposure Report, (Oct. 1, 2015)*

A Vision of Sustainable Transportation[1]

- Reduce oil dependence
- Avoid pollution
- Create jobs
- Manufacture better cars, trucks and alternatives to petroleum
- Enable the widespread commercialization of a portfolio of hydrogen and fuel cell technologies[2]

1. U.S. Department Of Energy (DOE*) Office Of Energy Efficiency And Renewable Energy*, *Sustainable Transportation (Fact Sheet),* *http://energy.gov/sites/prod/files/2013/11/f4/55295.pdf , (last accessed October 15, 2015).*
2. U.S. Department Of Energy (DOE*) Office Of Energy Efficiency And Renewable Energy*, Fuel Cell Technologies Office Multi-year Research, Development, And Demonstration Plan ES-2 *http://energy.gov/sites/prod/files/2014/03/f9/exec_sum.pdf , (last accessed October 15, 2015).*

Photo Credit: Dennis Schroeder / NREL

The Realization

NO infrastructure = NO FCEVs

Where we are

"Early lessee Paul Berkman of Corona del Mar, for one, is frustrated.

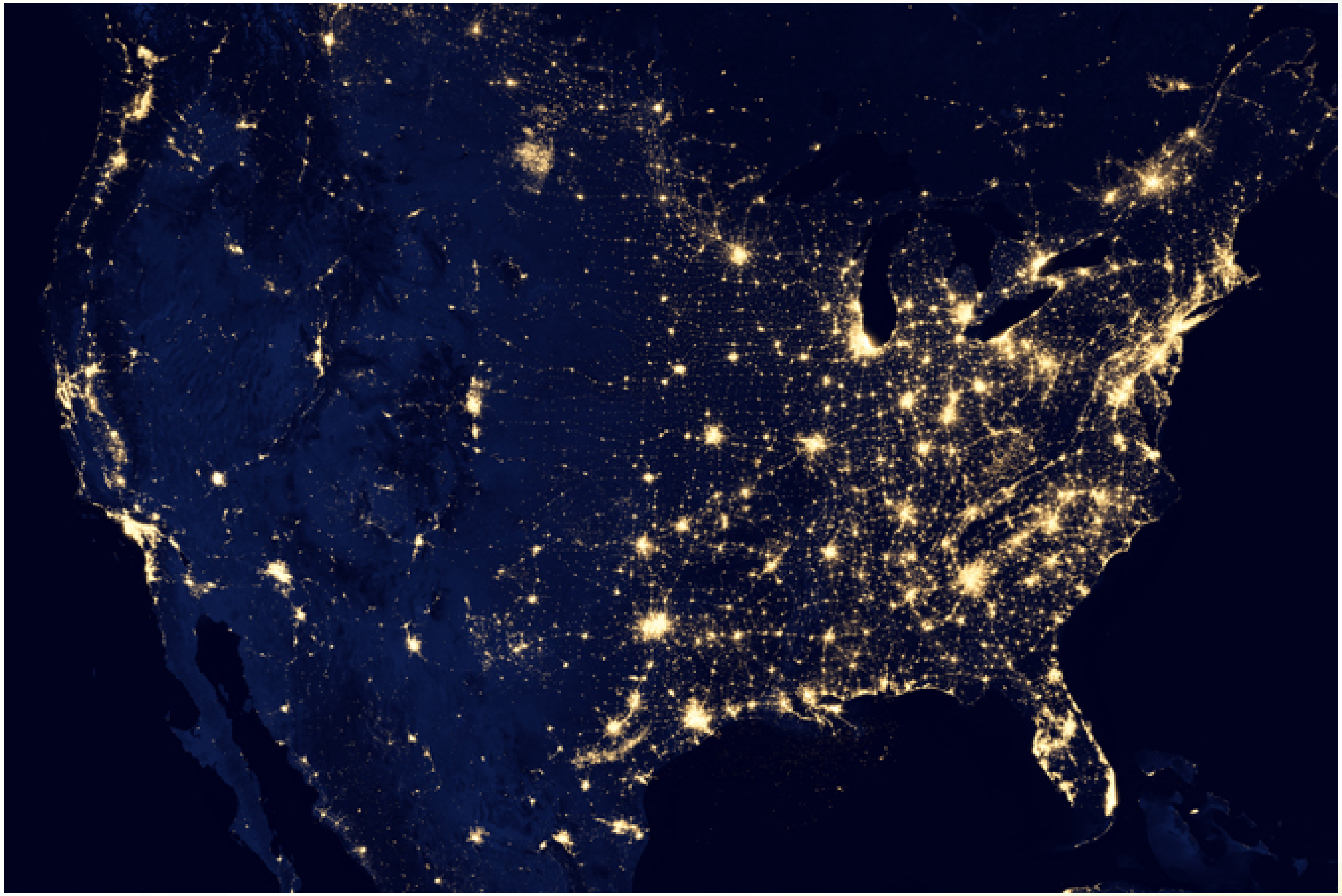
He's paying $500 a month for a vehicle he hasn't been able to drive for five weeks, because all three hydrogen stations within 20 minutes of his home or workplace have been down for more than a month."

1. John Voelcker, *CA Fuel-Cell Car Drivers Say Hydrogen Fuel Unavailable, Stations Don't Work*, www.greencarreports.com http://bit.ly/1jqZ3Pu (Jul 25, 2015).

