



Hydrogen Fueling Infrastructure Research and Station Technology (H2FIRST) Overview

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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



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.



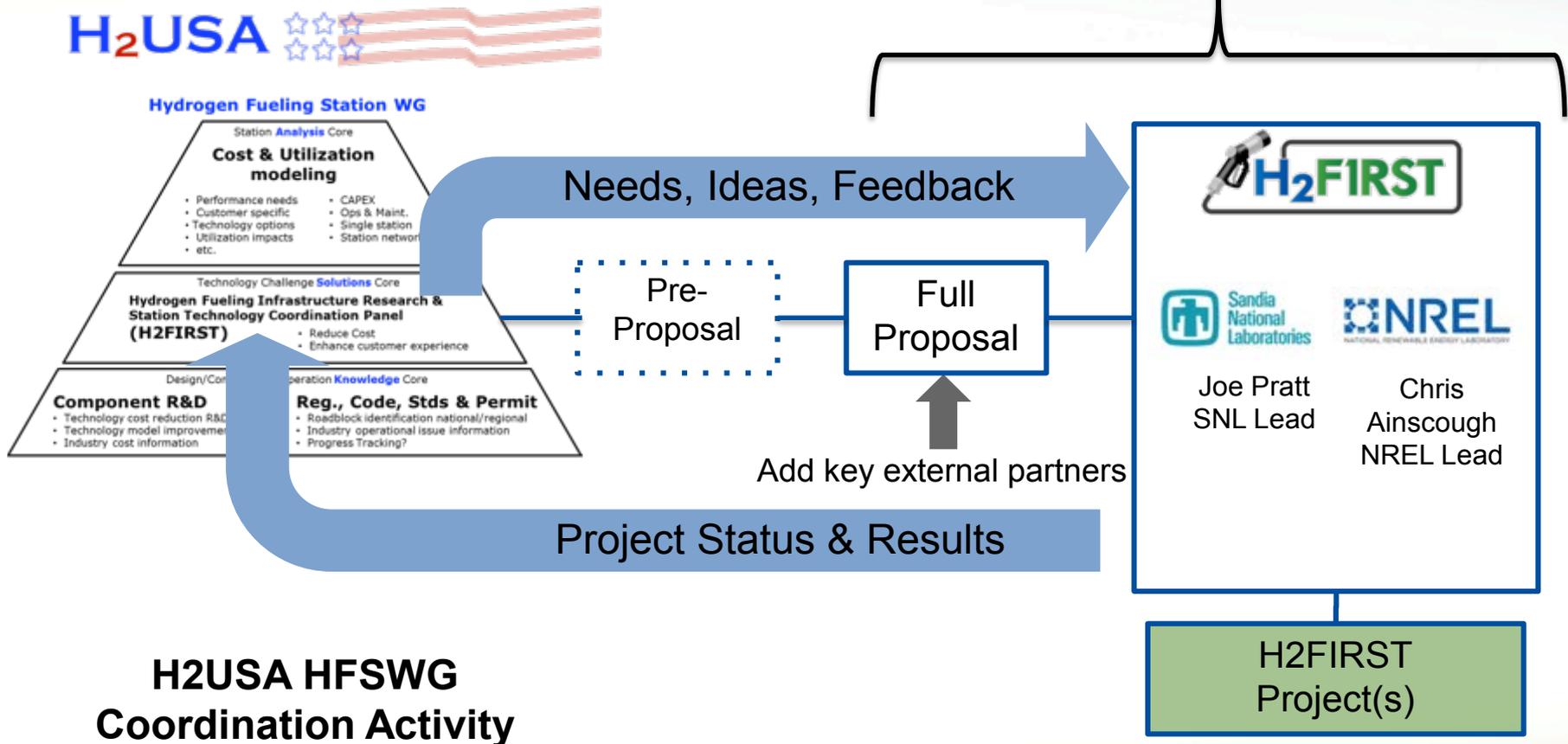
- *Co-led by NREL and SNL*
- *Leverages lab core capabilities*
- *Supports goals and objectives of H2USA*



H2FIRST Project Coordination (Review)



DOE FCTO Decision Authority



H2FIRST Project Partners Activity

1. Logo credit H2USA.
 HFSWG – Hydrogen Fueling Station Working Group; FCTO – Fuel Cell Technologies Office

Denver skyline¹, Oct. 15, 2015



Non-attainment areas²

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

A Vision of Sustainable Transportation¹



- 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 technologies²



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

NO infrastructure = NO FCEVs

“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

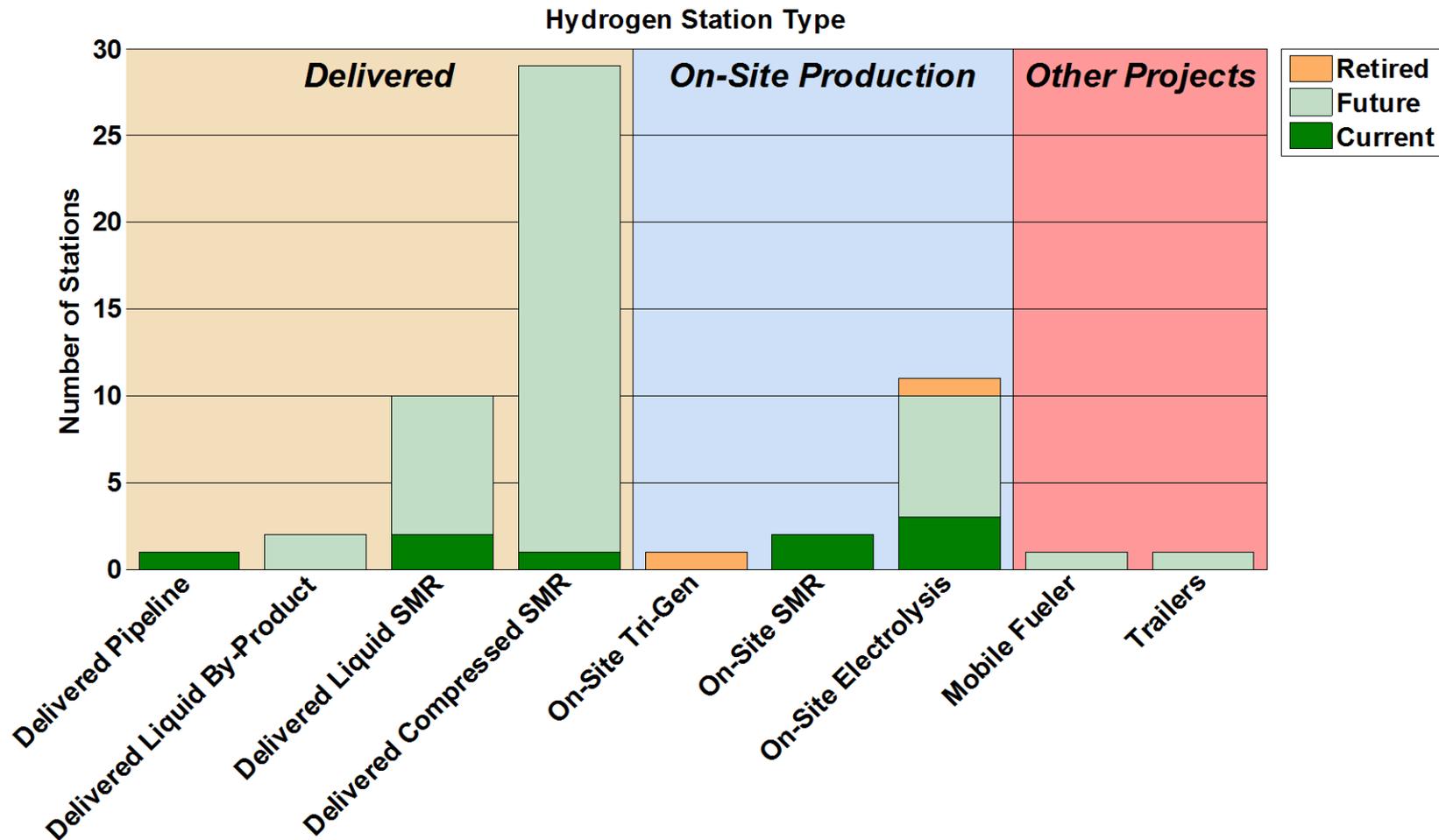


Credit: NASA Earth Observatory/NOAA NGDC, https://www.nasa.gov/mission_pages/NPP/news/earth-at-night.html#.Vh_sXot2190

Uniqueness

REFERENCE STATION DESIGN

Hydrogen Stations, a mélange



NREL cdp_infr_11

Created: Apr-24-15 10:29 AM | Data Range: 2009Q1-2014Q4

SMR – Steam Methane Reformer

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

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



- **Primary results**

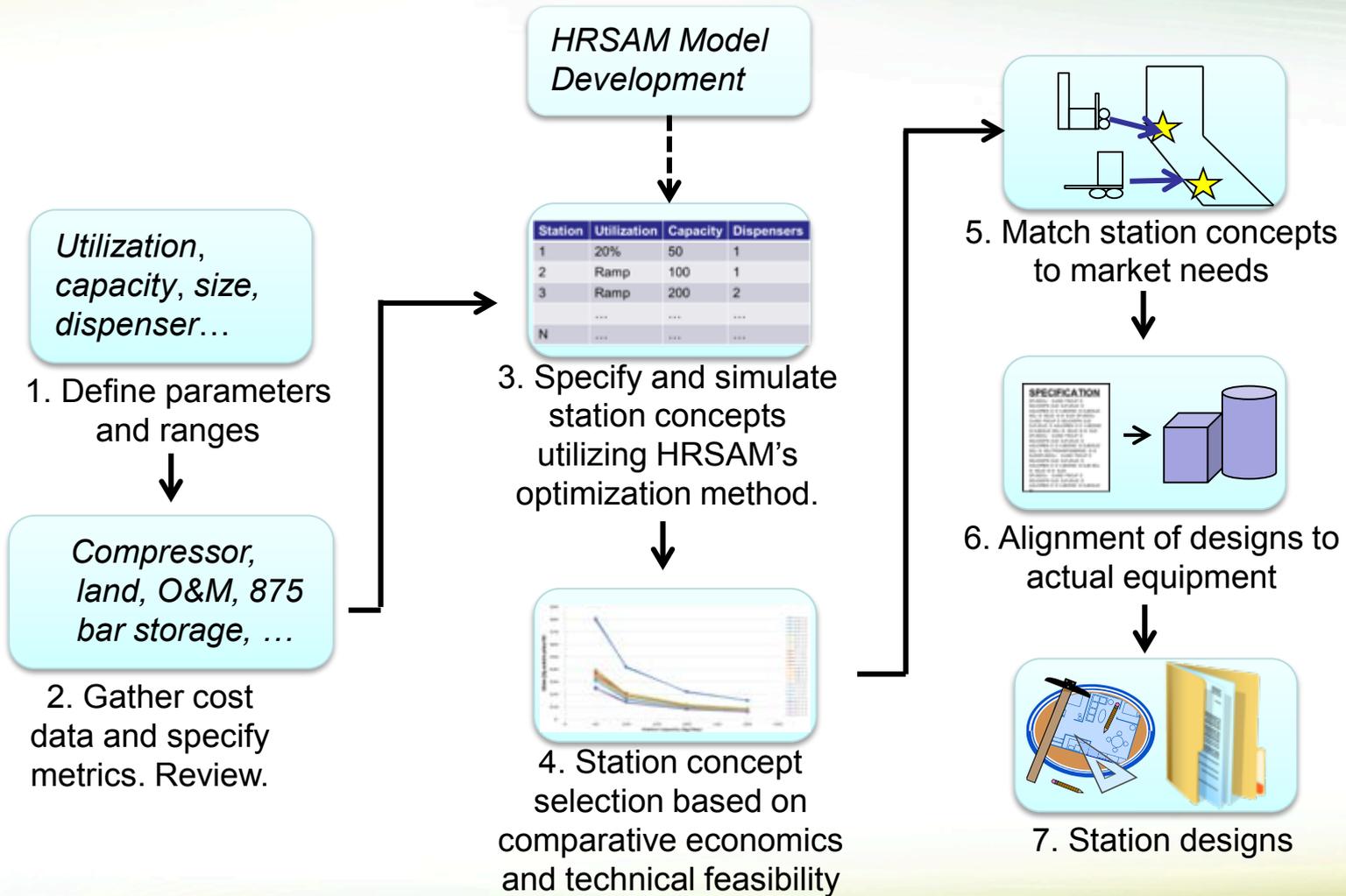
- Selected four high-priority, near-term station concepts based on economics, technical feasibility, and market need
- Produced spatial layouts, bills of materials, and piping & instrumentation diagrams

- **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

- **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.