Five key issues H2FIRST is addressing

1. Uniqueness
2. Contamination
3. Delay
4. Cost
5. Accuracy

This is where we want hydrogen stations

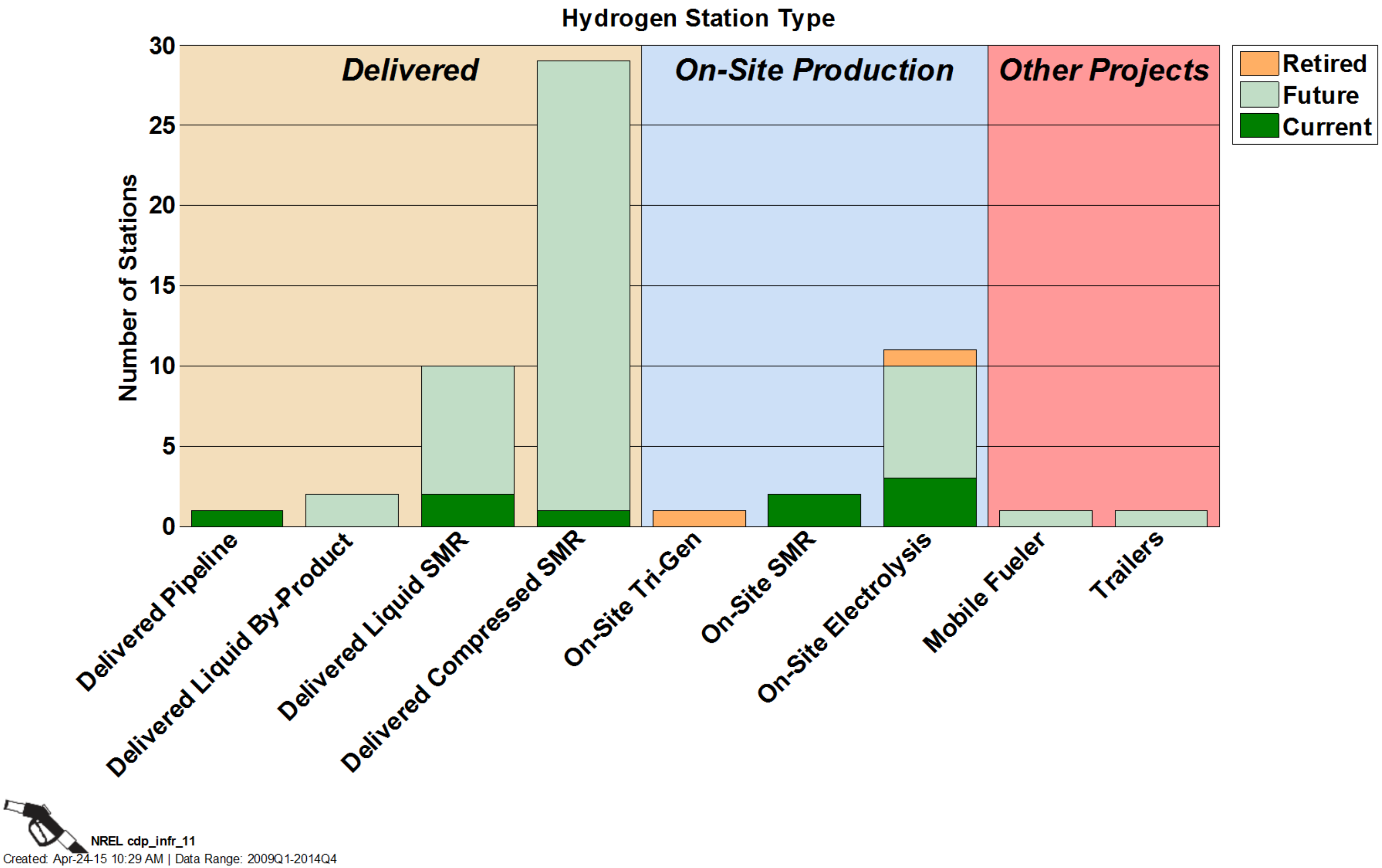


Credit: NASA Earth Observatory/NOAA NGDC, https://www.nasa.gov/mission_pages/NPP/news/earth-at-night.html#.Vh_sXot2190

Uniqueness

REFERENCE STATION DESIGN

Hydrogen Stations, a mélange



SMR – Steam Methane Reformer

Credit: NREL, *Next Generation H2 Station CDPs (Spring 2015)*, http://www.nrel.gov/hydrogen/proj_infrastructure_analysis.html

Reference Station Design Objective

Objective: Speed acceptance of *near-term* hydrogen infrastructure build-out by exploring the advantages and disadvantages of various station designs and propose near-term optima.

- H2FIRST team updated economic modeling tools to give outputs relevant to **"now-term" station development**
- H2FIRST incorporated **current codified setback distances** into station layout designs to present realistic usage implication and identify needs for improvement
- H2FIRST **looked at the whole picture**, from macro-scale FCEV and station roll-out factors to component level station designs

Summary of Results

- **Primary results**
  - Selected four high-priority, near-term station concepts based on economics, technical feasibility, and market need
  - Produced spatial layouts, bills of materials, and piping & instrumentation diagrams
- **Ancillary Results**
  - Near-term FCEV rollout scenario analysis year-by-year
  - Near-term hydrogen station rollout analysis year-by-year including number of stations, capacity, and overall utilization
  - Compilation of current costs for all station components
  - Costs of 120 station permutations: capital cost and station contribution to cost of hydrogen, including effect of different utilization scenarios

Audience

- **Station developers**: quick evaluation of potential sites and needs; lower investment risk; general cost and return estimates.
- **Local authorities**: understand devices, components in a typical station.
- **Code developers**: understand near-term needs for code refinement.
- **Other H2USA groups**: new tool and baseline for economic studies.
- **Businesses/entrepreneurs and R&D organizations**: Identification of near-term business solution and technology needs.
- **Local municipalities and the general public**: high-level understanding of typical stations lowering acceptance risk.
- **Funding agencies**: Understanding of current technological capabilities, costs, and market needs.

Approach

Utilization, capacity, size, dispenser…

1. Define parameters and ranges

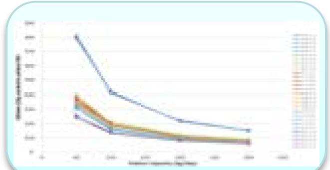
Compressor, land, O&M, 875 bar storage, …

2. Gather cost data and specify metrics. Review.

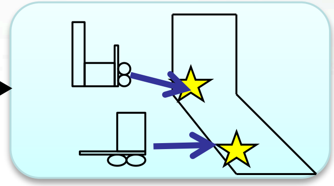
HRSAM Model Development

Station	Utilization	Capacity	Dispensers
1	20%	50	1
2	Ramp	100	1
3	Ramp	200	2
	...	...	...
N	...	...	...

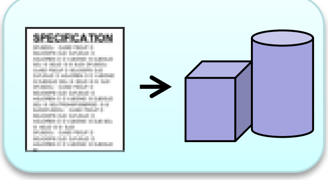
3. Specify and simulate station concepts utilizing HRSAM's optimization method.



4. Station concept selection based on comparative economics and technical feasibility



5. Match station concepts to market needs



6. Alignment of designs to actual equipment

7. Station designs

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

HRSAM – Hydrogen Refueling Station Analysis Model

Determined station parameters with near-term ranges of interest

Performance Parameter	Values Used for Screening
Design capacity (kg/day)	50, 100, 200, 300
Peak performance	2, 3, 4, 5, 6 consecutive fills per hose
Number of hoses	1, 2
Fill configuration	Cascade, booster compressor
Hydrogen delivery method	Gas (tube trailer), liquid trailer

Another critical parameter needed: Utilization

The values for the five performance parameters were chosen with industry input to reflect near-term station requirements and most common characteristics.

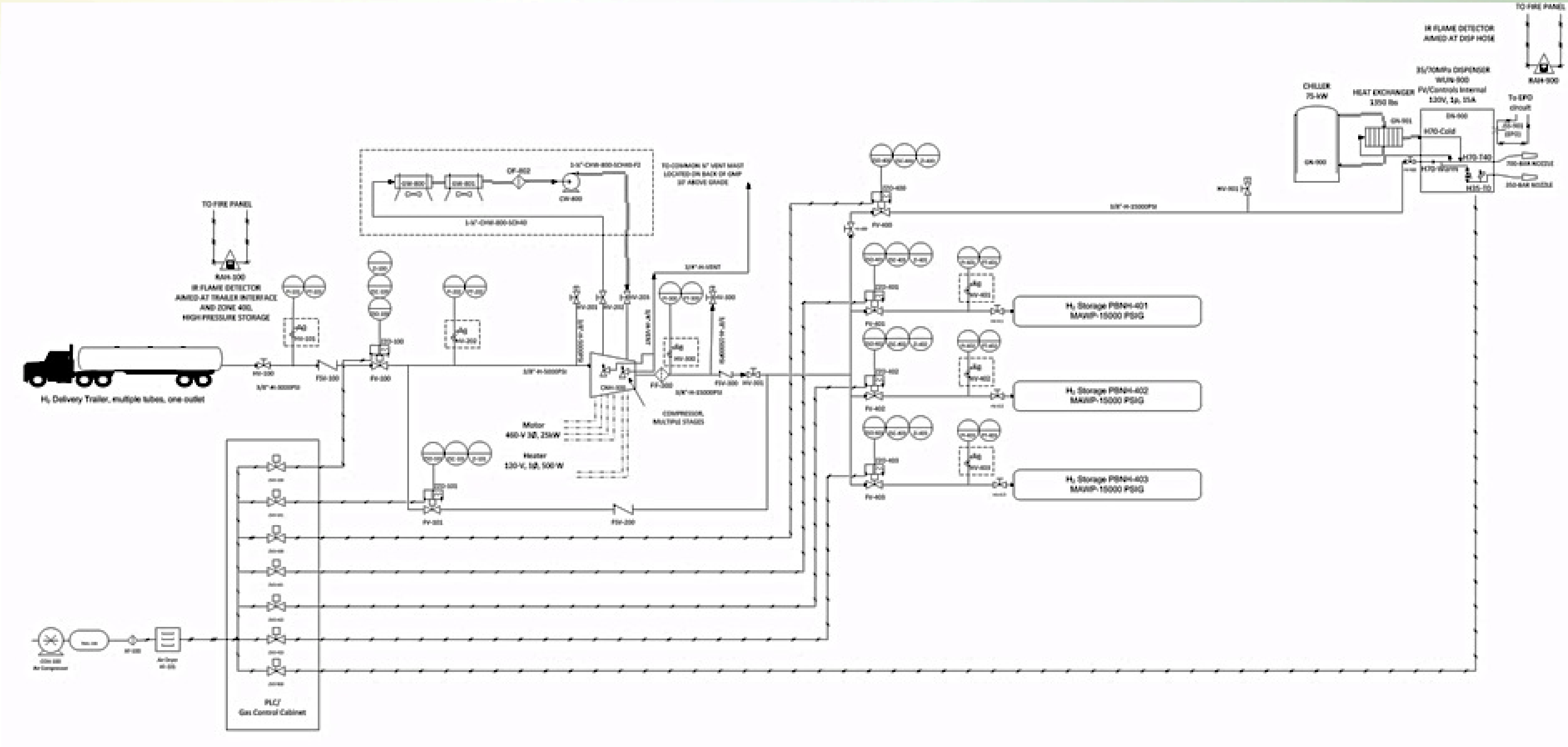
Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

The top-performing station types that best-matched market needs were selected for detailed conceptual design.