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)

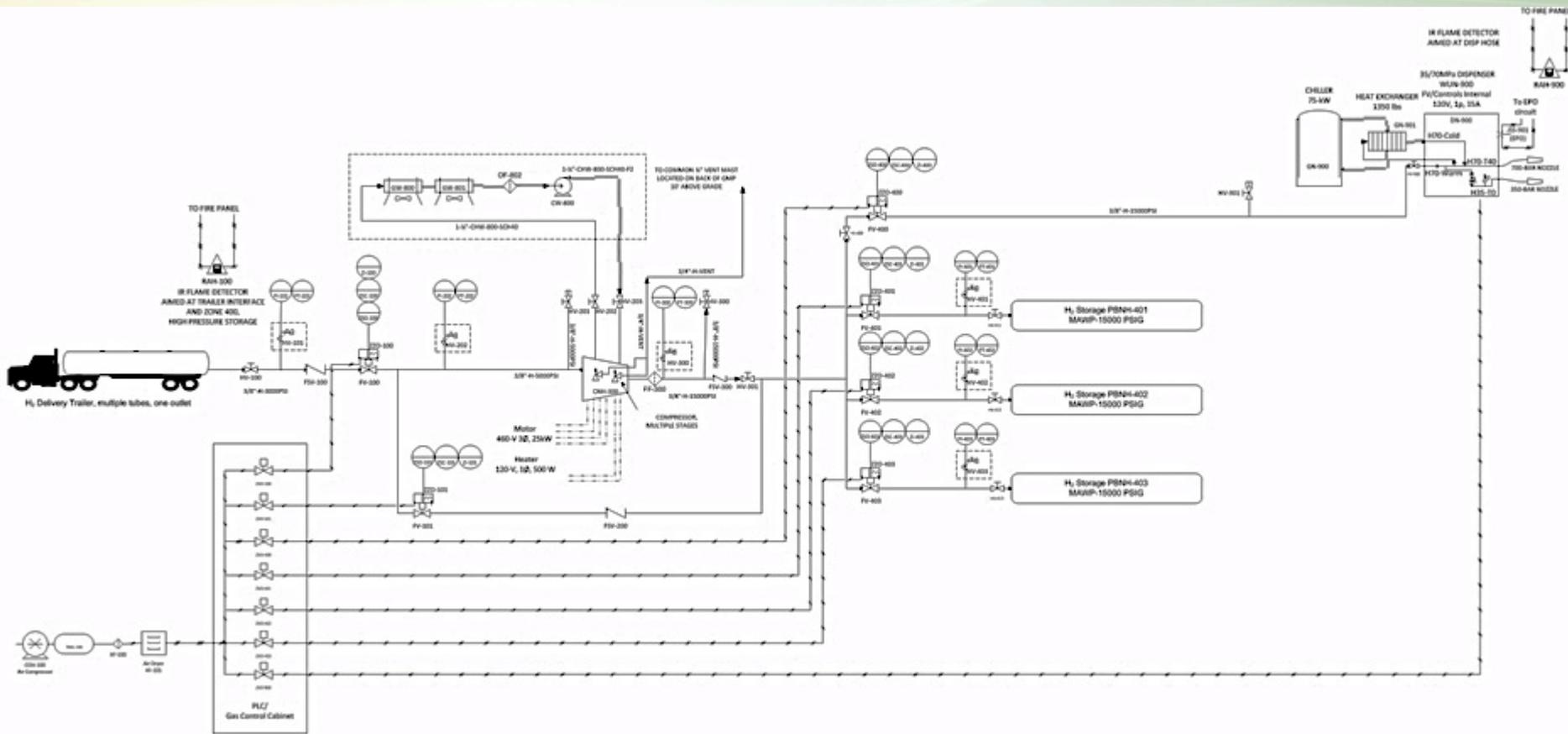
The top-performing station types that best-matched market needs were selected for detailed conceptual design.



| 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)

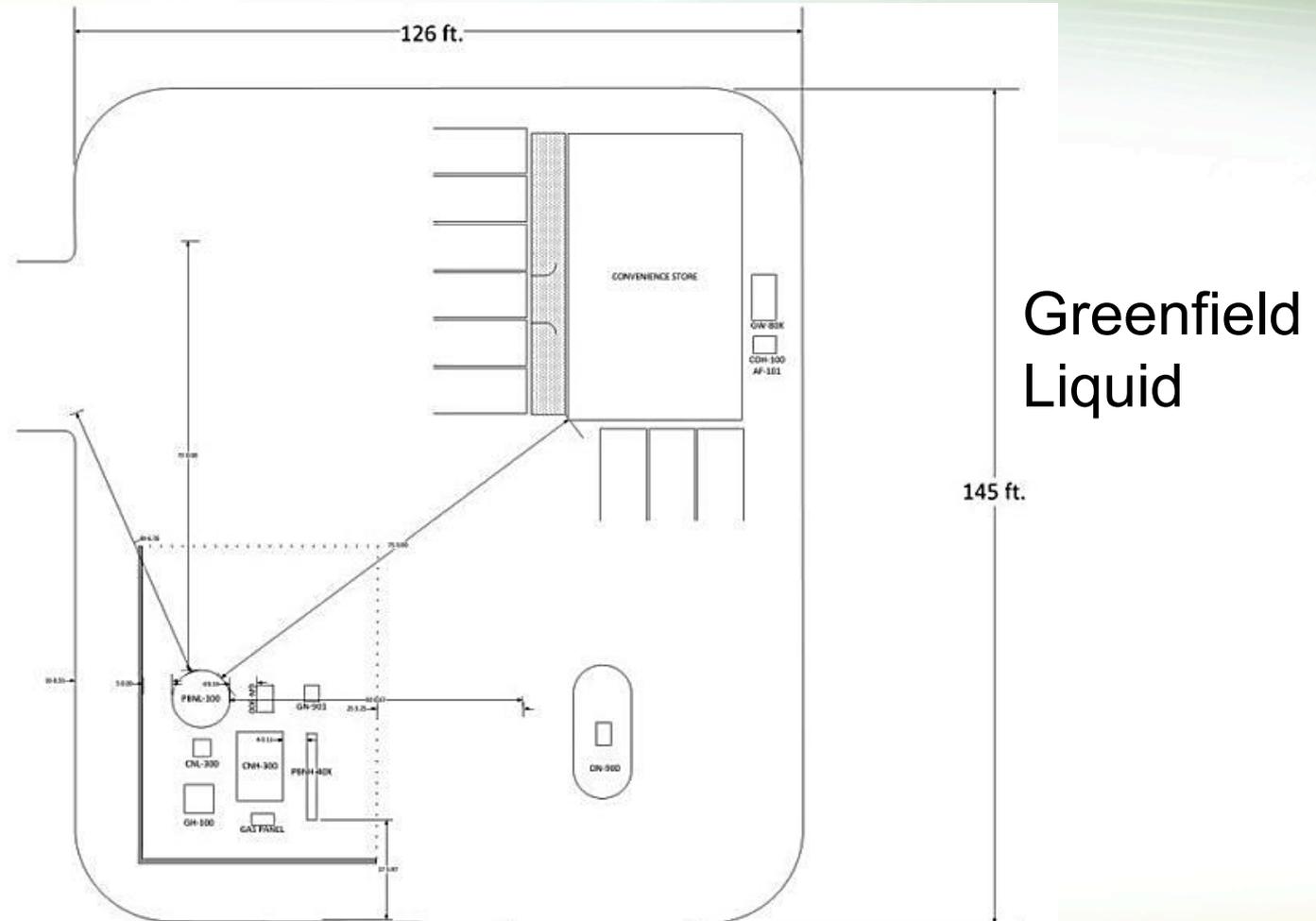
Produced Piping and Instrumentation Diagrams (P&IDs)...