Profile	Site Type	Delivery	Capacity (kg/day)	Consecutive Fills	Hoses	Station Contribution to Hydrogen Cost ($/kg)	Capital Cost (2009$)
High Use Commuter	Gas station or greenfield	Gaseous	300	6	1	$6.03	$1,251,270
High Use Commuter	Greenfield	Liquid	300	5	2	$7.46	$1,486,557
Low Use Commuter	Gas station or greenfield	Gaseous	200	3	1	$5.83	$1,207,663
Intermittent	Gas station or greenfield	Gaseous	100	2	1	$13.28	$954,799

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

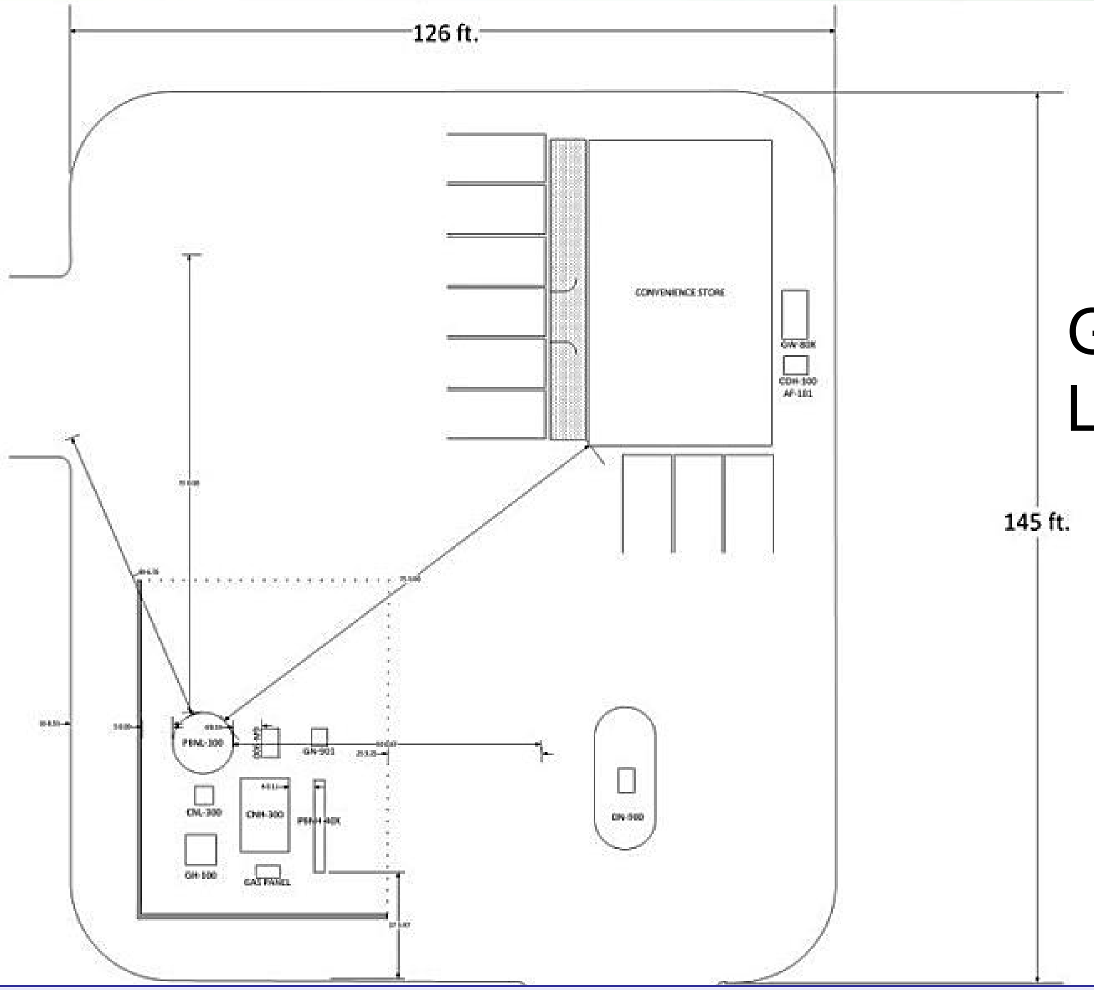
Produced Piping and Instrumentation Diagrams (P&IDs)…



The P&IDs illustrate typical system designs for gaseous and liquid delivery stations.

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

…physical layouts considering NFPA-2 setback distance requirements…

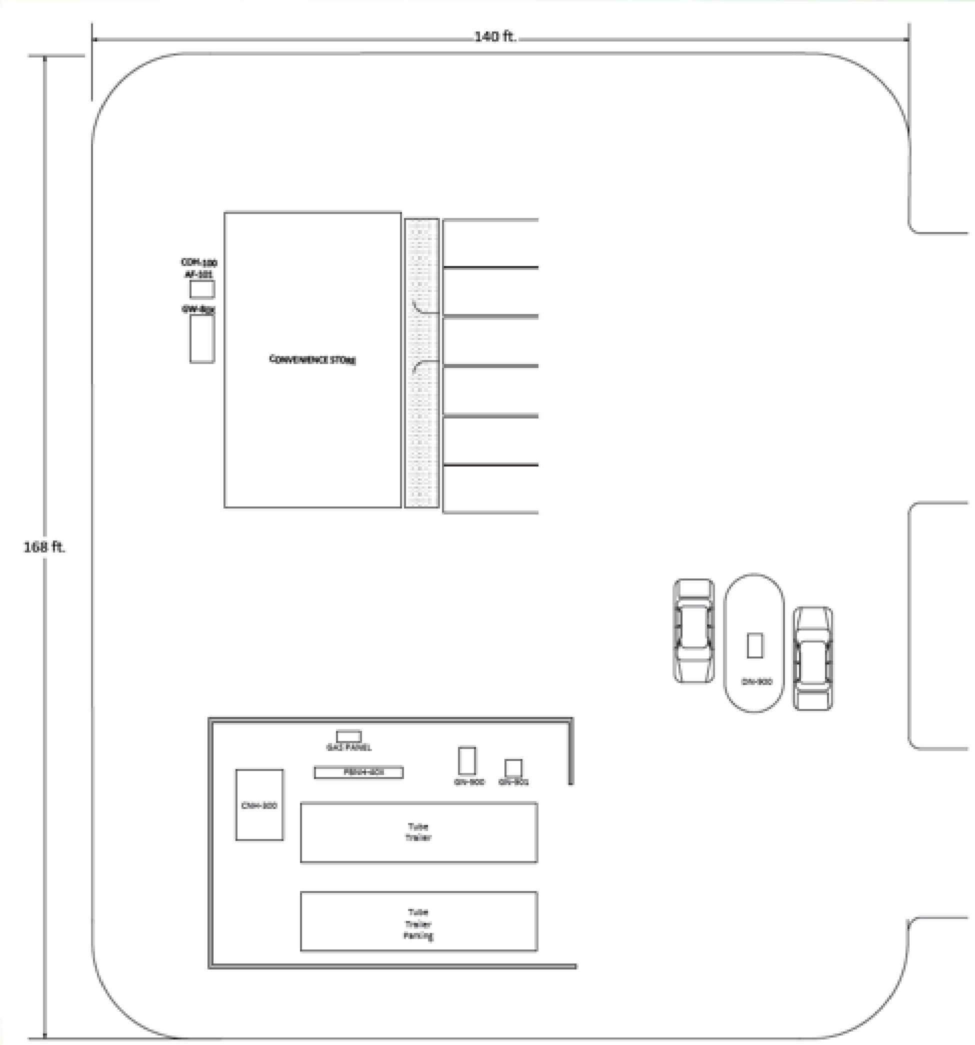


Greenfield
Liquid

The layouts show the amount of space required to install these stations to code.