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)

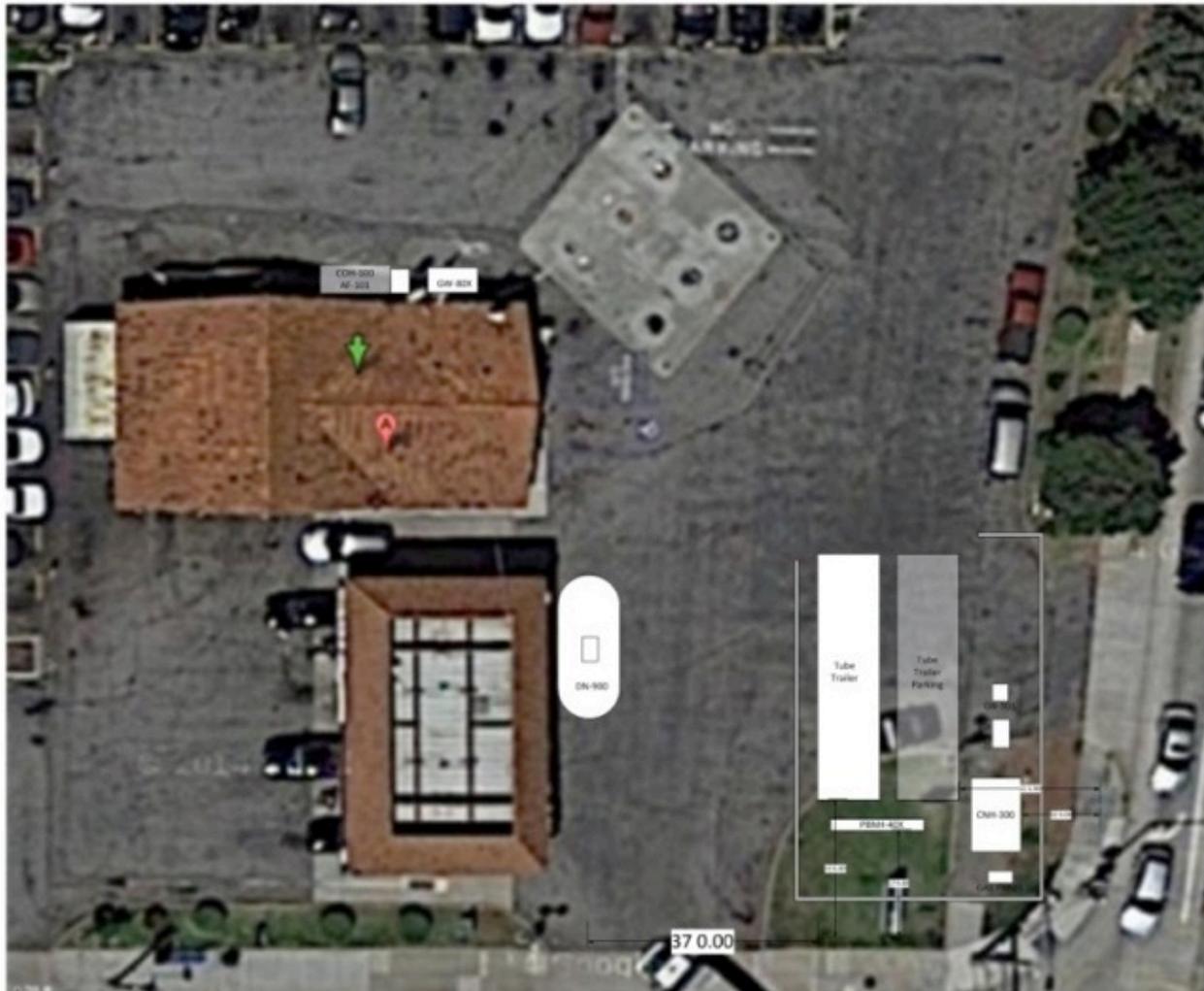
...physical layouts considering NFPA-2 setback distance requirements...



Greenfield
Liquid

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

...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

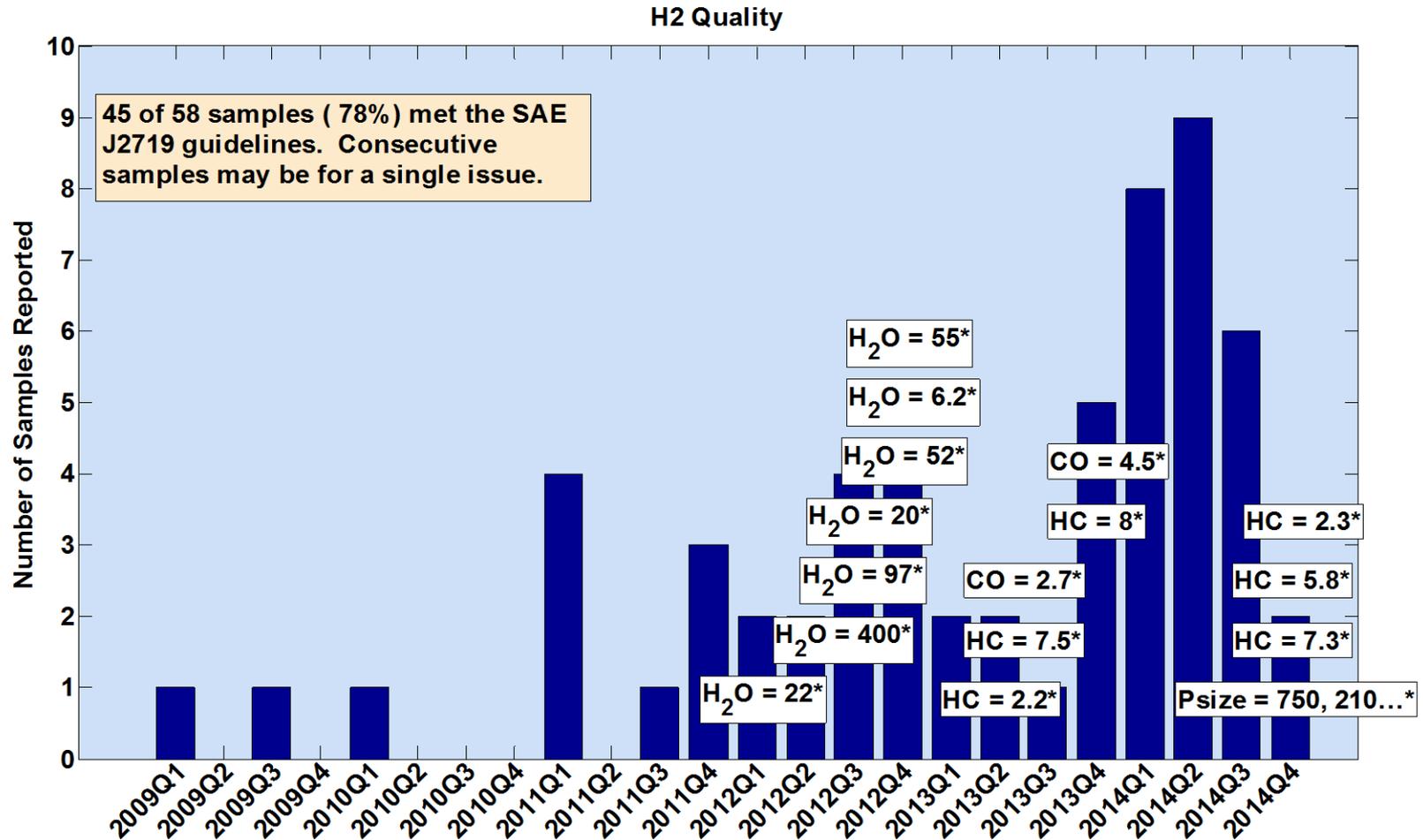
Contamination

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.



* 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

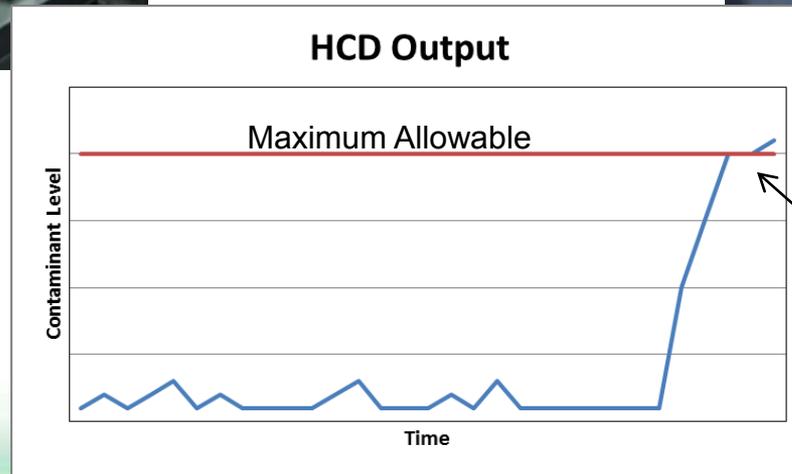
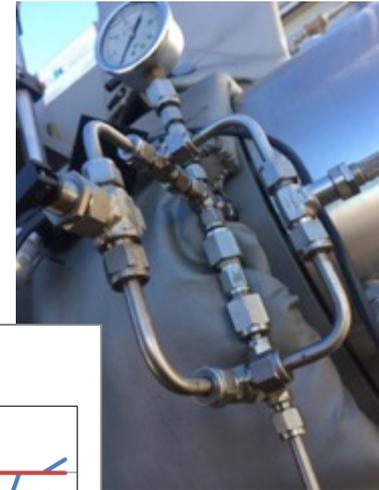
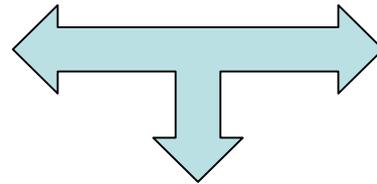
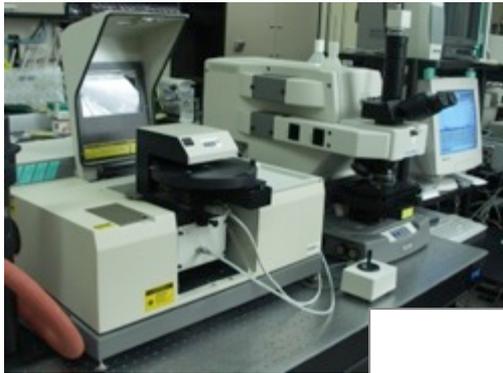
Contaminant Detector Objective