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

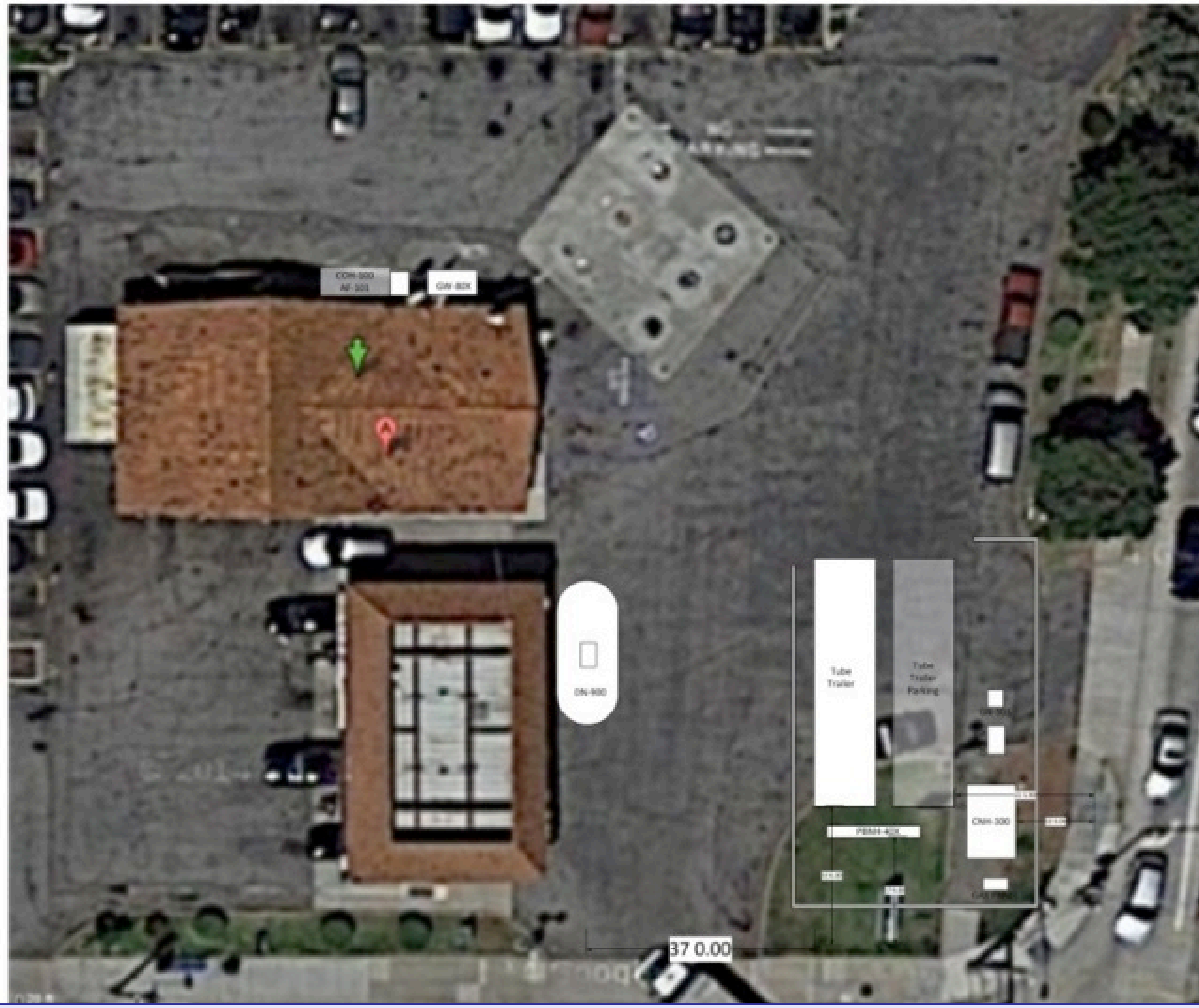
NFPA – National Fire Protection Association



Greenfield
Gaseous

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

…and at existing gasoline stations…



The layouts also show how a station can be sited at an existing gasoline station.

1. Credit: Satellite image: Google Earth. Drawing overlay, H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

…and Bills of Materials (BOMs) with off-the-shelf components and costs.

Table 14. Bill of Materials for the 100 kg/day Gaseous Station

Description	Tag Number	Quantity	Approx Cost	Ext Cost
Hydrogen tank 401	PBNH-401	1	$40,000	$40,000
Hydrogen tank 402	PBNH-402	1	$40,000	$40,000
Hydrogen tank 403	PBNH-403	1	$40,000	$40,000
Pressure transmitter w/ indicator	PT-101	1	$1,000	$1,000
Pressure transmitter w/ indicator	PT-202	1	$1,000	$1,000
Pressure transmitter w/ indicator	PT-300	1	$1,000	$1,000
Pressure transmitter w/ indicator	PT-401	1	$1,000	$1,000
Pressure transmitter w/ indicator	PT-402	1	$1,000	$1,000
Pressure transmitter w/ indicator	PT-403	1	$1,000	$1,000
Block and bleed valve	HV-101	1	$500	$500
Block and bleed valve	HV-202	1	$500	$500
Block and bleed valve	HV-300	1	$500	$500
Block and bleed valve	HV-401	1	$500	$500
Block and bleed valve	HV-402	1	$500	$500
Block and bleed valve	HV-403	1	$500	$500

The BOMs list typical components needed for stations along with present-day costs.

Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

What's Next?

In Phase II we will:

- Analyze and produce station designs for four new station concepts:
  - Conventional layout station with on-site electrolysis generation
  - Conventional layout station with on-site SMR generation
  - Modular station with delivered H2 gas
  - Modular station with on-site electrolysis generation