- **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



- 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

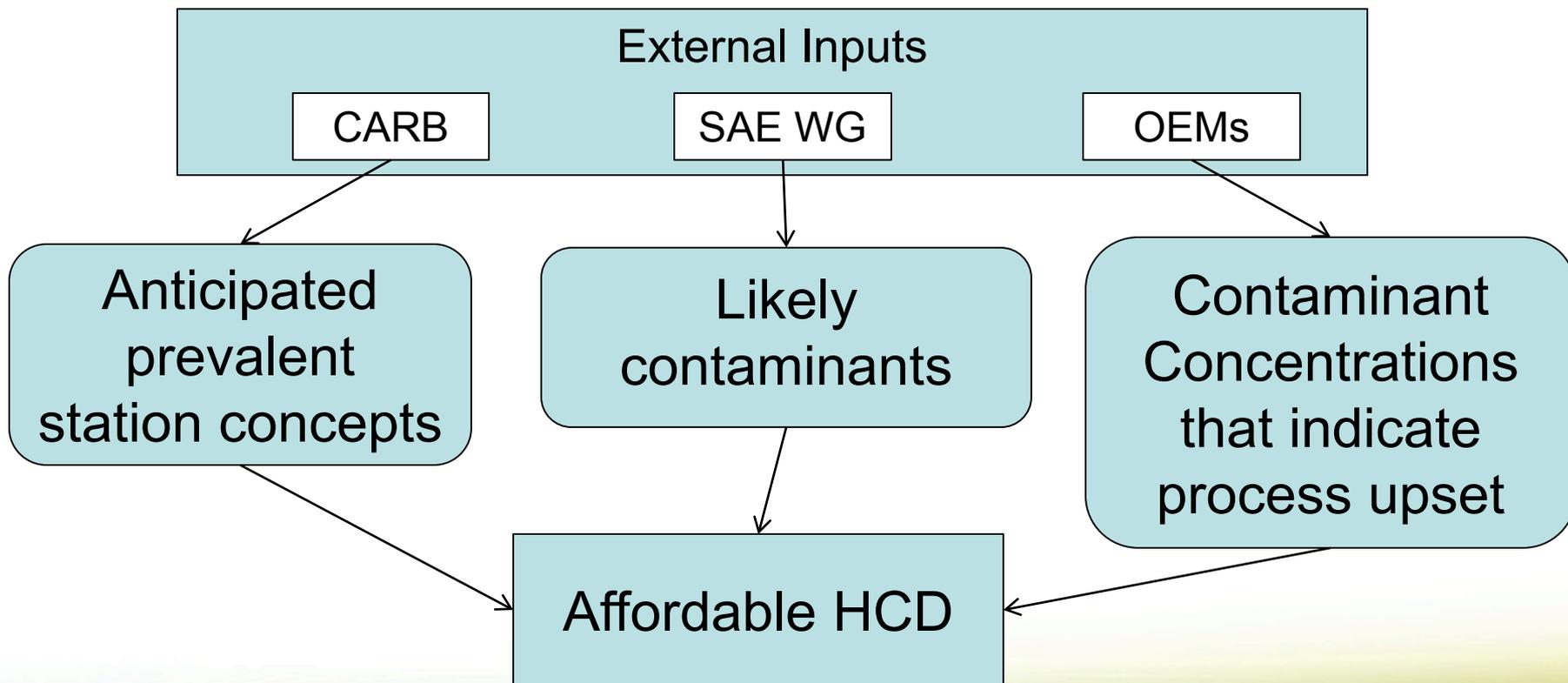


Alarm station operator

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



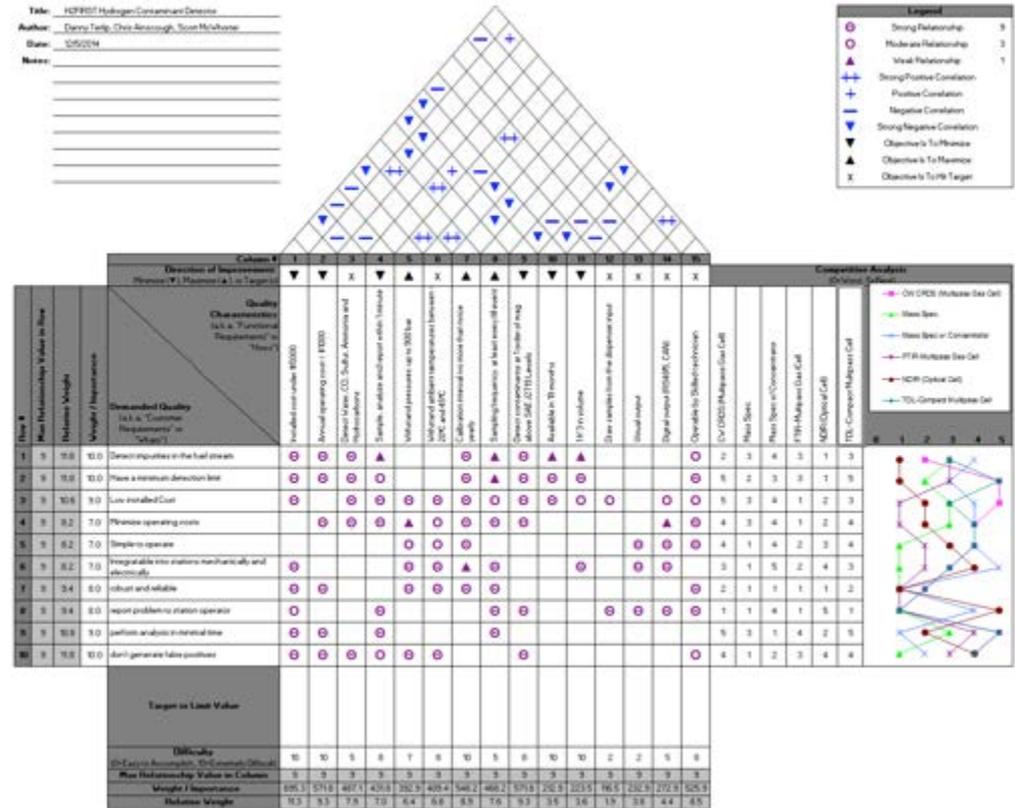
CARB – California Air Resources Board; OEM – Original equipment manufacturer

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

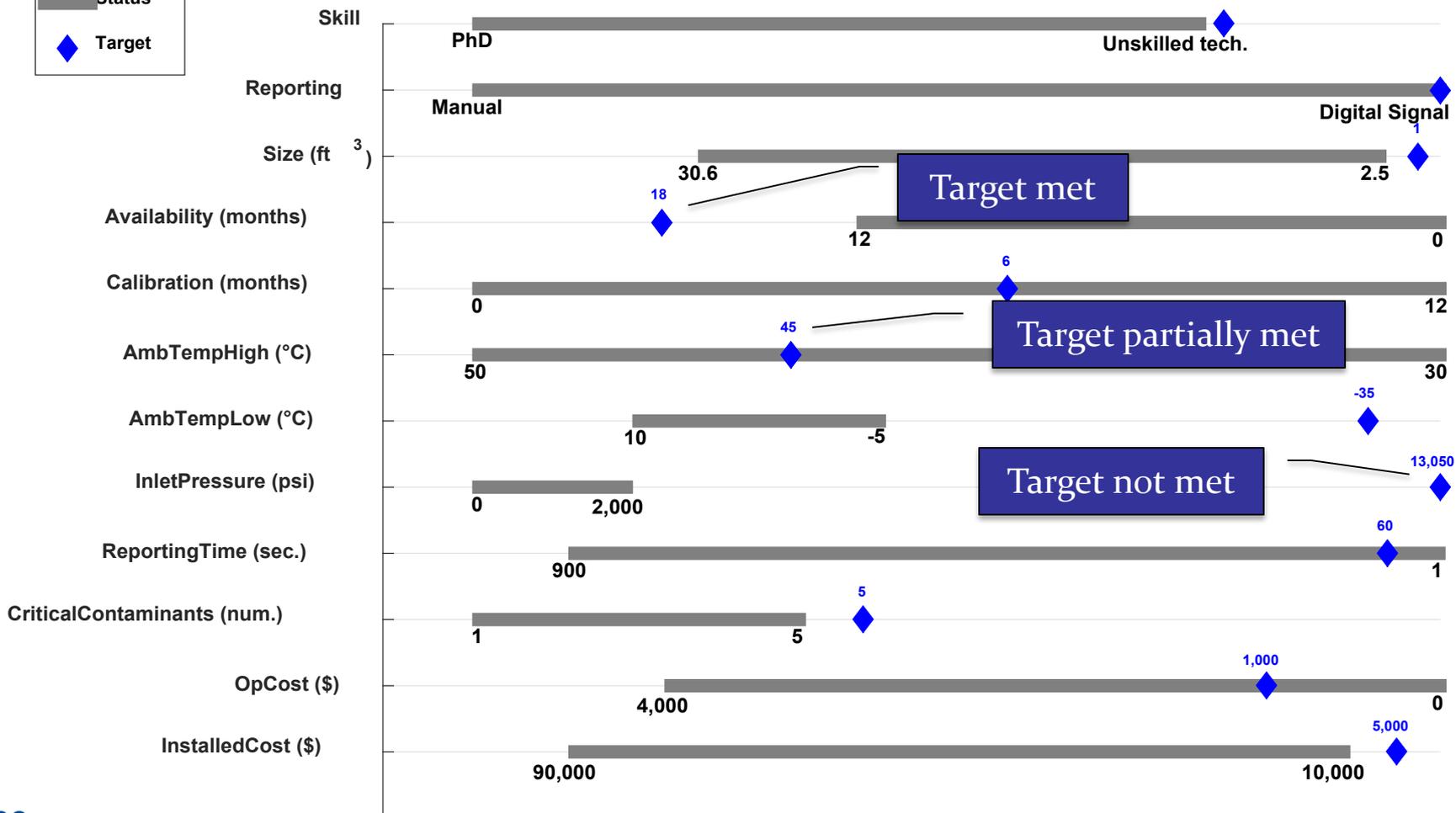
In-line Contaminant Detector Gaps



No available technology meets all requirements.

Hydrogen Contamination Detector Gap Analysis

Status
 Target



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

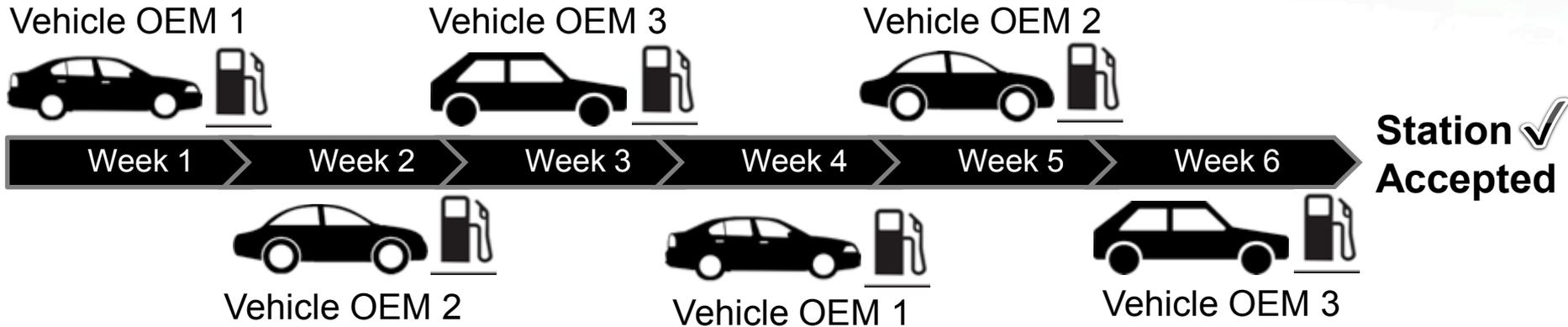
Delay

HYSTEP Hydrogen Station Equipment Performance 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 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 H₂ 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