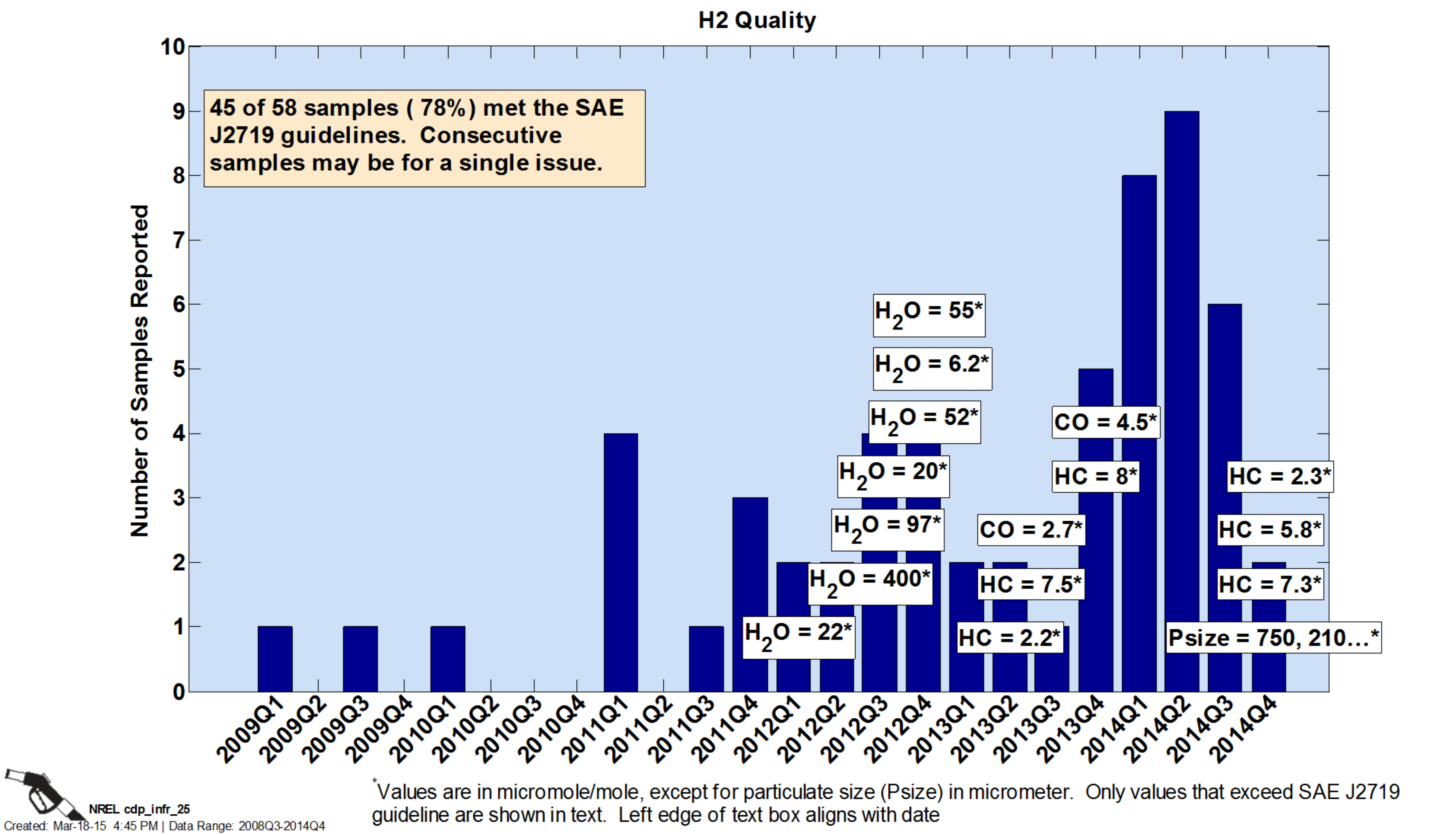
Contamination

HYDROGEN CONTAMINANT DETECTOR

How do we detect bad fuel today?

- CEC requires sampling to SAE J2719 every six months, at commissioning, and after major maintenance.
- Each test costs several thousand dollars.
- In spite of this, often, poor quality fuel is first detected by drivers who just put it in their cars.
- The FCEV is the canary in the coal mine.

Bad gas



*Values are in micromole/mole, except for particulate size (Psize) in micrometer. Only values that exceed SAE J2719 guideline are shown in text. Left edge of text box aligns with date

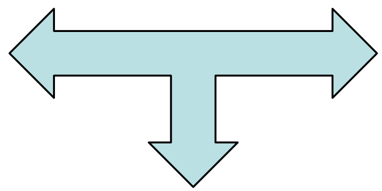
Credit: NREL, *Next Generation H2 Station CDPs (Spring 2015)*, http://www.nrel.gov/hydrogen/proj_infrastructure_analysis.html

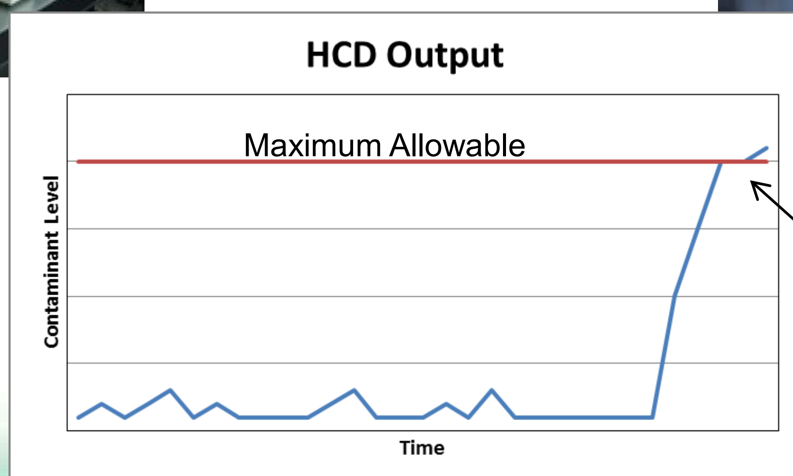
Contaminant Detector Objective

- ***Goal*** - Ensure high quality fuel is dispensed to FCEV customers for optimal FC operation by testing for critical contaminants in the fuel before it is dispensed
- ***Impact***
  - Determine application requirements, current device capabilities, and the gaps between them.
  - Educate station operators about contaminants relevant to station type
  - Inform station developers of current status of relevant technology
  - Validate stated performance of analyzers
  - Determine requirements for station integration
  - Provide information for technology developers

Approach: Define a Hydrogen Contaminant Detector

- A hydrogen contaminant detector (HCD) is defined as a gas analyzer and integration apparatus
- An integrated HCD must identify and report poor quality fuel BEFORE it is dispensed to FCEV customers

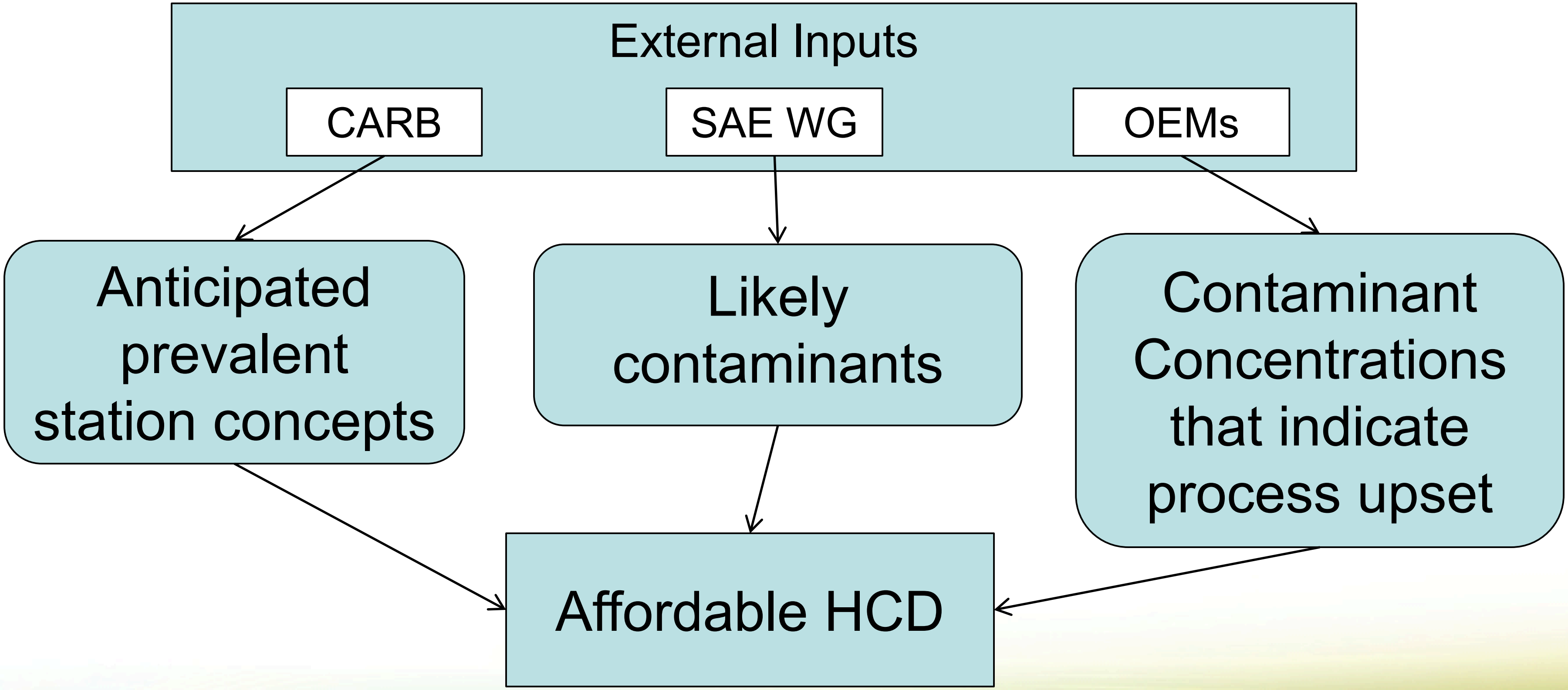




Alarm station operator

Approach: Refine the Application

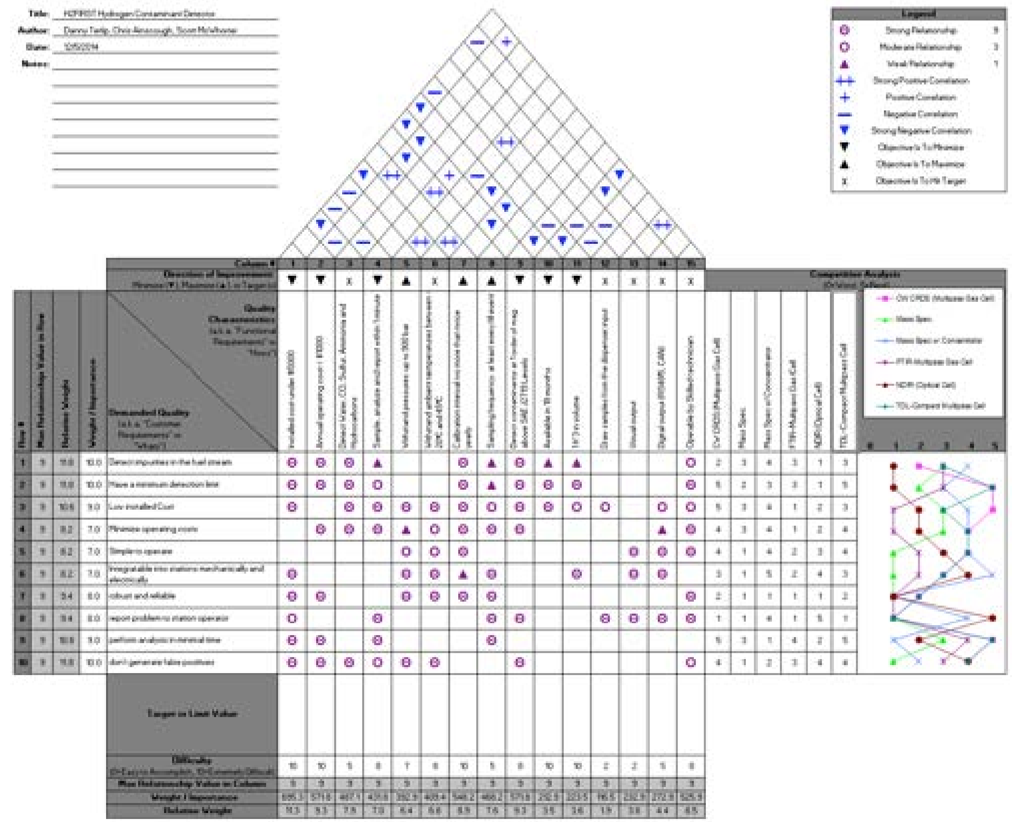
- Unfeasible to detect all contaminants listed in SAE J2719 at required levels
- Not meant to replace regular sampling and laboratory testing
- Target station characteristics to reduce requirements of HCD



CARB – California Air Resources Board; OEM – Original equipment manufacturer

House of Quality

- **ENGINEERING REQUIREMENTS** – developed with input from industry, state agencies, codes and standards committees
  - Detection abilities
    - Types
    - Concentrations
  - Cost
  - Availability
  - Ambient environmental
  - Gas sampling
    - Pressure
    - Temperature
    - Volume



Customer and functional requirements compared

Credit: H2FIRST, *Hydrogen Contaminant Detector Task Requirements Document and Market Survey*, NREL/TP-5400-64063 (2015).

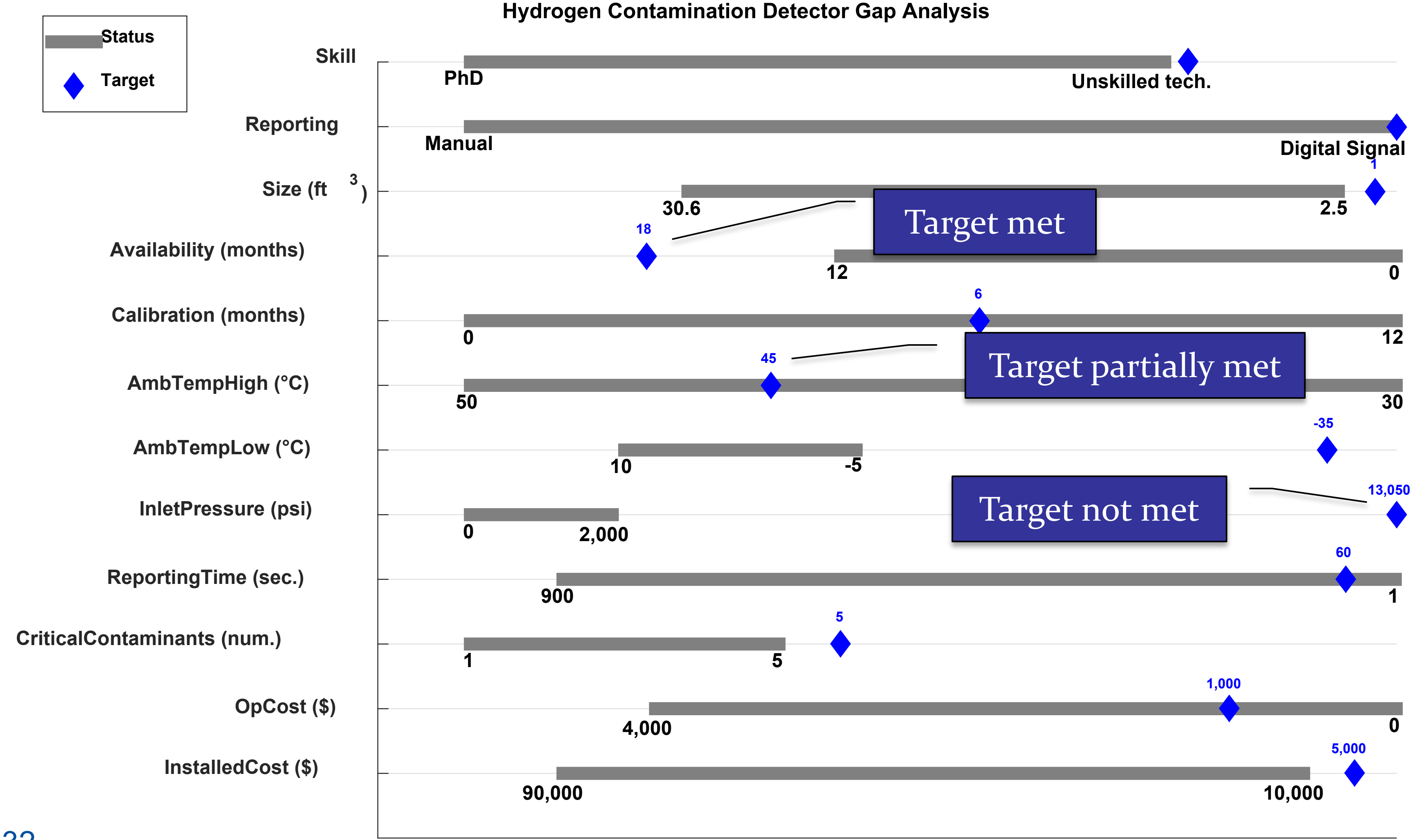
Research & Development Effort
In-line Contaminant Detector Functional Requirements

Functional Requirements	
Installed cost under \$5,000 (¥617,000/€4,450)	Calibration interval no more than twice yearly
Annual operating cost <\$1,000 (¥123,000/€890)	Sampling frequency at least every fill event
Detect water, CO, sulfur, ammonia and hydrocarbons	Detect contaminants at 1 order of mag. above SAE J2719 Levels
Sample, analyze and report within 1 minute	Available in 18 months
Withstand pressures up to 900 bar	1 ft^3 (28 L) in volume
Withstand ambient temperatures between -20˚C and 45˚C	Draw samples from the dispenser input
Visual and digital output	Operable by a skilled technician

Credit: H2FIRST, *Hydrogen Contaminant Detector Task Requirements Document and Market Survey*, NREL/TP-5400-64063 (2015).