| 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



| 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



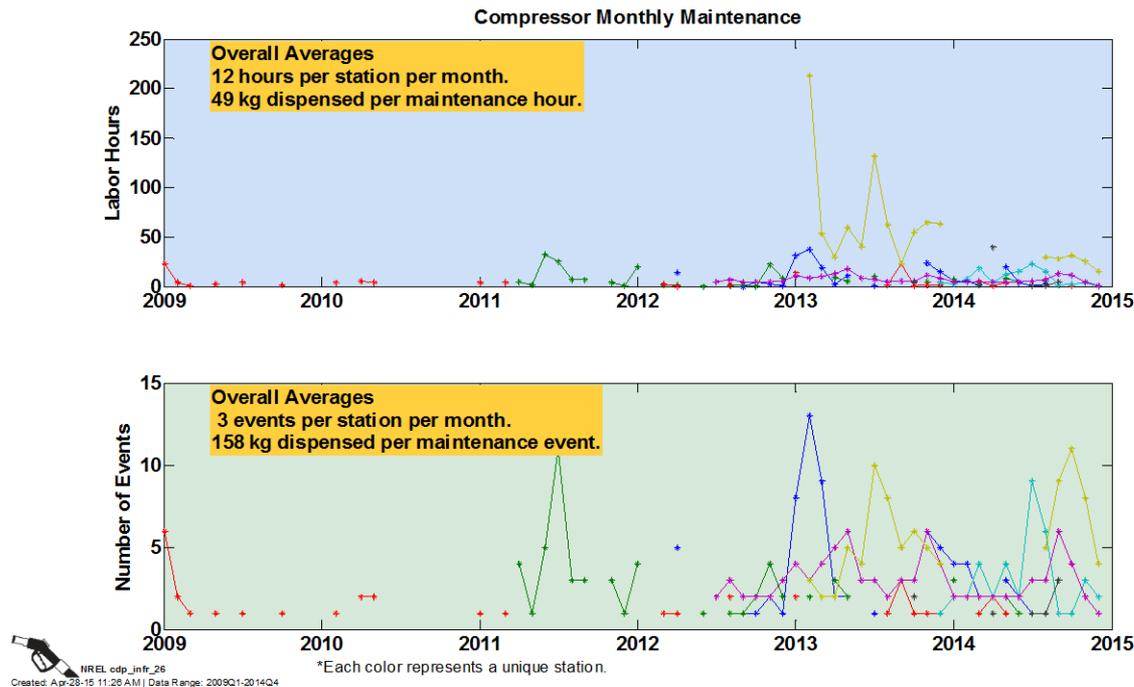
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Credit: H2FIRST, *Reference Station Design Task*, NREL/TP-5400-64107 SAND2015-2660 R (2015)

Consolidation Objective



- Reduce the compression contribution to hydrogen cost (in terms of \$/kg H₂) by approximately 50%.
- Current compressors for large stations ~500 kg/day can cost ~\$1M).



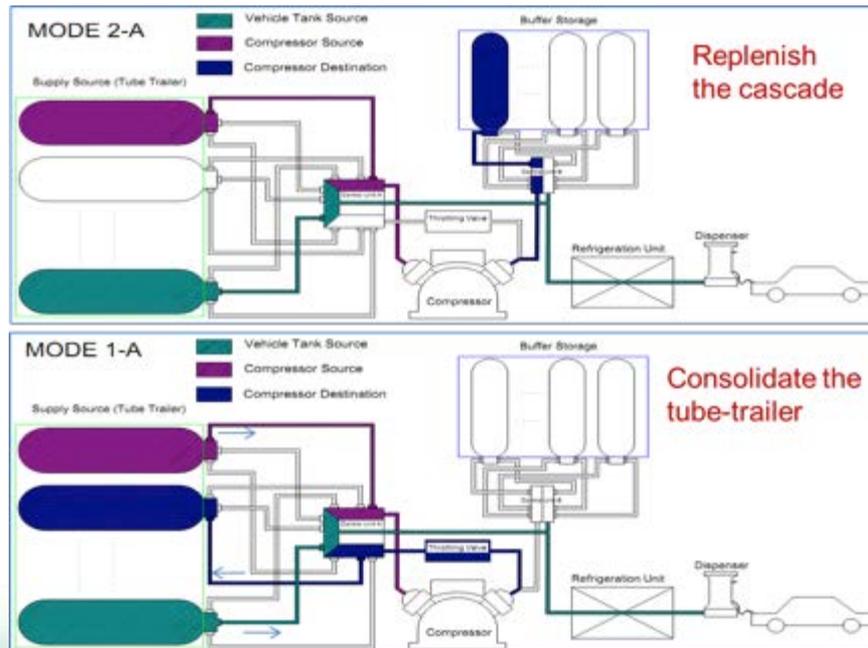
Credit: NREL, *Next Generation H₂ Station CDPs (Spring 2015)*, http://www.nrel.gov/hydrogen/proj_infrastructure_analysis.html

How to reduce compressor cost?

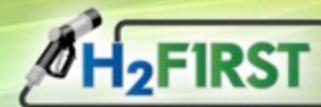
Make it smaller



- 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

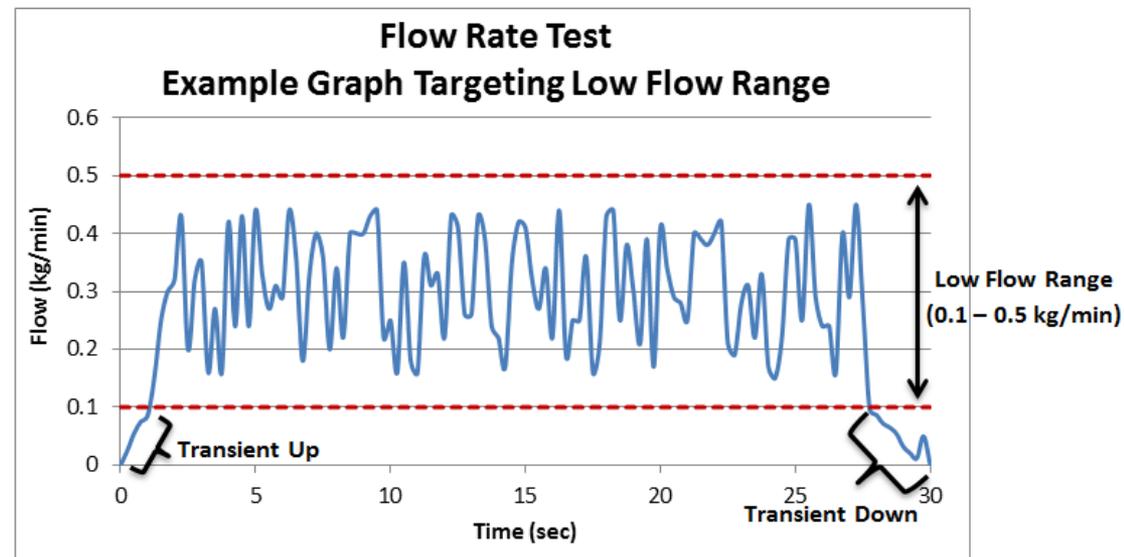
NIST – National Institute of Standards and Technology

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.





H2FIRST Hydrogen Contaminant Detector Task

Requirements Document and Market Survey

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National Renewable Energy Laboratory

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Savannah River National Laboratory

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC, under contract DE-AC36-08GO28308.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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>

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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