Research & Development Effort
In-line Contaminant Detector Gaps

No available technology meets all requirements.



Credit: H2FIRST, *Hydrogen Contaminant Detector Task Requirements Document and Market Survey*, NREL/TP-5400-64063 (2015).

What's Next?

In Phase II we will:

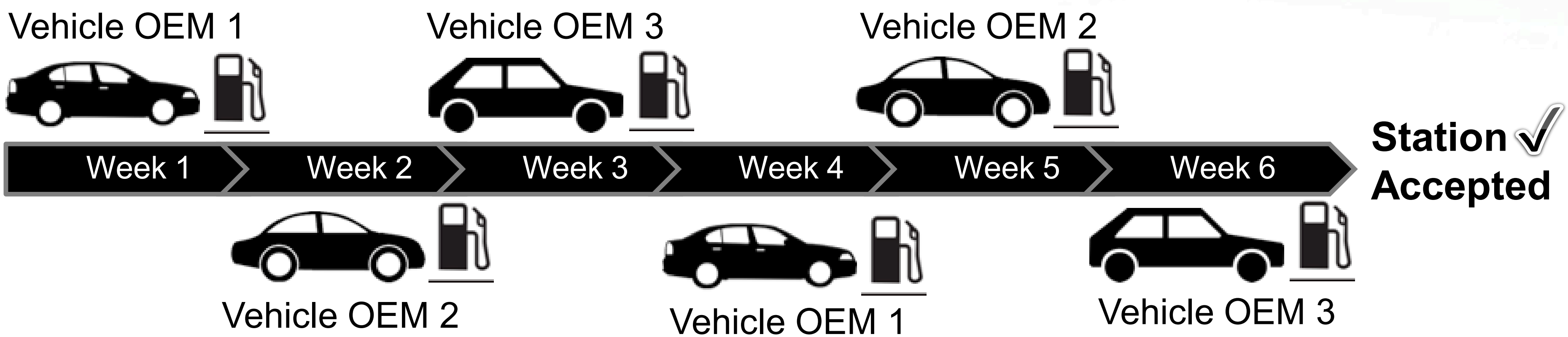
- Evaluate the performance of existing contaminant detectors that can be installed at stations
- Assess
  - Implementation ability
  - Detection ability and accuracy
  - Functional ability
  - Reliability and robustness
  - Maintenance

Delay

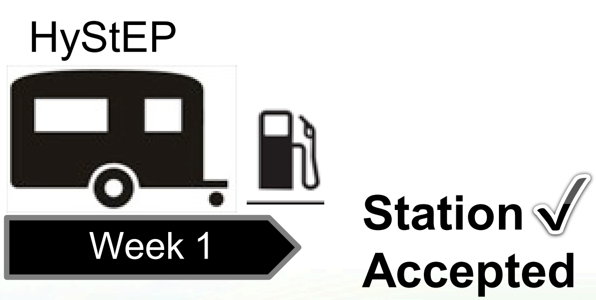
HYSTEP **Hy**drogen **St**ation **E**quipment **P**erformance Device

Relevance: HyStEP Device will shorten lengthy station acceptance process

Today's Problem: Each OEM performs vehicle test fills to validate the station



Tomorrow's Solution: HyStEP Device is surrogate for vehicles, operated by testing agency



HyStEP Objectives

Main Objective – *Accelerate commercial hydrogen station acceptance by developing and validating a prototype device to test hydrogen dispenser performance.*

- **Fill safely:** Common goal of vehicle manufacturers, consumers, station operators, and state stakeholders
- **Follow standards:**
  - SAE J2601-2014 (fueling protocol), specifies how to fill hydrogen vehicles safely.
  - CSA HGV 4.3 (test method), defines how to test dispensers for compliance with SAE J2601.
- **Test stations:** HyStEP Device will execute CSA HGV 4.3 test methods.
  - Task Output: DOE-owned device that has been validated to test station performance relative to standards.
  - Once pre-deployment testing is complete, the unit will be loaned to a designated Cal. agency.
  - The resulting HyStEP Device design will be published and freely available.

Specifications

Specifications for HyStEP

- Device is mobile: Mounted in a trailer
- Type IV 70 MPa tank(s) with at least a 4–7 kg capacity
- Designed to perform subset of CSA HGV 4.3 tests, may add others in the future (e.g. MC [Mass/Heat Capacity] fill)
- SAE J2799 IrDA for communication tests and fills
- Tank and receptacle instrumented with multiple P, T sensors to monitor pressure ramp rate, ambient, tank, and gas conditions.
- Leak simulation to check dispenser response

Type IV tanks in HyStEP

HyStEP Device was fabricated by Powertech Labs

- Co-designed by H2FIRST HyStEP Project Team
- Powertech fabricates 70 MPa H2 refueling stations and has H70-T40 testing capability
- SAE J2601-2014 validation testing was performed at Powertech
- Experience with mobile, high pressure H_2 systems
- Designed and built hydrogen station test devices for commissioning fueling stations

Trailer that will house HyStEP, and the control panel.

P – pressure; T – temperature; IrDA – Infrared Data Association

Collaborations: HyStEP Project Team consists of key stakeholders

H2FIRST

Partner	Project Roles
Sandia National Laboratories	Project lead, management and coordination; device design; safety analysis
National Renewable Energy Laboratory	Device design; safety analysis; device validation testing
Air Liquide	Device design; safety analysis; facilitate pre-deployment testing
Boyd Hydrogen	Device design and safety analysis
CA Air Resources Board	Device design; safety analysis; facilitate pre-deployment testing
Toyota	Device design; safety analysis; vehicle participation/comparison for pre-deployment testing
PNNL H_2 Safety Panel	HyStEP design and safety review by HSP

PNNL – Pacific Northwest National Laboratory; HSP -- Hydrogen Safety Panel

HyStEP Testing Plan/Schedule

H2FIRST

Month/week	Activity Schedule	Parallel Meetings
Oct 21 – Nov 25	5+ weeks Validation at NREL	*FCS Nov 16 – 19, LA Auto show
Nov 23 – 27	Thanksgiving week	LA Auto Show
Nov 30 – Dec 4	CA Operator training at NREL	ISO 197 meeting 30 – 4 CaFCP WG 2 -3
Dec 7 – 11	Ship NREL to CSULA	HSP Meeting
Dec 14 - 18	CSULA Shakedown, Testing, Analysis	
Dec 21 – Jan 1	Christmas/New Years Holiday weeks	Optional Data Discussions
Jan 4 – 8	OEM/HyStEP Validation/Analysis APCI/SCAQMD	Field testing
Jan 11 – 15	OEM/HyStEP Validation/Analysis APCI/SCAQMD	Data Analysis
Jan 18 – 22	OEM/HyStEP validation Air Liquide/Anaheim	Field testing
Jan 25 – 29	OEM/HyStEP validation Air Liquide/Anaheim	Data Analysis

Credit: Cal. Air Resources Board, *California HyStEP Task Force Team Update* (October 1, 2015).

Cost

TUBE TRAILER CONSOLIDATION

Hydrogen Stations are Expensive

Profile	Site Type	Delivery	Capacity (kg/day)	Consecutive Fills	Hoses	Station Contribution to Hydrogen Cost ($/kg)	Capital Cost (2009$)
High Use Commuter	Gas station or greenfield	Gaseous	300	6	1	$6.03	$1,251,270
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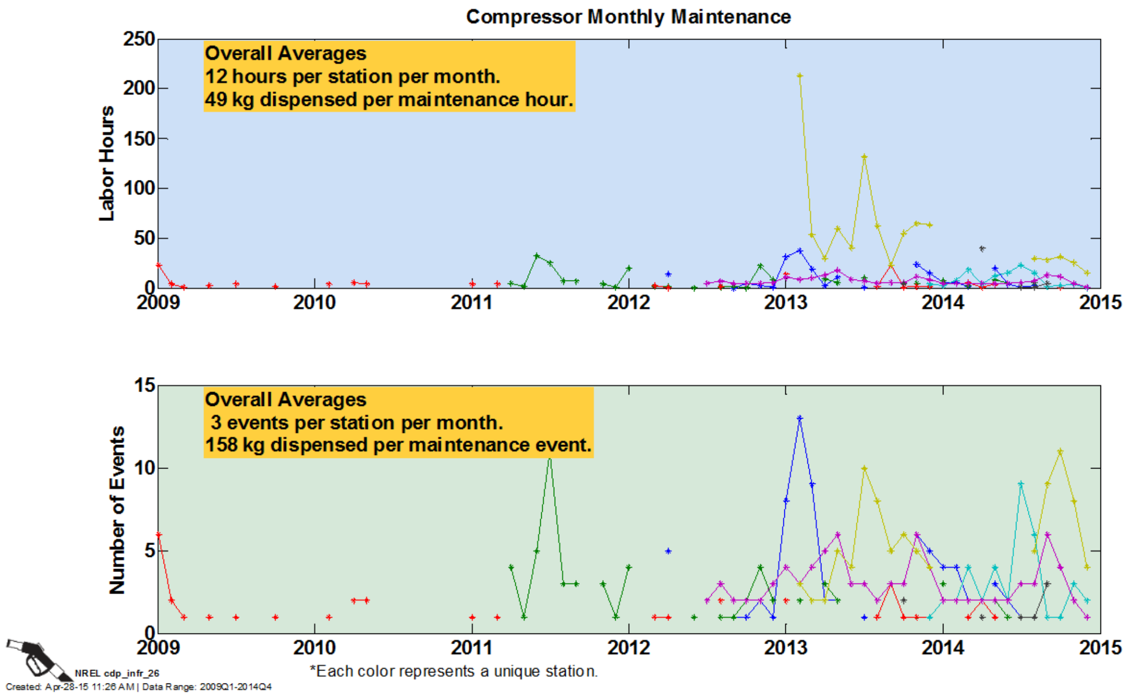
Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

Consolidation Objective

H2FIRST

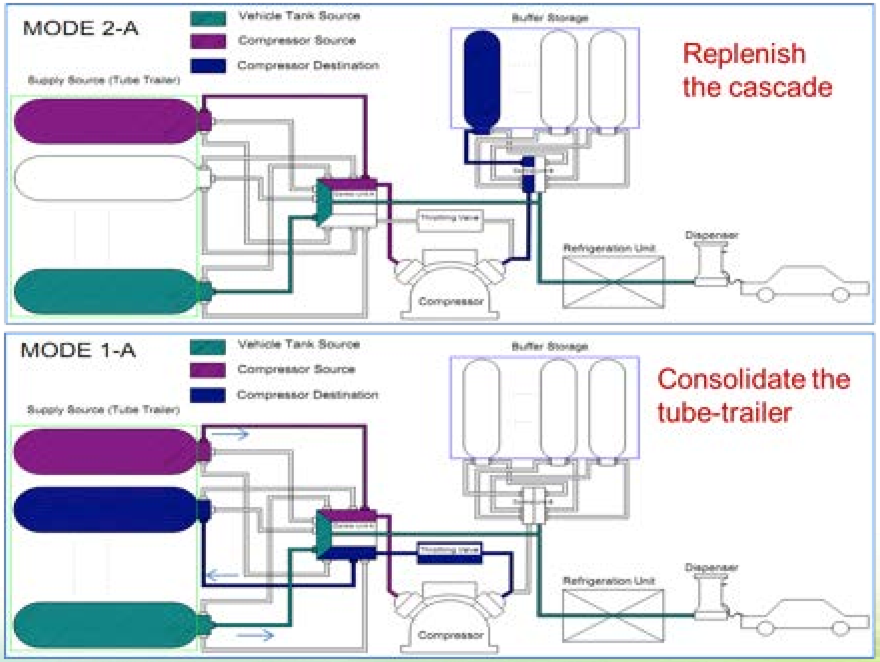
- Reduce the compression contribution to hydrogen cost (in terms of $/kg H_2) by approximately 50%.
- Current compressors for large stations ~500 kg/day can cost ~$1M).



Credit: NREL, *Next Generation H2 Station CDPs (Spring 2015)*, http://www.nrel.gov/hydrogen/proj_infrastructure_analysis.html

How to reduce compressor cost?
Make it smaller

- Compressors have higher throughput if the pressure on the inlet is higher.
- The consolidation scheme will move low pressure gas into higher pressure tubes in the off hours.
- The result is a much smaller compressor for the same throughput.



The project

- H2FIRST, Argonne National Laboratory and PDC Machines will test the concept at full scale at the Hydrogen Infrastructure Test & Research Facility at DOE's National Renewable Energy Laboratory.

Credit: John De La Rosa/NREL

Accuracy

METER BENCHMARKING

Measuring Hydrogen Accurately

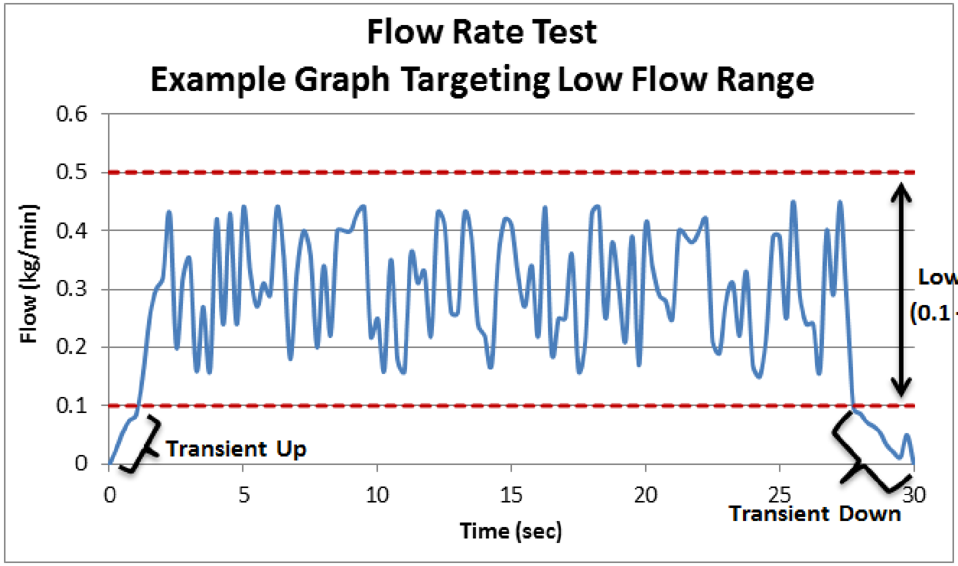
- In the U.S., the guidelines are governed by the NIST-44 handbook
- No cost-effective meters are currently available that can meet these requirements.
- California had to implement a tiered accuracy class system of maintenance tolerances at 2%, 3%, 5%, and 10% with sunset provisions starting in 2018.[1]

NIST – National Institute of Standards and Technology

1. Kashuba, M., ***Hydrogen Dispenser Certification*** *Hydrogen Field Standard, Test Program and Results to Date* (2014) (available at: https://www.cdfa.ca.gov/dms/hydrogenfuel/pdfs/DOE_PosterSession_H2_DispCert.pdf)

Meter Benchmarking Objective

- Complete benchmark testing of three commercially available meter technologies.
- Fabricate a laboratory grade apparatus capable of measuring hydrogen flow meters against the NIST Handbook 44
- Work closely with meter manufacturers and stakeholders to understand and improve meters.



Recent Publications

H2FIRST Hydrogen Contaminant Detector Task

Requirements Document and Market Survey

Danny Terlip, Chris Ainscough, and William Buttner
National Renewable Energy Laboratory

Scott McWhorter
Savannah River National Laboratory

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Technical Report
NREL/TP-5400-64063
SAND2015-xxxx
April 2015

H2FIRST Reference Station Design Task

Project Deliverable 2-2

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Argonne National Laboratory

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Technical Report
NREL/TP-5400-64107
SAND2015-xxxx
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http://energy.gov/eere/fuelcells/h2first

Summary: Five key issues

1. Uniqueness – Reference Station Designs
2. Contamination – Inline Contaminant Detector
3. Delay – HyStEP
4. Cost – Consolidation
5. Accuracy – Meter Benchmarking

Conclusion

Photo Credit: Ellen Jaskol/NREL,

Questions

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